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The Dr. Fridtjof Nansen Programme 1975–1993

Investigations of fishery resources in developing regions
History of the programme and review of results

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NORWEGIAN AGENCY FOR DEVELOPMENT COOPERATION

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Preparation of this document

Unfortunately, the main author Gunnar Sætersdal passed away in July 1997, before this document could be finalized. However, he agreed to major revisions of the original manuscript and to adding the final review chapter.

The research vessel DR. FRIDTJOF NANSEN operated for 18 years (1975 to 1993), surveying shelves and slopes of tropical and subtropical regions. The main objective was to provide developing countries with relevant information on their fishery resources.

Gunnar Sætersdal played a key role in the conception of the programme and led its development throughout. In the early 1960s he worked for FAO, first in Chile and Peru, and then at Headquarters in Rome. Having become aware of the difficulties experienced by developing countries to map and assess their marine fisheries resources, he strongly supported the idea of making available, through the Norwegian Agency for Development Cooperation (NORAD), a research vessel fully equipped and staffed, able to provide immediate information on the marine fishery resources. It was the combination of his insight, deep concern and determination to contribute to the development of third world nations, that made the programme possible. Only after his retirement in 1992 did Gunnar Sætersdal find the time to dedicate to the writing of this history. It is intended to provide the general background of survey planning and execution, documenting the changes that took place in survey objectives, types and performance of the equipment used, and finally to capitalize the experience drawn from this unique survey programme.

He invited Tore Strømme and Gabriella Bianchi to participate in this endeavour. Tore Strømme had taken part in the programme since its early years as cruise leader of acoustic and bottom trawl surveys, making important contributions to improving data collection and storage through the development of the NAN-SIS database. Gabriella Bianchi had earlier been working in the FAO Species Identification Programme and participated in surveys with the DR. FRIDTJOF NANSEN. Furthermore, she had gained a good insight in the data by using bottom trawl data and oceanographic data collected through the surveys to study the patterns of distribution of species assemblages.

In June 1993 NORAD agreed to financing the production and printing of the history, while FAO agreed to provide a critical scientific review and co-ordinate some of the work involved. At a later stage, Siebren Venema, of the FAO Fisheries Department became involved in reviewing and editing the document. His familiarity with the DR. FRIDTJOF NANSEN operations and fishery research and development in many developing nations, on the one hand, and the subject matter, on the other, made him a key collaborator to this project. He contributed substantially by proposing important changes in the structure of the original manuscript and improvements in its content and presentation.

Besides those already mentioned, a large number of colleagues from different institutions contributed, at various stages and in different ways, including Serge Garcia, Mike Mann, Ross Shotton (FAO), and Asgeir Aglen, Odd Nakken, Steinar Olsen (IMR). Many of the original figures were redrawn by Ståle Kolbeinson (Institute of Fishery and Marine Biology, University of Bergen). Valantine Anthonipillay and Oddgeir Alvheim (IMR) also helped in improving and reproducing some of the illustrations. Mari Sætersdal helped her father with formatting earlier versions of the manuscript and the late Drawn Spencer (a retired FAO editor) provided editorial guidelines. Jane Ugilt took care of typing and page composition in addition to carefully checking the document for inconsistencies in the presentation of tables and figures.

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ABSTRACT

This document provides a review of practically all the surveys carried out with the research vessel "Dr. Fridtjof Nansen" from 1975 to the middle of 1993 in the Indian, Atlantic and Pacific Oceans. Complete lists of all surveys carried out by this R/V, and reports produced and of scientific staff participating in the surveys are provided as annexes.

Chapter 2 provides an overview of survey methodology and also describes the development in the acoustic equipment used and associated problems.

Particular emphasis is placed on the surveys carried out in the Arabian Sea, supplemented by a review of surveys carried out by the sister ship "Rastrelliger" off Southwest India. The results of the first surveys of the "Dr. Fridtjof Nansen" are revised on the basis of the latest knowledge of acoustic equipment and properties and consequently many results of the earlier surveys have been sized down.

Other areas covered are: the Bay of Bengal off Bangladesh and Myanmar, sea areas around peninsular Malaysia and areas off western Thailand and Indonesia; the Southwest Indian Ocean; the Atlantic Ocean off Northwest Africa, Southwest Africa, with special emphasis on surveys off Angola and Namibia and the shelf area between Suriname and Venezuela; shelf areas in the Pacific Ocean between Southern Mexico and Colombia.

The R/V Dr. Fridtjof Nansen has provided some of the best groundtruthing of the rough estimates of the potential resources first published by FAO in 1970. In Chapter 10 the survey results are compared with those early guesses and estimates based on acoustic and trawl surveys of the productivity per unit area of small pelagic and demersal fish are provided.

The results of the surveys have also been used for analyses of demersal fish assemblages, reviewed in the various chapters by area and in Chapter 10 and for the production of a number of FAO Fish Identification Sheets and Field Guides, of which the references are given in Chapter 11.

Distribution:

NORAD
Institute of Marine Research, Bergen, Norway
Participating countries and institutes
Participants in surveys
All FAO Members and Associate Members
All FAO Offices
FAO Fisheries Projects
FAO Fisheries Department
Other interested Nations, International Organisations and NGOs

Foreword

Norwegian development co-operation has mainly been aimed at alleviating poverty in the poorest developing countries. Support to fisheries development, and particularly to fishery research and management, has been an important item in Norwegian development co-operation during the last thirty years. There are two main reasons for this. In the early 1970s, many developing countries, wanting to develop their fishing industry based on marine resources, found that they had very little knowledge about the abundance of these resources. This created great uncertainty as regards the possibility for increased fish production. The need for support in fishery research was even more strongly felt in the late 1970s, with the extension of the national jurisdiction and the establishment of EEZs in most coastal countries. The second reason relates to the fact that Norway itself is a coastal country with important fishery resources, and has a longstanding experience in marine fisheries research as a tool for managing its marine fish resources. It was felt that this experience should be shared with the developing world.

This work could only have been carried out because the Institute of Marine Research in Bergen, Norway, the Food and Agriculture Organization of the United Nations (FAO) and the United Nations Development Programme (UNDP) took upon themselves the task of coordinating and implementing this programme. The main instrument in this work has been the research vessel "Dr. Fridtjof Nansen", first funded by Norway in 1974. The vessel has been able to carry the UN flag throughout this period, facilitating its deployment in many different countries.

In 1991 Norway approved a continuation of the Nansen Programme, with two extended aims, i.e. to assist developing coastal countries in strengthening their capability of managing their marine fish resources, and to assist in improving the information basis for monitoring the marine environment. In principle, this was a decision to continue financing this work for another 15-year period, because it involved building a new research vessel. Monitoring the most important fish resources and advising in resources management and fisheries management has become the focus of the new programme.

This new programme is more geographically focused, as Norway's partner countries in development have been given priority so far. Furthermore, national institution building has become a main item in the new programme, while such activities had a more modest role in the previous periods of the programme. The Norwegian Directorate of Fisheries has become another pillar of the new programme, providing competence in fisheries management in the broader sense of the word. It is our hope that the co-operation between the Norwegian institutions involved and the institutions in cooperating countries will enhance the knowledge base and the sustainable management of the marine fish resources in these countries.

During the period of reporting as laid out in this book, the late Prof. Gunnar Sætersdal of the Institute of Marine Research has been most instrumental in bringing forward the needs of developing countries in this area, having himself been in charge of the co-operation involved. The combination of being a front figure in fishery research, strongly promoting the utilisation of fishery research as a basic tool for fisheries management, and his deep political engagement and understanding of the problems that developing nations were facing, have played a key role in shaping present Norwegian development aid in the field of fisheries.

Norway is proud to have been a part of this programme for so many years, and wishes the reader a good journey into this book summarising the results and outcomes of the first phase of a programme that still continues.

Oslo, October 1999

Tove Strand
Director General
NORAD

GLOSSARY

SYMBOLS, TERMINOLOGY AND ACRONYMS

Symbols, acoustic and biological terminology

A	=	condition factor in length-weight relationship $W = aL^3$
C value	=	conversion factor used to convert the output of the echo integrator measured over a certain distance, into quantities of fish
CV	=	coefficient of variation
D1	=	day layer No. 1 of mesopelagic fish from 100 to 200 m
D2	=	day layer No. 2 of mesopelagic fish from 250 to 350 m
d	=	degree of coverage, distance sailed relative to the square root of the area investigated (common value = 10)
dB	=	decibel = logarithmic ratio used to express relative levels of acoustic or electrical signals
eurobathic	=	distributed over a wide depth range
incidence	=	percentage of trawl hauls in which species was caught
isobath	=	line of equal depth (on bathymetric charts)
isopleth	=	line drawn on a map through all points of equal value
kHz	=	kiloHerz = frequency of 1,000 per second
L	=	length of a fish (usually total length)
N1	=	night layer No. 1 of mesopelagic fish from 10 to 100 m
N2	=	night layer No. 2 of mesopelagic fish from 250 to 350 m
n.c. or n.s.	=	not covered (by survey)
nmi	=	nautical mile = 1852 m
nmi^2	=	nautical mile squared = 3.43 km^2
tonne	=	1,000 kg
t	=	metric ton (1,000 kg) = tonne
physoclistous	=	with a closed swimbladder
physostomous	=	swimbladder with opening (pneumatic duct to esophagus)
TS	=	target strength = ratio of the echo intensity at 1 m from a target to the incident intensity
TVG	=	Time Varied Gain = accurately controlled amplification (gain) relative to time after transmission, used to correct for transmission loss
W	=	weight of individual fish

Acronyms

BOBP	=	Bay of Bengal Programme
CECAF	=	Committee for the Eastern Central Atlantic
CINECA	=	Cooperative Investigation of the Northern part of the Eastern Central Atlantic
CTD	=	continuous temperature depth recorder
EEZ	=	Exclusive Economic Zone (200 n. miles)
ENSO	=	El Niño/Southern Oscillation
FAO	=	Food and Agriculture Organization of the United Nations
GLO/79/011, GLO/82/001, GLO/92/013	=	symbols of three UNDP/FAO projects associated with the DR. FRIDTJOF NANSEN survey programme
GPS	=	geographic positioning system
GRT	=	Gross Register Ton 1 GRT = 100 ft^3 = 2.831 m^3
ICES	=	International Council for the Exploration of the Sea
ICNAF	=	International Commission for the Northwest Atlantic Fisheries (now NAFO)
ICSEAF	=	International Commission for the Southeast Atlantic Fisheries
IGY	=	International Geographic Year
IIOE	=	International Indian Ocean Expedition (1959/65)
IIP	=	Instituto de Investigaçiones Pesqueiras, Maputo, Mozambique and Luanda, Angola
IMR	=	Institute of Marine Research (Bergen, Norway)

IOC	=	Intergovernmental Oceanographic Commission
IOFC	=	Indian Ocean Fisheries Commission
IOP	=	Indian Ocean Programme (officially International Indian Ocean Fishery Survey and Development Programme)
ISMR	=	Indian Summer Monsoon Rainfall (index)
JICA	=	Japanese Agency for International Cooperation
LOA	=	Length Over All
LOS	=	Law of the sea
NAFO	=	Northwest Atlantic Fisheries Organization
NORAD	=	Norwegian Agency for Development Cooperation
ORSTOM	=	Office de la Recherche Scientifique et Technique d'Outre Mer
SCSP	=	South China Sea Programme/Project
SEC	=	South Equatorial Current
TAC	=	Total Allowable Catch
UNDP	=	United Nations Development Programme
WECAFC	=	Western Central Atlantic Fisheries Commission

FAMILY NAMES IN ALPHABETICAL ORDER

Scientific family name	English family name	Genera mentioned in text
	SHARKS AND RAYS	
Carcharinidae	Requiem sharks	*Rhizoprionodon*
Sphyrnidae	Hammerhead sharks	*Sphyrna*
Dasyatidae	Stingrays	*Dasyatis*
	BONY FISHES	
Albulidae	Bonefishes	*Albula*
Acanthuridae	Surgeonfishes	*Acanthurus*
Acropomatidae	Splitfins	*Synagrops*
Apogonidae	Cardinalfishes	*Apogon*
Argentinidae	Argentines	*Argentina*
Ariidae	Sea catfishes	*Arius, Tachysurus, Bagre*
Ariommatidae	Driftfishes	*Ariomma*
Balistidae	Triggerfishes	*Balistes*
Batrachoididae	Toadfishes	*Porichthys*
Bothidae	Lefteye flounders	*Cyclopsetta*
Carangidae	Scads, jacks, bumpers, lookdowns	*Alectis, Atule, Carangoides, Caranx, Selene, Decapterus, Megalaspis, Selar, Trachurus, Gnathonodon, Trachinotus, Selaroides, Hemicaranx, Chloroscombrus, Oligoplites, Seriola*
Chlorophthalmidae	Greeneyes	*Chlorophthalmus*
Clupeidae	Herrings, sardines	*Dussumieiria, Etrumeus, Ilisha, Sardina, Sardinella, Tenualosa, Pellona, Hilsa, Sardinops, Opisthonema, Chirocentrodon*
Diodontidae	Porcupine fishes	*Diodon*
Engraulidae	Anchovies	*Anchoa, Engraulis, Stolephorus, Thryssa, Cetengraulis*
Gempylidae	Snoek	*Thyrsites*
Gerreidae	Mojarras	*Pentaprion, Diapterus*
Haemulidae	Grunters	*see Pomadasyidae*
Harpadontidae	Bombay duck	*Harpadon*
Lactariidae	False trevallies	*Lactarius*
Leiognathidae	Pony fishes	*Leiognathus*
Lethrinidae	Emperors, scavengers	*Lethrinus*
Lophiidae	Anglerfishes	*Lophius*
Lutjanidae	Snappers	*Lutjanus, Pristipomoides, Rhomboplites*
Merlucciidae	Hakes	*Merluccius*
Mullidae	Goatfishes	*Upeneus, Pseudupeneus*
Muraenesocidae	Pikecongers	*Muraenesox*
Myctophidae	Lanternfishes	*Benthosema, Diaphus*
Nemipteridae	Threadfin breams	*Nemipterus, Scolopsis*
Nomeidae	Driftfishes	*Cubiceps*
Ophidiidae	Cuskeels, brotulas	*Genypterus*
Polynemidae	Threadfins	*Polydactylus, Galeoides, Pentanemus*
Pomacentridae		
Pomadasyidae	Grunters	*Diagramma, Plectorhynchus, Pomadasys, Brachydeuterus, Orthopristis, Haemulon*
Priacanthidae	Bigeyes	*Priacanthus*
Sciaenidae	Croakers, drums, weakfishes	*Argyrosomus, Chrysochir, Johnius, Atractoscion, Cynoscion, Otolithes, Protonibea, Umbrina, Pseudotolithus, Miracorvina,*

		Pentheroscion, Ctenosciaena, Micropogenias, Macrodon, Isopisthus
Scombridae	Mackerels, tunas, wahoos	*Auxis, Euthynnus, Rastrelliger, Scomber, Scomberomorus, Sarda*
Scorpaenidae	Scorpionfishes, rock fishes, rose fishes	*Scorpaena, Pontinus, Helicolenus*
Serranidae	Groupers, sea basses	*Epinephelus, Hemanthias, Diplectrum, Pronotogrammus*
Siganidae	Rabbitfishes	*Siganus*
Soleidae	Soles	*Dicologoglossa*
Sparidae	Seabreams, porgies	*Argyrops, Boops, Dentex, Cheimerius, Pagellus, Sparus*
Stromateidae	Harvestfishes	*Stromateus, Peprilus*
Synodontidae	Lizard fishes	*Saurida, Synodus*
Tetraodontidae	Puffers	*Sphoeroides*
Theraponidae	Tigerfishes	*Therapon*
Trichiuridae	Hairtails, cutlass fishes	*Lepturacanthus, Trichiurus*
Triglidae	Searobins	*Prionotus*
Zei dae	Dories	*Zeus*
	SHRIMPS	
Aristeidae	Aristeid shrimps	Aristeus, Aristaeomorpha, Plesiopenaeus
Nematocarcinidae	Spider shrimps	Nematocarcinus
Pandalidae	Pandalid shrimps	Heterocarpus, Plesionika, Parapandalus
Penaeidae	Penaeid shrimps	Metapenaeopsis, Penaeopsis, Metapenaeus, Penaeus, Parapenaeus, Xiphopenaeus
Sergestidae	Sergestid shrimps	Acetes
Solenoceridae	Solenocerid shrimps	Solenocera, Pleoticus
	LOBSTERS, etc.	
Galatheidae	Langostinos	Pleuroncodes
Nephropidae	True lobsters	Metanephrops, Panulirus
Palinuridae	Spiny lobsters	Puerulus
	CEPHALOPODS	
Amphitretidae	Deep sea squids	
Bolitaenidae	Deep sea squids	
Lepidoteuthidae	Deep sea squids	
Octopodidae	Octopus	Octopus
Sepiidae	Cuttlefishes	Sepia, Sepiella
Loliginidae	Squids	Loligo, Alloteuthis, Loliolopsis, Lolliguncula
Ommastrephidae	Flying squids	Illex, Todaropsis, Todarodes, Dosidicus

1 THE DR. FRIDTJOF NANSEN SURVEY PROGRAMME FROM 1975 TO 1993, PLANNING, OPERATION AND REPORTING

Conception and early planning

The concept of the DR. FRIDTJOF NANSEN survey programme, which was to use a fully equipped and manned research vessel as a means to support fisheries in developing regions was proposed in 1963 by Klaus Sunnanå, Director of Fisheries of Norway at that time. His broad experience in fisheries included two years in India with the Indo-Norwegian fisheries project and continued association with that project. His proposal related to Norway's experience in the execution of that ambitious, and for its time, large programme.

Sunnanå's proposal was submitted to the Board of the Indo-Norwegian project, the forerunner of NORAD, in a memorandum entitled: “Norway's aid to the fisheries of developing nations: the construction and operation of a research vessel”. Here it was put forward that insufficient information on the natural basis for fisheries must be seen as a major impediment to the expansion of fisheries in developing regions. Systematic marine research was necessary to assess the magnitude of the resources and describe their composition and biology. In addition, there was a need to study environmental relationship and the extent to which fishing methods, gear and vessels from developed areas would have to be adapted in order to be effective under local conditions. After 10 years' experience from the Indo-Norwegian project it could be concluded that fishery research and trial fishing should have been an early and important objective of the project. In view of Norway's position as a leading fishing nation, the international community would have expectations of continued Norwegian engagement to aid fisheries in developing regions. Such expectations should be met, and an appropriate and effective form of aid could be the construction of a suitable research vessel operated by Norway, to serve several developing countries, in regions such as the Arabian Sea, the southwestern Indian Ocean, the Bay of Bengal and possibly also Indonesian and West African waters. Co-operation with FAO and regional fisheries organizations would be essential. This represented a fair description of the programme as launched some seven years later.

Initiatives to assist fishery development in the third world in the 1960s and 1970s had their wider background in the global fisheries situation at about that time. By the early 1970s world fisheries had been through two decades of great expansion, but were heavily biased towards northern regions and industrial countries. Total global catches had expanded steadily and rapidly from some 20 million tonnes in 1950 to more than 60 million t in 1970. This growth started in the post-war period of economic expansion in industrialized countries and was facilitated by important technological advances in the fishing sector: synthetic fibres for fishing gear, gear-handling deck machinery, fish-finding equipment, increased size and power of vessels, etc.

The expansion in the 1950–70 period came first from increased fishing in the developed northern regions, the North Atlantic and the North Pacific which by 1970 accounted for about half the total world landings of 61 million t. With the exception of the remarkable development of the Peruvian anchoveta fishery to some 12 million t in 1970, there was only modest growth in the central and southern regions. In those regions where growth occurred during this time, a considerable part must be ascribed to increased activities by long-range fleets of developed fishing nations.

There was thus a lag on the part of the developing countries in world fishery development in the two or three decades after 1950. Many developing nations perceived this lag as a situation of non-equitable sharing of the biological resource wealth of the sea; and there was an increased pressure for development assistance toward the establishment of the Law of the Sea (LOS) regime in the 1970s.

The expansion of world fisheries into developing regions and the related recognized requirements for information on the resources created a need for increased fishery research in these regions. Starting in the late 1950s a number of coastal developing countries established fishery research institutions with economic support from the international community, UNDP's Special Fund or other sources, and with technical support from FAO. Bilateral programmes of assistance in fishery research between fishing nations in the developed and the developing regions were also formulated. The duration of support needed to create viable institutions was at first estimated at only a few years, but it soon became evident that this was wholly insufficient, and most arrangements were renewed several times or new longer programmes were agreed.

The background for a major programme of assistance to developing countries in fishery resource surveys was thus favourable around 1970. World fisheries were in a state of rapid development, coastal countries in the developing regions were keen to claim their share of the local resources, the importance of obtaining detailed and reliable information on the resources was understood and direct methods of resource appraisal by surveys were encouraged by the scientists. In 1970, after contacts between Mr H. Watzinger, Director of FAO Fisheries Industries Division at the time and the then Director General of NORAD, Mr R.K. Andresen, Mr Sunnanå's idea from 1963 was submitted to FAO's Fisheries Department in the form of an offer of a research vessel to be built by Norway and put at FAO's disposal with operational costs to be shared.

The proposal was warmly welcomed by FAO, and a joint FAO/NORAD Working Group was established to study the technical and organizational issues involved. The Group's report formed the basis for the further formal steps that were taken in 1971 consisting of two agreements; one between FAO and NORAD confirming that a vessel would be constructed and placed at the disposal of the Organization with costs to be shared and one between FAO and the Institute of Marine Research, Bergen (IMR) concerning the operation of the vessel.

The joint FAO/NORAD Working Group's description of the general arrangement, lay-out and size of the vessel - which included lists of proposed instruments, equipment and fishing gear was used as the basis for the development of the design and technical specifications of the vessel and its components.

Named DR. FRIDTJOF NANSEN the vessel was commissioned in October 1974. The contractual building cost was NKr 14,850,000, but with the addition of scientific equipment and instruments and fishing gear the total cost was NKr 16,500,000 (which would correspond to about NKr 66,000,000 in 1995, the equivalent of about US$ 12,500,000).

The DR. FRIDTJOF NANSEN proved to be a practical and versatile research vessel and a further three vessels of this type were constructed, the BIEN DONG and the NORUEGA built by NORAD for Viet Nam and Portugal respectively, and the MICHAEL SARS built by the Directorate of Fisheries for use in Norway.

Vessel, instruments and fishing gear

The DR. FRIDTJOF NANSEN was built in 1974 as a fishery research vessel to the Norwegian VERITAS class IAI-stern trawler. Figure 1.1 shows an early photograph of the vessel. The specifications were: LOA 46.35 m, width 10.3 m, depth 6.5 m, 491 GRT. She had a 1500 hp main engine and berths for 28 persons. All deck machinery was hydraulic and there were freezer- and cool rooms.

The deck machinery included split trawl winches and two hydraulic drums for trawl nets. With the use of combination trawl doors there was no delay in switching between bottom and mid-water trawling.

Originally the vessel was also equipped for purse-seining, but this gear proved of little use in survey work and the arrangements were removed during a refit in 1979.

Navigational equipment included satellite navigation systems.

The acoustic equipment included a 24 kHz sonar and 38, 50 and 120 kHz echosounders. Three generations of SIMRAD™ echosounders and integrators were used: EKS combined with analog QM integrators until 1984, EK400 combined with digital QD integrators up to 1991 and the EK500 system in the remaining years. This equipment is further discussed in Section 2.3.

Figure 1.1 The DR. FRIDTJOF NANSEN

Assignments and operations

The responsibility for the strategic planning of the programme was shared between Norway, FAO and UNDP. In the 1970s and 1980s fisheries development in developing regions was supported by large-scale FAO/UNDP funding programmes and the DR. FRIDTJOF NANSEN served several: the Indian Ocean Programme, the South China Sea Programme, the Committee for the Eastern Central Atlantic Fisheries (CECAF). The FAO/UNDP share of the operational costs was in part drawn from these programmes, but was later provided from special UNDP projects created for this purpose under the global programme GLO/79/011 "Assessment and Development of World Renewable Marine Resources"; GLO/82/001, "Survey and Identification of World Marine Fish Resources" and GLO/92/013 "Global Investigations of Fishery Resources."

When gaps occurred in the FAO/UNDP funding, Norway assumed the full costs and made use of the vessel under bilateral agreements arranged by NORAD such as in Pakistan in 1977, Mozambique in 1977/78 and Sri Lanka in 1978/79. The overall objectives and the main area of operation were, however, not affected by these changes in funding.

When costs were shared, the apportionment was 40% assumed by FAO/UNDP from the start up to about 1983. It was then reduced to 20% and from 1987 on only a nominal amount was maintained in the UNDP budget. The programme continued, however, to benefit from the good offices of FAO and UNDP both at headquarters and in the field and in particular from the invariable support of and good co-operation with FAO Fisheries Department staff in Rome.

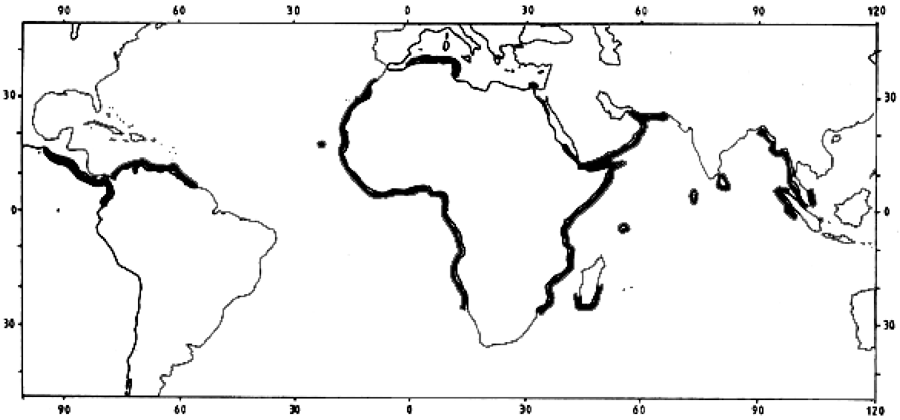

Figure 1.2 Map of the areas covered by the DR. FRIDTJOF NANSEN, 1975–93

Table 1.1 lists areas or countries covered in approximately 18 years of vessel operations, a more detailed list is presented in Appendix II. Figure 1.2 provides an overview of all areas covered. About half the time was spent in the Indian Ocean for which, by the mid-1970s information on the fishery resources was scarce. The first two-year survey of the northwest Arabian Sea had the largely exploratory objective of testing whether this region, known to be very promising from the viewpoint of basic biological productivity, held fish resources similar to those from other highly productive regions such as the eastern boundary current upwelling regions off West Africa and the west coasts of the Americas.

Table 1.1 Summary of survey assignments of the DR. FRIDTJOF NANSEN by major sea areas and years

Area (countries)	Years	Relevant chapter
Arabian Sea and adjacent Gulfs (Pakistan, Iran, Oman, Yemen, Somalia, and Djibouti*)	1975–79 1981, 1983, 1984	3
Eastern Indian Ocean and South China Sea (Sri Lanka, Bangladesh, Myanmar, Thailand, Malaysia, Indonesia and the Maldives*)	1978–80 1983	4
Southwest Indian Ocean (Kenya, Tanzania, Mozambique, Seychelles* and Madagascar*)	1977–78 1980, 1982–83 1990	5
Red Sea and Mediterranean* (Ethiopia*, Egypt*, Tunisia* and Algeria*)	1981	-
Atlantic Ocean off northwest Africa (Morocco, Mauritania, Senegal, the Gambia, Guinea- Bissau, Guinea, Sierra Leone, Liberia, Côte d'Ivoire, Ghana, Togo*, Benin*, Nigeria*, Cameroun*, Equatorial Guinea, São Tomé e Principe and Cape Verde Islands*)	1981–82 1986 1992	6
Atlantic Ocean off southwest Africa (Gabon, Congo, Angola, Namibia)	1985–86 1989–93	7
Pacific Ocean off Central America (Colombia, Panama, Costa Rica, Nicaragua, El Salvador, Guatemala and Mexico)	1987	8
Caribbean Sea off northern South America (Suriname, Guyana, Trinidad & Tobago, Venezuela and Colombia)	1988	9

*) Resources of these countries and area have not been reviewed in this report

Most of the subsequent assignments in the Indian Ocean had a character of providing inventories by countries. This period coincided with that of the establishment of EEZs by many coastal States and there was a great interest in obtaining descriptions of the resources found in these zones. These surveys were detailed and comprehensive and in most cases repeated in order to confirm main findings and to study seasonal variations.

Another type of survey in the Indian Ocean was related to one of the main findings of the first exploratory surveys of the northwest Arabian Sea: the very high abundance in a part of the region of mesopelagic fish, mainly Myctophidae. To study these fish in more detail, special surveys were mounted in the Gulfs of Oman and Aden in 1979, 1981 and 1983.

The objectives in the two years of surveys off the Americas, on the shelves of the Eastern Central Pacific and of the north coast of South America respectively, were to provide detailed information on the resources as a basis for further development of mostly existing fisheries.

The background was different for the assignments on the West African shelf, Morocco to Ghana, Angola and later Namibia. In these upwelling regions, there was a history of both fisheries and fisheries research and the task of the DR. FRIDTJOF NANSEN programme was to provide up-to-date information on the state of the stocks for purposes of management of the resources as well as for further fisheries development.

IMR was responsible for the tactical planning of the assignments, a responsibility shared with the co-operating scientific institutions in the countries of operation. Representatives of FAO's Fisheries Department and of existing field projects often assisted in this process, especially in the case of regional programmes when formal meetings were called for planning purposes.

IMR's responsibility included the technical operation of the vessel, which was crewed from Norway, but often complemented with fishermen/deckhands from the region of operation; this also served training purposes. Technical breakdowns at times caused problems in regions where shipyards and dock facilities were scarce. From 1981, a new mode of operation was adopted involving two months of continuous operation followed by a one month's lay-up. This facilitated repair and maintenance and saved crew costs while maintaining an annual operational period in excess of 200 days.

The annual operational costs of the vessel started at about NKr 15 million (recalculated to the 1995 price index level). There was some increase after the early years, and since 1980 the cost level was NKr 17–18 million (US$ 3.4 million at the 1995 exchange rate) with no trend, but with variations caused by major refits. The main component (50–60%) was, however, crew wages, social insurance and travel. Scientific management and execution, together with reporting, meetings, scholarships, etc., represented a considerable additional cost estimated at some NKr 4 million (US$ 630,000).

The IMR scientific survey staff consisted of about five persons. In addition in each assignment arrangements were made for participation in the survey of a contingent of scientists and technicians from the countries included in the programme. They were selected and appointed by the respective government authorities and represented fisheries research institutions and sometimes universities. Their role in the work was of utmost importance and served several purposes. These include: to be made acquainted with the techniques and methods used in the survey and with the fish fauna in the area, to be trained in these aspects, to assist in the overall activities on board, especially sampling, logging and first analysis of data and, after the completion of the assignment, to help the authorities in recognising and understanding the reported findings. About five scientists/technicians from the relevant counterpart agency participated in survey execution and data processing on a rotation basis (see Appendix III). Professional co-operation also included scholarships for leading scientists from the counterpart institutions both at IMR and at the University of Bergen.

Review of evaluations - the extended programme

In 1982 NORAD organized an evaluation of the DR. FRIDTJOF NANSEN programme by an independent team which visited six developing countries where the EEZs had been extensively surveyed by the vessel. The team held consultations with FAO and CECAF key personnel and otherwise based its analysis on replies to questionnaires from 29 countries which had been part of the survey activities up to 1982 (Hallenstvedt *et al*., 1983). The objective of the evaluation was in particular to assess the impact of the programme on the elaboration of fisheries sector development plans and fisheries management plans in the developing countries.

The findings of the evaluation team were largely positive. The vessel's survey data were used in many fisheries development plans and had in some cases played an important role in changing existing plans. The quality of the scientific work was considered high as was that of the reporting. The evaluation, however, noted a shortcoming to the programme: an insufficiency in the follow-up work. The information contained in the scientific reports was in many cases neither easily available nor fully understandable to the managers and entrepreneurs. This could be improved by dissemination of results through national and regional seminars with broad participation, an approach which was followed in later programmes when appropriate.

In 1986, with the end of the vessel's life time in view, NORAD requested FAO to undertake an evaluation of the future need for the deployment of fisheries research vessels in support of research and development programmes of third world nations. The terms of reference for this task were wide and comprehensive, and in addition to a core team of three specialists, FAO recruited consultants to provide expertise on resources, development planning and survey methodology. After a year's work, which included meetings with NORAD, UNDP, FAO and IMR, a final report was submitted (Anderson *et al*., 1987).

The main thrust of this study was an assessment of future need for a vessel like the DR. FRIDTJOF NANSEN, and the group was not asked to undertake any specific evaluations of the vessel's programme. It made use of the 1982 evaluation and was provided with reports of the later assignments. The group's main conclusion: “that the programme of research and survey of the marine resources of the developing countries, initiated by DR. FRIDTJOF NANSEN, be continued with a new replacement vessel…” must indirectly be considered as a mainly positive evaluation of the programme so far undertaken by the first vessel.

In 1988 the Norwegian Ministry of Development Co-operation commissioned a group of three independent specialists to undertake a “Review of available evaluation and information material in order to reach a decision on the possible continuation of the work of the fishery survey vessel DR. FRIDTJOF NANSEN through the building of a replacement vessel.”

The report from this group was submitted in January 1989 (Anon., 1989). On the basis of the review made of available material concerning the work of the vessel and interviews with relevant persons, the consultants agreed with the main recommendation of Anderson *et al.* (1987), for a continuation of the programme with a replacement vessel. Issues regarding the organization of the programme and co-operation with other aid efforts were dealt with in a number of specific recommendations.

In 1991 NORAD, in consultation with FAO and UNDP, proposed a new phase of the programme to entail the following components

- building a new research vessel
- more emphasis on institutional support and management aspects
- inclusion of environmental issues of relevance to fisheries and

- concentration of effort in fewer countries.

The new programme was approved by the Norwegian Government in 1992. The old DR. FRIDTJOF NANSEN finished her last survey in June 1993 in Namibia and was sold. The new vessel, inheriting the name DR. FRIDTJOF NANSEN, was commissioned in October 1993 and started operations in January 1994.

Reporting

Reporting was done in two stages. Preliminary cruise reports describing the work undertaken and a brief outline of the findings were usually issued at the end of each cruise, and full survey or summary reports were submitted after the termination of assignments. In addition, a number of seminars were organized to present and discuss the final reports usually in co-operation with the FAO Fisheries Department.

A complete list of all Cruise Reports and Summary Reports is presented in Appendix I, while the list of cruises in Appendix II contains a cross-reference to relevant Cruise and Summary Reports. Several Summary Reports have been translated into the languages of the area concerned (Spanish, Portuguese or French). Most reports have had a limited distribution, mainly in the countries directly concerned with the survey.

Chapters 3 to 9 of the present document form partly a summary and partly a revision of the main findings and conclusions as presented in the Summary Reports that were published for each area. However, in addition an attempt is made to link the results of all the surveys in terms of productivity and ecological criteria (Chapter 10). The revisions were made on the basis of the documented performance of the acoustic instruments, which is discussed in Chapter 2.

For the sake of completeness, and partly because of close operational links, the results of a survey project executed by NORAD/IMR for UNDP and FAO in the Arabian Sea off Southwest India, have also been included (Section 3.2).

For more details on each survey readers are referred to the original reports, which are available at local research institutes, offices of FAO Representatives, the FAO Fisheries Library and IMR, where also the computerized data are available for further research by authorized scientists.

2 SURVEY METHODOLOGY

General

The classic method of investigating the potential of fish stocks and the effect of fishing on them, for which the models of exploitation were developed, relies on the use of statistics of catch and effort and biological sampling from the commercial fishery. This method can be inexpensive, as the basic data may already be collected for other purposes, and because it may be based on a large number of observations from many vessels, the sample variance can be small. The method depends, however, on the existence of a fishery over a number of years and of significant intensity exploiting the main component of the stock, as well as a systematic collection of statistics and biological information including age determination of the fish.

Reliable and comprehensive data of this type are in fact far from being available for all major fisheries even today and in the 1970s these conditions were seldom found in the developing regions, where often, the only long-term fishery was artisanal and small-scale, limited to exploiting the shallow littoral part of the continental shelf. Data from the often shifting effort of long-ranging foreign fleets operating in those regions seldom provided the time-series needed for assessments.

A rough appraisal of resources in unexploited areas may be made by using general information on oceanographical characteristics and basic productivity of the waters and comparing that with similar information from areas with developed fisheries. Around 1970 this formed the basis for several estimates of the potentials of unfished regions in the tropics and sub-tropics (Gulland, 1970). This type of appraisal was, however, of little tactical value for the purposes of development and investment. For sound planning of fishery development the resource information should, in addition to estimates of yield potentials, include main features of life history, distribution, behaviour, catch rates, catchability, size, quality, etc., for each target species. For most resources these basic data can best be obtained from research vessel surveys using acoustic instruments combined with sample fishing to study small pelagic fish, and fishing with bottom trawls to study the demersal species.

The method of research vessel surveys has the disadvantage of being relatively expensive and requiring advanced technology. Historically, there has been a tendency in natural renewable resource sectors such as fisheries, to expect low research costs on a total sector value basis (Sætersdal, 1975), an attitude which may have contributed to management failures and other losses. The world fisheries community in general now considers the acquisition of detailed resource data to be a basic condition for industrial fisheries, and research vessel surveys, although costly, form part of most major programmes of resources research and management. In addition to providing information on unexploited stocks, investigations with research vessels have proved indispensable also in more advanced research on those stocks which are being monitored through fishery statistics and biological sampling, for example, by providing data on recruitment and growth, independent estimates of biomass or basic biological information needed to study species interactions and ecosystems.

The main objectives of the DR. FRIDTJOF NANSEN programme were, however, especially in the first 10 years, of a basic and exploratory nature with emphasis on general descriptions of the composition, distribution and abundance of the resources and overviews of their environment. With these broad objectives the special technical problems of the methodology such as accuracy and precision of biomass estimates, were perhaps not as critical as in more advanced stock assessment studies. However, since these first surveys often described the resources at a stage of low exploitation, which is of value for later reference, there is an interest in reviewing the biomass estimates and as far as possible checking and evaluating their accuracy and reliability.

The investigation and assessment of stocks of small pelagic fish was maintained as a main task in most assignments. The description which follows of the acoustic methods used in these investigations is somewhat detailed because of the importance of this task in the programme and also because the acoustic survey techniques and instrumentation went through considerable developments during the life-span of the DR. FRIDTJOF NANSEN.

In applying the acoustic technique, fish observed in layers close to the bottom were classified and recorded as demersal or semi-demersal fish and identified by sampling with bottom trawls or pelagic trawls just above the bottom. In most of the assignments from 1978 onwards special studies of demersal resources by bottom trawl surveys were included as an additional activity. The problems encountered and experience gained in using this method are discussed below.

2.1 BOTTOM TRAWL SURVEYS

The distribution, composition and abundance of the demersal resources in a defined area of the ocean may be studied by sampling with a bottom trawl. To give valid estimates of precision the sampling should be random with respect to the distribution of the fish. Stratified random sampling meets needs of survey efficiency and is generally used. When dealing with multispecies target stocks, as was usually the case in this programme, stratification by depth ranges would seem most practical.

When combined with an acoustic survey the most convenient positioning of the trawl stations is at fixed distances along a rectangular grid pattern with adjustment, within depth ranges for the depth stratification. This results in a semi-random positioning of the trawl hauls. Although not randomly selected in the strict sense, such stations will almost certainly be randomly positioned in relation to the distribution of the fish as discussed by Saville (1977).

The precision of the abundance estimates obtained from trawl surveys varies greatly with the characteristics of distribution of the species and with sampling effort. Confidence limits from trawl surveys in the ICNAF area were quoted to range from ±25% to ±50% at the level of effort usually deployed in such programmes (Doubleday, 1981). Examples from the DR. FRIDTJOF NANSEN surveys were: ±28% from 105 fishing stations of several surveys of the Omani shelf comprising all demersal fish (Strømme, 1986), while typical confidence limits for biomass estimates of the main species in the Angola surveys ranged from ±32% to ±150% (Strømme and Sætersdal, 1991), and for Namibian hake from ±11% to ±16% within three main regions, (IMR, 1993b). The latter survey was especially planned for hake with a semi-random distribution of fishing stations.

Although the resulting estimate of variance may not satisfy all demands of statistical theory, the results may be interpreted to indicate that the effort of investigation has been at a reasonable level. For species with a highly contagious distribution such as Namibian hakes the sampling effort was increased in areas of high fish density and the data processed following post-stratification by densities.

The existence of possible systematic errors in the method may not be so important when dealing with estimates of relative abundance from a series of similar surveys. Changes in abundance in a given area may thus be observed and comparisons made between relative fish densities in different areas. For absolute abundance estimates, however, all possible sources of bias must be considered. Absolute densities in the survey area are estimated from the catch, the area swept by the trawl and the catchability coefficient, the proportion of fish in the area fished to that retained by the gear. The bottom trawl, designed as shown in Figure 2.1, was especially selected for sampling a wide range of targets: a high-opening small-meshed shrimp-cum-fish trawl with a small meshed inner lining of the cod-end. This gear was used throughout the programme. Later instrumented tows indicated a headline hight of approximately 6 m and a distance between wing tips of 18–19 m.

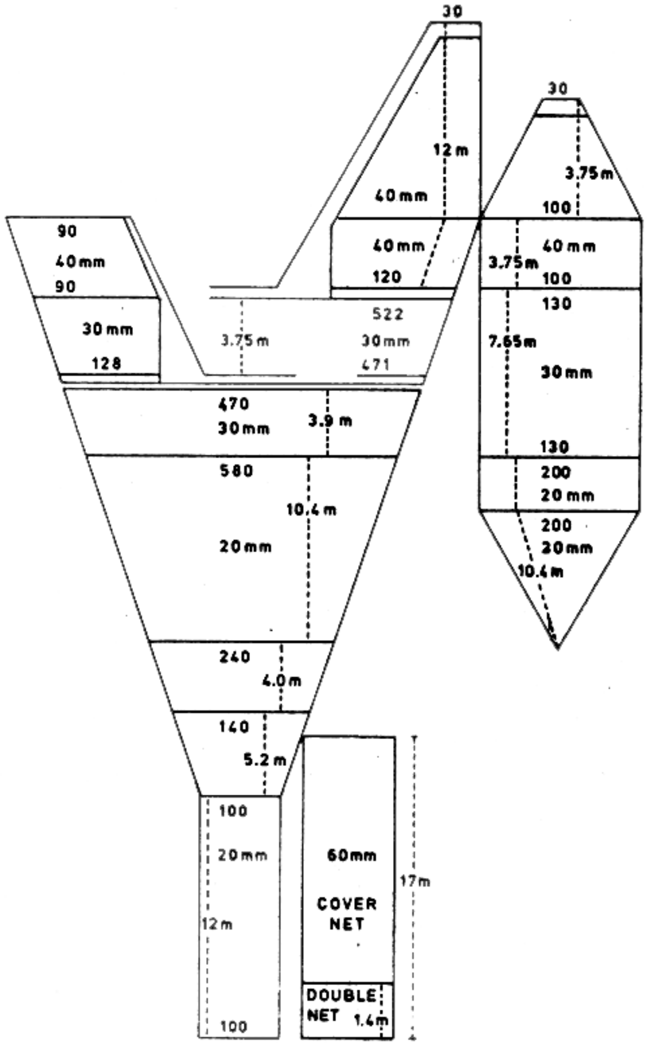

Figure 2.1 Design of the bottom trawl used throughout the programme

This type was chosen in the expectation that it would capture a wide size range of fish and crustaceans with little escapement through the small-meshed forward parts. The catchability of this gear for different species is, however, likely to have varied considerably especially when it was used with bobbins on the footrope as often had to be the case on unknown or rough bottoms. Indications from comparisons with commercial catch rates and comparative fishing trials were that the trawl used by the DR. FRIDTJOF NANSEN had a low efficiency for truly benthic shrimp and fish such as flatfish and monkfish (*Lophius* sp.). A tickler chain was at times used to improve the catch of these benthic targets.

The trawled distance was determined from the ship's log adjusted for currents as observed by navigational instruments. From 1991 on the distance was estimated directly from a GPS navigator giving a precision within 2–4% of the towed distance. The starting point of the tow was, however, based on the navigator's estimate of the time the gear made bottom contact after shooting. Later instrumented observations have shown that this estimate was reasonably accurate at depths down to 150–200 m, but that it was probably biased in hauls at the continental slope at depths of 300 m and more, resulting in overestimates of the swept-area by perhaps 15–20%.

The tow direction with respect to the current varied, but was most often with the current. The geometry of the trawl was observed with SCANMAR™ instruments under survey conditions and the direction has probably not been a source of significant bias.

The most important source of bias in trawl surveys is, however, related to the assumptions concerning catchability. Dickson (1993 a and b) found that estimates of gear efficiency varied considerably both between species and between different sizes of the same species and also by the type of ground gear used. A simplistic assumption was made that the same proportion of all fish in the path of the trawl between the wing tips, irrespective of species or size, would be caught and retained. Therefore, in most surveys the coefficient of catchability (q) was assumed to be equal to 1 for the swept-area between the wing tips, which had a mean width of 18.5 m. This does not necessarily assume that there is no avoidance of gear or vessel, but it implies that avoidance and escapement are approximately balanced by the herding of fish by the trawl bridles and sweep lines.

Trawl survey estimates may also be affected by other important sources of bias. Most demersal fish will tend to rise from the bottom at night and thus be above the headrope of the trawl. But even if fishing is limited to day-time as in most of these surveys, mid-water occurrence may still cause a bias since a number of species classified as demersal fish (snappers, hakes, various sea breams, grunts, silver smelts and others) are commonly found in mid-water and above the headrope of a bottom trawl also during the day. In some of the surveys this source of bias was overcome by making an acoustic estimate of this pelagic component of the demersal fish to be added to the stock estimated by the “swept-area method”.

In most assignments in the Indian Ocean demersal or semi-demersal fish, seen in layers or as single fish near the bottom and in the lower part of the water column were commonly recorded by the acoustic system, and identified and estimated as a special group. These observations included night-time recordings where the demersal fish were rising. The biomass estimates of this group at times exceeded those estimated from the bottom trawl surveys of the same shelf areas (Stømme and Sætersdal, 1982). The group included ponyfish and hairtails which are semi-pelagic and which may in other surveys have been classified as belonging to the pelagic community.

2.2 ACOUSTIC SURVEY METHODOLOGY

In order to be able to follow the developments in the acoustic instruments and methods used on the DR. FRIDTJOF NANSEN and to understand the adjustments that have been made in many cases to the biomass estimates based on corrections induced by later findings, it is desirable to give first a short resumé of the acoustic survey technique as applied on the DR. FRIDTJOF NANSEN. This is partly based on a note prepared by K. Olsen for an Evaluation Report (Hallenstvedt *et al.*,1983).

The use of vertical ranging echosounders and horizontal ranging sonars in fisheries research has a 30–40 year history. Acoustic methods were promoted through international symposia, training courses and user's manuals especially in the period 1960–80 and they now form an indispensable tool in the study of the distribution and abundance of pelagic and semi-pelagic resources. IMR has participated from the outset in the development of acoustic techniques and their application, and the NANSEN programme has benefitted from the close association with an active group of specialists at IMR.

Echosounders combined with echo integrators have proved to be particularly useful for investigation of small pelagic species such as herring, sardine, anchovy, capelin and other species with similar distributions in mid-water schools and layers. Surface schools can be observed with horizontal ranging sonars, but this method poses more problems of quantification than echosounding. Fish situated very close to the bottom may escape acoustic observation, but many demersal species - during feeding, migration and spawning - often have a major part of their biomass in mid-water and combined assessment through bottom trawl and acoustic surveys has been used for such stocks. Acoustic surveying is not suitable for fast-swimming large pelagic fish such as tunas.

The echo integration method has undergone several drastic changes since it was first introduced in the late sixties. The first system consisted of a scientific sounder SIMRAD™ EKS coupled to an analog integrator SIMRAD™ QM, which produced an output in the form of a graph measured in mm. In the next generation of instruments, the SIMRAD™ EK400 sounder coupled to the digital SIMRAD™ QD integrator, the system of using an output index expressed in mm was still maintained at first, but later it was replaced by a new type of measurement, that is independent of the performance of the instruments, the so-called fish constant. In 1991 the SIMRAD™ EK500 system was introduced, an echosounder/integrator system in one unit. All these changes in instrumentation have led to considerable improvements in the acoustic estimation procedures. Findings in later years with better instruments have often shed doubts over the validity of earlier survey results obtained with more primitive instruments.

The original echo integration method is based on the assumption that the recorded echo intensity is proportional to the fish density, when the transmission losses of the received echo are compensated for through the Time Varied Gain (TVG) applied in scientific echosounders. The received echoes are converted into voltage signals, which are squared and integrated by a separate instrument, the echo integrator. The signals are also recorded on paper, which is called an echogram. The output of the echo integrator is considered to be proportional to the density of fish along the course track, as follows:

$$\rho = C \times M$$

where ρ is fish density, M is the output of the echo integrator (expressed in mm with the QM and QD integrators), while C is a conversion factor that depends on the performance and settings of the instruments and on the strength of the echo that is returned by the fish (target strength or TS).

The sonar equation forms the physical basis of the method:

$$EL = SL + TS - 2TL$$

Where EL (echo level) is the level of the reflected sound, SL (source level) is the level of the incident sound, TS is target strength, and 2 TL is two-way transmission loss due to spreading and absorption. Knowledge of the source level of the system and the target strength of the fish is thus critical for using the observed echo levels for fish abundance estimation.

The integrator output generated by a given echo level depends on the voltage response (VR) of the receiving system, gain settings and the Time Varied Gain (compensation for transmission loss and range dependent beam area).

The source level (SL) and the voltage response (VR) are monitored through acoustic calibration. Other control measurements required for proper monitoring of the system are band width, pulse length, frequency, beam width, time varied gain function (TVG) and integrator performance.

Calibration of SL, VR, TVG and pulse length should ideally take place before and after each major cruise.

From the applied value of C and available instrument records the applied target strength can be checked. The analytical relationship between C expressed in tonnes/nmi^2/mm and the instrument characteristics can be written

$C = 3430 \text{ antilog } 0.1[-(SL + VR) + 20\log R + 2\alpha R - 10\log c\tau/2 - 10\log\psi - A + V_0 - TS/kg]$

where:

SL + VR	is instrument performance (source level + voltage response)
R	is maximum TVG range in m
20logR + 2αR	one-way spherical spreading and two-way absorption loss in dB
c τ/2	is half pulse length in m, τ = pulse duration, c = speed of acoustic waves
10logψ	is equivalent beam width in dB/1 steradian
A	is integrator gain in dB
V_0	is integrator performance constant
TS/kg	is target strength of 1 kg of fish in dB

A log-linear relationship has been assumed between TS/kg and fish length (L):

$$TS/kg = -10\log L - B \text{ dB}$$

Based on a length/weight relationship $W = a\,L^3$, where a is the so-called condition factor this is equivalent to assuming the relationship between target strength and fish length for individual fish as:

$$TS = 20\log L - A \text{ dB}$$

With information on the condition factor (a), the transformation between the target strength of 1 kg of fish and of each of n equal-sized fishes weighing a total of 1 kg will be:

$$TS/kg = TS + 10\log n$$

where TS is the target strength of one fish of that length.

The TS is defined by reference to the backscattering cross section of a target as follows:

$$\mathbf{TS} = 10 \log \left[\frac{\sigma}{4\pi} \right]$$

Among the methods of studying target strength of fish mention should be made of cage experiments which in the 1970s represented an early advance. With this method the acoustic system was calibrated against a known density of caged fish. Cage calibrations could provide integrator conversion factors, C, without the need of instrument performance data, an important advantage considering the low precision of acoustic calibration at that time.

The split-beam technique, through which the position of individual fish within the beam is determined, has greatly improved facilities for *in situ* observations of target strength, although with hull-mounted transducers the opportunities of observing single fish targets which may be representatively sampled with fishing gear are rare, a situation confirmed by various efforts for such studies in the DR. FRIDTJOF NANSEN surveys.

The integrator output obtained over a certain sailed distance (usually 5 nautical miles) represents the total density of all species and size groups contributing to the output. The outputs are first compared with the corresponding echograms, and with corresponding catches of targets with pelagic or bottom trawl hauls made along the tracks, before being plotted on the survey track. Contour lines of equal densities are then drawn, which allows a multiplication of echo density by a certain area usually expressed in square nautical miles. Such maps can be drawn for all species combined or separately by species if there is sufficient information to do this. Subsequently, the areas occupied by the fish can be summed on a regional basis and provide estimates of the standing biomass expressed in tonnes.

In order to come up with reliable estimates based on this method it is necessary to know and check the performance of the instruments, to know as much as possible of the daily and seasonal behaviour of the target species and to take very frequent samples of the target species by fishing with pelagic and bottom trawls.

Examples of specific findings and problems encountered during the surveys with the DR. FRIDTJOF NANSEN will be presented in Section 2.4.

2.3 REVIEW OF THE ACOUSTIC INSTRUMENTATION, CONVERSION FACTORS USED AND ESTIMATES OF APPLIED LEVELS OF TARGET STRENGTH

Three generations of SIMRAD™ echo integration systems were used in succession over the programme period, each representing considerable advances made in the instrument component of the acoustic survey technique (Table 2.1). Records of the state and use of the instruments were entered in the logbooks and reports of the electronic engineers of the programme, and are still available.

Table 2.1 Echo integration systems used

Year	Echosounder/transducer	Integrator
1975	Scientific sounders EKS 38, EKS 120	QM (analog)
1979	New ceramic transducer EKS 38	
1980	New TVG function	
1984(April)	EK 400/38, EK400/120 ES 400 split-beam	QD (digital)
1991	EK500, 38 and 120 (38 kHz with split-beam)	EK500

The EKS instruments equipped with TVG belong to the first generation of "scientific sounders" for fishery research purposes. The performance of the EKS 38 was increased significantly with the introduction of ceramic transducers in 1979. They were used with the QM analog integrators. Imperfections of the system included: a relatively limited dynamic range of both the echosounder receiver and the QM integrator thus causing saturation in cases of dense fish recordings; an unsatisfactory bottom discrimination function resulting in the inclusion of dense fish aggregations near the bottom into the bottom echo; and a low dynamic range of the paper recorder which complicated the discrimination of recordings of fish in plankton layers.

All of these imperfections would have tended towards a bias of underestimation of fish abundance.

Table 2.2 shows the history of calibrations of the EKS 38 kHz sounder with hydrophones and later solid spheres. The first survey plan prescribed acoustic calibration once a year with dry measurement monitoring in between, but experience soon demonstrated the need for more frequent checks. The first transmitter was a radio value type, which proved unstable at high performance, necessitating a reduction of transmitting effect in mid 1975 for a more stable performance.

A more stable transistorized transmitter was installed in 1979 together with a ceramic transducer, which was expected to be 3 dB more efficient both in transmitting and receiving functions, resulting in a 6 dB increase in performance of the system.

The accuracy of measuring the performance of the systems increased greatly when the method of calibration with a solid sphere was introduced. Since the solid sphere calibrations gave consistent levels of 138 to 139 dB through 1980–83 it seems reasonable to conclude that this represented the true stable level of the system with the ceramic transducer. Assuming a 6 dB increase in efficiency after the installation of the ceramic transducer, it can be deduced that at the beginning the system had a performance of 133 dB with the nickel transducer.

Table 2.2 Record of *in situ* calibrations of the EKS 38 kHz sounder system, 1974–83

Date and equipment change	Gain setting	SL + VR dB Hydrophone	SL + VR dB Assumed	SL + VR dB Metal spheres
Nickel transducer				
Oct 74	85	132.2 + 6.1	133	
May 76	85	130.3 + 7.7	133	
Apr 77	82	130.1 + 3.1	130	
Ceramic transducer				
Apr 79	85	132.5 + 12.5	145	
Aug 79	85	133.5 + 12.5	145	
Oct 79	85	155		
New TVG				
Apr 80	79			132.5*
Apr 80	79			133.0*
Jul 80	79	132 + 5		133.0*
Aug 80	79	133 + 7		133.0*
Sep 80	79			132.9*
Sep 80	79			133.2*
Jan 81	86			138.0**
Feb 81	85			139.2*
Sep 81	85			139.0***
Nov 81	85			137.8***
Feb 82	85			137.6***
May 82	85			138.4***
Aug 82	85			137.9***
Nov 82	85			137.9***
May 83	85			137.8***
Dec 83	85			137.9***

* 13 cm steel ball
** 50 mm copper ball
*** 60 mm copper ball

The original TVG function was replaced by a new improved design in April 1980. Measurements of the TVG of the EKS 38 sounder in 1979 and in 1981 respectively revealed a substantial difference, 5 to 6 dB in the resulting gain curves (Aglen *et al.*, 1982), thought to result from a special adjustment to absorption in tropical waters of the original TVG. However, this could not be confirmed and it must be assumed that the 5 to 6 dB higher gain was the effect of drift of component performance prior to 1979. The change in gain is confirmed by differences in the results of intercalibrations with the 120 kHz system in September 1979 (EKS 120 = 0.8 * EKS 38, Nakken and Sann Aung, 1980) and in April/May 1980 (EKS 120 = 3.9 * EKS 38, Sætersdal *et al.*, 1980). It is assumed that the TVG change took place in 1978. This performance level, 144–145 dB is also indicated by the hydrophone calibration of April 1979, a measurement undertaken during a home refit visit of the vessel.

During a period in 1980 the receiver gain was reduced from 85 to 79 dB in an attempt to avoid problems experienced at the higher setting of distinguishing between recordings of fish and of spurious sources recorded.

The factors used to convert mean echo levels to biomass, the conversion factor C, which has been reported for each survey, can be used together with the instrument performance for the respective period listed in Table 2.2 to estimate the mean value of the target strength actually applied. The data are shown by assignments in Table 2.3.

The C value used in 1975–77 (C = 10.5) was based on an intercalibration with the R/V RASTRELLIGER of the UNDP/FAO Project IND/69/593 “Survey of the Pelagic resources on the Southwest Coast of India”. RASTRELLIGER's constant was derived from calibrations of live fish in cages (Nakken, 1974). The target strength level in these calibrations was -29 dB/kg for catfish of about 17 cm.

The C value of 10.5 was adjusted to fish size by bringing along the 17 cm fish size from the RASTRELLIGER cage calibration in the form of 0.6 * L.

Table 2.3 Echosounders used for integration, estimated performance, conversion factors used and estimates of applied TS-levels by assignments (TS/kg for 17 cm fish), 1975 to April 1984

Surveys area/year	Main echosounder (transducer)	Receiver gain dB	Estimated performance dB	C-value	TS/kg dB
NW Arabian Sea 75–76	EKS 38 (n)	85	133	10.5	-29
Pakistan 77	EKS 38 (n)	85 or 82	133 or 130	10.5	-29 or -32
Mozambique 77–78	EKS 38 (n)	****	****	****	****
Sri Lanka 78	EKS 38 (n)	85	138*	0.6*L	-34
Sri Lanka 79 (April)	EKS 38 (c)	85	144*	0.25*L	-36
Mesopelagics 79	EKS 38 (c)	85	144*	0.1*L	-32
Myanmar 79	EKS 120	**		0.25*L	-36
Bangladesh 79	EKS 38	85	144*	0.2*L	-35
Sri Lanka 80	EKS 38	79***	144*	0.25*L	-36
Myanmar 80	EKS 120	**	*	0.25*L	-36
Bangladesh 80	EKS 120	**	*	0.25*L	-36
Mal. Thai. Ins. 80	EKS 120	**	*	0.25*L	-36
Mozambique 80	EKS 38	85	139	0.8*L	-36
Kenya 80	EKS 38	85	139	0.2*L	-30
Mesopelagics 81	EKS 38	85	138	0.6*L	-34
Tunesia 81	EKS 38	85	138	0.8*L	-35
W. Africa 81–82	EKS 38	85	138	0.8*L	-35
Mozambique 82	EKS 38	85	138	0.8*L	-35
Tanz./Kenya 82	EKS 38	85	138	0.8*L	-35
Mesopel./Oman 83	EKS 38	85	138	0.6*L	-34
Mozambique 83	EKS 38	85	138	0.8*L	-35
Pakistan/	EKS 38	85	138	0.6*L	-34
Iran 83	EKS 38	85	138	0.8*L	-35
Oman 83	EKS 38	85	138	0.6 or 0.8*L	-34 or -35?
Pakistan 84	EKS 38	85	138	0.6*L	-34?
Yemen, Somalia 84	EKS 38	85	138	0.6*L	-34
Ethiopia 84					

* Adjusted for drifted TVG
** C-factors and TS estimates from intercalibration with 38 kHz echosounder, Sept. 79
*** Integrator readings adjusted to 85 dB gain
**** Instrument monitoring incomplete
(n) = nickel transducer; (c) = ceramic transducer

The next generation of SIMRAD™ echosounders for scientific use, the EK400 series, was brought into use in April 1984. The main improvement of this system was the digitalization of the integration process in the QD integrators, which reduced the problem of saturation at high signal levels experienced with the analog QM integrators. To facilitate *in situ* target strength measurements a split-beam transducer was also constructed for this system.

The EK400 sounder was used with its normal transducer from April 1984 to October 1985 (Table 2.4). The performance was repeatedly measured at 140.8 dB and with a conversion factor of 0.94 this corresponded to -33.2 dB/kg for fish of 17 cm total length.

From November 1985 onwards the ES split-beam transducer was used and the target strength which corresponded to the conversion factors used then was estimated at -33.4 dB/kg. Frequent calibrations of this system showed unexplained variations in its performance of the order of 1 to 2 dB. The conversion factors were, however, adjusted accordingly and it may be assumed that the level of target strength used was -32 to -33 dB/kg for 17 cm fish.

From October 1986 onwards the instrument constant was adjusted to give integrator readings in units of reflecting (backscattering) surface proportional to m^2/nmi^2. This had the advantage of providing comparable acoustic indices independent of the state of the instrument. A "fish constant" only depending on the choice of target strength and the condition factor was then used for conversion to biomass estimates.

A target strength of TS = 20 log L-72 dB was used, corresponding to TS/kg (17 cm fish) = -34 dB to -35 dB depending on the condition factor used.

Table 2.4 Instruments used for integration, performance, conversion factors and applied TS-levels by assignments from May 1984 to June 1993

Survey period	Equipment changes	Main echosounder	Performance SL + VR dB	C-value	TS (dB)
84 (May) to 85 (Oct)	QD integrator EK400	EK400 38 kHz	140.8	0.94	-33.2* (ref. 1 kg)
85 (Nov) to 86 (Sep)	ES split-beam transducer	EK400 ES 38 kHz	137.1	2.28	-33.4* (ref. 1 kg)
86 (Oct) to 90 (Dec)	None	EK400 ES 38 kHz	**	Fish constant 2.86	-34 to -35*** (ref. 1 kg)
91 (Jan) to 93 (Jun)	EK500 system	EK500 38kHz			20 logL-72**** 20 logL-68*****

* TS valid for fish with a total length of 17 cm
** Fish constant, in units of backscattering surface
*** TS level depending on condition factors
**** TS used for small pelagics, adjusted to condition factor
***** TS used for demersals, adjusted to condition factor

For multispecies estimates the condition factor applied from 1986 to 1991 showed that the TS level corresponded to -35 dB. From then on condition factors for the main species were estimated during the surveys and included in the biomass estimates. The result was that for pelagic fish TS = 20log L-72 dB was maintained, while for special surveys of demersal fish TS = 20log L-68 dB was used.

The EK500 system was brought into use in 1991. Its greatly improved dynamic range solved the problem of saturation of the previous systems at high density levels. Frequent calibrations showed very little drift, so this system gave reduced bias and improved precision. It may be appropriate to note that several of the most likely systematic errors of acoustic surveying, such as vessel avoidance by schools, and reverberation loss in dense schools, will still tend towards underestimation of the biomass.

Data logging and processing, the NAN-SIS package

The scientific observations and data were acquired, logged, processed and analysed through a set of work systems which may be classified as follows:

System:	Observations:	Log-book:
Navigational	Position, drift	Diary, ship's journal
Acoustic	Depth, echo levels	Acoustic log
Fishing	Catch rates, composition, biological data	Fishing log
Hydrographical	Temperature, salinity, oxygen	Hydrographic log

The origin and flow of data in these systems may be described as follows:

In the acoustic system, the observations from the echosounders were recorded as diagrams, while the backscattering from mid-water targets was at the same time quantified by the integrators. These data were then subjected to an evaluation process where the targets were classified on the basis of the characteristics of the diagrams, their contribution to the integrator output and information from the fishing system. The output was recorded in the acoustic log by groups of species or by species. Data on bottom depth and type may also have been logged.

The information flow through the fishing system provided data on catches and catch rates by species or species groups, which besides being used for abundance estimation and identification of acoustic targets also provided information on catchability and catch rates. Sampling of catches in addition provided important biological data on key species. Representative sampling of catches for species and size compositions posed special problems and the procedures adopted for this purpose in the programme are described by Strømme (1992).

The hydrographical system provided information on the ocean environment. These data were at times supplemented by observations of surface currents from the navigational system.

The flow of the information in the various systems is shown in Figure 2.2. The processed outputs were then evaluated and formed the basis for the conclusions of the survey work. All original logs were as a rule preserved and stored at IMR for permanent access.

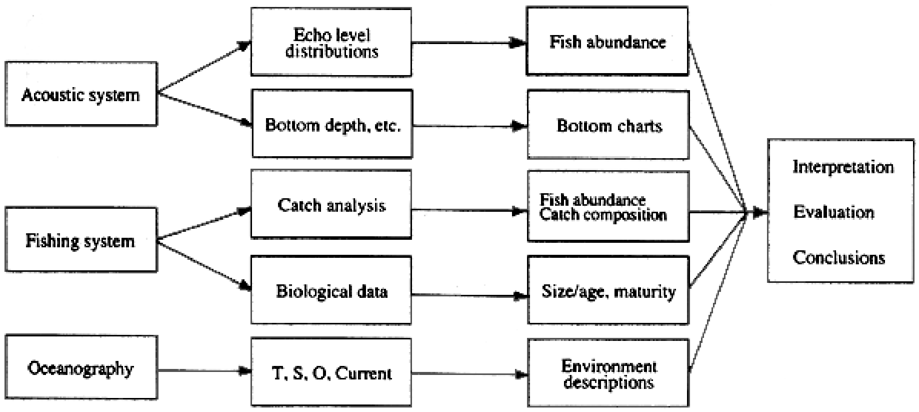

Figure 2.2 Main data flow

The volume of survey data collected increased greatly when, after the first few years of mainly pelagic investigations, the objectives of the assignments were expanded to include studies of demersal fish by bottom trawl surveys. The processing and analysis of the data then became very time-consuming tasks and computerization became necessary. Its purpose was also to facilitate multiple access to the data. In about 1981 a comprehensive system for logging and analysis of survey data was started and this was further developed into the NANSIS software package (Strømme, 1992). It is a Survey Information System for logging, editing and analysis of scientific trawl survey data (trawl-catch data and length-frequency data). It provides summaries of user-selected sub-sets of catch and size data, defined by geographical sector, species or other groupings, depth, gear type, etc. Swept-area calculations can be made for data grouped by user-defined limits.

The multitude of species in tropical waters is handled through a mnemonic species code system. These species codes are converted into scientific or local names using project-based species name catalogues as well as a global catalogue.

NAN-SIS was originally intended only for the DR. FRIDTJOF NANSEN surveys, and was made available to the counterpart co-operating institutions. The program is, however, general and can be used for other trawl fishery resources surveys.

The published version of NAN-SIS does not include the programs for the logging, editing and analysis of acoustic data from the SIMRAD™ QD integrator and the SIMRAD™ EK500 system which were developed and used for the specific equipment of the DR. FRIDTJOF NANSEN.

Nearly all the trawl survey data from 1981 were stored in computerized files. Data collected prior to the development of NAN-SIS were recently entered in this database. The data are accessible for analysis through the NAN-SIS package at the Institute of Marine Research in Bergen, Norway.

2.4 OBSERVATIONS REGARDING ACOUSTIC SURVEY TECHNIQUES AND TACTICS AS APPLIED ON THE DR. FRIDTJOF NANSEN

Identifying fish species from target echoes cannot yet solely be done on an acoustic basis. Studies of the characteristics of echo records and related measurements of signal strength offer, on the other hand, a wide range of clues to the nature of the targets, and may often also permit estimation of their individual size. For a positive identification, however, reliance is placed on sampling by fishing with gears adjusted to the probable type and size of the target organisms, bearing in mind processes of avoidance and selectivity.

The plan for the first Arabian Sea survey stipulated that fishing for species identification and sampling should be undertaken “whenever the character of the fish recordings changed”. This proved in practice perhaps a not very useful directive and instead a simple rule of experience was developed that all targets of any substance should be sampled by fishing for species and size compositions. The incidence of fishing was found to be too low in the first surveys and therefore more time was allowed for fishing in later surveys.

Most small pelagic fish can be caught with a mid-water trawl guided by a netsonde. Gear avoidance of larger-sized fast-swimming fish (sardinellas, mackerels and horse mackerels) was, however, often experienced, especially when these were found in waters of higher temperatures. This was probably related to the limited size of the mid-water trawl and relatively low towing speed of the DR.FRIDTJOF NANSEN and was most pronounced in daytime schools. Catchability was also low for fish in the surface layer when the mid-water trawl was towed with short warps in the wake of the ship. Raising the headline by placing floats on the headline, extending warps and curved towing greatly improved the success of such fishing operations. To sample fish in mid-water in very shallow areas, the bottom trawl was often used with floats.

The bottom trawl with an approximate hight of the headline of 6 m, was used in a normal way to identify and sample fish aggregations expected to be less than 6 m from the bottom.

One survey technique, which was developed with experience included returning to an area with low catchability for sampling under different conditions, usually by taking advantage of the generally higher catchability during nighttime.

An important feature of the practice of acoustic survey methodology as developed by IMR is scrutinizing echograms, in conjunction with the outputs of the echo integrators and data from fishing. The purpose of this exercise is an identification of targets at species-group or species level and an allocation of their contribution to the integrator values. This is done on a daily basis whilst all main survey events are fresh in the minds of the engineers and biologists involved in the continuous monitoring of the instruments and in the fish sampling work.

Many aspects of acoustic surveying techniques need to be adjusted to the target stocks and must in this sense be developed through experience. In particular, account must be taken of existing patterns in the behaviour and distribution of the type of target fish, e.g., related to spawning or feeding cycles when deciding on the design and coverage of the surveys. For the DR. FRIDTJOF NANSEN surveys this basic knowledge had to be acquired for the often virgin areas and stocks covered.

Diurnal changes in behaviour pattern were often observed, such as surface schooling in daytime and the forming of scattering layers at night (except at full-moon periods). The day was then often used for mapping areas with schools while the school areas were resurveyed at night for abundance estimation using echo integration when the fish was found in dispersed layers. Sardines, sardinellas and other small pelagics at low latitudes could diurnally (or at other intervals) migrate towards and from the coast, a behaviour which at times brought parts of the fish biomass into shallow waters where the vessel could not navigate.

At times small pelagic fish in an area would disappear from the recordings of the acoustic instruments after nightfall, but could then be observed, by bioluminescence or in the lights of the vessel, swimming in small dispersed schools in the surface layer.

Sampling and mapping

The overall distribution pattern of a stock was often found to consist of a number of smaller areas of high abundance, “fish field areas”, separated by areas of zero or low fish density thus forming highly contagious distributions. Occasionally the survey data would, however, include a single or few highly dispersed observations of very high fish density in an otherwise empty area, representing an unknown incidence. Such exceptional observations were usually discarded during subsequent analyses.

For stocks with highly contagious distributions adaptive survey designs were applied. Relying on experience the basic grid net of vessel transects was designed so that it was dense enough to find the larger areas of fish abundance and a denser coverage adopted when an area with fish was encountered. This ensured an adjustment of survey intensity to fish density.

The main procedure used for analysis of the acoustic data was recording fish density indices by species or species groups by chart, with post-stratification obtained through contouring of density levels. This procedure is highly practical for comparison with environmental and fishing data, for life history studies and for generally describing distributional characteristics, but it makes estimates of the sampling variance by classic statistical methods unreliable. This approach to survey design and data processing was, however, maintained throughout because it was felt to represent the best use of costly survey effort. In consideration of the errors in acoustic assessments, the scientists applying the method seem historically to have been more concerned with the practical tasks of reducing systematic errors than with estimating precision, perhaps due to a judgement on their part of the priorities involved.

In order to obtain some information on survey precision for “tropical stocks” experiments were undertaken within the programme by repeating surveys of well-limited areas of fish aggregations within a short time period (Strømme and Sætersdal, 1987). The tests included Namibian and Moroccan sardines as well as sardinellas off Senegal. The final biomass estimates varied within 15–20%, a result similar to those of other trials of this kind (Simmonds *et al.*, 1992).

Precision in biomass estimates is related to survey effort when the technique and method in general meet set standards. Aglen (1989) found an empirical relationship between the coefficient of the variation (CV) and the degree of coverage (d), estimated from repeated and partial surveys, where degree of coverage is defined as “distance sailed relative to the square root of the area investigated”. The larger d, the smaller the CV, although this also depended on the type of fish distribution. A common degree of coverage (value of d) for stock assessment surveys is of the order of 10 which gives coefficients of variation ranging from 0.1 to 0.4. For this degree of coverage the precision gained by a moderate increase in effort is small (Aglen, 1989). This measure of the degree of coverage will be presented for the vessel's surveys targeted on coastal small pelagic fish, in order to give an impression of the sufficiency of the survey effort.

Target strength issues

The advances in acoustic instrumentation and techniques, made during the programme period, eliminated or reduced some important sources of systematic errors. Through the sequence of generations of scientific echosounders used (SIMRAD™ EKS, EK400 and EK500), the dynamic range and stability of the systems have been greatly improved, for example solving the early problems of signal saturation. These developments have been discussed in Section 2.3.

There still exist, however, important sources of possible systematic errors: use of inaccurate target strength and the partly related avoidance reactions by fish; signal loss by attenuation in dense schools; and others. The problem of choice of target strength was discussed earlier.

In subtropical and tropical seas, backscattering of sound from non-fish targets in mid-water is at times both widespread and intensive, and creates problems for the discrimination of fish targets especially for fish found in dispersed layers. The origin of this backscattering is difficult to verify, but because of its passive appearance in echograms and as widespread distribution it is assumed to be planktonic. Observations during surveys in Sri Lanka and Myanmar showed that discrimination of fish targets was facilitated by using a higher frequency. A special study was made comparing backscattering of plankton and of fish in simultaneous operations of 38 kHz and 120 kHz systems (Sætersdal *et al.*, 1983). Many observations from surveys in Myanmar and off West Africa confirmed a frequency-dependent backscattering with a mean of 4 dB higher volume backscattering coefficient from fish targets and from 2–7 dB lower values for “plankton” targets at 120 kHz compared with 38 kHz.

Clay and Medwin (1977) identify siphonophores as the source of “planktonic” recordings of echosounding which, with their gas-filled pneumatophores or released gas bubbles, have a profound sound scattering effect due to resonance. Estimated resonance frequencies covered 38 kHz, but did not reach 120 kHz; this may explain the observed higher volume backscattering coefficient of plankton at the lower frequency.

Experimental observations also seemed to confirm a higher target strength of fish at higher frequencies, while later *in situ* measurements have only shown a small difference of about 1 dB between the two frequencies (Ona, personal communication). The difference between frequencies in backscattering from the tropical type of “plankton” seems real and has been confirmed in a general way in other surveys.

For a proper assessment it is necessary to distinguish fish targets from plankton. The decrease in backscattering of fish targets and the increase of that of plankton targets at 38 kHz, reduces the possibilities of separating both types of targets. Therefore, in some areas the 120 kHz system was used, in shallow shelf areas, which could be covered with the limited range of about 100 m of this system (see Table 2.3). In other areas the 120 kHz system was mainly used as an aid in the discrimination of fish traces recorded by the 38 kHz system.

The first-generation echosounder, the SIMRAD™ EKS was less stable than the later models and its maintenance and control represented a technical challenge, especially under tropical conditions. A special problem was the recommended procedure for acoustic calibration at that time which involved the use of a test hydrophone lined up on the acoustic axis in a rig underneath the transducer. This method was found unsatisfactory by IMR and other users because it showed inexplainable variability of instrument performance. A procedure using standard targets in the form of metal spheres with known target strength was developed (Foote *et al.*, 1987) against which the performance of the system, including the integrator could be calibrated. This method was adopted from late 1980 onwards from which calibrations are assumed to have had a high accuracy.

The general state of knowledge has, however, increased considerably since the 1970s. Accumulated data indicate a difference in backscattering cross section between physostome fish represented by clupeoids, and physoclist fish represented by gadoids and a large portion of other fish. Foote (1987) reviewing data on target strength measurements of fish found that the relationships best approximating the many estimates obtained through measurements and by theoretical computations based on swim bladder form are: TS. = 20log L - 67.4 dB for physoclist; and TS = 20log L - 71.9 dB for physostome fish. That this type of relationship between target strength and fish size seems to give the best fit to observed data is explained by the backscattering cross section being related to the square of the fish length.

The observed within-species variation in scattering cross-sections is within each group of the same order of magnitude as the reported between-species differences. The within-species variation seems to depend on such factors as behaviour, recent vertical migration and fat content. In particular, swimming behaviour, by changing the orientation of the fish relative to the acoustic axis, causes great variations in target strength.

Assuming that the within-species variation in target strength is related to fish behaviour and fish condition at the time of the survey and to the particular survey method used, this variation need not have any effect on the precision of the estimated relative abundance indices in a series of similar surveys. In order to improve the accuracy of the estimate of true abundance, however, observations of the actual *in situ* target strength of the fish during the survey are required.

Through the life of the programme the applied mean TS levels reflect largely views held at the time of the survey and vary accordingly. The first TS values used derived from cage calibrations and were at a level of TS/kg = -29 to -30 dB for 17 cm fish. Assuming a linear relationship between TS/kg and fish length and using a condition factor of 0.8–0.9 and proportionality between weight and length cubed, this corresponds to TS = 20 log L - 68 dB. From 1981 on, this level was thought to be too high and the conversion factors were adjusted to the relationship

$$W = a\,L^3$$

TS/kg = -10logL - 22 dB, partly based on a similar relationship used by FAO (Aglen *et al.*, 1982). This gives -34 dB/kg for 17 cm fish and corresponds to approximately 20 log L - 72 dB which is about 4 dB lower and results in more than a doubling of the biomass estimate. This has been the intended TS level in all subsequent surveys, but the actually applied values have at times differed somewhat from this level because of uncertainties regarding the instrument performance.

In reviewing the biomass estimates over the entire period there is a need for adjustment to a uniform TS level for time-series of surveys where the level has varied and where the level used has deviated significantly from the level intended. Since the fish in the sea are a mixture of physostome and physoclist species, use has been made for such adjustments of TS = 20 log L - 70 dB which corresponds to a TS/kg = -32 dB for fish of 17 cm total length.

It should be recalled, however, that the target strength represents only one of the likely sources of systematic error in the biomass estimates. An overestimate caused by the use of a too low target strength may have been balanced by an underestimate caused by instrument saturation, a bias likely to have affected the results from the first EKS scientific sounder period and to some extent the results of the EK400. It would thus seem most important to adjust for use of TS levels that are too high.

Acoustic distribution charts

A number of charts in this review show fish distribution by levels of density based on acoustic data: scattered, dense, very dense. Reference is made to ranges of integrator levels used for density levels. It should be noted that these levels are not directly comparable through the period of operation of the vessel as they refer to different instrument systems. The ranges chosen were also to some extent adjusted to fish abundance in the survey area and were for instance different in Northwest Africa and in the Eastern Central Pacific. The purpose of the charts is to show the main patterns of fish distribution and within regions, the depth of shading, which has been used in the charts, should demonstrate these patterns.

2.5 ENVIRONMENTAL STUDIES

The available bathymetric charts for some of the survey areas were found to have inaccuracies which at times were substantial and of significance for the survey work. Based on the greatly increased accuracy of satellite navigation simple plots of echosounder depth at intervals along the cruise tracks were in such cases used to prepare more correct bathymetric charts of the main shelf and slope areas. These were used to estimate the areas within depth contours over the shelf and slope and for purposes of survey design.

The type of bottom, with special reference to its suitability for bottom trawling - smooth, rough or steep, was observed on the basis of the echograms, and charts were prepared of these characters for all main surveys.

In addition to its significance for sampling, the type of bottom substrate has also faunistic implications, influencing the composition and distribution of demersal fish. Ordinary echo recording provides some information on bottom substrate, but usually only enables distinction between hard rocky or coral bottom and soft muddy bottom. Attempts were made in surveys off Angola and Namibia to calibrate an early version of the ROXANN™ acoustic system for bottom substrate discrimination against the bottom conditions in these regions by a grab sampling programme. These attempts met with only limited success, but there is no doubt that systematic recording of this character would represent important additional information on the environment of the demersal fishery resources.

Continuous records with a thermograph were made of the sea temperature at 5 m depth. Casts with Nansen bottles were used to record temperature and take water samples at standard depths. Salinity was analysed on board by salinometer and usually also dissolved oxygen by the Winkler method. A CTD sonde was used from 1991 onwards.

Hydrographic profiles were designed to cover the shelf and slope with observations extending to 500 m depth and with some stations, usually two, occupied oceanwards beyond the 500 m depth line. In some surveys vessel drift was recorded for the description of surface currents. Logistic use was made of the vessel for mooring of current meter rigs in the Somali Current in 1976 in co-operation with the University of Miami and the Institute of Marine Science in Kiel. Co-operative programmes were conducted with the objective of comparing *in situ* temperature observations with data from remote sensing from satellite systems.

Besides presenting a general description of the hydrographic environment, the analysis of these data concentrated on features of the environment which were expected to influence the distribution, composition and abundance of the resources, such as surface salinity in estuarine areas, depth of the thermocline, oxygen-depleted water in the bottom layers, upwelling as an indicator of enhanced productivity, prevailing currents ocean fronts and seasonal changes of the main parameters and in the regime as a whole.

2.6 TAXONOMY AND BEHAVIOURIAL CLASSIFICATIONS

Tropical and subtropical regions are characterized by the high species diversity of their flora and fauna. The marine environment is no exception and nearly 40% of all known fish species occur in the shelf waters of tropical oceans. The Indo-Pacific region, in particular, contains by far the most diverse fauna of any marine zoogeographic region.

The DR. FRIDTJOF NANSEN programme started its operations in the Indian Ocean and in Southeast Asia and, not surprisingly, species identification constituted a major problem. In addition to the complexity of the fauna, at that time most of the taxonomic information was only available in specialized scientific journals and was thus practically inaccessible or inappropriate for field work. The two main monographs on fish taxonomy available were the J.L.B. Smith's 'Sea Fishes of Southern Africa' (Smith, 1972) and one of the first sets of the 'FAO Species Identification Sheets for Fishery Purposes' covering FAO fishing areas 57/71 (Fischer and Whitehead, 1974). These documents had, however, great limitations, both in the erroneous classification of many taxa and in their limited coverage of species and geographic range.

The scanty literature, coupled with the lack of experience amongst Norwegian scientists in tropical fish taxonomy, may have affected the data quality in the first years of the programme, at least as far as identification to species level was concerned. Attempts were made to overcome this problem, at least in part, with the help of international experts or experienced local counterparts. The first taxonomist was engaged for a special survey of deep-water resources off Kenya in 1980. His findings indicated that better taxonomic classification was urgently needed (Nakken, 1981; Venema, 1981).

Since a good collaboration was established with the FAO Species Identification Programme, based on mutual interests: FAO provided, whenever possible, a tropical-fish expert to help with species identification and this constituted at the same time a unique opportunity to collect valuable field information. Sets of Species Identification Sheets and field guides under development were tested in the field, specimens of 'problem species' collected, and distribution charts modified according to field observations. New occurrence records, both by depth and geographic range, were usually confirmed by sending specimens to relevant taxonomists. The Identification Sheets for the Eastern Central Atlantic, Fishing Areas 34/47 (in part) (Fischer *et al.*, 1981) and those for the Western Indian Ocean, Fishing Area 51 (Fischer and Bianchi, 1984) benefitted from this collaboration.

On board the DR. FRIDTJOF NANSEN, apart from the identification work, the large database on species records was routinely updated and nomenclaturial errors corrected.

As new areas were covered by the surveys and whenever there was a clear need for compiling or updating taxonomic information on the marine resources, the programme took the initiative of starting the preparation of new field guides and provided both funds for printing and the opportunity to collect field data. This was always done in collaboration with the FAO Species Identification Programme, responsible for the implementation of this activity. The above resulted in the publication of the field guides for Angola (Bianchi, 1986), Morocco (Bianchi, 1984), Mozambique (Fischer *et al.*, 1990), Namibia (Bianchi *et al.*, 1993), Pakistan (Bianchi, 1985a), Sri Lanka (De Bruin *et al.*, 1994), Tanzania (Bianchi, 1985b), Northern Coast of South America (Cervigón *et al.*, 1993) and the Eastern Central Pacific (Fischer *et al.*, 1995).

As years passed, the greater availability of adequate taxonomic literature and the growing experience of Norwegian participants allowed for a more detailed identification of the catches, usually including all species caught. Although identification of all species was not a priority (major food fishes were the main target of the surveys), those data constitute a unique evidence of species occurrence and diversity.

A number of scientific names used in early survey reports are now outdated and are considered synonyms. However, these denominations have been maintained in the reviews contained in this volume for reasons of consistency.

Not only taxonomic classification has been a major challenge. As already mentioned in earlier sections, the use of operational categories such as pelagic and demersal, widely used in fishery research, soon proved inadequate. In fact, there is hardly any fish species whose behaviour strictly conforms to either. From observations on board the vessel, many species traditionally assigned to either group show intermediate types of behaviour. As a consequence the allocation of any species to those categories is difficult if not impossible. For example, in waters over the continental shelf, many so-called pelagic groups are usually observed near the bottom and are caught in the bottom trawl, including several Carangidae of the genera *Trachurus, Chloroscombrus, Selene, Caranx* etc., barracudas, Scombridae (mainly *Scomberomorus*) and even Clupeidae. Also further offshore, large schools of sardinella may be found resting on the bottom during daytime.

On the other hand, it is well known that many demersal fishes rise from the bottom at night. Many species, however, occur in mid-water without a clear pattern of vertical distribution, e.g., ponyfishes, snappers, seabreams, etc. Unfavourable conditions near the bottom on a seasonal basis (for example, as with the occurrence of oxygen-depleted waters) may trigger off a pelagic behaviour. This has been observed, for example with catfishes of the genus *Arius*, dragonets (family Callyonimidae), threadfin breams (*Nemipterus*) etc. especially in the shelf areas of the Arabian Sea.

The same species may have different types of behaviour in different regions, for instance being more pelagic where upwelling is more extensive in duration or strength. Such adaptations are typical for the horse mackerel *Trachurus trecae* which occurs off central and southwest Africa. The changes in behaviour might be due either to temperature preferences or to changes in the availability of food.

These observations indicate that the categories 'demersal' and 'pelagic' are ecologically and operationally inadequate. Most species seem to possess a wide range of adaptations and flexibility, responding in different degrees to regular or stochastic fluctuations in ecological conditions.

A deeper analysis of various types of behaviour and of the environmental factors generating them would be desirable. Apart from increasing the understanding of the ecological adaptations to the marine environment, it would improve the application of methods used in investigations on the distribution, composition and abundance of marine resources.

In this review, in addition to the two classical categories pelagic and demersal, three other categories are used: semi-demersal, for species traditionally defined as demersal, and with a body shape more adapted to living close to the bottom, but often observed in mid-waters; and semi-pelagic indicating those species usually designated as pelagic, and with body shape adapted to mid or upper-water layers, but often found close to the bottom and caught in the bottom trawl and meso-pelagics, fish that reside during the day at depths around 300 m and that may rise to near the surface at night.

3 SURVEYS IN THE ARABIAN SEA AND ADJACENT GULFS

3.1 RESEARCH HISTORY OF THE INDIAN OCEAN AND OVERVIEW OF ASSIGNMENTS OF THE DR. FRIDTJOF NANSEN

Until the 1950s, the Indian Ocean had to a large extent been neglected by marine scientists compared with the long history of explorations and investigations of the Pacific and Atlantic Oceans. This was one of the reasons why, following successful international co-operation in oceanographic research in the Pacific and Atlantic Oceans during the International Geophysical Year (IGY) 1957, oceanographers agreed to collaborate and concentrate oceanic investigations in the Indian Ocean for a period of several years starting in 1959. This evolved into an international venture in marine science on an unprecedented scale: the International Indian Ocean Expedition (IIOE), which during 1959/65 attracted about 40 research vessels from 20 countries at a total estimated cost of about US$ 60 million (Behrmen, 1981).

The Indian Ocean had the attraction of the unknown, but another main reason why marine scientists from so many countries joined the IIOE was the professional interest in this unique area, closed by land masses in the north in contrast to the Pacific and Atlantic Oceans, and with its regular seasonal reversal of circulation caused by the monsoon shifts.

Although not all expectations for a systematic coverage of observations in time and space were met - the venture has been described as a five-year series of more or less unco-ordinated expeditions - the IIOE resulted in a greatly increased state of knowledge of all basic processes in the Indian Ocean. The fishery sector had been held out as the main potential beneficiary of the IIOE, but direct fisheries research was not among the types of investigation made. Nevertheless, the data and information on physical, chemical and biological oceanography acquired were of great interest for fisheries.

FAO's Fisheries Department was keenly awaiting the presentation of the findings of the IIOE and commissioned a special analysis of data relevant to fisheries which was submitted in the form of an “Atlas of the Arabian Sea for Fishery Oceanography” (Wooster *et al.*, 1967). Reviewing data on primary production and considering the fishery implications, the authors of the Atlas concluded: “that it may quite confidently be stated that the western side of the Arabian Sea is one of the more productive parts of the world oceans”.

The mean productivity of the entire western portion of the Indian Ocean up to several hundred miles offshore was reported to be on average several times that of the mean of the world oceans with an estimate as large as or larger than that encountered in such upwelling areas as the eastern boundary currents off Peru and off West Africa. Since the Peruvian fishery in its contemporary remarkable expansion had by 1967 grown to give an annual yield of 8 to 9 million t, the comparison with its primary productivity was a very optimistic signal for Indian Ocean fisheries. One of the authors of the atlas, Schaefer, estimated later a potential annual yield of the Arabian Sea of 10 million t (Shomura *et al.*, 1967) and fishery adviser Wib Chapman, in one of his widely circulated discussion letters at that time indicated a range of 10–20 million t.

The Indian Ocean had been a largely neglected area not only with regard to scientific research, but also fisheries development. Following the encouraging findings from the IIOE of high primary productivity, FAO took the lead in creating a programme for support and co-ordination of fisheries research and development in the Indian Ocean. After a preliminary discussion at the First Session of the FAO Committee on Fisheries (COFI) in 1967, at its Second Session in 1968 COFI recommended the establishment of an Indian Ocean Fishery Commission (IOFC) having as one of its major objectives the promotion of research and development activities in the area through international efforts and in particular with the assistance of international aid programmes. A special International Indian Ocean Fishery Survey and Development Programme or Indian Ocean Programme (IOP) was planned at IOFC's First Session in 1968 and was subsequently established with financial support from UNDP.

In its first phase, estimated to last one year, the IOP was to assemble and examine all existing data and information so as to provide a synopsis of the current status of knowledge regarding the resources of the area. This was to be followed by an operational phase of three years and a concluding one-year period.

The final operational plan of the programme, presented in Marr *et al.* (1971), included a synopsis of special consultations and detailed studies made during its preparatory phase. This plan first reviewed all the important questions regarding resources and potential yields. A simple catch projection for the Indian Ocean as a whole was made by extrapolating the catch per unit area obtained in the Pacific and Atlantic Oceans based on the not unreasonable assumptions that these catch rates should be roughly comparable. In 1968 the actual catch per unit area in the Indian Ocean was only about one-sixth of that of the other two oceans and about one fourth if the areas compared were those of the continental shelves. Since the Pacific and Atlantic Oceans were at that time assumed to produce only about half of their maximum yields, the total potential of the Indian Ocean would on this comparative basis be some 8 or 12 times the 1968 catch.

A more comprehensive analysis of Indian Ocean potential, based both on observations of productivity and on extrapolations and comparisons of yield or biomass densities presented by Shomura (in Gulland, 1970) estimated the total yield to be about 14 million t, or some six times the 1968 catch. This level was used in the operational plan of the IOP to demonstrate possible growth rates of Indian Ocean fisheries over a 20-year period.

The review by Marr *et al.* (1971) also made reference to other available studies of the Indian Ocean's potential. Based on observations of primary productivity and considerations of trophic relationships, Cushing (1971a and 1971b) estimated annual production at the third trophic level at about 9.5 million t for the upwelling areas, and Prasad *et al*. (1970) gave an estimate based on ratios of carbon production and results from exploratory surveys of 11 million t annual sustainable yield. Although these estimates indicated a lower total potential yield than 14 million t, they agreed in holding out considerable scope for expansion of the fisheries.

Among its various recommendations, the IOP's Plan for Fishery Development in the Indian Ocean contained a series of pre-investment fishery development surveys. Priority was given to a pelagic fish assessment survey in the northwest Arabian Sea to be conducted by one vessel over one year. This part of the ocean had been reported in several studies as one of the most promising and it was thought that the high productivity would sustain abundant stocks of small pelagic fish as in the Pacific and Atlantic Oceans in upwelling systems of eastern boundary currents.

Survey assignments

The planning of the IOP preceded that of the DR. FRIDTJOF NANSEN programme by about one year. FAO and UNDP saw the little-researched Indian Ocean as an important potential region of operation for the DR. FRIDTJOF NANSEN and the high-priority task of an acoustic-cum-fishing survey of the small pelagic fish in the northwest Arabian Sea represented a very suitable first assignment. This initiated a long period of investigations with the vessel in this region. Nine of the first ten years of operation (1975–84) were spent in various parts of the Indian Ocean (Table 1.1 and Appendix II). This reflected the special need which existed for more information on its fishery resources and also demonstrated the expectations as to its development potentials.

Figure 3.1 shows the geographical coverage of DR. FRIDTJOF NANSEN surveys in the Indian Ocean: most of the Indian Ocean's coastal areas were included, except those of India, Australia and most of Indonesia. The southwest coast of India was already covered by a survey programme with similar objectives, the FAO/UNDP Pelagic Fishery Project (IND/69/593) in the period 1971–76 and its successor (Pelagic Fishery Investigations on the Southwest Coast - Phase II (IND/75/038) (FAO, 1982).

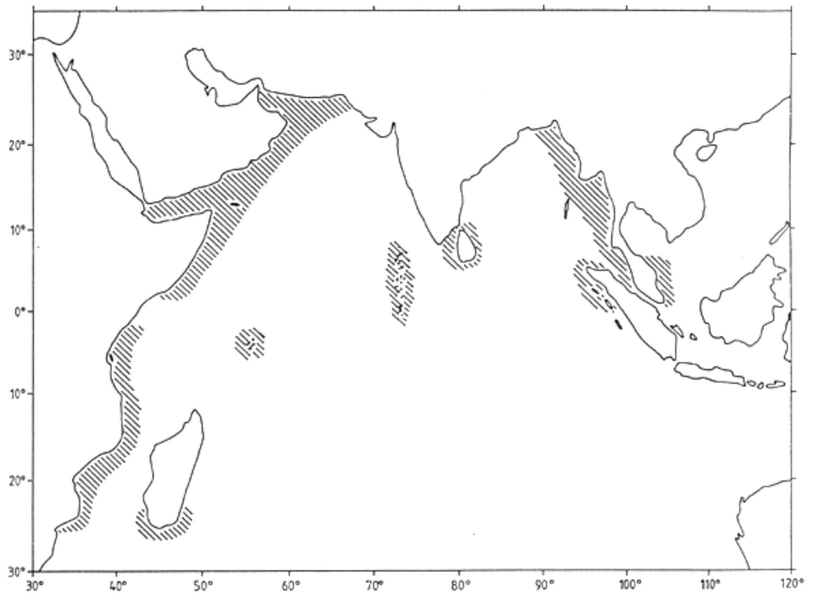

Figure 3.1 Location of the DR. FRIDTJOF NANSEN surveys in the Indian Ocean and South China Sea, 1975–84

During the first two years (1975 and 1976), the DR. FRIDTJOF NANSEN surveys differed from later assignments in having an exploratory character, investigating wide and largely unknown areas in order to obtain a first appreciation of the distribution, composition and the magnitude of the pelagic fish stocks in these waters. In retrospect, this first exploratory phase could be considered unnecessarily long, and a change to more detailed investigations of specific areas could have been made after only one year. The situation after the completion of one pre-monsoon and one post-monsoon coverage was, however, one of considerable uncertainty (IMR, 1976b). Although survey results confirmed the occurrence of small pelagic fish in the known highly productive inshore areas, their estimated abundance was nowhere as high as expected. On the other hand, the very high abundance of mesopelagic fish over the whole survey area was an unexpected finding. There was thus a need to confirm these general results and check on possible inter-annual variations. The character of the work and main objectives were therefore maintained in the continued survey, although there was some redistribution of survey intensity with more attention being given to the most promising parts.

Subsequent assignments were based on a different approach as regards both the general organization of the surveys and their objectives. Even though still operating under the umbrella of the IOP until its termination in 1979, each assignment was now planned and executed in closer co-operation with authorities of the countries concerned and the survey period was estimated to allow detailed repeated investigations of all the resources which could be targeted by the methods used as well by environmental studies.

In the late 1970s there was considerable interest in fishery research among the coastal countries of the Indian Ocean. FAO, through IOFC and IOP, had made the countries aware of the potentials for fishery development. In addition most States in the region had by the late 1970s established EEZs in accordance with the provisionally agreed text of the Law of the Sea Convention and were conscious of a need for more information on the fishery resources within their EEZs.

The sequence of new DR. FRIDTJOF NANSEN assignments did not follow a long-term plan, but was adjusted to meet priorities set in part by FAO/UNDP, and in part by NORAD. In many cases assignments were renewed in a region or coastal zone already covered. The objective was then to confirm and supplement previous work and to study interannual fluctuations of the composition, distribution and abundance of the resources.

The IOP's original plan for a pelagic fish assessment survey of the North Arabian Sea included the whole shelf and adjacent ocean from Somalia to Cape Comorin (the southern tip of India) (Midttun *et al.*, 1973). In order to provide a more complete overview of the pelagic resources of the entire North Arabian Sea reference will also be made to the findings from the almost contemporary (1971–75) survey programme off the southwest coast of India, the FAO/UNDP Pelagic Fishery Project (IND/69/593). This project was not part of the DR. FRIDTJOF NANSEN programme, but IMR was involved in its scientific execution and there was an important intercalibration between the project vessels RASTRELLIGER and DR. FRIDTJOF NANSEN. In order to maintain a time sequence in the review, this project will be presented first (see Section 3.2).

Section 3.3 deals with the first exploratory period of the DR. FRIDTJOF NANSEN which covered the highly productive northwest Arabian Sea from Pakistan to Somalia in 1975–76. Relevant findings of the Pakistan assignment of January-June 1977 are also included.

The joint findings of these surveys represented at that time the first, and in retrospect apparently fairly conclusive, replies to the important questions concerning the fish potentials of the Arabian Sea and adjacent Gulfs for which such high expectations had been held out.

The mesopelagic fish, which in their high abundance are restricted to the slope of the continental shelf and the adjacent oceanic parts of the northwest Arabian Sea, are described separately in a section which includes the special follow-up surveys mounted for these species in 1979, 1981 and 1983 (Section 3.4).

Section 3.5 describes the follow-up surveys for small pelagic and demersal fish from Pakistan to Somalia from 1983 to 1984 on a country-by-country basis.

Other parts of the Indian Ocean are dealt with in Chapters 4 and 5.

3.2 PELAGIC FISHERY INVESTIGATIONS OFF SOUTHWEST INDIA, 1971–75: RESULTS OF THE FAO/UNDP PROJECT IND/69/593

Project objectives and effort

The southwest coast of India (Malabar coast) is included in this review for reasons of completeness. This will allow comparisons between the upwelling system off the Somalia-Arabian coast and that off the Malabar coast. The survey methods used were more or less identical to those of the DR. FRIDTJOF NANSEN programme, a result of IMR's involvement in both programmes.

The project resulted from a request from the Government of India to UNDP/FAO in 1967. The background was the experience of wide fluctuations in the yields of the important inshore fisheries for oil sardine (*Sardinella longiceps*) and mackerel (*Rastrelliger kanagurta*) on the coast from Cochin to Goa resulting in shifts between seasons of glut and years of failing fisheries with extremely low landings. It was envisaged that an expansion to offshore fishing could stabilise production, but prior to such attempts investigations were required to determine the distribution, migrations and abundance of the two species. Such investigations were the main objectives of the project with the addition of fish behaviour studies related to fishing methods as well as experimental fishing.

Equipment and installations of importance for the project were available at the headquarters of the former Indo-Norwegian project at Cochin. This institution continued as a Government of India organization after the termination of the Norwegian co-operation and was given responsibility for the project on the Indian side. The major FAO/UNDP components were sub-contracted to the Norwegian Agency for International Development (NORAD) with the IMR acting in the field.

The main project work was to be based on acoustic-cum-fishing surveys with two research vessels. Project duration was about five years, 1971–75. Following a later decision, a second phase (IND/75/038) with FAO as the executing agency, was continued until 1979. The long-term objective of this second phase was to assist in developing the pelagic fishery off the southwest coast within the framework of government policy as expressed in the five-year plan 1974–79. Principal elements of that phase were vessel and gear development, fish handling, transport, utilization and marketing. Although resource surveys were mounted, their results contributed no information additional to that provided by the first phase and thus these surveys are not included in this review.

The effort expended in the first phase was considerable, with two project research vessels, RASTRELLIGER (46 m LOA) for offshore and SARDINELLA (16.5 m LOA) for inshore waters, support of exploratory vessels from the former Indo-Norwegian project and additional aerial surveys for supporting observations of surface schools. Personnel in the first phase totalled 35 man-years of expatriate and 55 man-years of national staff. Training through fellowships and on-the-job was an important element of the project.

Environmental components of the project included oceanographic investigations with particular reference to the effects of monsoon shifts and related upwelling process, and zooplankton and fish egg and larva investigations to study production and spawning cycles.

The work programme was conducted successfully, with dense coverages both in time and space by the survey vessels of the shelf between the Gulf of Mannar in the south and Ratnagiri in the north. A very large amount of data and material pertaining to all the objectives of the project was collected in a systematic way, processed and reported on. This was a unique and major research programme, an intensive study of an assemblage of important pelagic resources affected by distinct seasonal environmental changes in a highly productive tropical upwelling area. The results are described in detail in 18 Progress Reports (see references under IMR/NORAD/FAO), and a brief summary is available in a Terminal Report, (IMR/NORAD/FAO, 1976h). Participating Indian scientists have reported special scientific findings in Indian journals, but a historical report with a comprehensive description and analysis of the results of the pelagic fishery investigations on the southwest coast of India has unfortunately not been attempted.

The project is of interest also regarding the investigation methods used. The preceding Indo-Norwegian project initiated sea-going research already in the late 1950s, but this consisted mainly of exploratory and experimental fishing with some oceanographical work. The emphasis in this new project was placed on systematic acoustic-cum-fishing surveys, using an echo integrator. The acoustic integration technique was, however, soon found to be inadequate in surveying the predominantly surface-schooling oil sardine and mackerel and therefore a multi-vessel school survey with synoptic observations from aerial surveying was tried. Echo integration was applied for assessing other pelagic and benthopelagic stocks. In retrospect it is seen that in this initial phase of the echo integration technique, problems of its application were unavoidable. The most serious constraint was the lack of a reliable method of instrument calibration (see Section 2.3).

Figure 3.2 shows the project area and examples of coverage during the oil sardine/mackerel and echo integration surveys. The shelf width to 200 m depth increases from about 30 nmi in the south to about 60 nmi in the north. Data on the survey area are given in Table 3.1 which also shows approximate estimates of the resulting survey intensity of the course tracks shown in Figure 3.2. The estimate is based on the area covered for the oil sardine/mackerel survey and on the total shelf area for the general surveys. The survey intensities are high compared with efforts in similar exercises.

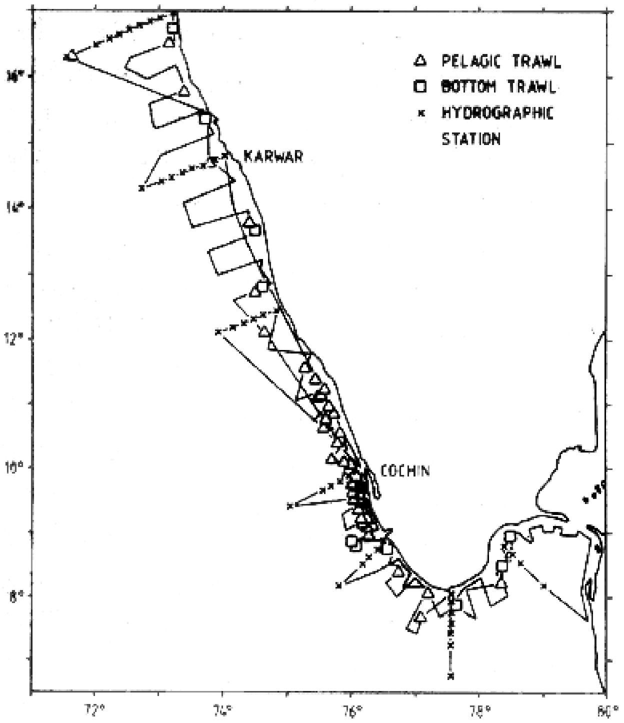

Figure 3.2 Example of course tracks, hydrographic stations and fishing trials in a survey coverage of the project area (from IMR/NORAD/FAO, 1976g)

Table 3.1 Survey area and approximate degree of coverage

Length of coastline	820 nmi
Shelf area to 200 m	33,000 nmi^2
Degree of coverage:	
Oil sardine, mackerel	18
Echo integration	17

The project's main survey activities are summarized in Table 3.2. The SARDINELLA was available from June 1971 and the RASTRELLIGER from January 1973. The post-monsoon season, September-October, was selected for synoptic surveys of the schooling oil sardine and mackerel while the numerous main integration-cum-fishing surveys covered all seasons, with the RASTRELLIGER also during the southwest monsoon. There are thus four post-monsoon surveys of the oil sardine and mackerel schools, 1972 through 1975, and three years of echo integration surveys, 1972–73, 1973–74 and 1974–75.

Table 3.2 Summary record of the project's main resource surveys 1971–75 using the research vessels SARDINELLA and RASTRELLIGER, auxiliary vessels and aerial scouting

Time	Craft	Objectives
Jun 71-Sep 72	SARDINELLA	Introductory surveys
Oct 72	SARDINELLA & Aerial	Sardine & mackerel stocks
Oct 72-Aug 73	SARDINELLA & RASTRELLIGER	Eight echo integrator surveys
Oct 73	SARDINELLA, RASTRELLIGER, Aerial & 5 auxiliary vessels	Sardine & mackerel stocks
Sep 74	SARDINELLA, RASTRELLIGER, Aerial & 4 auxiliary vessels	Sardine & mackerel stocks
Sep 75-Oct 75	RASTRELLIGER & SARDINELLA	Sardine & mackerel stocks
Sep 73-Oct 74	RASTRELLIGER & SARDINELLA	Ten echo integrator surveys and surface school observation
Nov 74-Sep 75	RASTRELLIGER & SARDINELLA	Seven echo integrator and sonar surveys

A programme of oceanographic observations in seven fixed sections was followed from June 1971 to October 1975 with observations of temperature, salinity and dissolved oxygen. No comprehensive reporting of the project's results as regards experimental fishing is available, but findings are discussed in the progress reports.

Hydrography

The profound seasonal changes in the environment represent keys to the understanding of many features of the distribution and behaviour of the fish stocks. The oceanography programme is described in IMR/NORAD/FAO 1973b and 1976e and in Johannessen *et al*. (1987). During the northeast monsoon, November-March, there is a weak northward-flowing current along the coast transporting low salinity water originating from the Bay of Bengal. The surface layer is stable and the water on the shelf is well aerated. The current reverses in March-April responding to the main wind field in the northwest Indian Ocean, and during the southwest monsoon season from May-June to September-October the current flows southward at a much higher velocity than the northward current.

In the southward current the isopleths tilt upwards towards the shore. This appears to start already in March-April. With the start of the southwest monsoon in May-June the sloping intensifies and upwelling occurs along the coast with increased primary production. There has been some uncertainty regarding the forces driving this upwelling, but according to Longhurst and Wooster (1990) the prevailing westerly local monsoon has an equatorward component which advects surface water offshore leading to the upwelling of water already tilted by the anticyclonic gyre spun by the southwest monsoon.

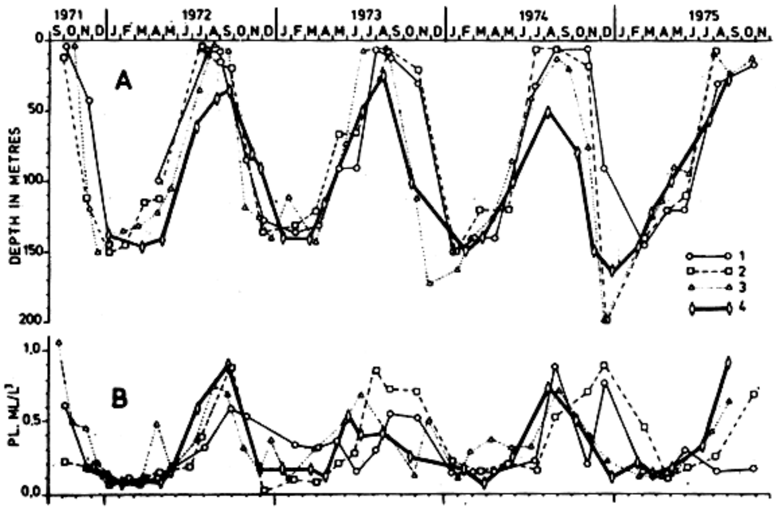

Figure 3.3 A: Depth of the intersection between the 1 ml/1 oxygen isoline and the bottom
B: Zooplankton biomass in ml plankton per m³ water filtered.
1: Karwar section; 2: Kasaragod section; 3: Cochin section; 4: Quilon section
from Johannessen *et al.*, 1987

The shoreward tilting of the isopleths in the southward current and the upwelling causes penetration of low-oxygen water, less than 0.5 ml/l, over the entire shelf almost on to the shore. The regularity of this process and hence of the upwelling is demonstrated in Figure 3.3 which shows the intersection between the 1 ml/l oxygen isoline and the bottom in four sections along the coast from 1971 to 1975. The direct effect of upwelling on production is demonstrated by the observed densities of zooplankton biomass in these sections. It is notable that the minimum zooplankton biomass is observed in February-March with the trend of increase starting already in April-May prior to the onset of the local southwest monsoon.

The upwelled low-oxygen water affects the fish distribution on the shelf. The surface layer of aerated water which forms the habitat of the oil sardine and the mackerel is very thin and restricts the depth distribution of these fish. Changes in the distribution along-shore were also noted, both for demersal fish and anchovies with restriction to the southern shelf and Gulf of Mannar in the southwest monsoon period.

Biomass estimates from the echo integration surveys

The reliability of the abundance estimates using this method depends *inter alia* on whether the constants used for converting acoustic indices to biomass were appropriate for the various types of fish and based on a proper calibration of the system. As discussed in Chapter 2, the methods used in the first part of the 1970s of measuring the performance of the echo integration system had a low precision. The hydrophones were generally unreliable and their use under field conditions such as in the project reviewed here were especially difficult. Under these circumstances, experimental determination of the conversion factors by cage calibration on live fish as chosen by the project was the best approach, but this involved cumbersome and time-consuming experiments not suitable for regular monitoring of the instruments.

The performance of the 120 kHz EKS sounder which was used throughout for echo integration was reported in IMR/NORAD/FAO (1974a) to be 104.9 dB (probably the level measured after installation in Norway). Cage calibrations with catfish (*Arius thalassinus*) showed a mean target strength of -29 dB/kg corresponding to a conversion factor C of 6.5 t/nmi²/mm. Further experiments were made in 1974 (Nakken, 1974), which confirmed this value of C for 17 cm fish and indicated a stable performance of the system. However, -29 dB/kg seems a high target strength level for these fish. A more likely level is -32 dB/kg which would correspond to an instrument performance of 108 dB.

Unfortunately, cage calibrations with anchovies were not possible. Although an attempt was made to determine the target strength level of these small-sized fish (IMR/NORAD/FAO, 1974a), the proportional relationship between fish size and conversion factor C which solves this problem was only adopted by IMR after the termination of the project. Assuming a size of the anchovy of 8 cm for the seasons of their high abundance, the conversion factor C for estimating biomass would have to be reduced by about 50% to adjust for this size of fish.

The instruments of the research vessels were maintained and kept operational by the project's experienced electronic engineers. The maintenance reports are no longer available, but through interviews it has been established that a major repair with replacement of electronic parts was undertaken in late 1974. No further cage calibrations were made, but in June 1975 an intercalibration was performed with DR. FRIDTJOF NANSEN which showed that

120 kHz RASTRELLIGER = 120 kHz DR. FRIDTJOF NANSEN * 7.9

The performance of the 120 kHz system of the DR. FRIDTJOF NANSEN was later found to be 103 dB in calibrations with a metal sphere (standard target). If this was the performance also in 1975, the 120 kHz echosounder of the RASTRELLIGER must have had a performance of 112 dB. This indicates an increase in performance after the repair of 112 - 108 = 4 dB or 2.5 times.

The details of this assumed history of the performance of RASTRELLIGER's system are not much more than guesswork, but the intercalibration strongly suggests that a significant increase of the performance must have taken place between 1974 and 1975.

The project's time-series of the biomass estimates of anchovies shows an approximate doubling from the 1974 to the 1975 season. Substantial increases of biomass of the order of three to seven times from 1974 to 1975 were also reported for the other groups covered by the echo integration surveys. It seems difficult to find a biological explanation for such large and simultaneous increases in the abundance of all the groups of both short-lived and long-lived fish.

The survey programmes included many fishing trials with the pelagic trawl for identification and biological sampling. Although a simple relationship between catch rates and abundance in these trials cannot be expected, an overall biomass increase of about three times for the target fish should be reflected in the catch rates. Table 3.3 shows mean catch rates in comparable series of data from the fishing programmes of the two vessels RASTRELLIGER and SARDINELLA taken from the Cruise Reports (IMR/NORAD/FAO, 1974/75).

There is no reflection in these data of generally higher catch rates in 1975 than in 1974. The July-August 1975 data are from fishing operations on concentrated anchovy in the Gulf of Mannar, and are therefore not comparable with the other data.

This tends to confirm that the observed high abundance in 1975 resulted from an increase of the performance of the echo integrator system, most likely through a change in the TVG-receiver gain function.

Table 3.3 Comparison of catch rates in fishing trials for identification and sampling (kg/haul)

	No. of hauls	Total catch	Anchovy catch
SARDINELLA			
Trawl 100 m^2 opening:			
1974, April-May	36	48.7	11.6
1975, April-May	29	16.9	4.8
RASTRELLIGER			
Trawl 100 m^2 opening:			

1975, April-May	60	13.4	6.7
1975, May-June	55	55.9	25.9
RASTRELLIGER			
Trawl 400 m² opening:			
1974, August	11	202.2	94.4
1975, July-August	10	290.3	236.6
Source: Cruise reports 1974–75			

With small claims to accuracy, a revision of the biomass estimates has been made based on a reduction by 50% of the anchovies throughout due to their small size (see above) and a reduction of all 1975 estimates by 2.5 times corresponding to an increase of the integrator deflections from a 4 dB higher performance. The final results are presented in Table 3.4 and Figure 3.4.

Table 3.4 Revised biomass estimates from the echo integration surveys by target groups (1,000 t)

Year	Month	Anchovies	Scads	Ribbonfish Catfish	Other fish	Shallow-water mix	Total
	May-June	204	*	**	193	69	466
	Jun-Jul	260			436	142	838
1973	Jul-Aug	220			832	25	1,077
	Sep-Oct	35	86		447	13	581
	Oct-Nov	115	64		547	22	748
	Dec	29	45		303	25	402
	Jan-Feb	19	89		383	15	506
	Mar-Apr	114	24		370	18	526
	Apr-May	204	48		357	6	615
	Jun-Jul	35	56		625	19	735
1974	Aug	390	105		288	3	786
	Sep-Oct	405	179		487	29	1,100
	Oct-Nov	77	229		624	64	994
	Nov-Dec	40	94		482	13	629
	Feb-Mar	86	158	118	218	36	616
	Apr-May	301	221	116	207	26	871
1975	May-Jun	285	163	282	404	74	1,208
	Jul-Aug	175	108	241	203	12	739

* Scads not distinguished from other fish till September 1973
** Ribbonfish and catfish not distinguished from other fish till 1975

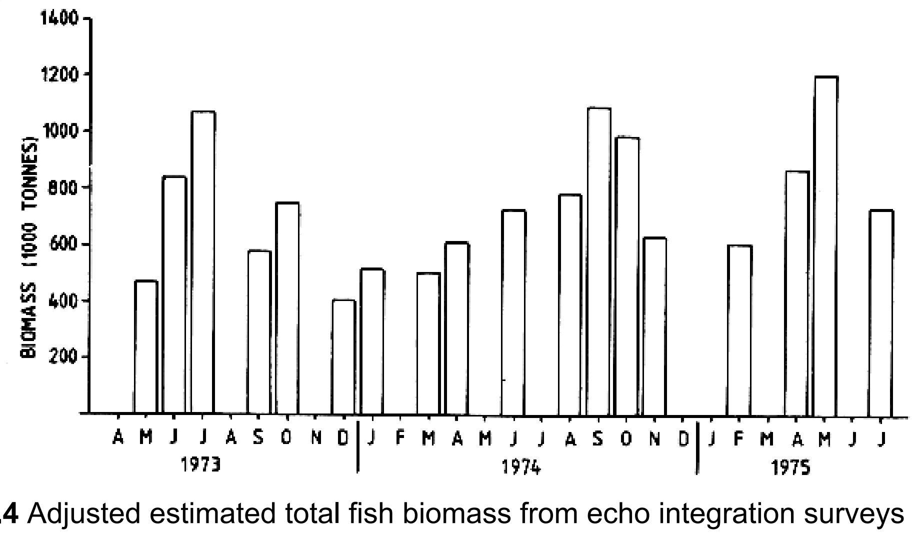

Figure 3.4 Adjusted estimated total fish biomass from echo integration surveys (for adjustments see text)

The maxima of the anchovy biomass are now seen to vary between 260,000 and 405,000 t and the total biomass of all groups covered by the echo integration surveys reaches levels of about 1.1–1.2 million t each year. The anchovies show the clearest seasonal fluctuations largely reflecting an annual production cycle in these short-lived fish. For the other groups the variation of the estimates between surveys is in addition to survey variance, likely to have been caused by seasonal changes in availability of the stocks which may have a distributional area which exceeds that covered by the surveys.

This comprehensive and long-time series of biomass estimates shows features which give some grounds for confidence. Apart from the obvious seasonal cycle for anchovies, there is a degree of consistency in the proportion between the groups which tends to confirm their proper identification, and there is some regularity in the seasonal variation in total biomass. Although allowance must be made for underestimation due to bias caused by signal saturation effects in the scientific echosounder/integrator system of the first generation, the estimates are still of historical interest as they represent a stage of low exploitation of the stocks.

Experimental fishing

A planned report consolidating the project's work on experimental fishing did not become available, but several progress reports refer to this. Thus in reporting on the first six months work in 1971 with SARDINELLA (IMR/NORAD/FAO, 1971) the experience of purse-seine trials on adult mackerel is said to confirm parallel results obtained earlier by the Indo-Norwegian project's M-boats that these schools of mackerel are readily caught with suitable purse-seining techniques.

In describing the offshore distribution of oil sardine and mackerel demonstrated by the 1971/72 surveys (IMR/NORAD/FAO, 1973a) the possibility of extending the fishing season through offshore purse-seining is indicated. Reference is again made to successful purse-seine trials of the Indo-Norwegian Project with various sizes of boats and purse-seines. The point is made that an offshore fishery would increase the exploitation of large adult fish which are present in the inshore fishery only to a small extent. The offshore fishery would thus only partly exploit the resources on which the traditional fishery depends. This point is also made in IMR/NORAD/FAO (1974a), where reference is made to purse-seine catches of oil sardine of up to 40 t/set by the SARDINELLA with her 180 fathom seine as well as to the successful fishing of offshore schools by various vessels of the Integrated Fisheries Project. It is concluded that the technique of an offshore purse-seine fishery is well established, but it is recommended that before attempting to develop such a fishery a pilot-scale programme of experimental and demonstration fishing be conducted.

Mid-water trawls were tested on anchovies and other types of fish. In IMR/FAO/NORAD (1974a) night fishing with SARDINELLA's 100 m^2 trawl was reported to yield catches of 1.2 t/h. In IMR/NORAD/FAO (1976a) catch rates of anchovies with RASTRELLIGER's 400 m^2 trawl in the Gulf of Mannar are reported to have been about 4 t/h during daytime and about 13 t/h at night. Reference is also made to purse-seine sets of 1–4 t of scads by the Integrated Fisheries Project's vessel SAMUDRADEVI. Catch rates of “other fish” of 1.6 t/h were reported for SARDINELLA's small pelagic trawl. In IMR/NORAD/FAO (1976b) mackerel and oil sardine purse-seine sets of 0.4 to 5.5 t are reported for SARDINELLA and of 2 to 27 t for SAMUDRADEVI. Up to 1.6 t of catfish and ribbonfish were obtained with the mid-water trawl and up to 1 t/h of shallow-water mix and 3.8 t/h of “other fish”.

Through project activities in this field of fishing experiments as well as that of the previous Indo-Norwegian Project and the Integrated Fisheries Project the feasibility of offshore purse-seining for mackerel and oil sardine and perhaps also scads seemed to have been well established. It was also demonstrated that “interesting catch rates” of anchovies, shallow-water mix, ribbonfish and catfish and "other fish" could be obtained by mid-water trawl.

Oil sardine and Indian mackerel

The assessment of the stocks of oil sardine (*Sardinella longiceps*) and Indian mackerel (*Rastrelliger kanagurta*) was a main objective of the project and the method to be used was carefully considered. The first period of exploratory surveys with SARDINELLA showed that in the post-monsoon months August-October the two species could be found in belts of surface schools 6–20 nmi offshore extending for at least 200 nmi along the coast (IMR/NORAD/FAO, 1973a). Further observations indicated that the oil sardine and the Indian mackerel mainly occurred as dense schools and that school formation was maintained also during the night even if they were then less densely packed. With this near-surface distribution it was concluded that the echo integration technique could not serve as the main method of biomass assessment because of avoidance of the vessel and it was decided to try aerial surveys combined with visual, sonar and echosounder observations from vessels. The best period for the aerial survey was judged to be September-October when the schools appeared to have an extreme surface-bound distribution prior to their inshore migration.

Surface schooling is common behaviour among small pelagics, especially sardinellas and sardines, but usually interspersed with occurrence in schools or layers at greater depths. The more consistent restriction to the surface layer of the two species along the Malabar coast may be related to the limits set by the low oxygen content of the water at greater depth. When school-counting with sonar was adopted as a part of the routine survey techniques in 1974–75, observations demonstrated that sardine and mackerel occurred in schools on the shelf through most of the year also in the southwest monsoon period when, due to rough weather, they could not be seen at the surface (IMR/NORAD/FAO, 1976d).

Table 3.5 Summary review of results of oil-sardine and mackerel post-monsoon aerial and vessel surveys (totals and separated by species where possible)

Year	No. of schools 1,000	Mean volume 1,000 m^3	Total volume mill m^3	Packing density kg/m^3	Biomass estimate 1,000 t
1972	19	15.5	292	0.25	75
1973	61				800–850
Sardine	25	18.5	495	0.6	350–400
Mackerel	36	16.0	597	0.6	450
1974	101				166
Sardine	52	0.6	32	1.6	52
Mackerel	49	1.2	58	2.0	114
1975					1,000
Sardine	255	2.1	536	1.9	700
Mackerel					300

The main data from the series of annual oil sardine and mackerel surveys are reviewed in Table 3.5. The basic data are the estimated number of schools, their mean volume and packing density.

In the 1972 survey the main effort was by aircraft and only one vessel, the SARDINELLA, provided supporting data on submerged schools that had been missed by the aerial survey and additional observations for estimation of schools dimensions and packing densities. The project assessed that this survey had produced an underestimate and it was not included in later summaries. The calculation of school volume was, as in 1972, based on echosounder observations of submerged schools. This may have introduced a bias as effective vessel avoidance by schools may be dependent on school size. Estimates of the size of sardine schools from aerial photographs was on average only a quarter of that from echosounders.

The basis for the 1973 survey was a much larger combined effort by aircraft and vessels which would be expected to give an improved estimate of school numbers. In the 1974 and 1975 surveys, school volumes were estimated from sonar records where vessel avoidance is not critical, and these showed volumes about 10 times smaller. The aerial observations in 1974 were of more limited value partly because of unsuitable weather, and also because fish behaviour differed from previous surveys with more schools being submerged. A systematic sonar coverage was, however, made of the whole area and there would not seem to be any apparent bias in the estimate of total school numbers. The last survey, that of 1975, was without aerial support and consisted of a multi-vessel effort based on sonar records and visual surface observations. In this series of surveys from 1973 to 1975 the data on total school numbers is likely to be the most consistent, perhaps not in terms of precision, but as regards year-to-year changes in serious bias.

In 1973 and 1974 separate assessments were made of the sardine and mackerel stocks based on aerial identification. In 1975 the assessment was combined for the two species, but based on samples of observations of school identification, oil sardine was estimated to represent about 70% of the total.

An interesting point of methodology in this type of investigation is that from 1974 a correction was introduced for the effect of the elliptical shape of the schools. The previous assumption of circular shape had caused a negative bias.

Use of the sonar of the RASTRELLIGER transmitting at 90° to the vessel's course represented a new and it seems improved approach to the difficult problem of describing the distribution of the oil sardine and mackerel stocks and assessing their abundance (Smith, 1971; IMR/NORAD/FAO, 1975c). This method was applied in a systematic way from September-October 1974 onwards on all main surveys and the results were presented in the form of distribution charts and as estimates of the total areas within which schools were numerous.

The series of distribution charts based on the sonar method which cover one year from November 1974 to September-October 1975, shown in Figure 3.5, are among the project's principal achievements. These represent an adequate response to one of the project's main objectives: to describe the temporal and spatial distribution of these main species. When not presumably inshore as in December 1974 the stocks were found in well-defined school areas which cover large parts of the shelf including the Gulf of Mannar in the period February-March to July-August 1975. These stocks would thus be available to offshore fishing over a large part of the year.

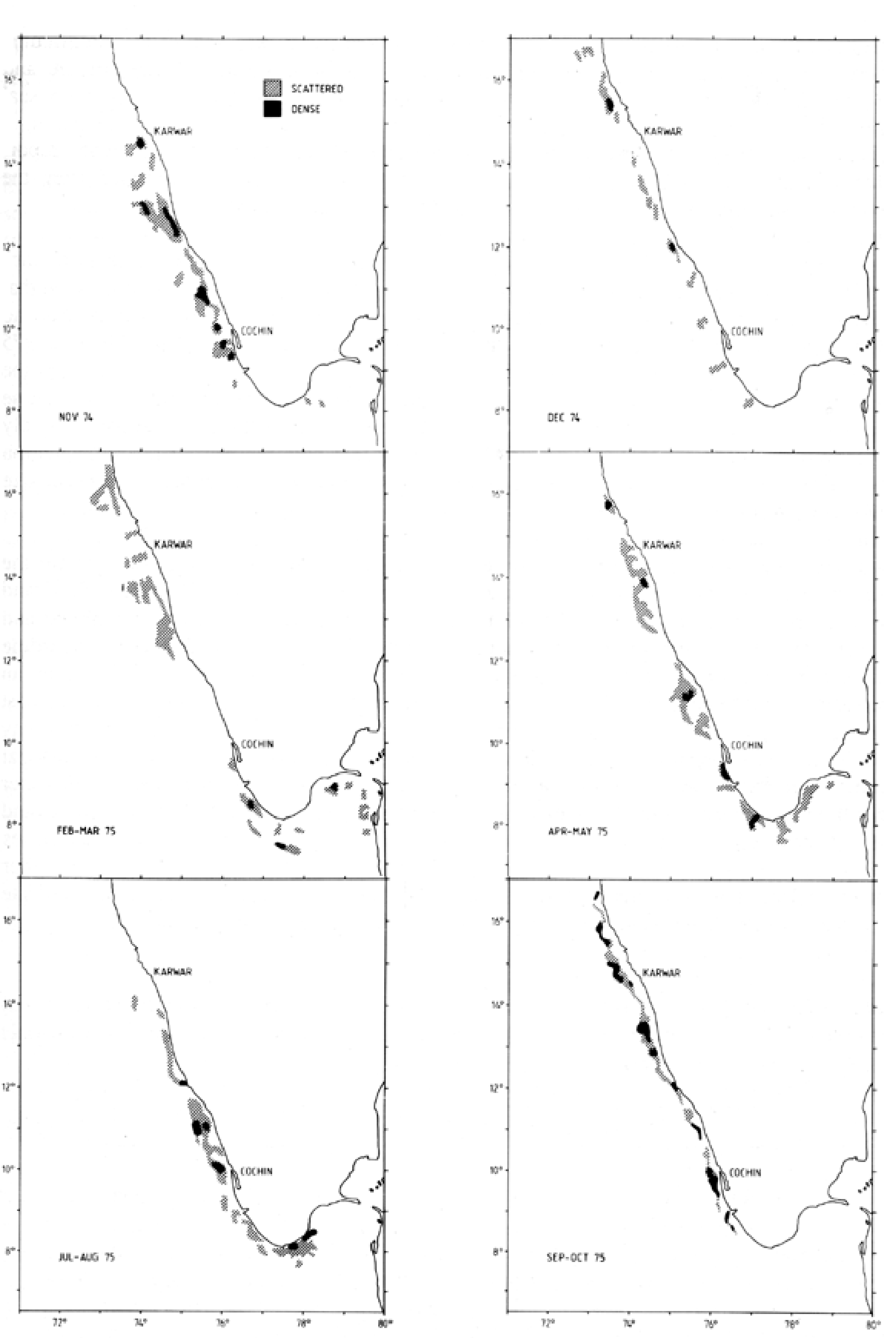

Figure 3.5 Distribution of mackerel-and oil sardine schools from sonar surveys with the RASTRELLIGER, Oct 74-Nov 75. Source: IMR/NORAD/FAO, 1976b

Observations of school areas of oil sardine and mackerel were also part of the programme of the project's main fish surveys conducted by the two vessels SARDINELLA and RASTRELLIGER prior to September-October 1974, but they were then based on visual surface observations (IMR/NORAD/FAO, 1976a) and it seems doubtful whether it is appropriate to present the two sets of data as the time-series shown in the summary report (IMR/NORAD/FAO, 1976g). The extent of the distribution areas as determined from the sonar surveys only, shows an increasing trend from September 1974 onwards.

Whereas schooling behaviour, e.g., school size and packing density would be likely to vary with fish size, physiological state and environmental conditions, it is generally considered that it is largely unrelated to total stock abundance. There were as far as can be established no wide differences in fish size between the three post-monsoon surveys in 1973, 1974 and 1975 and they were conducted in the same season. It is thus not unreasonable to assume that the estimates of the total number of schools represent the best index of stock size. These numbers, 61,000, 101,000 and 255,000 for the respective years then describe rapidly increasing stocks from 1973 to 1975. This also conforms with the project recommendation that increased reliability can best be obtained by improved estimates of school size (IMR/NORAD/FAO, 1975c).

This trend may be compared to the landings in the inshore fishery (Table 3.6), where the totals for the calendar years from FAO's Yearbooks of Fishery Statistics Volumes 38,42 and 44 have been re-allocated with 64% and 36% in subsequent years as used by Longhurst and Wooster (1990) to estimate seasonal landings. There was a sequential decline in oil sardine landings from a level of about 200,000 t in 1970–71 to 92,000 t in 1973–74 followed by an increasing trend towards 1976–77 to about the previous high level which was maintained past the end of the decade. The landings must be expected to relate to stock abundance, but may also be affected by the inshore availability of the schools which may vary with seasonal variations in oceanography. The monsoon conditions as presented by Longhurst and Wooster (1990) do not show any special anomalies in these years and the trends of initial decline and subsequent increase over a six-year period indicates a stock effect. The project's time-series (1973–75) of total school numbers reflects this trend of increase although indicating a higher rate of growth. The estimates of total “school areas” from the sonar surveys also demonstrate an increase from the survey in September-October 1974 to that of October 1975.

Table 3.6 Landings of oil sardine and mackerel on the Malabar coast (1,000 t) (redistributed over subsequent years) and estimated total number of schools determined by surveys

Season	Oil sardine	Mackerel	Total	No. schools
1970–71	220	155	375	
1971–72	179	165	344	
1972–73	106	91	197	
1973–74	92	51	143	
1974–75	130	33	163	61,000
1975–76	154	44	198	101,000
1976–77	194	44	238	255,000
Source: FAO Yearbook of Fishery Statistics, Vols. 38, 42 and 44				

One general conclusion of interest for survey methodology which may be drawn from the results shown in Table 3.5 and the discussion above is that observation of school volume and packing densities are the most critical parts of biomass assessment based on school surveys. Visual observations in the 1974 survey indicated that packing density could be calculated from an assumption of a distance between individual fish of 1.5 times the fish length. Some fishing experiments seemed to confirm this. Statistical data on the school volume estimates from the sonar surveys are not available. Estimation of school size by experienced skippers (IMR/NORAD/FAO, 1974c) showed a highly skewed distribution with 80% lying within a range of 2–10 t but reaching up to 60 t causing a low precision of the mean of 8. According to Marchal and Petitgas (1993), the sampling problem of increasing the precision of the school size estimate was the major impediment to improved biomass assessment of school surveys of small pelagics, mainly sardinellas in Venezuela. They found a similar strongly skewed distribution and suggested that school numbers which can be estimated with good precision may be a better index of stock size.

The mean school size of 4 t estimated for the 1975 survey may seem of the right order of magnitude. This average size indicates a total biomass of 1 million t in 1976–77. Judged from the levels of yield of the fishery this is likely to be an underestimate because it seems improbable that an inshore fishery conducted in a limited season only should take as much as 20% of the mean standing biomass.

Anchovies

The predominantly surface schooling behaviour of oil sardine and mackerel, the main target species of the project, was a setback for the researchers who had expected to be able to apply the echo integration technique in the investigations of these important stocks. In the introductory surveys with SARDINELLA in 1971–72 echo surveys had already revealed the presence of abundant resources of other types of fish on the Malabar shelf, and their investigation was included as a part of the work programme. Among these other fish, anchovies (whitebait) were found to be an important component of the pelagic community and the study of their biology, distribution and abundance was given considerable attention throughout the project. The behaviour of the anchovies made them a suitable object for the echo integration technique: they were mostly found in dense layers, sometimes dense schools at or near the bottom during daytime and in more dispersed layers higher up at night. The observations and material for these studies were derived from the main project surveys which covered the whole shelf with the multi-purpose objectives of acoustic recording, fish sampling, zoo- and ichthyoplankton studies, oceanography, and visual school mapping. A total of 25 such surveys were completed over the last three years of the project representing a very good seasonal coverage and a collection of an appreciable amount of information and material.

The anchovy stock was found to consist of several *Stolephorus* species of which *S. heteroloba* and *S. bataviensis* were the most abundant with *S. zollingeri* also occasionally abundant (Figure 3.6). The species were observed to be short-lived, reaching the adult size of 8–9 cm after about 6 months (IMR/NORAD/FAO, 1976g). Seasonal fluctuations in size composition and biomass would thus be expected and were indeed found. Anchovies were an easily identifiable acoustic target and the progress reports present distribution charts for each coverage which show a clear seasonal and quite remarkable pattern repeated in the data from 1974 and 1975. In January and up to April-May, the anchovies were distributed all along the coast. In the period of the southwest monsoon (July-August) and until November this group was almost exclusively found south of about 10°N with most of the biomass located in the Gulf of Mannar. Figure 3.7 shows the anchovy distribution in April-May and July-August 1975 respectively. This change of distribution was assumed to result from migration or southward displacement of the biomass with the fairly strong southward current set up by the southwest monsoon.

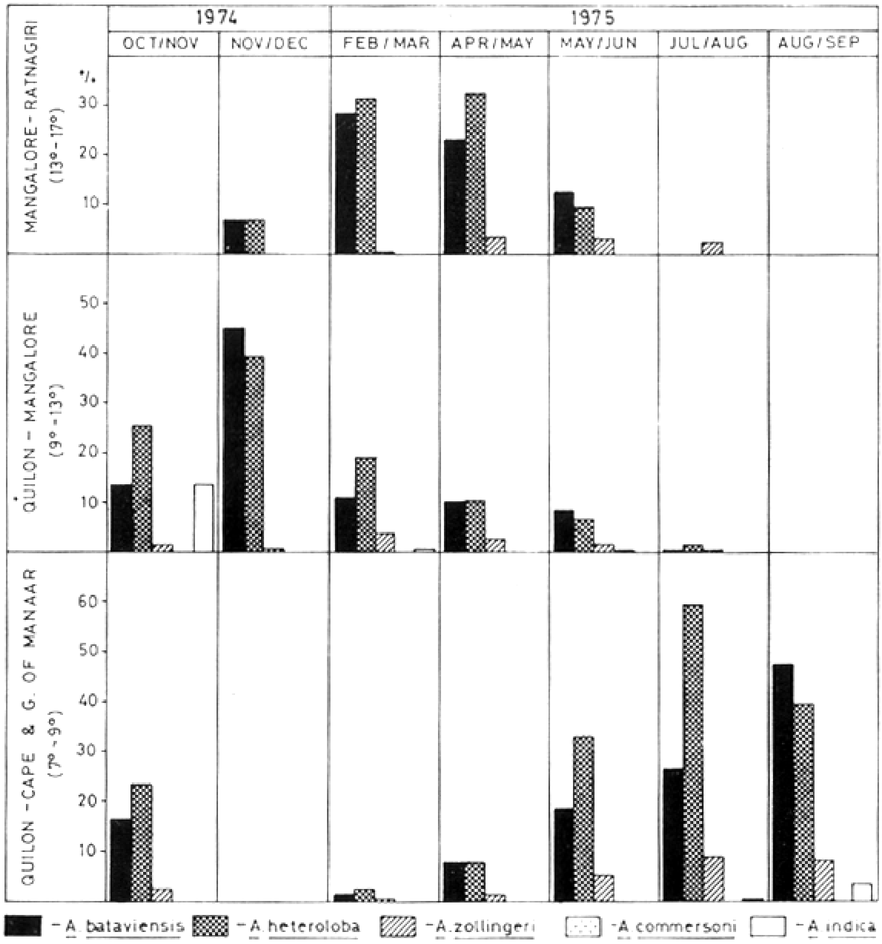

Figure 3.6 Relative abundance of anchovies (*Stolephorus* spp.) by areas for each coverage Oct-Nov 1974 to Aug-Sept 1975 (from IMR/NORAD/FAO, 1976b)

The production of the short-lived anchovy species must be expected to be closely related to that of zooplankton and perhaps to some degree also to the phytoplankton, both of which fluctuate sharply with the monsoon upwelling. The biomass estimates of anchovy by surveys (for adjustments see below) are shown in Figure 3.8. The zooplankton standing crop starts its seasonal increase in April-May, (Figure 3.3B and IMR/NORAD/FAO, 1974b) apparently prior to the start of the wind-driven upwelling. Nearly all the high anchovy estimates fall within the May-October period. The data indicate a 6–7 month production period, from March-April to September-October of the *Stolephorus* species with a southward displacement of the total biomass in July-August. This fits with the main trends in the observed seasonal appearance of larvae and juveniles.

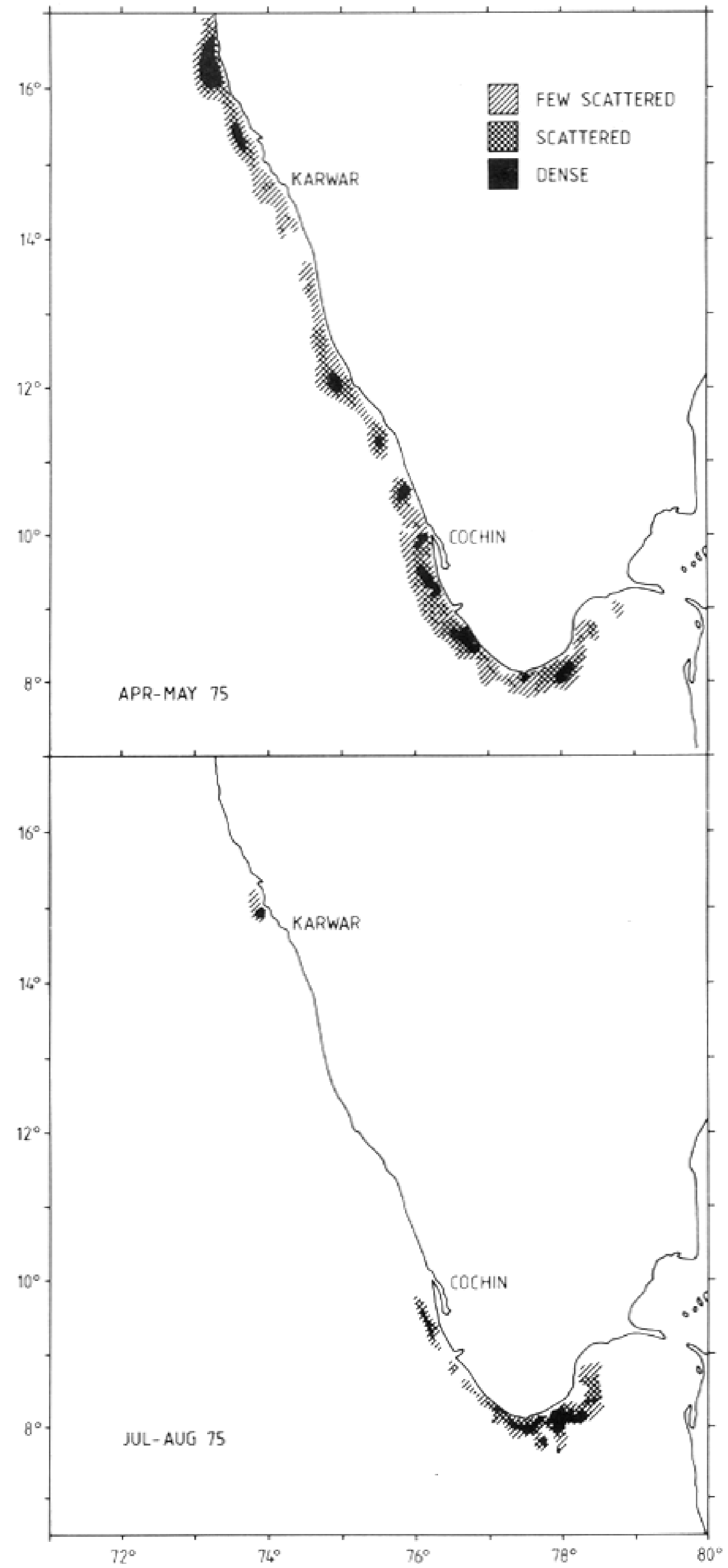

Figure 3.7 Distribution and abundance of anchovies in April-May and July-August 1975, from IMR/NORAD/FAO, 1976b

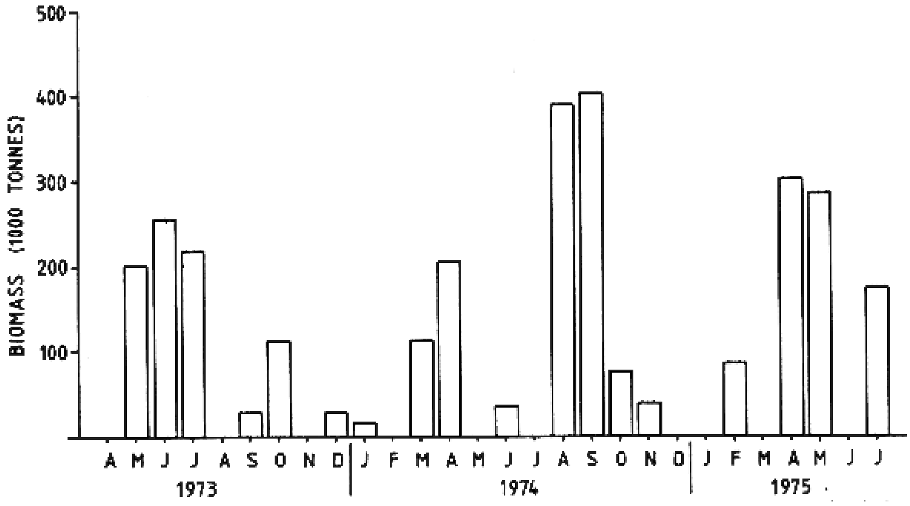

Figure 3.8 Estimated anchovy biomass by surveys. For adjustments of original data in IMR/NORAD/FAO 1976g, see text.

It is possible that the survey area falls short of the total distributional area of the anchovies as indicated by the high biomass found in April-May 1975 in the northern subarea which may have originated further north. The project's data series on biomass show an apparent high variation between years. The highest estimates for biomass in the surveys of 1973, 1974 and 1975 were 520,000, 800,000 and 1,500,000 t respectively.

A review of these estimates and their basis, i.e., the state of the acoustic system and the target strength function was presented above.

Several other groups of fish were identified as recognizable targets of the echo integration system representing more or less co-occurring species. The annual summaries of the results of the main fish surveys presented in the progress reports include detailed descriptions of the distribution, composition and abundance of these groups as well as biological data on the most important species. The groupings used changed somewhat as experience was gained. Their general characteristics and species composition are described below (IMR/NORAD/FAO, 1976a and 1976b).

The scad group

The main species were torpedo scad (locally called horse mackerel) (*Megalaspis cordyla*), Indian scad (*Decapterus russelli*), trevallies (*Caranx* spp.) and less common frigate mackerels (*Auxis* spp.) and small tunny (*Euthynnus affinis*). These fish were mostly recorded as distinct schools in mid-water or close to the bottom, but also as single fish scattered over wider areas. They were most often found on the middle or outer shelf, but sometimes closer inshore or even beyond the shelf over deep-waters. Figure 3.9 shows examples of distribution charts for this group for May-June and July-August 1975. There is also a tendency for this group to have the highest abundance in the south during the southwest monsoon. The May-June distribution with the high abundance in the north indicates that the project area may only represent a part of the distributional area of this group and that changes in the abundance may be caused by migrations into and out of the area covered.

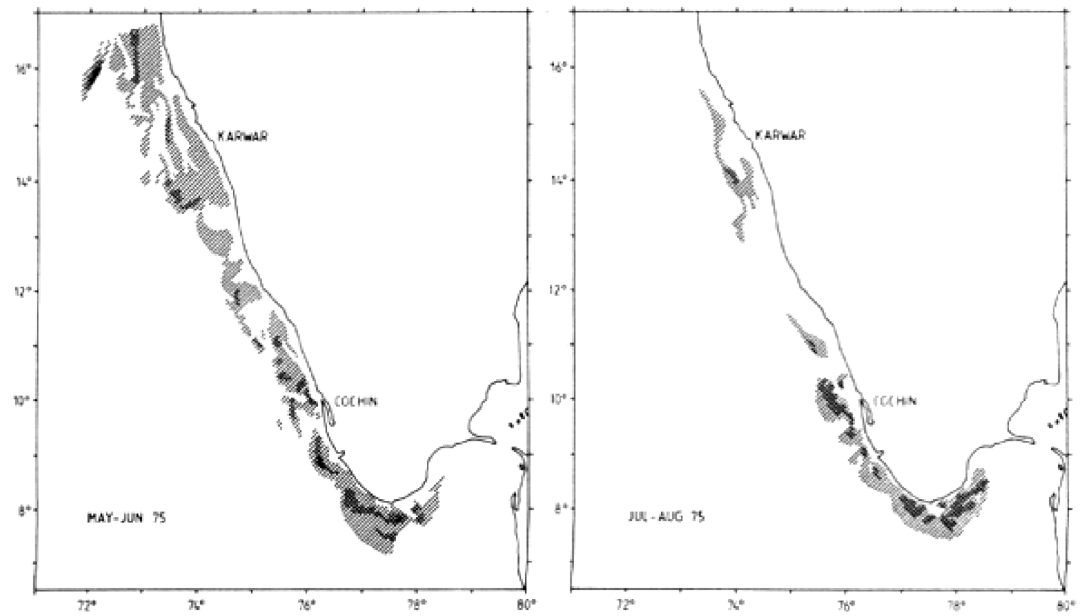

Figure 3.9 Distribution and abundance of the scad group in May-June and July-August 1975, from IMR/NORAD/FAO, 1976b

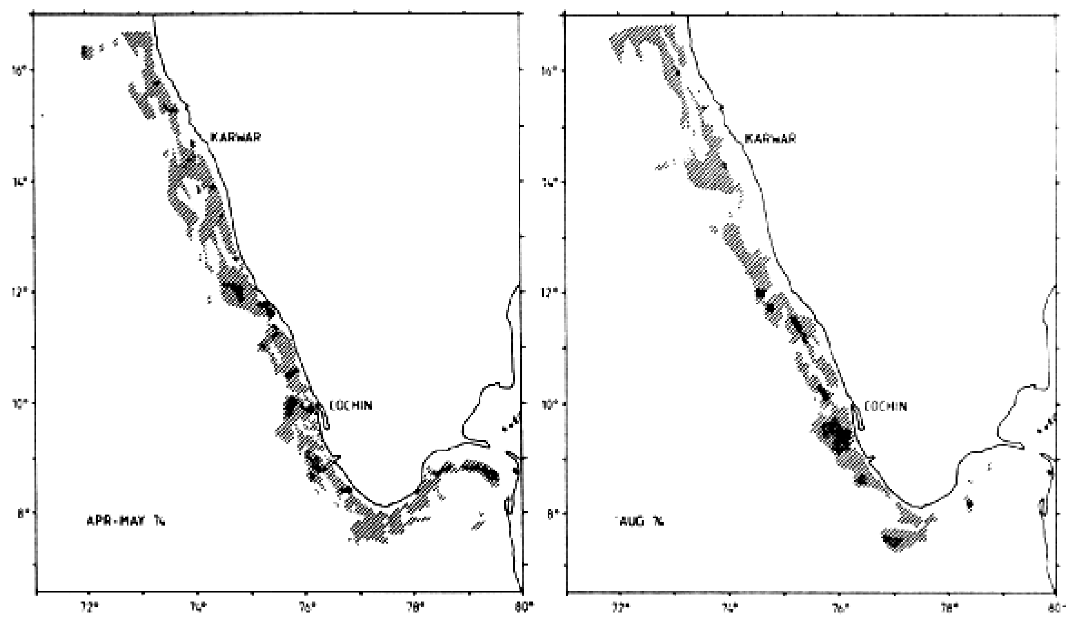

Figure 3.10 Distribution and abundance of “other fish” during the surveys in April-May and in August 1974, from IMR/NORAD/FAO, 1976a

Shallow-water mix

These fish, largely benthopelagic in behaviour, were grouped mainly because of their location within bottom depths of less than 15–20 m and because their distributions form close inshore belts. Typical species are ponyfishes (*Leiognathus* spp.), golden scad (*Caranx calla*) and butterfish (*Lactarius lactarius*). Especially the juvenile stages of a number of species from farther offshore were also found in this zone.

Other fish

This group did not represent a fish assemblage, but was used to describe the remaining part of the recorded biomass, although catfish (*Tachysurus* spp.) and ribbonfish (*Trichiurus* spp.), about 50% of this group, were often found together. These species are mainly benthopelagic and were treated as a separate group in the 1975 surveys. Their highest abundance was usually found on the mid-shelf at about 50 m of bottom depth and they were often the only species within relatively large areas. Other common species in the group were pomfret (*Stromateus* spp.), threadfin bream (*Nemipterus japonicus*), seerfish (*Scomberomorous* spp.), barracudas (*Sphyraena* spp.) and lizard fish (*Saurida* spp.). Bottom fish such as groupers (*Epinephelus* spp.), breams (*Lethrinus* spp.) and snappers (*Lutjanus* spp.) also contributed to the group as did sharks, rays and squids. Small amounts of mackerel and oil sardine found dispersed in the water column would also be included. In general the recordings of "other fish" were found over large parts of the shelf, usually scattered, but with some aggregated areas and with higher abundance in the south in the southwest monsoon season. Figure 3.10 shows examples of distribution charts of this group (including catfish and ribbonfish) for April-May and August 1974.

The proportions of the various groups of the total (adjusted standing stock) biomass estimates excluding schooling oil sardine and mackerel were as follows (mean over three years 1973, 1974 and 1975):

Anchovies	26%
Scads	13%
Shallow-water mix	7%
Ribbonfish/catfish	21%
Other fish	33%

Summary of stock estimates

In the task of describing the composition, distribution and abundance of the surface schooling oil sardine and mackerel stocks, project scientists encountered problems of methodology, e.g., measurements of school sizes and packing density with which today's acoustic researchers are still struggling. Considerable experience was, however, gained over the period and the combined estimate of 1 million t for the 1975 season may well have been approximately right. It undoubtedly demonstrated the existence of a potential for expanding the exploitation of these stocks. The 1974–75 sonar surveys provided comprehensive information on the offshore distribution of these stocks throughout the year.

In retrospect it can also be seen that in this early phase of the echo integration technique there were considerable problems with its proper application and with full instrument control which must have affected the results. The rough revisions of these data have resulted in significant changes in some of the biomass estimates. The compilation of adjusted data shown in Table 3.6 may represent fairly realistic although probably underestimated biomass levels of the various resources.

Because of the seasonal changes in biomass and availability, the best estimate of standing stock size is likely to be closer to the maximum than the mean of each year's data. This approach would give stock biomasses from the echo integration surveys from Table 3.4 as follows (1,000 t):

	1973	**1974**	**1975**	**Mean (rounded)**
Anchovies	260	405	301	320
Scads	86	229	221	180
Other fish	832	625	686	700
Shallow-water mix	142	64	74	90
Total				1,290

Assuming an additional combined biomass of oil sardine and the Indian mackerel of 1 million t, the total biomass of neritic pelagic and benthopelagic fish in 1975 in the area from Palk Bay to Ratnagiri was thus in excess of 2.2 million t. This represents a mean density for the shelf area of 67 t/nmi^2 or about 200 kg/ha, a level found in highly productive systems.

It is of interest to compare this estimate of total standing stock with the annual yield of these types of fish in the area. Using data on landings by categories and states for 1989–1990 with the India Handbook on Fisheries Statistics (Ministry of Agriculture, New Delhi) and FAO's FISHSTAT Database as sources, an attempt has been made to estimate total annual catches in the project area. Almost all the reported catch of oil sardine and mackerel and roughly 60% of other pelagic and mesopelagic fish is according to the India Handbook from the project area and it is assumed that these proportions have remained unchanged since 1973. The additional groups comprise the following: *Caranx* spp., Carangidae, anchovies, hairtails, catfishes, Clupeidae and wolf-herrings. The group listed as "Marine Fish NEI" is also included as it is thought to contain a major component of small pelagic fish. The results are shown in Table 3.7.

Table 3.7 Approximate levels of landings of neritic pelagic and benthopelagic fish in the Project area (Malabar coast, southwest India) (1,000 t)

Year	Landings	Year	Landings
1973	290	1983	362
1974	340	1984	462
1975	293	1985	480
1976	368	1986	428
1977	373	1987	390
1978	429	1988	408
1979	425	1989	704
1980	334	1990	675
1981	396	1991	660
1982	344		
Sources: Indian Handbook on Fisheries Statistics, 1989–90 and FAO FISHSTAT Data Base			

Mean annual landings for the mid 1970s (1973–1977) are about 330,000 t which compared to a standing stock level of 2.2 million t represents a very low fishing mortality and demonstrates considerable potential for expansion at that time. It seems that this has been and is being realized, first slowly with a mean catch of 420,000 t in 1983–1987, but approaching 700,000 t from 1989 on.

3.3 DR. FRIDTJOF NANSEN SURVEYS OF THE SHELF RESOURCES FROM SOMALIA TO PAKISTAN, 1975–77

The results of these surveys were briefly described in cruise reports (IMR, 1975; 1976a, 1976c, 1976d, 1977a), summarized in a Status Report (IMR, 1976b) and a Final Report (IMR, 1977b) and reported in a more comprehensive review by Kesteven *et al.* (1981).

Planning and execution of the surveys

A document setting out an elaborate plan to deal with all aspects of the survey work was submitted by IMR to the IOP in 1973 and this formed the basis of the survey plans (Midttun *et al.*, 1973). The main target was the stocks of small pelagic fish, and the highest priority for survey areas was accorded to the coastal and upwelling zones from East Africa to the Gulf of Oman, including highly-productive offshore zones. It was uncertain, even doubtful if these productive offshore waters would hold abundant resources of small pelagic fish, but this represented an important issue to be solved. The two main seasons relating to the northeast and the southwest monsoons would need to be covered and a total survey period of two years was recommended. Weather conditions were not expected to affect work except at the height of the southwest monsoon. Acoustic observation and estimation was to be the principal method, supported by fishing with trawl and purse-seine for identification and sampling. The survey grid was to be flexible and adjusted according to fish density. Hydrographic profiles would be worked in selected positions for purposes of fishery oceanography. Plankton sampling for fish eggs and larvae would be made at hydrographic stations.

This plan was based on IMR's experience of acoustic surveys in the Norwegian and Barents Seas, but with additional experience on the part of some of its scientists from work in upwelling areas off Peru, West Africa and the southwest coast of India. Nevertheless, in scope and magnitude this was a unique undertaking not only for the IOP and IMR, but on a global basis. The task was to explore and investigate fishery resources off 3 410 nmi of coastline initially in a "blindfold" condition, since basic information on the behaviour and general distributional characteristics of the fish, normally used for deciding survey tactics and techniques, was not available from this largely unexploited ocean area. This first assignment of the DR. FRIDTJOF NANSEN was seen as an adventurous and exciting undertaking.

The region surveyed and its divisions are geographically described in Figure 3.11 and Table 3.8, adapted from Kesteven *et al.* (1981). The continental shelf is extremely narrow along the western shores of the Arabian Sea with mean widths ranging from 5 to about 20 nmi; this feature has important faunistic implications. The Pakistan shelf is wider with a mean of 30 nmi.

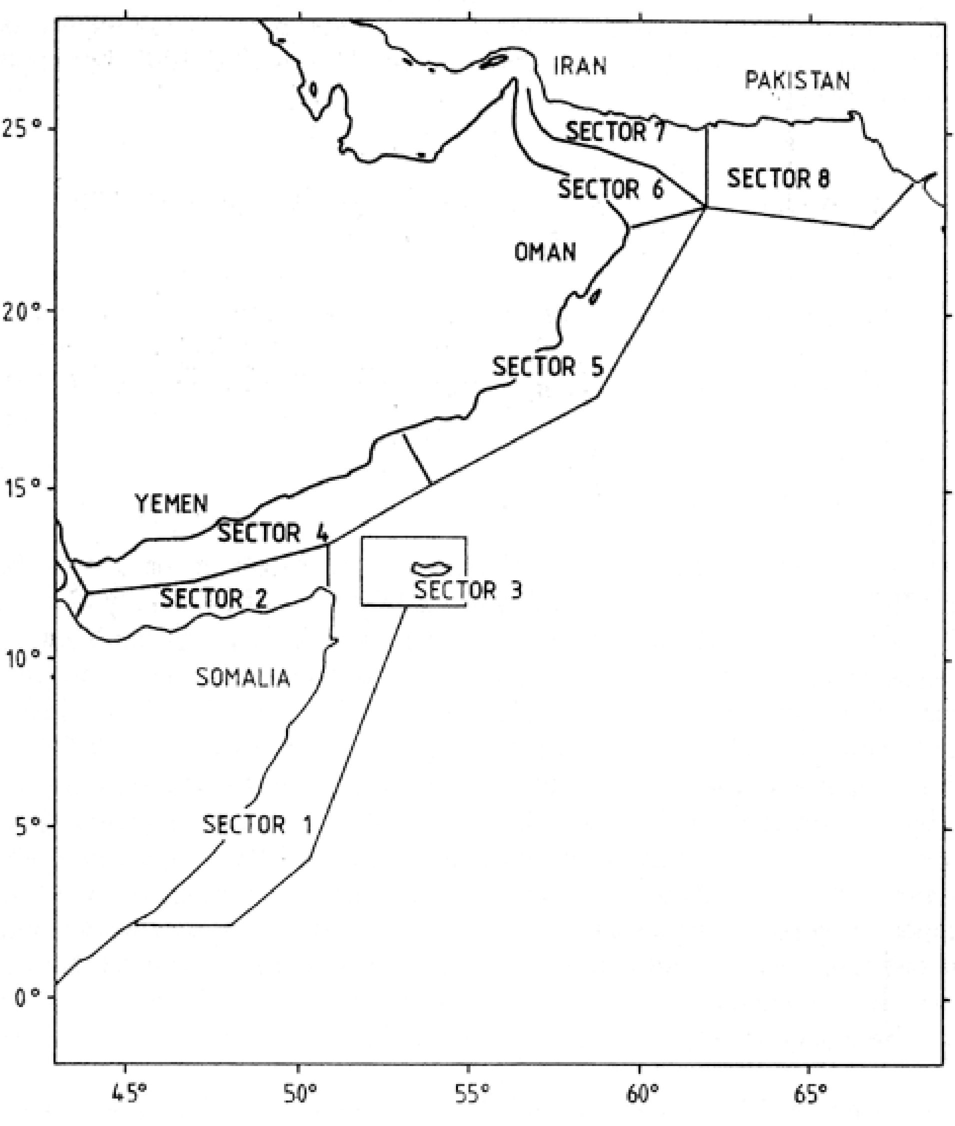

Figure 3.11 Sectors in first main surveys 1975–76

Table 3.8 Geographic specifications of the sectors of the surveyed region. Coastline length (nmi) and shelf area from 0 to 200 m (nmi^2)

Sector (see Fig. 3.11)	Coastline length nmi	Shelf area nmi^2	Mean shelf width nmi
1 Somalia E	470	7,200	15
2 Socotra	150	3,920	
3 Somalia N	500	2,650	5
4 Yemen S	640	6,680	10
5 Oman S	580	12,330	21
6 Oman N	350	4,250	12
7 Iran	300	4,790	16
8 Pakistan	420	12,770	30
Total	3,410	54,590	

Table 3.9 shows the timing of the surveys in 1975–76 in relation to the southwest monsoon, and the survey effort in terms of distance steamed, inshore and offshore. The effort was reduced, especially in the offshore part after the first survey. The surveys covered the pre-and post-monsoon periods and also the northeast monsoon in the early part of the year. Sampling for identification was by pelagic and bottom trawls. Purse-seining was attempted, but the gear needed adjusting to local conditions of current and bottom which proved impracticable, and few trials were made.

Table 3.9 Timing of the surveys, surveyed distance (nmi) and number of fishing stations

	1975		1976		
Survey No.	1, 2	3	4	5	6
Survey months	II–VII	VIII–XI	I–III	IV–VI	IX–X
Survey distance					
Inshore	7,600	7,900	6,400	5,900	7,200
Oceanic	5,400	3,900	3,300	3,000	3,500
Total	13,000	11,800	9,700	8,900	10,700
Fishing stations	138	150	137	103	127

Figure 3.12 shows the course tracks of the first survey and Table 3.10 presents operational records. The extent of the densely covered inshore waters is shown as surveyed inshore area, the distances surveyed are given for the inshore and the offshore areas, and the survey intensity defined as distance of observations relative to the square root of the surveyed space is estimated for the inshore area. This index is not available for the oceanic part of the survey where surveyed space is difficult to estimate. For the Gulf of Aden and Gulf of Oman estimates were made based on both the inshore course tracks on both sides and the crossings of the Gulfs. These gave mean survey intensities of 13 and 11 for the Gulf of Aden and Gulf of Oman respectively showing that they were as a whole well covered.

Table 3.10 Operational records of the main surveys: surveyed shelf area, surveyed distance and degree of coverage. Mean of 5 surveys

Sector	Surveyed inshore area (nmi^2)	Surveyed distance (nmi) Shelf	Oceanic	Degree of coverage Shelf
1 Somalia E	10,596	885	235	9
2 Socotra	6,615	455		6
3 Somalia N	5,158	660		9
4 Yemen S	10,926	1,565	1,285	15
5 Oman S	14,344	1,090	830	9
6 Oman N	5,264	660	540	9
7 Iran	5,741	590		8
8 Pakistan	13,200	1,300	810	11

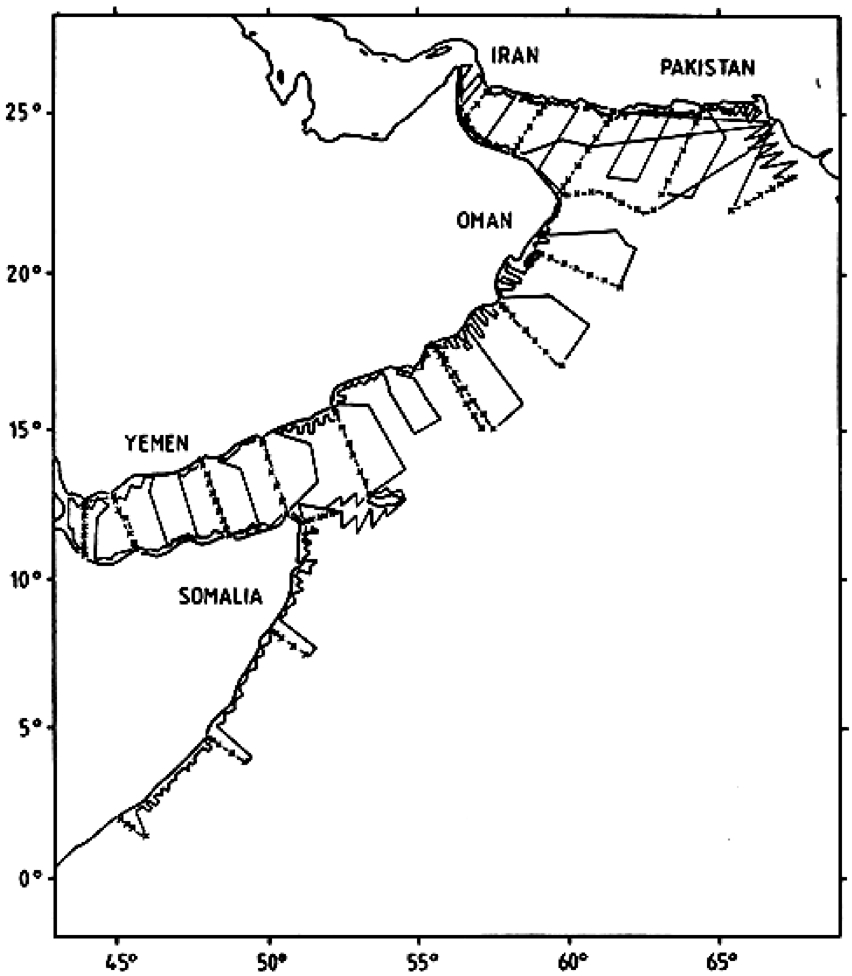

Figure 3.12 Course tracks of the first survey, February-June 1975

A comparison of Tables 3.8 and 3.10 shows that the estimates of the surveyed inshore space for all sectors exceeded the continental shelf areas thus demonstrating that the surveys extended well beyond the shelf. The degree of coverage was just about adequate.

Environmental observations included continuous recording of surface temperature and hydrographic profiles at selected positions as indicated by the course tracks in Figure 3.12. A total of 1,038 hydrographic stations were occupied in the five surveys, and 225 plankton samples were taken in the first two surveys. During the operations in 1976 seven current meters and temperature recorders were deployed and moored for six months on behalf of the University of Miami and the Institute of Marine Science in Kiel. The results of the oceanographic work carried out during the survey were analysed by Sandven (1979). They were essentially a confirmation of previous accounts and present no new features which could be directly related to the findings regarding the distribution and abundance of the resources. The environmental data are therefore not included in this review, but the data from the observations are available in the oceanographic databank system at IMR.

Small pelagic fish

The emphasis in this section is on the study relating to small pelagic fish which was the main objective of the surveys. Data on fish species recorded as “demersal”, but observed in mid-water and better classified as semi-demersal are included. Mesopelagic fish are reviewed in Section 3.4.

The small pelagic fish were only found inshore in close proximity to the coast. The charts of fish distribution of which Figure 3.13 is an example - presented for all the surveys as Figures 10 to 21 in Kesteven *et al.* (1981) - show these small pelagics to extend beyond the shelf in some areas especially off Somalia. A comparison with the course tracks, (Figures 2 to 6 in Kesteven *et al.*, 1981) indicated that the seaward limits of the resources have generally been established. No records identified as small pelagic fish were made during any of the oceanic tracks beyond the slope.

In the first presentations of the results (IMR, 1976b and IMR, 1977b), the biomass was estimated from the integrator deflections averaged over 1 ° squares. In Kesteven *et al.* (1981) use was made of the plots of integrator deflections to describe the distribution patterns as shown in Figure 3.13 and to estimate biomass. The estimates from these two approaches showed no systematic differences by sectors and differed only about 10%, with a nearly identical overall mean of all surveys. Table 3.11 shows the biomass estimates by sectors and surveys as reported in Kesteven *et al.* (1981). For Pakistan, which was not included in that report, the estimates are from plots of the original integrator readings. All of these data should be analyzed as regards coverage, species identification and possible bias.

Table 3.11 Summary of original, unadjusted estimates of biomass (1,000 t) of small pelagic fish by sectors and surveys

Sector	Surveys Months	1, 2 II–VII	3 VIII–XI	4 I–III	5 IV–VI	6 IX–X
1	Somalia E	238	385	1,087	507	794
2	Socotra	108	53	n.c.	n.c.	168
3	Somalia N	185	32	176	4	20
	Sub-total	**531**	**470**	**1,263**	**(511)**	
4	Yemen S	435	322	145	234	302
5	Oman S	78	817	567	484	527
6	Oman N	23	132	0	30	n.c.
7	Iran	39	137	3	68	n.c.
	Sub-total	**575**	**1,408**	**715**	**816**	**(829)**
8a	Pakistan W	174	98	240	124	257
8b	Pakistan E	504	195	444	150	155
	Sub-total	**678**	**293**	**684**	**274**	**412**
	Total	**1,784**	**2,171**	**(2,662)**	**(1,601)**	**(2,223)**

n.c.: not covered

Source: Kesteven *et al.*, 1981 (Sectors 1 to 7)

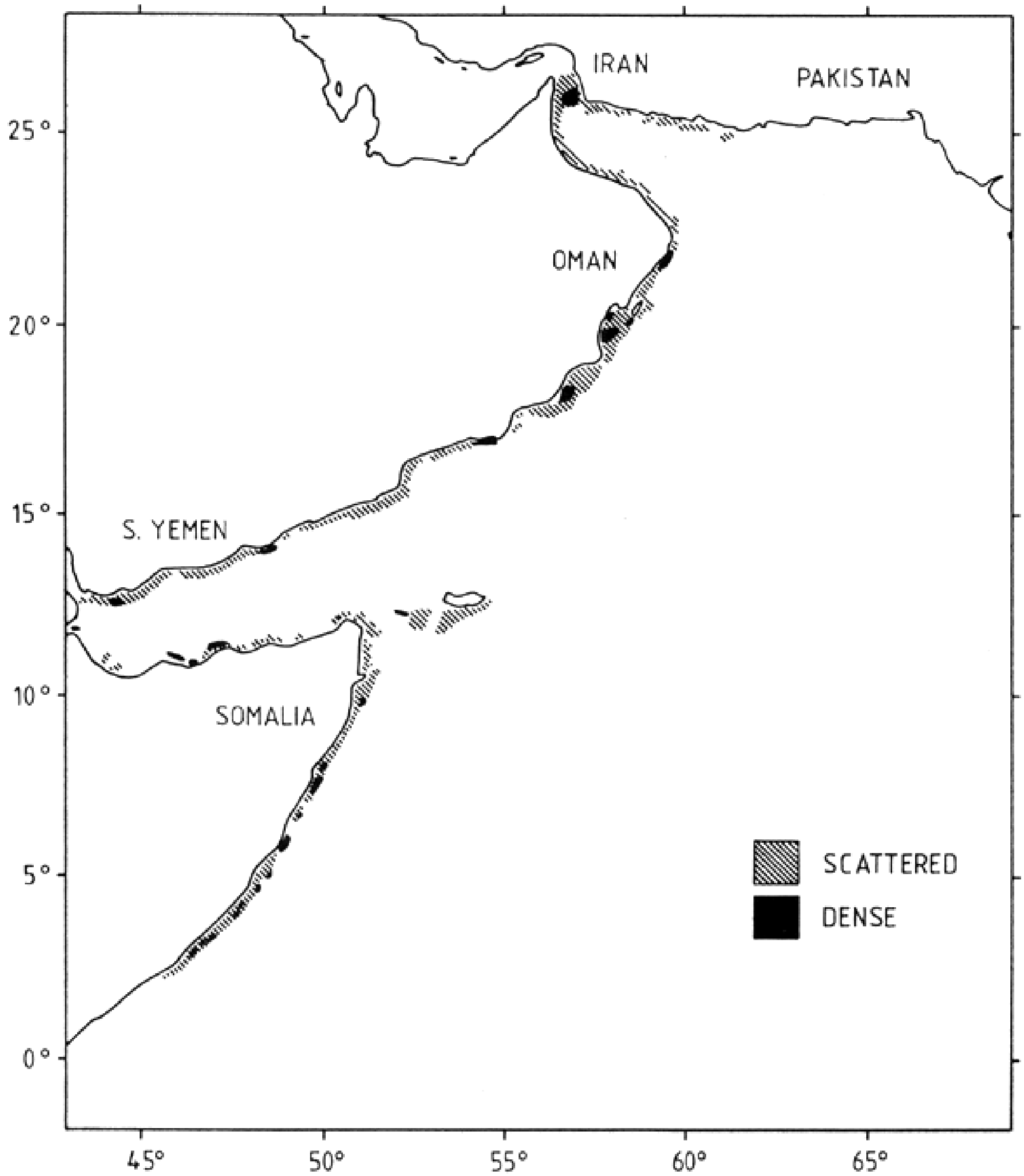

Figure 3.13 Fish distribution from echo integration during the second survey August-November 1975

Identification of the sources of the integrator deflections presented a special problem in this largely unknown area with its diverse fauna. The expectation was a fauna of small pelagics, the most abundant of which would be sardinellas, especially the oil sardine, (*Sardinella longiceps*), mackerels (*Scomber japonicus* and *Rastrelliger kanagurta*), scads (*Decapterus* spp.), jacks (*Caranx* spp.) and anchovies (*Stolephorus* spp.).

Apart from Indian mackerel these species were indeed among the most common. But in parts of the area, especially the east coast of Somalia, the recordings of these fish of commercial interest were often mixed with those of non-commercial fish such as porcupine fish (*Diodon* sp.), splitfins (*Synagrops* sp.) and driftfish (*Cubiceps* sp.). More intensive sampling could have improved the identification, but this was at times prevented by unfavourable weather conditions and strong currents. In some cases it could only be concluded that the attempts had not been adequate and the data had to be rejected. One such case related to the coverage of the Gulf of Oman in Survey 5. A further review of the fishing trials revealed that the recordings off the east coast of Somalia in Survey 3 had not been properly identified as small pelagic fish and that they should be rejected. In general, sampling and identification on the Somali east coast proved difficult and the results were considered less reliable than those of the other areas.

In retrospect it is evident that in these two first years of exploratory surveys there was not sufficient time for identification and sampling to allow a quantitative analysis by species or groups of species of the composition of the main group: the small pelagic commercial fish. Such estimations must be based on elaborate sampling combined in a concurrent analysis with the echo integration data. However, it was worth undertaking further analyses of the catch data from these first exploratory surveys. Inherent difficulties in interpreting catches and catch rates in pelagic trawl hauls in terms of species composition of the pelagic assemblages must be kept in mind as these also reflect differences in behaviour and catchability of the various species.

In the following summary the catch data of all surveys made in 1975–76 were grouped by main production regions (Kesteven *et al*., 1981). Only hauls with the pelagic trawl containing catches of small pelagic commercial fish were included. Table 3.12 shows the data for the most abundant species from the east coast of Somalia. The assemblage was dominated by Clupeidae. The high incidence of round herring (*Etrumeus teres*) was assumed to be due to the relatively high catchability of this species. Indian oil sardinella (*Sardinella longiceps*) was one of the main species. Less abundant were several other sardinellas, and among the Carangidae, scads (*Decapterus russelli*) and horse mackerel (*Trachurus indicus*).

Table 3.12 East Somalia: Species composition (main species only) of catches in hauls with the pelagic trawl containing small pelagic fish

Number of hauls: 13	**Incidence %**	**Part of total catch weight %**
Clupeidae	**85**	**50**
Sardinella longiceps	38	25
Etrumeus teres	62	25
Engraulidae	**8**	**11**
Engraulis japonicus	8	10
Stolephorus spp.	8	1
Scombridae	**31**	**40**
Scomber japonicus	15	38
Scomberomorus commerson	15	2

Large catches of mackerel (*Scomber japonicus*) were taken with the bottom trawl. This species with its partly bentho-pelagic behaviour seemed to be characteristic for the Somalia upwelling area and this may be related to the higher oxygen levels in deeper waters of this region as compared to the situation further north in the Arabian Sea (Wyrtki, 1971).

Table 3.13 shows the species composition in the somewhat more comprehensive sampling of the upwelling region off Yemen and the east coast of Oman. Some demersal hauls with a predominant catch of small pelagic fish were included. One haul of 12 t of *Sardinella albella* was excluded. This was an assemblage dominated by Clupeidae with *Sardinella longiceps* as the main species, especially off Yemen, but with a strong component also of Carangidae, with *Trachurus indicus* as a main species especially off Oman. The relatively low incidence but high catch of this species indicated a restricted distribution, but high local abundance.

Table 3.13 Yemen-Oman: Species composition of catches in hauls containing small pelagic fish, including all pelagic trawl and selected demersal trawl hauls with dominant catch of small pelagic fish

Number of hauls: 13	**Incidence %**	**Part of total catch weight %**
Clupeidae	**78**	**38**
Sardinella longiceps	41	15
Sardinella gibbosa	16	5
Sardinella albella	5	1
Sardinella sp.	3	-
Dussumieria acuta	14	8
Etrumeus teres	16	9
Engraulidae	**5**	**1**
Engraulis japonicus	3	-
Engraulis sp.	3	-
Carangidae	**43**	**60**
Trachurus indicus	11	46
Decapterus russelli	16	4
Megalaspis cordyla	5	1
Other Carangidae species	16	9
Scombridae	**14**	**2**
Scomber japonicus	3	-
Scomberomorus commerson	11	2

For Pakistan, additional information on the composition of the neritic pelagic fish became available in the special programme which followed the regional programme in January-June 1977 and included five surveys (IMR, 1978a). This more extensive sampling confirmed the earlier observations and showed an assemblage on this shelf different from that of the western upwelling areas (Table 3.14). The fauna was more varied with a larger number of species. The high incidence and catch of anchovies consisting of both *Stolephorus* spp. and *Thryssa* spp. was probably partly related to their high catchability, but they seem to have dominated, especially on the eastern Sind coast and Somniani Bay where the highest densities of small pelagics were found. The higher proportion of anchovies of the total small pelagics on the eastern Pakistan shelf as compared to the western upwellings is probably related to the wider inner shelf habitat of this coast compared to the narrow western shelves and to the effect of the discharges from the Indus river. Rainbow sardine (*Dussumieria acuta*), oil sardine (*Sardinella longiceps*) and Sind sardinella (*Sardinella sindensis*) were also common especially along the western Makran coast. The two scads (*Megalaspis cordyla* and *Decapterus russelli*) dominated the Carangidae. The Scombridae were represented by various *Scomberomorus* species which appeared with high incidence (about 30%), but low catch rates in the demersal hauls.

Table 3.14 Pakistan: Species composition of catches in hauls containing small pelagic fish, including all pelagic and selected demersal trawl hauls with dominant catch of small pelagic fish

Number of hauls: 13	**Incidence %**	**Part of total catch weight %**
Clupeidae	**33**	**26**
Sardinella longiceps	4	4
Sardinella sindensis	4	-
Sardinella sp.	4	1
Sardinella acuta	29	19
Engraulidae	**46**	**64**
Stolephorus indicus	13	21
Stolephorus buccaneri	8	1
Stolephorus sp.	4	1

Thryssa vitrirostris	13	7
Thryssa setirostris	4	26
Thryssa mystax	1	1
Thryssa sp.	1	8
Carangidae	**38**	**10**
Megalaspis cordyla	17	4
Decapterus russelli	16	6
Decapterus sp.	4	
Scombridae		
Scomberomorus spp.	± 30*	

* In all bottom trawl hauls

Revision of biomass estimates of small pelagics

As discussed in Section 2.2, the likely systematic errors of acoustic survey methodology are expected to result in underestimates of biomass, particularly for fish occurring in dense schools from which instrument saturation would be common. It was not possible to adjust for these biases, but the high target strength level used during the first two years of survey -29 dB/kg (for 17 cm fish) had to be adjusted in order to obtain data comparable to those of later surveys. In the discussion of methods in Chapter 2 it was suggested to assume a level of -32 dB/kg for small pelagic fish. A decrease of the target strength (TS) by 3 dB implies a doubling of the biomass estimates from the first two years of survey. For the western coastal upwelling areas dominated by Clupeidae a mean fish size of roughly 17 cm was used. For the Pakistan coast the value of C, the factor converting integrator deflection to biomass had to be adjusted to the smaller size (about 8 cm) of the dominating anchovies (Table 14 in Kesteven *et al*., 1981). An approximate adjustment is achieved through halving the C factor.

The survey-to-survey variation of the biomass estimates for each sector shown in Table 3.11 was considerable. Part of this may have been caused by displacement of stocks or points of high production between sectors. The bulk of the fish in Yemen waters was thus most often found eastwards in a distribution which seemed to continue along the Oman coast. South Somalia, Socotra and the eastern part of north Somalia would also seem to form one production area. These areas would relate to the coastal upwellings off the Arabian Peninsula and north Somalia respectively. A rearrangement of the biomass estimates for these general production areas is shown in Table 3.15 where the data have been adjusted to a 3 dB lower TS level (from -29 to -32 dB/kg) for all areas and in addition with the Pakistan estimates adjusted for small fish size (halving the C factor).

There was a considerable variation in the series of data for each area, and there was no apparent seasonal cycle for the two upwelling areas (Somalia and Arabian Peninsula). For the area south and southeast of the Arabian Peninsula the last three surveys gave fairly consistent estimates of close to 1.5 million t of which the Oman coast accounted for about two-thirds or 1 million t. The high estimates for Pakistan from January to May may have been an effect of a seasonal production cycle in the short-lived anchovies.

Table 3.15 Biomass estimates of small pelagic fish by major production areas and surveys, (1,000 t) adjusted for lower levels of target strength (see text and Table 3.11)

Surveys	**1, 2**	**3**	**4**	**5**	**6**	**Mean**
Months	**II–VII**	**VIII–XI**	**I–III**	**IV–VI**	**IX–X**	
Area (Sectors)						
Somalia (1–3)	1,060	940			1,960	1,320
Arabian Peninsula (4–7)	1,020	2,280	1,420	1,440	1,660	1,560
Pakistan (8)	680	290	680	270	410	470
Total	2,760	3,510			4,030	3,350

Catchability

The availability of a resource for commercial fishing depends on its appearance in catchable concentrations. An evaluation of the catchability can be made by examination of the distribution charts to ascertain the parts of the total biomass recorded at various degrees of densities: such data from Surveys 3 to 6 for the different areas appear in Table 3.16. As discussed in Chapter 2 the general experience from the DR. FRIDTJOF NANSEN surveys was that densities higher than about 300 t/nmi^2 represent areas where small pelagic fish are aggregated in “fish areas” or “school areas” where many schools were found especially during the day and where at night the fish were often found in more or less continuous more dispersed layers. Fish in such areas are vulnerable to commercial fishing. Table 3.16 shows that most of the biomass of the small pelagics in the northwest Arabian Sea was found in densities which should make them available to commercial fishing by purse-seining.

Table 3.16 Proportion of biomass found at levels of higher densities (%)

Survey	3	4	5	6	Mean
Somalia					
> 400 t/nmi^2	69			98	84
> 1,000 t/nmi^2	52			85	69
Arabian Peninsula					
> 400 t/nmi^2	90	90	86	85	88
> 1,000 t/nmi^2	75	90	70	49	71

The distributional characteristics of the small pelagics on the Pakistan shelf were entirely different. By far the main part of the biomass was found in scattered layers and small dispersed schools. School areas with higher densities were almost absent in the west on the Makran coast and Somniani Bay and were only found in the east on the Sind coast in the two spring surveys (1 and 3). Densities higher than 250 t/nmi^2 then only represented 9% and 17% respectively of the total biomass estimate. It is concluded that therefore these resources would not be a suitable target for purse-seine fishing.

Semi-demersal fish

In addition to the small pelagic schooling fish which represented the main objective of the surveys the reported data included acoustic records of targets recorded originally as demersal, fish from their appearance in layers, usually of low density close to the bottom or in the lower part of the water column, but for which semi-demersal would have been a better classification. Since many semi-demersal fish tend to rise off the bottom at night a distinction should be made between day and night recordings. This was done only in later surveys, and the averaging of day and night recordings in the first surveys reported here results in an underestimate of this category.

Special problems complicated the description of the fish species more closely associated with the bottom in this region. The monsoon cycle causes a seasonal intrusion of water with a low oxygen content onto the shelf during the southwest and post-southwest monsoon causing drastic changes in the distribution of demersal and semi-demersal fish (Bianchi, 1992a and b). As a consequence, a high variation in biomass estimates between different seasons can be expected. Another effect is that some fish normally considered as demersal, such as threadfin breams (Nemipteridae) and catfishes (Ariidae) have apparently adopted a more pelagic behaviour in this region.

Results of bottom trawling which was in general used for identification and sampling of the demersal fish component of the integrator contributions, was probably positively biased towards the true demersal species which were often reported to be the main component of the catches: groupers (Serranidae), croakers (Sciaenidae) and scavengers (Lethrinidae) and to some extent snappers (Lutjanidae), while it is likely that the acoustic mid-water targets may have been predominantly: threadfin breams (Nemipteridae), catfishes (Ariidae), hairtails (Trichiuridae) and ponyfishes (Leiognathidae). Ponyfishes were often found in considerable abundance and their echograms were probably correctly identified.

The very narrow shelf of East Somalia with its strong currents represented particular problems for fishing and hence for identification. It is thought that most of the recordings of semi-demersal fish in this region were not adequately identified and it must be assumed that they have consisted mainly of non-commercial species: porcupine fish (Diodontidae), lizard fish (Synodontidae) and small-sized cardinal fish (Apogonidae). Deep-swimming schools and layers of mackerel (*Scomber japonicus*) may also have been included. Bianchi (1992b) presented a study of the demersal assemblages on the continental shelves in this region based on bottom trawl surveys of later assignments.

Identification of the semi-demersal fish can thus not be based directly on an analysis of catch compositions since bottom trawl catches must be assumed to be biased. Furthermore, there was hardly any aimed fishing with mid-water trawls for these targets. However, a general identification based on knowledge of fish behaviour and on data from IMR (1977b), IMR (1978a) and Bianchi (1992a and b) is attempted in Table 3.17. There appears to be some difference in order of abundance, with ponyfish and threadfin breams being most common in Yemen and Oman, while hairtails and catfishes dominate in Pakistan.

A review of the biomass estimates of the semi-demersal group by surveys as presented in Table 12 in Kesteven *et al.* (1981) shows a considerable variation, which may partly be related to the seasonal changes in the environment. As most of the semi-demersals off the Somalia coast seem to have been non-commercial species, no estimate will be attempted for this region. For Yemen-Oman the hydrographic profiles show insurgence of low-oxygen water up to about 50 m depth during the post-monsoon season (surveys 3 and 6) which leaves estimates of 266,000, 46,000 and 137,000 t respectively for the three pre-monsoon surveys 1, 4 and 5 (Kesteven *et al.*, 1981). For Pakistan only Survey 5 represents a pre-monsoon coverage where the distribution of integrator readings suggests a fairly consistent identification of the demersal group. An estimate by area integration gives about 220,000 t. Table 3.18 shows the mean biomass estimates from the above selected surveys referred to a target strength level of -32 dB/kg (for 17 cm fish). It should be remembered that the assessment of semi-demersal fish was not a specified objective of the survey programme, and considerable reservations should be attached to these estimates. More confidence could perhaps be afforded to the combined pelagic/demersal estimates as representing a measure of the “total acoustic biomass”.

Table 3.17 Main contributors to the recordings of the semi-demersal group by production areas in approximate order of appearance in the catches

Somalia	Mainly non-commercial fish
Arabian Peninsula (Yemen-Oman)	Ponyfish (Leiognathidae) Threadfin breams (Nemipteridae) Catfishes (Ariidae) Hairtails (Trichiuridae)
Pakistan	Hairtails (Trichiuridae) Catfishes (Ariidae) Threadfin breams (Nemipteridae) Ponyfish (Leiognathidae)

Table 3.18 Biomass estimates of semi-demersal fish based on acoustic observations in selected pre-monsoon coverages (t)

Yemen-Oman	300,000
Pakistan	440,000

The special surveys of the more important parts of the northwest Arabian Sea undertaken later in the programme included bottom trawl surveys (swept-area estimates) which provided more comprehensive and reliable information on semi-demersal and demersal fish (see Section 3.5).

Mean biomass densities

The mean standing fish biomass per unit area may be a rough indicator of productivity. In the northwest Arabian Sea the distribution of the small pelagic fish extended in many cases beyond the narrow continental shelf and the survey area was in an approximate way adjusted accordingly, being defined as inshore surveyed space. The mean biomass density was referred to this area, but for general comparisons a reference to the continental shelf area was also made (Table 3.19). The estimated mean densities for the small pelagics were similar for the two upwelling areas, Somalia and the Arabian Peninsula, but about 50% lower for the Pakistan shelf.

Table 3.19 Mean biomass densities (t/nmi^2) in main production areas referred to inshore surveyed space and continental shelf

	Somalia	Arabian Peninsula	Pakistan
Surveyed space (nmi^2)	22,400	25,300	13,200
Small pelagics	59	62	36
Semi-demersals	(0)	12	33
Total	**59**	**74**	**69**
Continental shelf (nmi^2)	13,800	19,000	12,770
Small pelagics	96	82	37
Semi-demersals	(0)	16	34
Total	**96**	**98**	**71**

3.4 SURVEYS OF MESOPELAGIC FISH IN THE NORTHWEST ARABIAN SEA, 1975–84

Survey effort

One of the main findings of the DR. FRIDTJOF NANSEN surveys in the northwest Arabian Sea was the wide distribution and high abundance of mesopelagic fish. This result could perhaps have been foreseen.

The faunistic regimes of coastal upwelling systems are known to contain a shoreward assemblage of Clupeidae, Carangidae and Gadidae and an oceanward assemblage of mainly Myctophidae and Scombridae (Cushing, 1971b). The highly productive zones in the northwest Arabian Sea were observed to extend much further offshore than in the coastal upwelling zones of eastern boundary currents. Recordings of mesopelagic fish had already been made in the area, viz., those reported by the RSS DISCOVERY's participation in the IIOE (Anon, 1963). They were not at the time identified as mesopelagic fish, but this could have been deduced from the description of their distribution and behaviour. This was the only fish observation reported from the whole of the five year IIOE programme. There is now also evidence from otoliths in deep-sea cores of long-term prominence of Myctophidae in the region (Anon., 1991a).

Mesopelagic fish was an important element in the findings from the following assignments of the DR. FRIDTJOF NANSEN programme:

Main exploratory fish surveys:

February 1975-November 1976, 5 coverages northwest Arabian Sea
January-June 1977, 5 coverages Pakistan

Special surveys for mesopelagics:

July-August 1979, Gulf of Oman and Gulf of Aden
January-February 1981, Gulf of Oman and Gulf of Aden
February-March 1983, Gulf of Oman
September 1983 and May-June 1984, Iranian part of Gulf of Oman

The results regarding mesopelagics from the main fish surveys are described by Gjøsæter (1977, 1981b) and reviewed in Gjøsæter and Kawaguchi (1980). The Pakistan 1977 surveys are reported by IMR, 1978a. Of the special surveys for mesopelagics the 1979 survey is reported by Gjøsæter and Myrseth (1979) and also together with the 1981 survey in Aglen *et al.* (1982). The February-March 1983 survey is reported by Gjø;sæter and Tilseth (1983) and the fishing trials by Schärfe (1983). The 1983–84 surveys from Iran are reported by IMR (1983c) and Ona (1984a).

A summary follows of the findings of the main surveys 1975–77 regarding the distribution, composition and behaviour of the mesopelagics in this area and the reported biomass estimates. Since the biomass estimates of mesopelagics were very high and the catch rates obtained in some areas were promising there was a potential commercial interest in these resources. Special surveys were therefore mounted in the high density areas to provide more detailed biological and technological information; their results are reviewed below. They are of special interest as they were planned to resolve specific problems relating to these fish and were conducted by scientists who had by that time acquired considerable knowledge of their biology and behaviour.

Results of the main surveys, 1975–77

The intensive coverage of the shelf areas usually included the slope which forms the inner limit of the distribution of the mesopelagics, but the density of the course tracks in the central parts of the Gulfs of Oman and Aden and the open ocean was less, as can be appreciated from Figure 3.12 (Section 3.3) which shows the course tracks of one of the general surveys. The oceanward extent of the survey had been adjusted to correspond in a very general way with the seaward limit of the highly productive part of the western Arabian Sea. No attempt was made to adjust the survey area to the distribution of the mesopelagic fish.

The area from Somalia to the Pakistan-India border was covered five times during 1975–76 and the Pakistan shelf was covered five times during January-June 1977.

The acoustic instrumentation (38 kHz echo integration system) allowed observations within a 500 m depth range. Fishing for identification and sampling was made with a 1,360 mesh mid-water trawl.

During the day a deep-scattering layer named D2 layer was found throughout the area between about 250 and 350 m. In the northwestern part and occasionally in the Gulf of Aden, an additional layer D1 was found at 100–200 m. The depth of the layers changed at night when all or part of the D2 layer would migrate upwards and join the D1 layer, if existing, and form a near-surface layer, N1, at 10–100 m depth. Sometimes part of the D2 layer would remain in deep-water also during the night forming a layer named N2. Figure 3.14 which is based on acoustic observations from a fixed station in the Gulf of Oman in 1976 illustrates this diurnal behaviour. The vertical migrations were fast, the downward migration at sunrise often being completed within 20 min (Ona, 1984a).

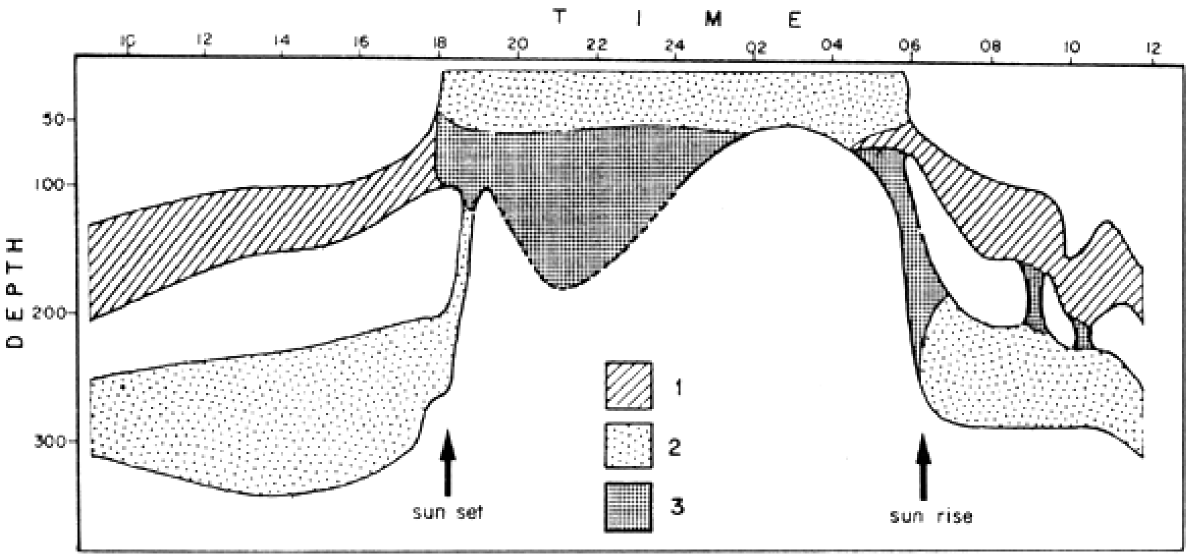

Figure 3.14 Vertical migrations of mesopelagic fish as observed during a diurnal station. (1) Schools and very dense aggregations, (2) dense recordings and (3) scattered recordings (from Gjø;sæter, 1981b)

Many species were identified from the whole area, but *Benthosema pterotum* dominated most catches in the high density areas in the northwest and this was the only species found in the area of the fixed station in the Gulf of Oman. *Benthosema fibulatum* and *Diaphus* spp. were also common. The size compositions (total length) in samples of *B. pterotum* ranged from 20 to 50 mm with most means between 30 and 40 mm. The *Benthosema* species were assessed to have a life cycle of one year or less.

Biomass density was estimated from the acoustic integration data. High densities were often encountered in the slope or adjacent areas, but analysis of observations further offshore in selected profiles of 150–200 nmi from different parts of the total coverage showed no general trends of decrease or increase in a seaward direction. There was thus, as shown in Figure 3.15, a very wide total distribution of the mesopelagics in contrast to other fish populations usually found in smaller contagious distributions.

The sub-divisions used in the analysis are shown in Figure 3.16. The mean biomass densities varied between areas in an at least partly consistent way as shown in Figure 3.17, with area A, the Gulf of Oman showing the highest mean densities in nearly all the surveys. Relatively high densities were also found in the Gulf of Aden in the first two surveys while in the last two surveys the density here was low, and the species composition had changed.

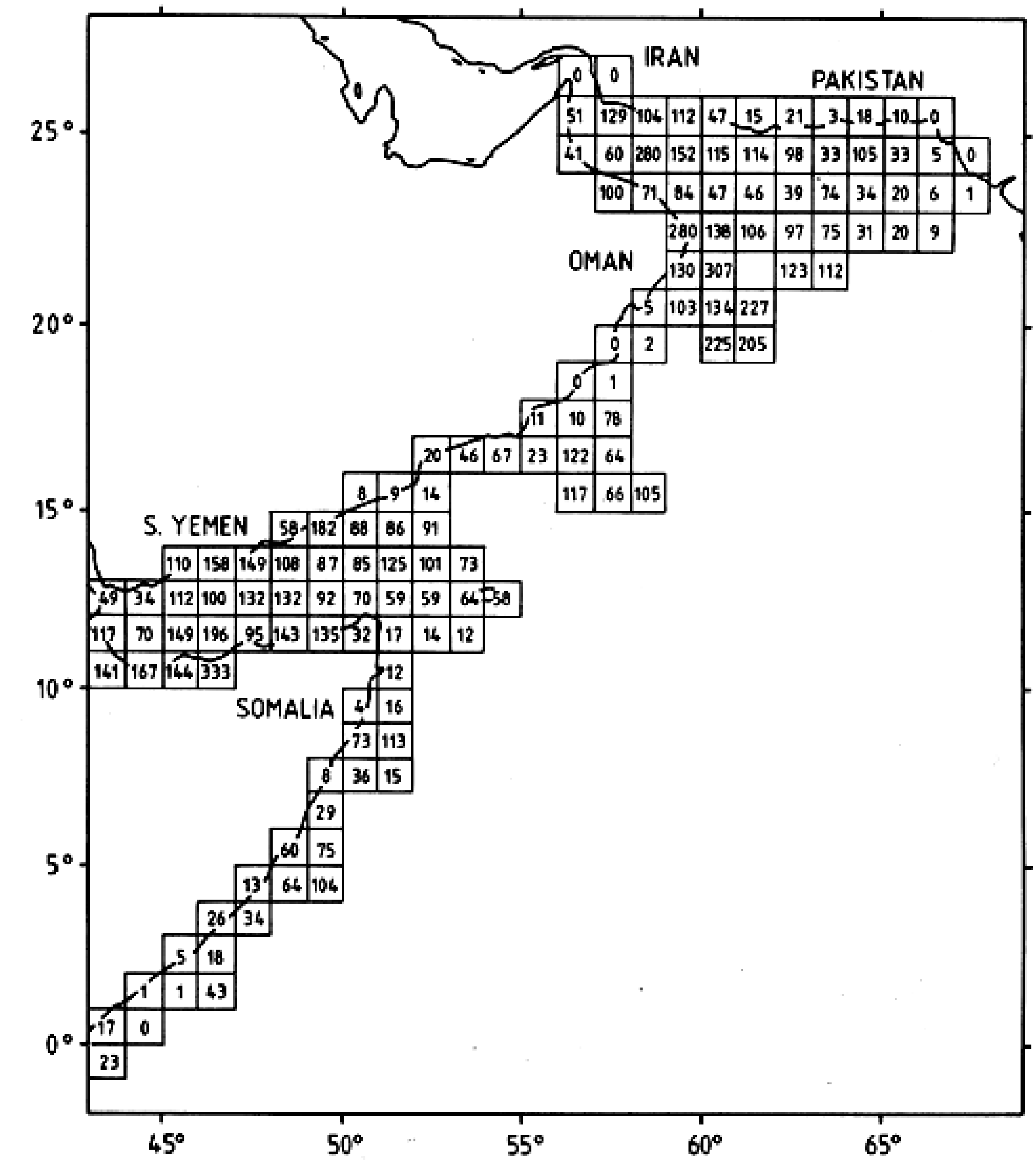

Figure 3.15 Mean integrator deflection of mesopelagic fish (Autumn 1975 survey)

Variations in catch rates between surveys seem to confirm that the observed variation in mean density was at least in part caused by changes in population density. Variance caused by the applied survey methodology may also have affected the data. Thus the persistent high observations during the first two surveys in nearly all areas may indicate some bias in the first survey, e.g. inadequate acoustic identification and sampling. The observations from this first survey will thus be omitted in further analysis of densities and abundance although they are included in the first historical account of the findings. In some surveys coverage may have been inadequate in certain areas.

Mesopelagic fish was also included in the five fish assessment surveys off Pakistan in January-June 1977. The biomass estimates of the first three surveys were somewhat higher than in 1975–76. Declining levels in the last two surveys off Pakistan were probably an artefact caused by a reduced performance of the acoustic system. Catch rates were generally low; only 9 of 33 hauls exceeded 400 kg/h and only 4 exceeded 1 t/h.

The estimated densities of mesopelagics observed in the 1975–76 surveys were used to calculate total biomass by surveys which was found to range between 56 and 148 million t for the whole area covered, with a mean of 100 million t. These were noted as remarkably high levels of fish biomass and their veracity has repeatedly been discussed and questioned since the first summary report by Gjø;sæter (1977).

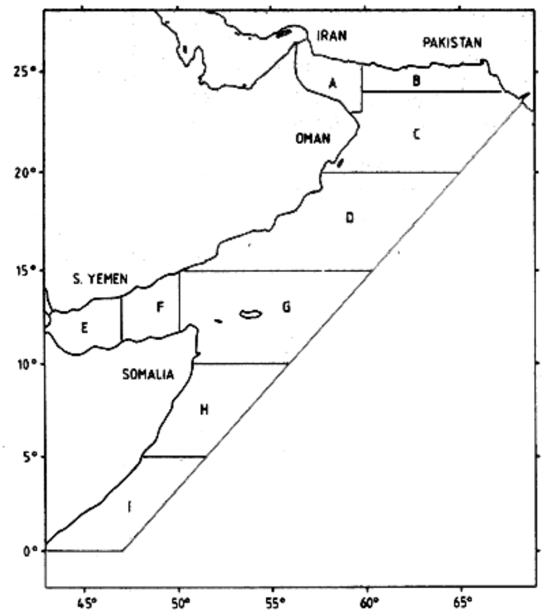

Figure 3.16 The investigated area and its subdivisions

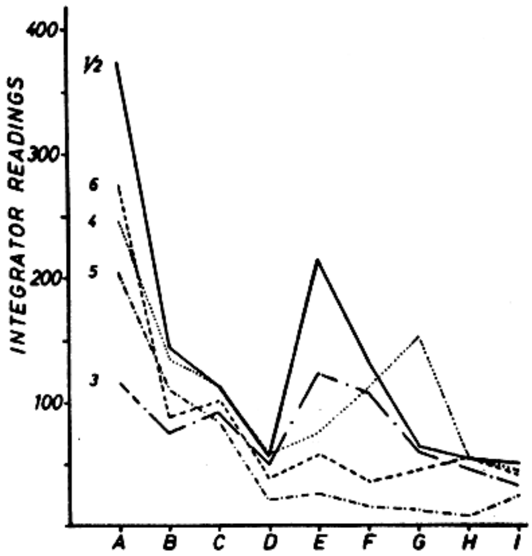

Figure 3.17 Mean integrator deflection for sub-divisions shown in Figure 3.16 and by surveys (from Gjø;sæter, 1981b)

The results of fishing experiments also demonstrated the existence of a considerable quantity of mesopelagic fish. Comparisons with estimates of density calculated from catch rates in fishing trials on selected good recordings of mesopelagics showed figures exceeding the mean acoustic density estimates. Some 26 stations gave catch rates higher than 400 kg/h of which 18 exceeded 1 t/h, of which six with 5 t/h and a highest rate of 20 t/h. The locations of these fishing stations cover, as shown in Figure 3.18, a very large area but indicate a restriction of high densities of fish to the Gulf of Oman and to the shelf break areas outside the Gulf of Oman. Catch rates in the open ocean were very much lower with no indication of possible commercial rates. The very high total biomass estimates were therefore primarily of interest in a context of total production and trophodynamics although this was perhaps not recognized at first.

Based on primary production estimates presented by Cushing (1971a) for the area covered by the survey, Gjø;sæter (1977) found that an annual assumed production of 100 million t of mesopelagics represents between 1 and 2 % of the primary production and about 10% of the secondary production. If an ecological efficiency of 10% is assumed at each trophic level, the mesopelagic fish would utilize the entire secondary production.

There are, as discussed below, reasons for suspecting the existence of a bias in these biomass estimates which may have caused a considerable overestimate, perhaps by a factor of 2–3. This, however, does not change the general finding of the surveys that the mesopelagics were by far the most abundant type of fish in the northwest Arabian Sea and that they represented a major component of the ecosystem.

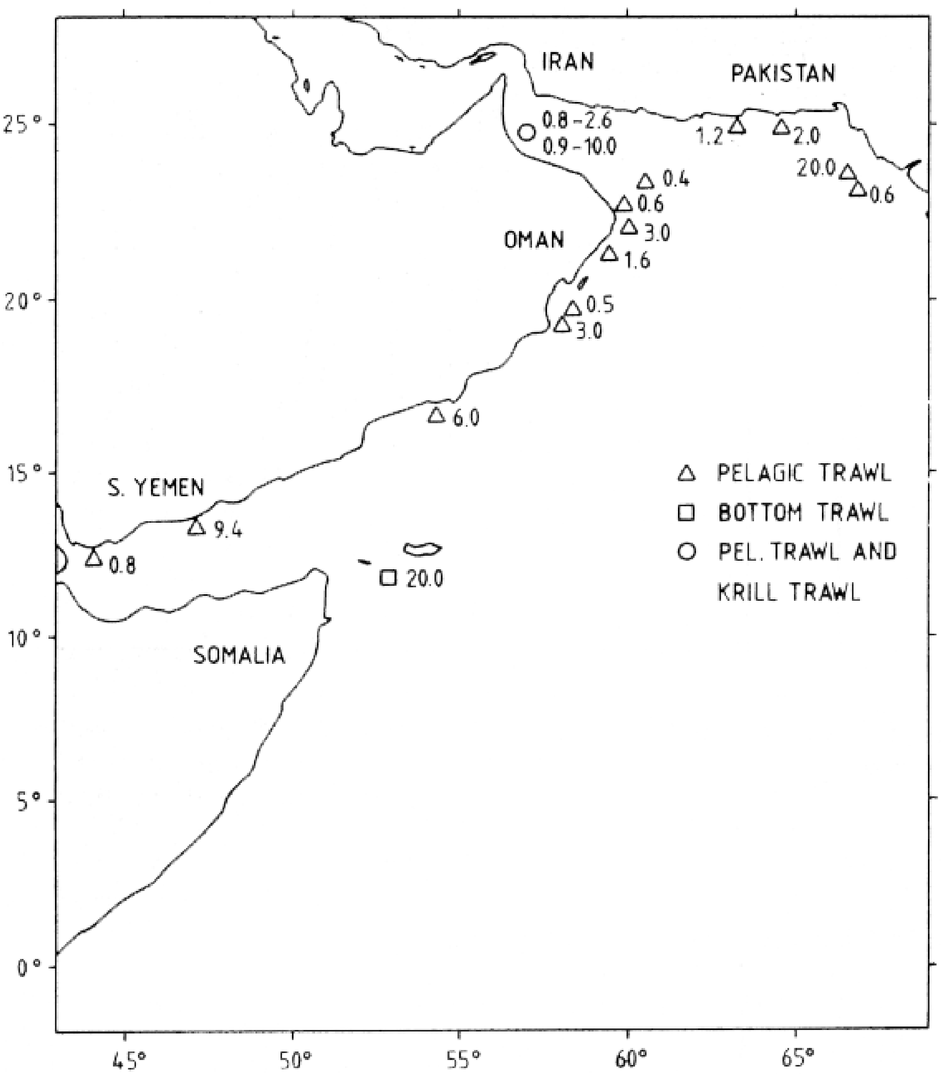

Figure 3.18 Trawl stations in the 1975–1976 surveys giving more than 400 kg/h of mesopelagic fish, catch rates in t/h (adapted from Gjø;sæter, 1981b)

Results of the special surveys, 1979–84

Further survey work on mesopelagic fish was restricted to the areas of highest observed densities: the Gulfs of Oman and Aden. The objectives were to: obtain new acoustic abundance estimates; provide other evidence of densities; collect data for further biological and ecological studies, and carry out experimental fishing.

In the special survey mounted in July/August 1979 the acoustic abundance recorded in the Gulf of Oman was found to be about 8 million t, which was within the range observed previously, but in the Gulf of Aden the biomass was estimated at only 4 million t. This low level compared with previous findings was confirmed by low catch rates.

An attempt to use mean catch rates from the main scattering layers for the estimation of total biomass gave proportions between 20 and 50% of the mean acoustic estimate assuming that the trawl would catch all fish passing through the trawl opening.

In January/February 1981 most of the work was conducted in the Gulf of Oman. Studies of the various scattering layers were made in repeated surveys of the main part of the Gulf and in six detailed surveys of a selected area.

Echo integration of a depth interval corresponding to that covered by the trawl opening during towing provided a set of observations for estimating apparent trawl efficiency: the ratio between catch/m^3 filtered water and acoustically-measured density. This was found to be very low for the D2 layer. A possible explanation given for this was the lack of a herding effect of the bridles and trawl wings at these depths.

Experiments testing the effect of underwater light on the mesopelagics were also conducted and underwater photographs of various layers were taken.

The 1981 biomass estimate for the total Gulf of Oman was 11 million t (also within the range of previous observations) and high catch rates were obtained. The Gulf of Aden estimate was higher than in 1979 at 16 million t, but the catch rates were very low and a change in species composition seemed to have occurred.

The February/March 1983 survey in the Gulf of Oman had various objectives: to continue the studies on behaviour and biology; to monitor the biomass of the mesopelagics, and to undertake a series of experimental fishing trials with gears specially designed for this purpose.

Two coverages gave biomass estimates of 8.0 and 4.7 million t, a rather high variation. An analysis of the contribution from the different types of scattering layers now showed significantly lower night than day levels. An examination showed that this was the case also for the 1981 data similarly analysed. The D2 layer gave especially high echo intensities. An observation of importance for the commercial fishing experiments to be carried out this season was that the mean fish density in the D1 layer was considerably lower in 1983 than observed in 1981.

The fishing experiments reported by Schärfe (1983) were conducted over an 11-day period with mid-water trawls adapted with enlarged forward extensions of large mesh netting, 800 mm and 1,600 mm stretched, which increased the opening of the trawl from about 250 m^2 to respectively two and three times that area.

The results are summarized in Table 3.20. Herding by the large mesh net must have been effective in the D1 layer as demonstrated by good overall catch rates there. Fishing was also effective with artificial light in the N1 layer. The results were described as successful and promising especially in view of the observed low general density of the D1 layer encountered in the trials as compared with the density found in 1981.

The densities estimated from acoustic integration during 27 hauls on “reasonably good” D1 layers in 1983 ranged from 20 to 412 g/m^2 with a mean of 80 g/m^2 corresponding to 0.7 to 24.2 g/m^3 with a mean of 4.3 g/m^3. It should be noted that these represent high densities in locations selected for fishing. On the other hand, the mean estimated density of fish in the D1 layer in the 1983 main surveys was 0.4–0.5 g/m^3 corresponding to 10–12 g/m^2. In the 1981 survey the D1 layer density was estimated by Gjø;sæter and Tilseth (1983) to be about 5 times higher with 2.4 g/m^3 and 59 g/m^2.

Table 3.20 Summary of fishing trials on lanternfish (adapted from Schärfe, 1983)

Krill trawl with front part of 800 mm mesh stretched				
	Tows	Hours fished	Catch t	t/h
On reasonably good D1 layers	10	10.9	41.2	3.8
On other layers	10	10.7	4.5	0.4
Sub-totals/average	20	21.6	45.7	2.1
Krill trawl with front part of 1,600 mm mesh stretched				
On reasonably good D1 layers	17	24.9	109.4	5.0
On other layers	4	6.4	8.4	1.3
Sub-totals/average	5	8.0	17.7	2.2
	26	39.3	135.5	3.4
On very dense D1 layer	1	about 0.5	about 50	100
Grand totals/average	47	61.4	231.2	5.8

The D2 and N2 layers were, however, reported by Schärfe (1983) to be “completely useless for commercial fishing”. The comments of Schärfe as an experienced fishing technologist after these tests are worth noting. The acoustic estimates of fish density made by integrating the layer in front of the trawl allowed testing of the efficiency of the gear. A very low apparent efficiency was experienced in the D2 layer causing Schärfe to suggest that further similar experience might make a reconsideration of the “conversion factor” for the D2 layer desirable.

The two last special surveys on mesopelagics covered the Iranian part of the Gulf of Oman in September 1983, IMR, 1983b and May-June 1984. The recordings were reported by Ona (1984a) to be generally scattered to dense, but belts of high density were found. The D2 layer, below 200 m was reported to give blurred recordings, but very high integrator values.

The reports, IMR (1983c) and Ona (1984a) show the distribution of mesopelagics by relative densities. The results of biomass estimates based on an assumed target strength of -34.2 dB/kg (17 cm fish) were as follows:

September 1983: 2,384,000 t in an area of 10,589 nmi^2
May-June 1984: 2,600,000 t in an area of 13,743 nmi^2

The distributions cover the deep-sea areas of the Gulf of Oman from the edge of the shelf to the mid line, from the border with Pakistan at about 61°30'E to Hormuz Strait. Densities seemed to increase somewhat westwards.

These are the only estimates from special mesopelagic investigations of the Iranian part of the Gulf of Oman. In the September 1983 survey the acoustic system was still the EKS echosounder with the analog QM integrator. In the May-June 1984 survey the new EK400 system had been installed with the digital QD integrator. Both systems had been well calibrated. It is of interest to compare the densities observed with those obtained in the Oman part of the Gulf. The closest survey in time is from February 1983 and covers the Gulf eastward to about 59°20'E. Table 3.21 shows a comparison of densities in the various parts of the Gulf from these surveys.

Table 3.21 Observed mean densities from parts of the Gulf of Oman in the 1983 and 1984 surveys (g/m^2)

Area	Time	Density
Oman West of 59°20'E	February 1983	89
Iran West of about 61°E	September 1983	66
Iran West of about 61°30'E	May-June 1984	55
Iran West of about 59°20'E	September 1983	73
Iran West of about 59°20'E	May-June 1984	70

Compared with the mean densities in Oman waters in February 1983 the density of mesopelagics in the whole of the Iranian EEZ up to the Hormuz Strait was about 50% lower in September 1983 and May-June 1984. In the Iranian part of the Gulf proper the densities were about 25% lower. It is uncertain whether these comparisons made at about six months intervals are valid. They suggest that extrapolated estimates of the biomass of the whole Gulf, made on the basis of observations from the Oman part only such as those from January-February 1981 and February 1983, may be about 12% too high.

The Iranian 1983 and 1984 surveys included only a few fishing trials for the purpose of identification and size sampling. Various programmes of commercial fishing trials have later been conducted in Iranian waters, but the results are not generally available. A 1992 programme with a powerful mid-water trawler yielded high commercial rates in a limited area in the western part of the Gulf according to Beltestad (1992).

Discussion of estimates of abundance

The biomass estimates of mesopelagic fish obtained in the northwest Arabian Sea with the acoustic integration technique show, according to Gjø;sæter and Kawaguchi (1980), mean densities of roughly an order of magnitude higher than found with micronekton tows and other methods elsewhere in the world's oceans. Its seems, however, likely that nekton tows and a method based on acoustic resonance estimation would give underestimates of the true densities.

The applicability of the acoustic integration technique to these very small sized fish was discussed in several of the reports, e.g., Gjø;sæter (1977), Gjø;sæter and Kawaguchi (1980); and comparison attempted with other observations of densities such as from catch rates as in Aglen *et al.* (1982) and Schärfe (1983). These comparisons showed reasonable correspondence with estimated densities from acoustics for fish in the D1 layer, but not in the D2 layers where catches were very low despite observed high acoustic densities. The “blurred” or “smoky” or “fluffy” appearance of the echosounder recordings from the D2 layer is noted in several reports. Therefore, an important question concerning the data is whether resonance phenomena may have affected the acoustic estimates.

A contribution to this discussion was submitted by Dalen and Ona (1984): “Resonance effects in acoustic population estimates of mesopelagic fish” (in Norwegian). This short paper considers the theoretical conditions for a possible depth relation in the backscattering sound energy from *Benthosema pterotum*, the main species in the mesopelagic fauna in the Gulf of Oman. The size of the swim bladder of this physoclist fish was assessed from shock-frozen specimens. The resonance frequency and its depth relationship will depend on the ability of the fish to compensate pressure-lost swim bladder volume through gas production. Gas production and absorbtion mechanisms have been demonstrated in this species, but it seems highly unlikely that the downward migration which occurs at speeds up to 4 m/min can be fully compensated. That would need a gas production capacity some 250 times greater than measured in other species with well developed secretion. Concerning the issue of energy budget, full compensation seems unlikely.

As a likely case the authors computed and demonstrated the resonance frequency/depth relationship for 30 mm fish assuming 1) a downward migration without compensation, 2) a process of compensation at an unknown rate and 3) completeness in the deep-layer and upward migration with full compensation (Figure 3.19).

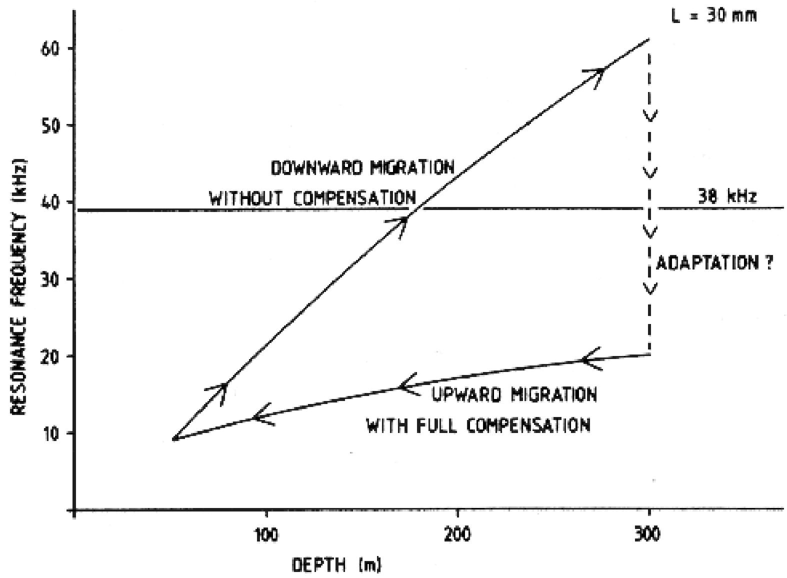

Figure 3.19 Relationship between depth and resonance frequency for likely strategy of depth adaptation for *Benthosema pterotum* of 30 mm length. Adapted from Dalen and Ona (1984)

The paper concluded that:

- The swim bladder in the smallest fish (<20 mm) can give resonance effects in the D2 layer irrespective of strategy for adaptation.
- The high speed of descent probably results in compression of the swim bladder, and fish at certain lengths can then give resonance effects over a wide frequency spectre at depths from 100 to 400 m.
- The very low apparent trawl efficiency found in fishing experiments in the D2 layer may indicate that the acoustic estimate of this layer is too high due to resonance.

The authors consider that resonance effects in the echoes easily can result in overestimates of the biomass of 2–10 times.

The paper ends with a proposal for an instrumentation with which resonance effects could be tested, but there has been no opportunity to implement it as IMR has not been involved in any subsequent investigations of mesopelagics.

Although an instrumented field test must await a future opportunity, it is possible to use some data derived from acoustic measurements of fish density from the various depth layers in a preliminary check on whether resonance is likely to have occurred.

If resonance primarily affects the deep-layers (D2 and N2) it should be expected that the total night estimates would be lower than the day estimates since the diurnal migrations usually bring a large part of the deep-layer biomass up into the shallower N1 layer. Gjø;sæter (1977) who covers the 1975–76 surveys, found no significant difference between the day and night densities in a selection of sections, but with observations from dusk and sunrise omitted.

Consistent lower night densities were, however, evident from the Gulf of Oman where repeated surveys were made covering the main area of the Gulf of Oman three times and a smaller selected test area six times in 1981 and the main area twice in 1983. Assuming that the difference between the day and night observations in each of these sets of data is the effect of the diurnal vertical migration between the deep and the shallower layers, the decline in an unbiased estimate of density in the deep-layer from day to night should be compensated by a corresponding increase of density in the shallower layer.

If, however, the backscattering from the fish in the deep-layers was affected by resonance, the increase of the N1 over the D1 (N1 minus D1) layer would be less than the decrease of the D2 layer, from D2 to N2 (D2 minus N2) and the rate between the two would be a measure of its effect.

The results of an analysis based on Tables 5 and 6 from Aglen *et al.* (1982) and Table 4 from Gjø;sæter and Tilseth (1983) are presented in Table 3.22.

Table 3.22 Comparison between the increase of N1 layer and decrease of D2 layer backscattering levels due to diurnal migration of mesopelagic fish (units mm of integrator deflection)

	No. of 5 nmi tracks	N1-D1	D2-N2	Ratio
Oman/81, 3 main surveys				
W of 58°E	93	111	195	1.8
E of 58°E	44	45	72	1.6
Oman/81, 6 repeat surveys	62	130	450	3.5
Oman/83, 2 main surveys				
W of 58°E	63	54	143	2.6
E of 58°E	57	48	86	1.8

This analysis indicated that measurements in the deep-layers increased the echo abundance, in units of integrator deflection in mm, by 1.6–3.5 times with a mean of 2.2.

Gjø;sæter and Tilseth (1983) discussed the possible reasons for the higher day than night densities observed in 1981 and 1983. A distribution close to the surface at night above the hull-mounted echosounder transducer would have such an effect, but tests with a towed upward-looking transducer did not confirm such a behaviour as a general phenomenon. Loss by too high threshold settings was also mentioned, but this would generally be expected to be greatest in the deep-layer.

The case may be summarized as follows:

- There are indications from well conducted surveys in the areas of highest concentrations of mesopelagics in the Gulf of Oman that the volume backscattering coefficient from the D2 layers is from 1.6 to 3.5 times higher than from fish in the shallow layer.

- There is a theoretical basis for relating this to resonance effects in the deep-layer.

- There is support for this in the low catch rates and apparent low catching efficiency in the deep-layers.

- The echograms from the deep-layers are reported to be different from those in the shallower layers, by being more “smoky” or “fluffy” in appearance.

It seems thus reasonable to strongly suspect that acoustic biomass estimates of mesopelagics may be influenced by resonance in the deep-layer recordings. Theoretical considerations show that resonance may also occur at shallower depths, especially for small-sized fish < 20 mm. This may perhaps explain why Gjø;sæter (1977) found no statistical difference between day and night recordings in observations from a series of sections during the 1975–76 surveys.

The observed variation of the assumed resonance effect for the data analysed may perhaps be related to differences in the size distributions of the fish, the depth of the recordings and the time of day when the main recordings are made.

The often high variance found in the biomass estimates from repeated surveys could more easily be explained in terms of variance in resonance effect than by actual short-term changes in the biomass or by survey variability.

On the other hand, the acoustic densities observed in the D1 layer seem to have been verified in a general way by the comparisons made between acoustic estimates and densities estimated from results of fishing experiments. Using swept-water-volume estimates from the area of the trawl mouth opening and towing distance Aglen *et al.* (1982) estimated the apparent trawl efficiency as follows: catch rate in g/m^3 filtered water in relation to acoustic density in g/m^3. They obtained mean ratios of 0.51 and 0.77 for D1 layers in 6 and 23 hauls in 1979 and 1981 respectively. In 1983 tows with special trawls enlarged with large-mesh frontal parts showed a mean ratio of apparent efficiency of 0.44, measured in a similar manner in 27 trials on reasonably good D1 layers.

The true catchability coefficient of the trawls for these small-sized fish is unknown. By definition it can not exceed 1, and about 0.5 is perhaps not an unreasonable level. If the true catchability is lower, the acoustic density would be an underestimate of the true density. It may perhaps be concluded that the fishing trials in a general way confirm the acoustic estimates as a minimum estimate of the fish density in the D1 layer.

Revision of biomass estimates

Although adjustment for bias caused by resonance in the D2 layer is still an uncertain process in view of the limited information available and the variation in the observed apparent effects, it still seems a worthwhile exercise to revise the biomass estimates.

Gulf of Oman (Sub-area A)

The first review was made of the biomass estimates from the best investigated area, the Gulf of Oman. Figure 3.20 adapted from Gjø;sæter and Tilseth (1983) shows the reported total estimates which range from 6 to 15 million t. The time varied gain function (TVG) of the echosounder is of special importance for fish recorded at great depths, and as reported in Chapter 2, when a new TVG card was installed in 1980, the old function was discovered to have drifted. This can have caused some of the variability in the data, but the early high short-term changes with a range of more than 50% seem to reflect real changes in biomass.

From 1981 on the TVG was controlled and the contributions from the various types of scattering layers were reported separately.

Three successive coverages in 1981 gave estimates of 8, 11 and 13 million t with a mean of 10.7 million t. On the assumption that backscattering from the deep-layers is doubled by resonance, the details of the contributions from the various layers indicate that estimates adjusted for the bias caused by resonance would be reduced by 69%, 65% and 72% respectively, which gives 5.5, 7.0, 9.4 million t and a mean of 7.3 million t.

Compared to 1981, the two acoustic coverages in 1983 showed a reduced abundance of 8.0 and 4.7 million t. Reducing the deep-layer contributions to half gives corrections to 70% and 78% respectively resulting in 5.6 and 3.7 million t a mean biomass estimate of 4.6 million t.

Furthermore, in both the 1981 and the 1983 estimates it had been assumed that the densities on the Iranian side of the Gulf of Oman were the same as those on the surveyed Omani side. If it is lower, as shown in Table 3.21, there would be a need for another adjustment reducing the mean values of 7.3 and 4.6 million t to 6.4 and 4.1 million t respectively, or an average abundance close to 5 million t for the entire Gulf of Oman.

Revisions of the assumed target strength for the mesopelagic fish might lead to further adjustments. The levels assumed in 1981 and 1983 were -35.2 dB/kg and -34.2 dB/kg (for 17 cm fish) respectively (Aglen *et al.*, 1982; Gjø;sæter and Tilseth, 1983). These were based on an average target strength of 10 log L - 22 dB/kg fish and comparable to the value of -28.4 dB/kg for 5.2 cm fish applied in the surveys with the R/V LEMURU of mesopelagics in the area (Lamboeuf and Simmonds, 1981). This corresponds approximately to the relationship TS = 20 logL - 72 dB as commonly used for small pelagic fish. Direct observations of the target strength of the very small-sized mesopelagic fish are not available. Keeping in mind the reasonable correspondance between the acoustic densities of the D1 layers and those estimated from the fishing experiments, any further adjustment should await new information on the target strength of mesopelagic fish. Therefore, there is no reason to further adjust the assessment of 5 million t of mesopelagic fish in the Gulf of Oman in 1981– 83. From an examination of the unadjusted estimates shown in Figure 3.20 it does not seem unreasonable to accept this estimate as representing an average level for the Gulf of Oman.

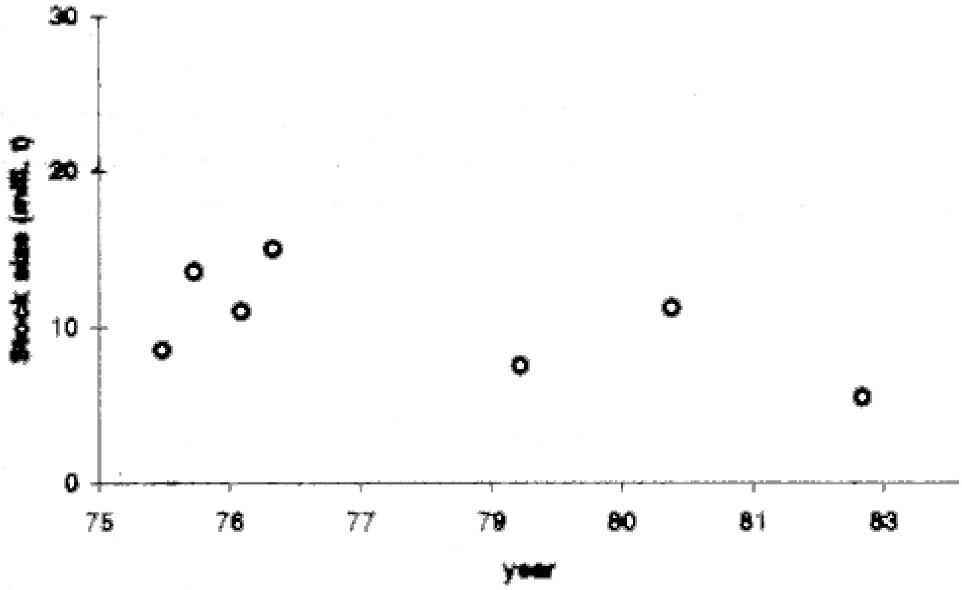

Figure 3.20 Estimated abundance of mesopelagic fish in the Gulf of Oman 1975–1983, unadjusted. Adapted from Aglen *et al.* (1982)

Estimates of the precision of the survey estimates have not been made. The degree of coverage for the surveys in the Gulf of Oman was as follows:

Mean for 1975–76	13
January 1981	6
March 1983	7

The 1975–76 data include coverage of the shelf on each side (see Section 3.3). These indices indicate a reasonable survey effort in the Gulf of Oman for the type of distribution represented by mesopelagic fish.

Gulf of Aden (sub-areas E and F)

The first series of surveys indicated that the Gulf of Aden could also be expected to have a high abundance of mesopelagic fish and therefore the special surveys in 1979 and 1981 also covered this area. Figure 3.21 shows biomass estimates ranging from 4 to 27 million t. However, the area of the Gulf of Aden is almost three times that of the Gulf of Oman and the fish densities are thus lower. A few high catch rates were obtained in the 1975–76 surveys, but the more extensive fishing trials in 1979 and 1981 gave only low catch rates with means of 40–50 kg/h. This may in part be related to the fact that the D1 layer is non-existent or weak. Also a change in species composition seemed to have occurred with a reduction of the proportion of Myctophidae from more than 90% in the early surveys to only 40–60% of the total biomass of mesopelagics in 1979–81. Furthermore, the species composition seems to have varied between the layers in the later surveys.

Diurnal vertical migration also characterizes the mesopelagics in the Gulf of Aden and with the additional phenomenon of the weak D1 layer, the bias in the acoustic abundance estimate may have been greater than in the Gulf of Oman. The wide variation in abundance estimates in the more recent surveys - 4 million t in 1979 and 16 million t in 1981 - is not supported by changes in catch rates which were insignificant in both years. A comparison of catch rates from the N1 layer in the Gulf of Oman and the Gulf of Aden shows a mean of 276 kg/h of Myctophidae in 23 hauls in the Gulf of Oman, but only 26 kg/h as a mean of 8 hauls in the Gulf of Aden, a ratio of about 10. The mean acoustic densities observed in the N1 layers in the two areas show a ratio of 1.5. Thus whereas the fishing experiments in the Gulf of Oman in general provide evidence which support the existence of a considerable density of mesopelagic fish, this is not the case for the fishing trials in the Gulf of Aden apart from a few hauls of the early surveys, and it seems reasonable to conclude that the acoustic abundance calculated for this area have been affected by a bias causing a substantial, but uncertain rate of overestimate.

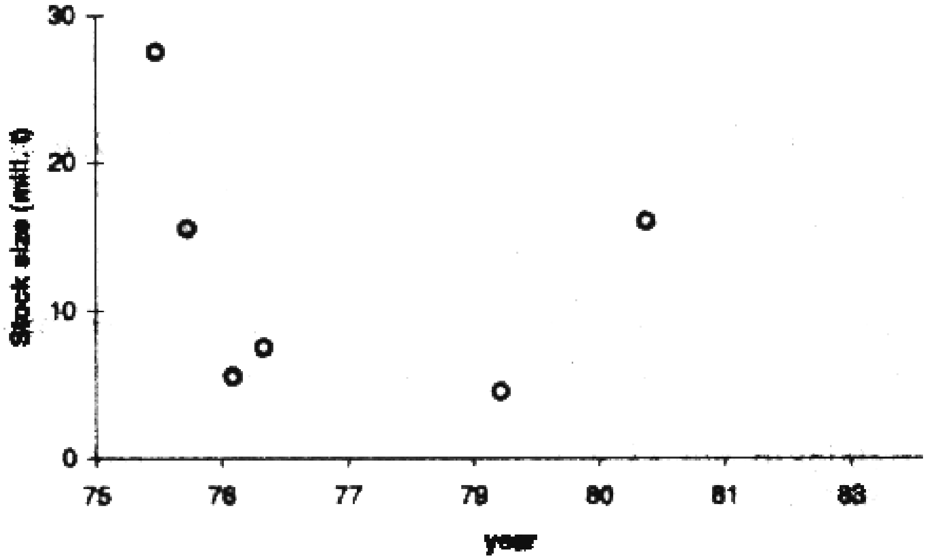

Figure 3.21 Estimated abundance of mesopelagic fish in the Gulf of Aden 1975–81 (adapted from Aglen *et al.*, 1982)

Pakistan (sub-area B)

In the five 1975–76 surveys the estimates of biomass of the mesopelagics in an area of roughly 47,000 nmi^2 off Pakistan ranged between 5 and 8 million t with a mean of 6.6 million t. The corresponding mean density was 70 g/m^2 against 147 g/m^2 in the Gulf of Oman (Gjø;sæter, 1981).

The catch rates from the Pakistan surveys confirmed the existence of mesopelagics at high densities. The number of hauls with catches exceeding 0.5 t/h was:

	0.5–1 t/h	1–2 t/h	Highest rate t/h
1975–76 surveys	2	4	20.0
1977 surveys	4	2	2.9

The most common species was *Benthosema pterotum*, but various *Diaphus* spp. and *Benthosema fibulatum* were important components of some of the catches.

A rough correction based on theoretical evaluation and observations from the Gulf of Oman would be to halve the original figures giving a total biomass in Pakistan waters of about 3 million t and a mean density of 35 g/m^2.

Northwest Arabian Sea (sub-areas C, D, G, H and I)

There is finally a need to discuss the estimates of total biomass of mesopelagics in those parts of the northwest Arabian Sea covered by the first surveys. Figure 3.22 shows densities by subareas in the four surveys from autumn 1975 to end 1976 with data from Table 1 of Gjø;sæter and Kawaguchi (1980). Relatively high mean densities were recorded in several of the areas, some extending far seawards in as in sub-areas C and G. Outside the Gulf of Oman the mesopelagics were found only as a D2 layer between 250 and 350 m during the day and migrating to a surface N1 layer at night. Highest densities were found near the edge of the shelf where high catch rates (up to 20 t/h) confirmed a high abundance of Myctophidae in the area as shown in Figure 3.18.

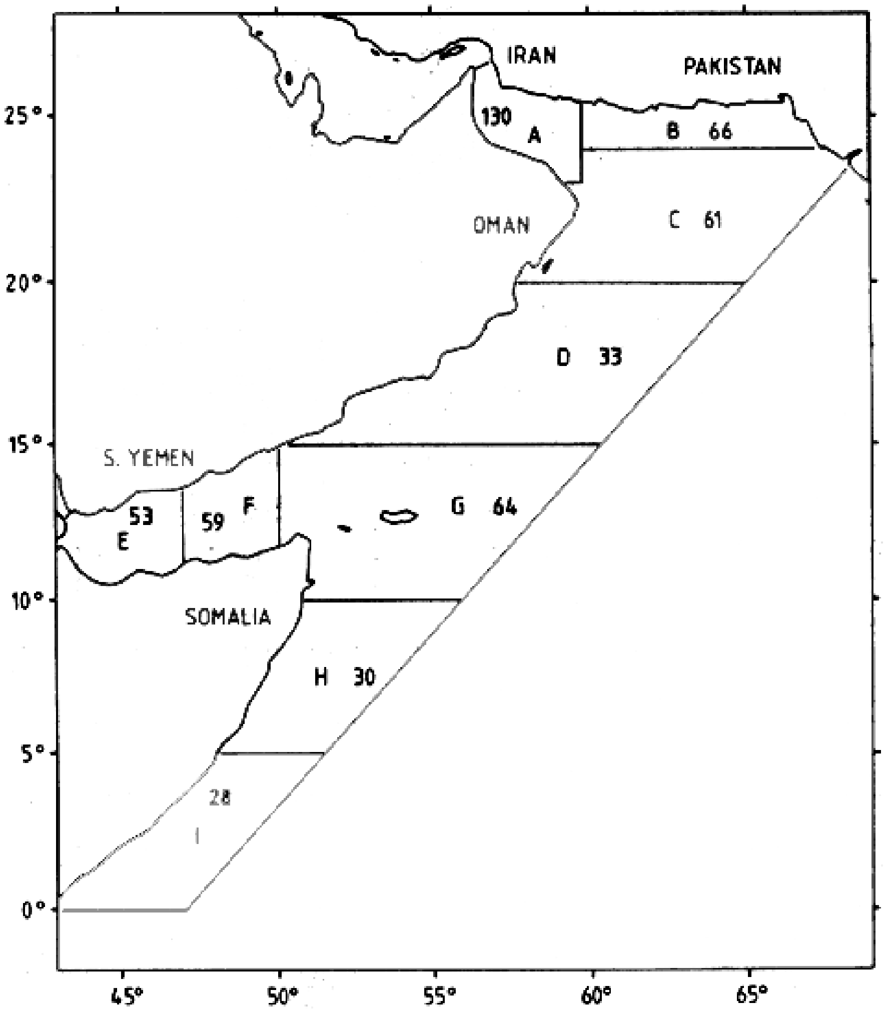

Figure 3.22 Mean acoustic densities (g/m²) by sub-areas in the four main surveys autumn 1975 to end 1976
(unadjusted data from Gjø;sæter and Kawaguchi, 1980)

Based on the mean densities of the four surveys, an average biomass level of 78 million t for the total area outside the Gulf of Oman was obtained. It is reasonable to suspect that also outside the Gulf of Oman the acoustic estimates were biased by resonance. Assuming a similar bias as deduced for the Gulf of Oman would reduce the estimate for the northwest Arabian Sea by about one-third to 52 million t.

However, another approach would be to assume that the 1983–84 estimate from the special surveys of the Gulf of Oman of 5 million t is an improvement on the mean estimate of 11.8 million t from this area obtained in the four main surveys from autumn 1975 to autumn 1976. The original estimate of the mean abundance of mesopelagics in the areas outside the Gulf of Oman in these four surveys was 78 million t. An adjustment proportional to that applied above for the Gulf of Oman would reduce this to 33 million t.

Similar adjustments of the combined mean densities shown in sub-areas C, D and G in Figure 3.22 gave the following results: a reduction by one-third to compensate for resonance gives a mean density of 36 g/m² or 122 t/nmi². An adjustment based on the assumption that the 1983–84 surveys gave an improved estimate of the Gulf of Oman biomass as assessed in the 1975–76 surveys gives a mean density of 22 g/m² or 75 t/nmi².

Even if it is difficult to provide a more precise assessment of the total biomass of mesopelagic fish in the northwest Arabian Sea, there is no doubt that the area is characterized by a very high abundance of these fish. The best current estimate based on acoustics and supported by density estimates from fishing trials for the Gulf of Oman is 5 million t. For the vast highly productive oceanic area and including the Gulf of Aden where the assessment is more uncertain it seems reasonable to indicate a range of 30–50 million t.

Summary of revised biomass estimates

The revised biomass estimates and corresponding densities are presented in Table 3.23.

Table 3.23 Summary of revised biomass and corresponding densities of mesopelagic fish in the Northeast Arabian Sea (1975–84)

	Subarea	Biomass million t	Density g/m²	Density t/nmi²
A	Gulf of Oman	5	73	250
B	Pakistan	3	35	120
C+	Arabian Sea	33	22	75
E, F	Gulf of Aden	5	24	83
	TOTAL	46		

3.5 PAKISTAN, FURTHER SURVEYS, 1983–84

Part of the DR. FRIDTJOF NANSEN programme under the global UNDP/FAO programme GLO/82/001 "Survey and Identification of World Marine Resources" was to provide more detailed information on important areas covered by the first regional survey of the northwest Arabian Sea in 1975–76.

In 1975–76 Pakistan was included in the large-scale exploratory surveys of pelagic fish in the northwest Arabian Sea, while the programme in 1977 was a special joint effort with the Marine Fisheries Department of Pakistan and the Institute of Marine Biology, University of Karachi, with the objective of describing the fishery resources and their physical and biological environment. These first survey programmes not only covered the shelf, but also the adjacent oceanic waters (Table 3.24).

Survey objectives and effort

The 1983/84 surveys supplemented a survey by smaller vessels of the UNDP/FAO Marine Fisheries Development Project (PAK/77/033), in order to provide further information on the shelf resources and the environment.

The distribution, composition and abundance of pelagic and semi-demersal fish were described in these surveys by the acoustic method combined with trawl sampling. The January-February 1984 survey also included a programme for the study of the demersal fish resources through a system of pre-determined bottom trawl stations in co-operation with the PAK/77/033 project.

Table 3.24 DR. FRIDTJOF NANSEN surveys of the Pakistan shelf

Period	**1975–76**	**Jan-Jun 1977**	**Sep 1983**	**Jan-Feb 1984**	**Jun 1984**
Survey type	**Acoustic**	**Acoustic**		**Acoustic & trawl**	
No. of coverages	**5**	**5**	**1**	**1**	**1**
Monsoon	All	NE, early SW	Post SW	NE	Early SW
Surveyed area nmi²	40,000	40,000	13,000	13,000	13,000
Survey distance nmi			2,000	1,800	1,600
Degree of coverage (d)			17	16	14
No. of trawl hauls:					
bottom		90	43	84	30
pelagic		88	14	11	11

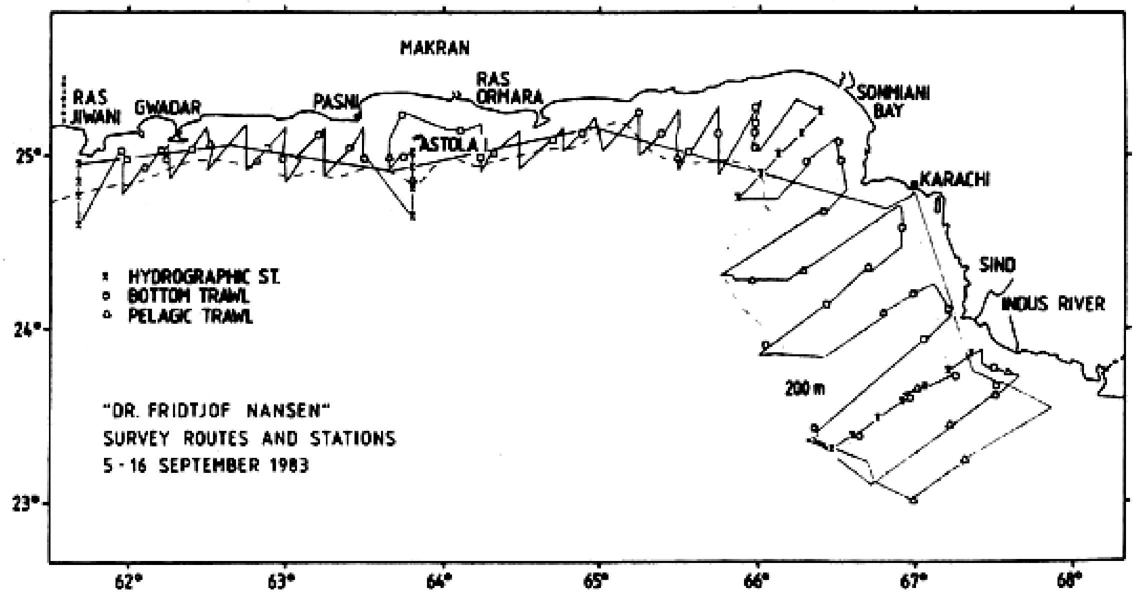

Figure 3.23 The Pakistan continental shelf and the survey routes and stations of the DR. FRIDTJOF NANSEN survey 5–16 September 1983

In all surveys hydrographical stations were occupied in a fixed set of profiles across the shelf. In all 1975/76 and in most of the 1977 surveys these profiles were extended well beyond the shelf and combined with observations on and sampling of mesopelagic fish.

The 1975/76 and the 1977 surveys are reviewed in Section 3.3 and as regards mesopelagic fish in Section 3.4. The 1977 surveys were briefly described in IMR, 1978a and data and material collected has been used as basis for a number of theses at the University of Karachi. Brief accounts of the 1983–84 surveys were given by Nakken (1983), IMR (1984a) and Ona (1984b). A summary report reviewing the results of these surveys was prepared for a Pakistan National Workshop on Fisheries Policy and Planning (IMR, 1986f). Data from the September 1983 and the January 1984 surveys were used by Bianchi (1992b) to describe demersal assemblages of the Pakistani shelf.

Figure 3.23 shows, as an example, the survey area and the course tracks and stations of the September 1983 survey. The indices of coverage (d) for the acoustic surveys were rather high for the 1983–84 surveys.

Bottom topography

The shelf off the long Makran coast is narrow (10–20 nmi), while the area from Sonmiani Bay to the border with India is 50–70 nmi wide, except where the swatch off the Indus Delta separates the Pakistan part of the Kori Great Bank from the shelf off the Sind Coast. As described by Abildgaard *et al.* (1986), the bottom of the Kori Bank is mud-covered; that off the Sind Coast is also generally muddy, but with hard patches between 60 and 80 m and also at greater depth. The bottom of Sonmiani Bay is mainly soft and muddy except for the deeper parts and the grounds closer to the Makran coast, where harder bottom occurs, while that off the Makran coast is predominantly hard.

The shelf areas by depth ranges assessed from Admiralty charts are shown in Table 3.25. The areas of shallowest depth range do not include the estuaries. The Makran shelf is shallow, while that of the Sonmiani Bay-Sind coast is deeper with the widest part between 50 and 100 m.

Table 3.25 Areas of the Pakistan shelf by region and depth ranges (nmi^2)

Depth	Makran coast	Sonmiani Bay-Sind coast
0–10 m	900	600
10–25 m	1,920	1,500
25–50 m	810	1,420
50–100 m	350	3,450
100–200 m	300	2,130
10–200 m	4,280	9,100

Hydrography

The Pakistan shelf waters were well covered by the hydrographic observations of the many surveys at the different seasons. The main features of interest for fisheries oceanography are related to the effects of the monsoons. The southwest monsoon June-Sept (July-Aug) results in an east-flowing current along the Makran coast and a south-flowing current along the Sind coast. The observations confirmed this situation with isopleths tilted towards the coast and a shallow mixed layer inshore. The series of hydrographic observations from the January-June 1977 surveys indicate that the tilting of the isopleths may start already in late April-early May before the onset of the local southwest monsoon. On the southwest coast of India a reversal of the north flowing current during the northeast monsoon was observed to start already in March-April with coastward tilting of isopleths, and deduced to be the effect of the onset of the anticyclonic gyre in the North Arabian Sea spun by the southwest monsoon (Longhurst and Wooster, 1990).

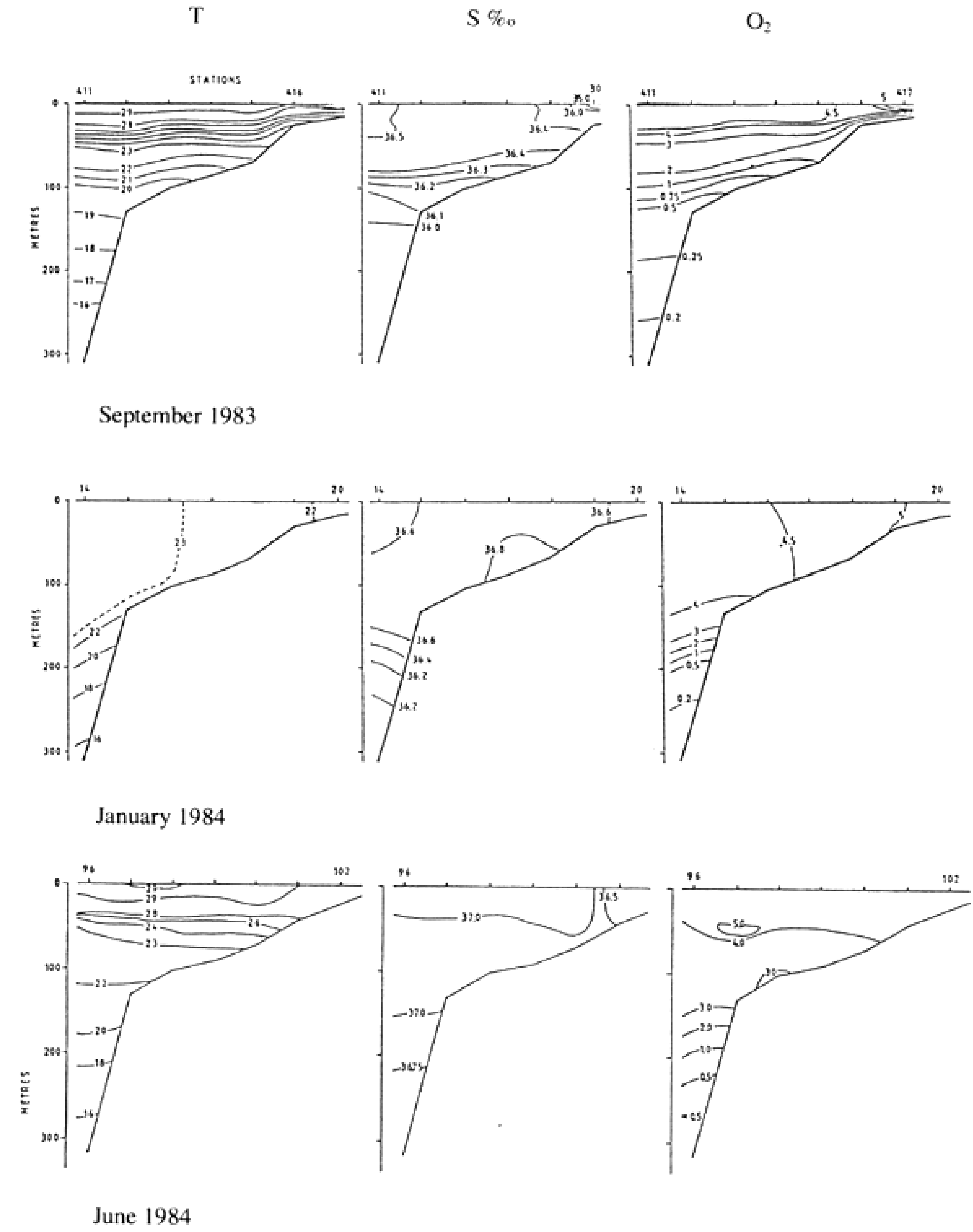

Figure 3.24 Hydrographic profiles from the Indus River to the southwest, September 1983 and January and June 1984

In the southwest monsoon season there is an intrusion of oxygen-deficient bottom water onto the Pakistan shelf and in September 1983 water of less than 2ml/l dissolved oxygen was found at depths between 15 and 30 m, see Figure 3.24. During the northeast monsoon the currents are reversed. The January 1984 observations showed that the mixed oxygen-rich surface layer was deep (100–150 m) and covered the bottom layers of the shelf beyond the edge. This shift between seasons of oxygen-deficient and oxygen-rich bottom water over a large part of the shelf has a marked effect on the distribution of the demersal fish which tend to avoid water with low oxygen content (Brandhorst, 1986, Bianchi, 1992b). The result is reduced availability of bottom fish in the deeper parts of the shelf in the southwest and post-southwest monsoon season and increased catch rates in bottom trawl in the inshore shallow parts.

A second important effect of the hydrographic shift during the southwest monsoon is that nutrient-rich deep water is lifted up into the photic zone resulting in an enhancement of the primary productivity. Off Somalia and Oman this process is intensive during the southwest monsoon. Brought about by wind-induced coastal upwelling it forms the basis for the high productivity of these areas. The process seems, according to available oceanographic observations, to be less intensive on the Pakistan shelf and appears mainly to be the dynamic effect of the seasonal current. During the May-June 1977 survey, however, an inshore area of low surface temperatures was observed along the east Makran coast demonstrating active upwelling at the onset of the southwest monsoon (IMR, 1978a).

On the Sind coast discharges from the Indus River cause low salinity in the surface layers resulting in eurohaline components in the fauna.

Abundance estimates

The reports already issued have served to present the main findings regarding the resources which the surveys had provided. On closer examination, only part of the data were found to be of value for a review and for further analysis. From the 1975–76 exploratory surveys the main data available are a series of acoustic estimates of small pelagic fish at different seasons and one acoustic estimate of semi-demersal fish in the pre-monsoon season (see Section 3.3).

Uncertainties exist regarding the state of the acoustic instruments during the 1977 surveys, therefore acoustic assessments from these surveys are not considered in this review. However, the catch data from the aimed fishing for identification and sampling of these surveys do represent valuable observations on the distribution and composition of the fish by depth and seasons.

In the analyses the trawl data were grouped into five surveys, numbered I to V in the various tables.

The catch data from the 1977 and the 1983/84 surveys are available at IMR as NAN-SIS files.

Acoustic estimates of small pelagic fish

In most of the 1977 and 1983–84 acoustic surveys small pelagic fish were found to be present over the major parts of the shelf inside 200 m depth both off the Makran coast and off Sonmiani Bay and the Sind coast. The densities were low over most of the area of distribution. Higher densities were only observed in limited locations inshore, and in some surveys also further out on the shelf, 40–50 nmi offshore in the Sonmiani Bay and off the Sind coast north of the swatch.

The revised estimated abundance of the small pelagic fish based on the acoustic integration technique was as follows (data from IMR, 1986f adjusted to a target strength of -34 dB/kg):

September 1983	550,000 t
January 1984	450,000 t
June 1984	800,000 t

The high June estimate may be an effect of an annual production cycle in the short lived anchovies as was found on the southwest coast of India (Section 3.2). The five estimates of small pelagics in Pakistan in the 1975/76 surveys (Section 3.3), showed a mean of 750,000 t (adjusted to the level of target strength used here). A mean standing biomass of 600,000 t seems the best available acoustic estimate.

Most of the biomass of pelagic fish was found at relatively low densities and not in dense school areas. This confirms similar findings from the 1975/76 surveys and is a distributional characteristic in contrast to that found for the small pelagics off the Arabian Peninsula and Somalia, where a major part of the biomass aggregated in high-density school areas. The difference in distribution and behaviour is probably related to the predominance of *Thryssa* spp. and *Stolephorus* spp. and to characteristics of the primary and secondary production on the Pakistan shelf. Even though the overall production seems also to be high off Pakistan, it is likely to be less concentrated in time and space and less patchy than in true upwelling areas with its local upwelling cells and wind dependent processes.

Species composition of small pelagic fish

Information on the small pelagic species composition is available from the aimed fishing with pelagic trawl for identification and sampling. Table 3.26 shows that the proportion by families varies considerably between surveys. This may have been caused by the generally low sampling success of this fishing method. These data agree, however, with similar data from the 1975/76 surveys in showing dominance of clupeids, engraulids and Carangidae.

Pelagic fish also formed an important part of the catches in the bottom trawl, especially in shallow water. Table 3.27 shows the composition by families in all hauls in the 10–25 m range for the Makran coast and the Sonmiani Bay-Sind coast separately. These data indicate that here may have been a difference between the two regions with Carangidae and Engraulidae dominating the Makran shelf, and Engraulidae and Clupeidae the Sonmiani Bay-Sind shelf.

Table 3.26 Proportion by families of small pelagic fish in catches from aimed fishing with pelagic trawl. Average catch composition of all hauls per survey in %

Survey		No. of hauls	Clupeidae	Engraulidae	Carangidae	Scombridae	Sphyraenidae
I	Jan-Apr 77	21	33	26	39	1	1
II	Apr-Jun 77	7	20	27	48	1	4
III	Sept 83	10	82	5	13	0	1
IV	Jan 84	4	74	23	1	1	1
V	June 84	3	20	23	15	17	25
	Mean		44	21	30	2	3

Table 3.27 Proportion by families of small pelagic fish in catches with demersal trawl in the 10–25 m depth range. All hauls (%)

Survey		No. of hauls	Clupeidae	Engraulidae	Carangidae	Scombridae	Sphyraenidae
Makran coast							
I	Jan-Apr 77	21	33	26	39	1	1
II	Apr-Jun 77	7	20	27	48	1	4
III	Sept 83	10	82	5	13	0	1
IV	Jan 84	4	74	23	1	1	1
V	June 84	3	20	23	15	17	25
	Mean		44	21	30	2	3
Sonmiani Bay-Sind coast							
I	Jan-Apr 77	12	30	64	1	0	5
II	Apr-Jun 77	7	45	12	35	6	3
III	Sept 83	3	61	33	6	0	0
IV	Jan 84	10	12	74	5	9	0
V	June 84	3	5	48	47	0	0
	Mean		28	52	14	4	2

All data show low catch rates of *Scomberomorus* sp. and Sphyraenidae, but these non-schooling larger pelagic fish no doubt form a much higher part of the total pelagic biomass than indicated by their appearance in the bottom trawl catches. The assessment of these stocks can only be made if they are identified as a separate acoustic target, larger fish in single fish distribution. This was not part of the acoustic programme in Pakistan.

As regards composition by species, the samples obtained by aimed pelagic trawling should be expected to give the most direct evidence, but the results indicate that the number of samples was insufficient to provide a representative picture. Thus while *Thryssa* spp dominated the Engraulidae in the samples from the 1977 surveys, *Stolephorus* spp. were most common in those from the 1983/84 survey. In both survey periods *Dussumieria acuta* dominated the Clupeidae, but the proportions of species of the genera *Sardinella, Ilisha* and *Tenualosa* varied. *Megalaspis cordyla* and *Decapterus russelli* were the most common Carangidae in the pelagic samples from both survey periods, but the catches were in the proportions 7:1 in the first period and 1:5 in the second.

The occurrence and the catch by weight of the pelagic fish in the demersal hauls was another source of information on their composition by species. The 1977 surveys provide the most comprehensive data, see Table 3.28 which includes only the species with the highest density in each family.

Table 3.28 Species composition of main pelagic families in demersal trawl hauls in all 1977 surveys. Incidence (%) and estimated mean density (t/nmi²)

Makran coast 32 hauls			Sonmiani Bay-Sind coast 79 hauls		
	Incidence %	Mean density t/nmi²		Incidence %	Mean density t/nmi²
Clupeidae			**Clupeidae**		
Sardinella longiceps	9	1.89	*Dussumieria acuta*	23	9.07
Sardinella sp.	13	0.12	*Sardinella* sp.	9	0.54
Sardinella sindensis	9	0.10	*Sardinella longiceps*	7	0.47
Engraulidae			**Engraulidae**		
Thryssa mystax	22	5.28	*Thryssa setirostris*	5	13.99
Thryssa dussumieri	22	3.11	*Stolephorus indicus*	11	8.92
			Thryssa mystax	16	0.15
			Thryssa malabarica	4	0.11
Carangidae			**Carangidae**		
Decapterus ruselli	9	0.24	*Carangoides malabaricus*	39	0.46
Scomberoides commersonianus	28	0.17	*Scomberoides commersonianus*	14	0.17
Carangoides malabaricus	31	0.07	*Atule mate*	9	0.15
Megalaspis cordyla	16	0.06	*Decapterus russelli*	19	0.07
Scombridae			**Scombridae**		
Scomberomorus guttatus	25	0.05	*Scomberomorus guttatus*	28	0.44

Because of the schooling behaviour of especially the Engraulidae and Clupeidae, the sample variance must be expected to be high. With the wide inner shelf off the eastern coast, *Stolephorus* spp. and *Thryssa* spp. as well as the rainbow sardine (*Dussumieria acuta*) are common here. Various scads, trevallies and queenfish had together with Spanish mackerels and barracudas a wide distribution, but generally low catch rates in the bottom trawl.

Biomass estimates of demersal fish

Survey IV of January 1984 with pre-determined trawl stations was used for biomass estimates applying the swept-area technique with shelf areas within depth ranges (Table 3.23) as substrata. The estimated distance between the wing tips, 18.5 m for the bottom trawl was also assumed to be its effective fishing width. Table 3.29 shows the results by main groups. The catchability coefficient was taken as 1.

There are various possible sources of bias in these estimates of which the unknown true effectiveness of the trawl is likely to be the most important. The pelagic fish is severely underestimated and the trawl estimate is of little interest, except perhaps to indicate that parts of this group, e.g., some of the Carangidae, have a demersal behaviour and therefore may not have been included in the acoustic estimate.

Table 3.29 Estimated biomass by species groups. Data from Survey IV, January 1984 (t)

	Makran coast	Sonmiani Bay-Sind coast	Total
Demersals (10 families)	62,300	83,500	145,800
Pelagics (5 families)	10,600	25,200	35,800
Sharks	3,700	3,200	6,900
Rays	16,800	8,900	25,700
Cephalopods	2,900	4,500	7,400
Other fish	9,600	22,100	31,700
Total	105,900	147,400	253,300

The lack of coverage of the inshore waters less than about 10 m depth represents a source of underestimation. A correction has been attempted for this, assuming the density in this part to be equal to that in the 10–25 m range.

Another source of bias may result from the escape of semi-demersal fish above the headline of the trawl. The biomass of fish identified as semi-demersal was estimated in surveys III, IV and V (IMR, 1986f). With adjustment to a target strength level of -32 dB/kg (17 cm fish) as seems suitable for this kind of fish the estimates were 147,000, 40,000 and 227,000 t for the three surveys respectively. This considerable variation is most likely due to a seasonal change in behaviour. The simple mean, 138,000 t indicates that a large biomass of semi-demersal fish which is not caught by normal bottom trawls may occur in Pakistan waters.

The difference in catch composition between aimed and random fishing (Table 3.31) and the higher catch rates in aimed fishing (Table 3.29) show that some of the types of fish occur in aggregations above the bottom which are easily identified by echosounders. The mid-water behaviour of many groups of demersal fish - such as hairtails, ponyfishes, catfishes, sharks - is well known. A quantification of the bias in trawl surveys caused by mid-water occurrence is, however, difficult. The indications are that for conditions such as in Pakistan, it could be considerable.

The main data on demersal fish were obtained from the catches by bottom trawl. Table 3.30 is an overview of the mean catch rates by main groups for the Makran coast and Sonmiani Bay-Sind coast for each of the surveys.

Pelagic fish include the families Engraulidae, Clupeidae, Carangidae, Scombridae and Sphyraenidae analysed above. Demersal fish include the following 10 families which were judged to be the most common and of greatest commercial interest: Ariidae, Lactariidae, Leiognathidae, Lutjanidae, Nemipteridae, Pomadasyidae, Sparidae, Sciaenidae, Polynemidae and Trichiuridae.

The mean catch rates in Surveys I, II, III and V, where fishing was done for the purpose of identification and sampling were, as can be seen, in most cases higher than those of Survey IV where fishing was at pre-determined positions. The aimed fishing gave catch rates which may simulate those of a commercial fishery.

Table 3.30 Mean catch rates by main groups in bottom trawl hauls (kg/h)

Survey	I Jan-Apr 77	II Apr-Jun 77	III Sept 83	IV Jan 84	V June 84
Makran coast					
No. of hauls	25	13	25	48	16
Pelagic fish	480	20	7	80	91
Demersal fish	1,160	308	1,200	430	1,576
Sharks and rays	160	52	33	139	90
Cephalopods	6	7	4	19	8
Others	106	185	178	72	218
Total	**1,912**	**572**	**1,422**	**740**	**1,983**

Sonmiani Bay-Sind coast					
No. of hauls	30	21	16	36	14
Pelagic fish	2,100	141	102	90	52
Demersal fish	841	2,318	1,590	260	417
Sharks and rays	79	74	334	39	22
Cephalopods	191	61	5	16	10
Others	128	208	212	70	73
Total	**3,339**	**2,802**	**2,243**	**475**	**574**

The depth distribution of the demersal fish on the Pakistan shelf is, as already mentioned, known to be affected by the intrusion of oxygen-deficient water onto the shelf in the southwest monsoon season. In the present series of data, those from the Sonmiani Bay-Sind coast which cover a broad depth range were best suited for an analysis of this phenomenon. Table 3.31 shows the mean densities of the ten families of demersal fish by depth ranges normalized for comparison. These observations confirm the seasonal change in depth distribution, with a shift of high density towards shallow water which started already in June, but is pronounced in September.

Table 3.31 Mean densities of demersal fish by depth ranges. Sonmiani Bay-Sind coast. Normalized and rearranged by month

Survey	IV Jan 84	I Jan-Apr 77	II Apr-Jun 77	V June 84	III Sept 83
10–50 m	23	37	27	100	100
50–100 m	50	48	30	77	77
100–200 m	100	100	100	65	7

The composition of the catches of demersal fish varied between surveys. Table 3.32 shows the composition by families for all surveys for the Sonmiani Bay-Sind coast and for the 1983– 84 surveys on the Makran coast (where the 1977 data proved inadequate). The mean composition in the surveys in which trawl hauls were made for the purpose of identification and sampling, is shown separately for comparison with that of Survey IV in which the predetermined fishing positions and the equal density of stations at different depth ranges should give compositions reflecting the correct biomass proportions of the groups.

Table 3.32 Composition of demersal fish in bottom trawl catches (%)

	Hauls for identification				**Identification**	**Systematic sample**
Survey	**I Jan-Apr 77**	**II Apr-Jun 77**	**III Sept 83**	**V June 84**	**Mean of hauls**	**IV Jan 84**
Sonmiani Bay-Sind coast						
No. of hauls	30	21	16	14		36
Ariidae	6.0	21.5	8.4	5.1	10.2	3.3
Lactariidae	10.4	4.5	4.1	4.0	5.8	5.3
Leiognathidae	12.5	0.4	0.1	4.0	4.2	1.6
Lutjanidae	1.7	0.3	0.1	2.9	1.2	1.4
Nemipteridae	17.0	15.8	4.1	36.5	18.4	52.6
Pomadasyidae	9.0	2.1	31.3	6.0	12.1	7.3
Sparidae	2.6	1.7	2.4	1.1	2.0	8.9
Sciaenidae	28.3	36.7	29.7	17.8	28.1	6.5
Polynemidae	2.0	2.5	6.5	1.4	3.1	1.4
Trichiuridae	10.5	14.5	13.7	21.1	15.0	11.8
Makran coast						
No. of hauls			25	16		48
Ariidae			2.7	15.6	9.2	31.1
Lactariidae			0.2	2.6	1.4	5.5
Leiognathidae			0.3	0.1	0.2	1.0
Lutjanidae			0.1	0.3	0.2	0.6

Nemipteridae	0.4	3.8	2.1	13.1
Pomadasyidae	2.3	11.2	6.8	20.0
Sparidae	2.7	4.1	3.4	8.1
Sciaenidae	13.8	24.2	19.0	9.5
Polynemidae	0.4	0.9	0.7	1.3
Trichiuridae	77.9	37.2	57.6	9.8

The two sets of data show that, compared with random fishing, the aimed fishing overestimates the relative abundance of Sciaenidae and Trichiuridae, but underestimates that of the Nemipteridae. The aimed fishing will mostly have been directed at echosounder targets over the bottom, and is thus likely to have caught a higher proportion of semi-demersal fish. These types of fish may on the other hand be under-represented in the random fishing survey because of their occurrence off the bottom. There may also be a seasonal variation in species composition as indicated by the low proportions of Nemipteridae in Survey III, September 1983. Lutjanidae and other hard bottom groups may have been under-represented because of restricted fishing on this type of bottom.

In view of these possible biases in the data, it may be difficult to determine the true order of abundance of the demersal fish. However, the five families: Trichiuridae, Nemipteridae, Sciaenidae, Ariidae and Pomadasyidae represented more than 80% of the catches in both sets of data. The relatively abundant fauna of demersal fish on the Pakistan shelf is thus dominated by a low number of families and these are again dominated by one or a few species, a type of fauna which should be seen in relation to the highly variable environment.

The proportion of sharks and rays in the catches was at about the same level as one of the abundant teleost families. Squids were abundant in the 1977 surveys in deeper waters, 50–100 m and 100–200 m. The squids occuring in the shelf area may have a seasonal production cycle.

This composition of the catches by bottom trawl corresponds well with that described by Abildgaard *et al.* (1986) from the surveys carried out in Pakistan waters in 1983–85.

Species identification and assemblages of demersal fish

Problems appear to have been encountered in some of the surveys in the identification to species level. The available information can be summarized as follows:

Trichiuridae (hairtails): Both *Lepturacanthus savala* and *Trichiurus lepturus* are reported to occur in Pakistan waters (Bianchi, 1985). In the 1977 surveys the two species were reported in varying proportions, usually with a dominance of *T. lepturus*. In the 1983/84 surveys, however, all catches of this family were identified as *T. lepturus*.

Nemipteridae (threadfin breams): In nearly all of the surveys all catches of this family were reported as Japanese threadfin bream, (*Nemipterus japonicus*). According to Bianchi (1985), however, this species is often caught (in Pakistan waters) together with a then undescribed species of this genus. This was described in 1986 as *Nemipterus randalli* (Russell, 1990). The *Nemipterus* species were found in highest densities on the deeper parts of the shelf, 50–100 and 100–200 m.

Sciaenidae (croakers): Appeared to have been inadequately identified to the species level in some of the surveys. The data indicate an approximate order of abundance of the main species as follows: *Otolithes ruber, Johnius* spp., *Protonibea diacanthus, Otolithes cuvieri* and *Argyrosomus* sp. The croakers were represented over the whole shelf, at times with high catch rates even beyond 100 m depth.

Ariidae (catfishes): Identification to species of catfishes was not attempted in any of the surveys. They were found in shallow waters with hardly any catches at depths greater than 50 m. Their density may have been underestimated because of lack of survey coverage inside 10 m depth.

Pomadasyidae (grunters): The javelin grunter (*Pomadasys kaakan*) was by far the dominant species of this family reported from both parts of the shelf in all surveys and representing an average of 70% of the catches of grunts. The saddle grunt (*Pomadasys maculatum*), also reported from all surveys, but with a more restricted distribution represented 19% of the grunt catches in seven area/surveys. The grunts were mainly found inside 50 m depth, but high catch rates were occasionally obtained beyond 100 m depth.

Sparidae (breams) and false trevally: The king soldierbream (*Argyrops spinifer*) dominated the Sparidae with a high incidence and representing 64% of all catches of sea breams. The false trevally (*Lactarius lactarius*) was common in all surveys.

In a description of the demersal assemblages of the Pakistan shelf based on the September 1983 and the January 1984 surveys Bianchi (1992b) found that the shelf may be divided into two major zones: a deeper zone from 50–80 to 200 m where environmental conditions change dramatically with the season. During the southwest monsoon with low oxygen and temperature near the bottom, only a few species, such as hairtails and threadfin breams, are found here, probably because of their ability to swim to upper water layers. During the northeast monsoon, with a mixed surface layer covering the whole shelf this deeper zone is “invaded” by the rich and diverse fauna of the second, shallow zone, where relatively stable temperature and oxygen values prevail throughout the year and where most of the fish fauna from the deeper zone may find seasonal shelter. The present review, which includes the additional data from surveys I, II and V (January-June 1977 and June 1984) confirms this.

Review of findings and comparison with later research and with development of the fishery

The review deals with data from a series of surveys of the Pakistan shelf during January-June 1977 and September 1983-June 1984 which provided information on the distribution, composition and abundance of pelagic, mesopelagic and demersal fish and on their environment.

An extensive programme of oceanographic observations confirmed the well known monsoonal effect on the hydrographic regime with shoreward tilting of the isolines during the southwest monsoon and intrusion of oxygen-deficient water onto the shelf. Active upwelling was observed on the Makran coast.

Small pelagic fish were found over wide parts of the shelf in all surveys, but no area with especially high densities was identified. Catch compositions indicated that Engraulidae and Carangidae dominated on the Makran coast and Clupeidae and Engraulidae on the Sonmiani Bay-Sind coast. The relatively low catch rates of Scombridae were thought to underestimate their abundance.

Table 3.33 Summary of estimates of standing biomass and mean density for the shelf

	Biomass (t)	Density (t/nmi²)
Acoustic estimates:		
Pelagic fish	600,000	45
Semi-demersal fish	140,000	
Meso-pelagic fish	3,000,000	
Swept-area trawl estimates:		
Demersals (10 families)	146,000	
Pelagics (5 families)	36,000	
Other fish	32,000	
Sharks	7,000	
Rays	26,000	
Cephalopods	7,000	
Total	**254,000**	**19**

The five families Trichiuridae, Nemipteridae, Sciaenidae, Ariidae and Pomadasyidae yielded more than 80% of the catches of teleost demersals. The mean catch rates in the aimed sampling trawling were higher than in the random trawling and were dominated by Trichiuridae and Sciaenidae against Nemipteridae in the random survey.

The estimates of standing biomass and density are summarized in Table 3.33.

Other surveys

Reporting on the results of three stratified trawl surveys with the Pakistan Governments research vessels MACHHERA and TEHKIK, (sister ships), Abildgaard *et al.* (1986) estimated the total demersal fish biomass on Pakistan's continental shelf between 10 and 200 m depth at:

October 1983 - March 1984	247,000 t
October 1984 - December 1984	241,000 t
January 1985 - March 1985	344,000 t

The variation in these estimates is ascribed to an apparent annual cycle in standing biomass of the demersal fish with high availability in the early part of the year and low availability in the last part, caused by migration. The estimate from the January 1984 DR. FRIDTJOF NANSEN survey of 254,000 t agrees well with those obtained in the season of low availability. It also seems likely that the semi-demersal fish, for which there is an acoustic biomass estimate of 140,000 t, was not fully represented in the bottom trawl catches. The “best” estimate of the mean standing biomass of the demersal resources from the DR. FRIDTJOF NANSEN surveys on the Pakistan shelf in 1983–84 is perhaps 300,000–350,000 t and 600,000 t for the pelagic resources.

Brandhorst (1986) adjusted the demersal biomass estimate from 1983–85 found in Abildgaard *et al.* (1986) for not-covered inshore and estuarine waters, concluding with a total biomass of demersal fish of 500,000 t, which could give an annual potential yield of 180,000 t. He estimated the 1984 landings of demersals to be 110,000 t, thus leaving a 70,000 t potential for an expansion of the demersal fisheries.

The observed biomass represented partly exploited stocks. In a comparison between the biomass estimates and the reported 1981 landings, IMR (1986f) concluded that there seemed to exist potentials for an increase especially of pelagic fish, but also for demersals such as hairtails, croakers and catfishes.

Pakistan's reported landings of marine fish increased from 261,000 t in 1981 to 400,000 t in 1991 (FAO, 1986 and 1992). The landings (t) by main groups in 1983 and 1991 were according to these sources as follows:

	1983	1991
Small pelagic fish	184,900	200,150
Large pelagic fish	14,700	31,950
Demersal fish	36,800	83,600
Sharks	8,150	26,350
Rays	10,100	18,750
Crustacea	28,300	33,250
Cephalopods	150	5,570
Total	283,100	399,600

(Reported unidentified marine fish is thought to consist mainly of small pelagics and has been included in that group, but is likely to include also demersal “trash fish” from shrimp by-catch, etc.)

The increased landings of demersal fish were mainly Ariidae, Sciaenidae, Pomadasyidae, Stromateidae and Trichiuridae. The Nemipteridae which had a high abundance in the surveys seem to be underutilized unless it is included in the unidentified group. Sharks and rays would seem to have been severely underestimated by the surveys.

3.6 OMAN, FURTHER SURVEYS, 1983–84

Survey objectives and effort

Information on the DR. FRIDTJOF NANSEN surveys in Omani waters is given in Table 3.34. For survey purposes Omani waters have been divided into three areas:

A. shelf area in the Gulf of Oman,

B. deep part in the Gulf of Oman and

C. shelf area in the Arabian Sea.

All the areas represented central parts of the first regional exploratory surveys in 1975/76. One of the main findings was a great abundance of mesopelagic fish of which the density was especially high in the Gulf of Oman. Therefore this area was chosen for a number of special surveys in 1979, 1981 and 1983 to study the distribution, biology and abundance of the mesopelagics. Finally, the shelf resources of demersal and small pelagic fish were investigated in more detail in three surveys in 1983–84.

In both the exploratory and the mesopelagic surveys the distribution, composition and abundance of the fish were determined by acoustic methods combined with sampling by trawl and experimental trawl fishing trials. The programmes of the 1983–84 shelf surveys were expanded and included investigations of demersal fish abundance using the swept-area method at pre-determined trawl stations.

Table 3.34 DR. FRIDTJOF NANSEN surveys in Omani waters

Type of survey	Exploratory Acoustic	Mesopelagics Acoustic	Shelf surveys Acoustic & trawl		
Dates	1975–76 5 surveys	1979–1983 5 surveys	Mar 83	Nov-Dec 83	Apr-May 84
Monsoon			Post NE	NE	Early SW
Survey areas	A, B, C	A and B	C	A and C	A and Ca
Area covered nmi²			12,150	14,000	14,000
Survey distance (nmi)	See	See	1,900	2,700	2,400
Index of coverage	Section 3.3	Section 3.4	17	23	20
No. of bottom trawl hauls			37	40	37
No. of pelagic trawl hauls			15	58	10

The results of the 1975/76 exploratory surveys are reviewed in Section 3.3 and the surveys for mesopelagics in Section 3.4. The results of the three shelf surveys in 1983–84 were first presented in cruise reports, (Strø;mme, 1983b, Strø;mme and Tilseth, 1984 and Strø;mme, 1984a). The results were further analysed in a final report by Strø;mme (1986). The Oman surveys are among the best described of the DR. FRIDTJOF NANSEN programmes in the Indian Ocean. In view of the importance of the area, and to facilitate comparisons with other areas, it is still considered valuable to include a description of these surveys in this review.

The continental shelf

Figure 3.25 shows a typical cruise track and the border of the shelf. Estimates of the dimensions of the shelf are given in Table 3.35. The northeast coast along the Gulf of Oman has a narrow shelf with a mean width of about 10 nmi and a steep slope. The shelf off the southeast Arabian Sea coast is wider, especially off the Bay of Masirah and the Sawqirah Bay, but also narrow west of the Kuria Muria Islands where a steep slope starts at about 100 m depth.

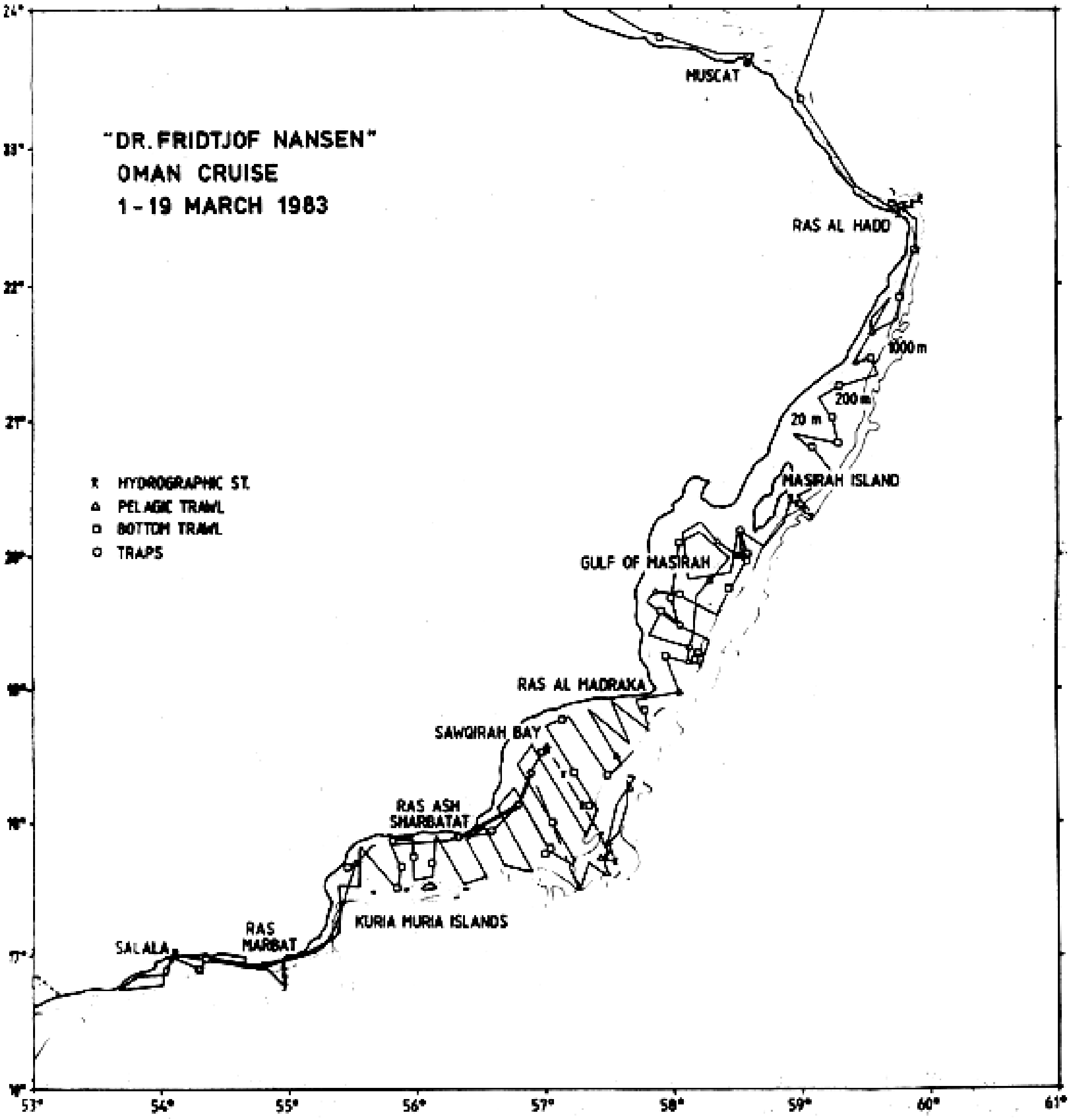

Figure 3.25 The Omani shelf and the cruise tracks of the March 1983 survey

Table 3.35 Dimensions of the Omani shelf

	Length of coastline (nmi)	**Mean shelf width (nmi)**	**Shelf area (nmi²)**	**Rough bottom %**
Gulf of Oman (Survey area A)	250	10	2,200	24
Arabian Sea (Survey area C)	640		12,000	39
Subdivisions of the Arabian Sea (C):				
Ras al Hadd to Masirah Islands	180	15	2,360	27
Masirah Island to Ras al Madraka	130	40	3,000	27
Ras al Madraka to Ras Marbat	250	40	6,000	55
Ras Marbat to Yemen border	80	10	640	55

According to Johannesson (1995) much of the bottom of the Omani shelf is rough and untrawlable. Bottom of this type was found to represent 24% of the shelf of the Gulf of Oman, 27% of the shelf from Ras al Hadd to Ras Madrakah and 55% of the shelf further west, a total of 39% of the whole shelf. Thus considerable parts of the shelf could not be sampled with the bottom trawl.

Hydrography

The main oceanographical features of Omani waters are the pronounced monsoonal shifts of the hydrographical regime causing high variability of important environmental factors, and the upwelling along the Arabian Sea coast during the southwest monsoon which provides the basis for the high productivity of the region.

The environmental change which most directly affects the fish and the fisheries is probably the intrusion of cold, oxygen-deficient water onto the shelf during the southwest monsoon. This affects the distribution of demersal fish and may at times cause mass mortalities of fish indicated by abundance of fish bones over an extended area of the shelf south of Ras al Hadd observed by the CHALLENGER expedition (quoted by Brongersma-Sanders, 1957).

Figure 3.26 shows the observations of oxygen content in a profile off the Kuria Muria Islands at various times during the 1975/76 surveys. A coastward tilting of the isolines could be observed from April to October. The 1 ml/l isoline for oxygen was found at about 100 m depth in April 1975, at about 80 m in May 1976, at 10 m in September 1976 and at some 20 m in October 1975. Similar observations from the 1983/84 surveys show that the 1 ml/l isoline was observed at 50 m depth in the Sauqara Bay in late November 1983 indicating that the process may last well into the post-monsoon season.

The upwelling off the Arabian Peninsula extends to at least 400 km offshore, but is most intense in a narrow band adjacent to the coast (Currie *et al.*, 1973), and is reported to last from April until September. The effect of the upwelling off the Arabian Sea coast of Oman was observed in the regional DR. FRIDTJOF NANSEN surveys 1975–76 with inshore surface temperatures at 24°C in April-May 1975, 23°C in May 1976 and 18°C in September 1976.

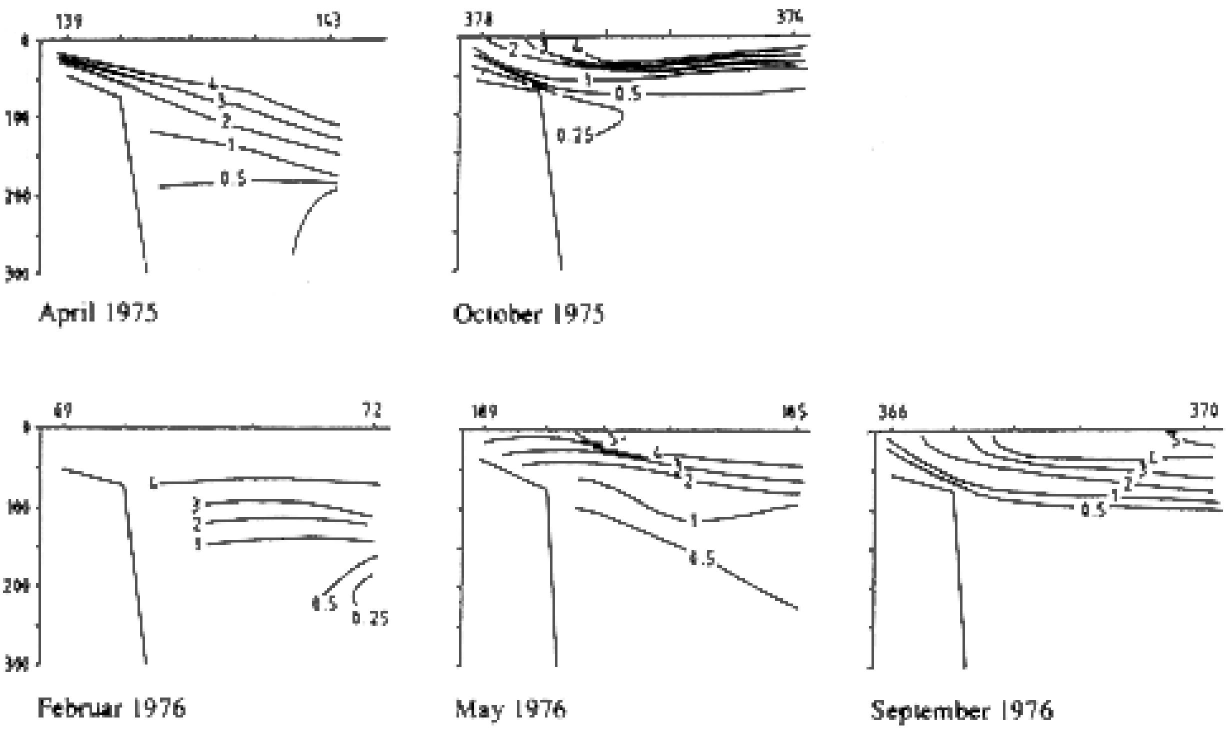

Figure 3.26 Oxygen profiles off the Kuria Muria Islands in the 1975/76 surveys

Measurements of rates of primary production made in the upwelling season off the Arabian Peninsula during the IIOE caused oceanographers to state that its productivity might be at a similar level as those of the upwelling areas off West Africa and Peru (Wooster *et al.*, 1967).

There is a large year-to-year variability in the monsoon winds (Swallow, 1984) and this is likely to be reflected also in upwelling and primary productivity as well as in the abundance of short-lived pelagic fish.

Water with high nutrient content is advected into the Gulf of Oman from the Arabian Sea coast by surface currents and this probably forms the basis for the high densities of mesopelagic fish found here. These fish migrate vertically between surface waters and 200– 300 m and their distribution in the Gulf of Oman may be affected by the flow of heavy water from the Persian Gulf (Bakun, FAO, pers. com.), which at a depth of 200–300 m follows the Omani deep slope. This water has an oxygen content of about 2 ml/l compared to less than 0.5 ml/l elsewhere in the Gulf of Oman at this depth.

Acoustic estimates of small pelagic fish

The main data available from the 1975/76 exploratory surveys were a series of estimates of the abundance of small pelagic and semi-demersal fish with information on species and length composition and distribution (Section 3.3). The 1983/84 surveys provided data on the distribution, composition and abundance of small pelagic- and semi-demersal fish from acoustic observations with sampling, and of demersal fish from swept-area trawl programmes.

The distribution charts of small pelagic fish based on acoustic recordings from the five 1975/76 surveys (Kesteven *et al*., 1981, Figures 17–21) and the three in 1983/84 (Strø;mme, 1986, Figures 4–6) show that in all surveys by far the largest part of the fish was found on the Arabian Sea shelf. The recordings from the Gulf of Oman shelf showed low densities and were of limited extent. In the Arabian Sea high-density recordings were obtained in the Gulf of Masirah for all eight surveys, in the Sauqara-Kuria Muria sector in four and in the Ras al Hadd-Masirah sector in three surveys. The Gulf of Masirah was thus the most consistent area of high densities of small pelagic fish. According to Strø;mme (1986) the distribution of small pelagics fish was not limited to the shelf proper, but extended in the Sauqara area also to the surface waters immediately off the edge of the shelf.

Figure 3.27 shows the distribution of small pelagic fish on the southeast coast in the March 1983 survey demonstrating high abundance in the Gulf of Masirah.

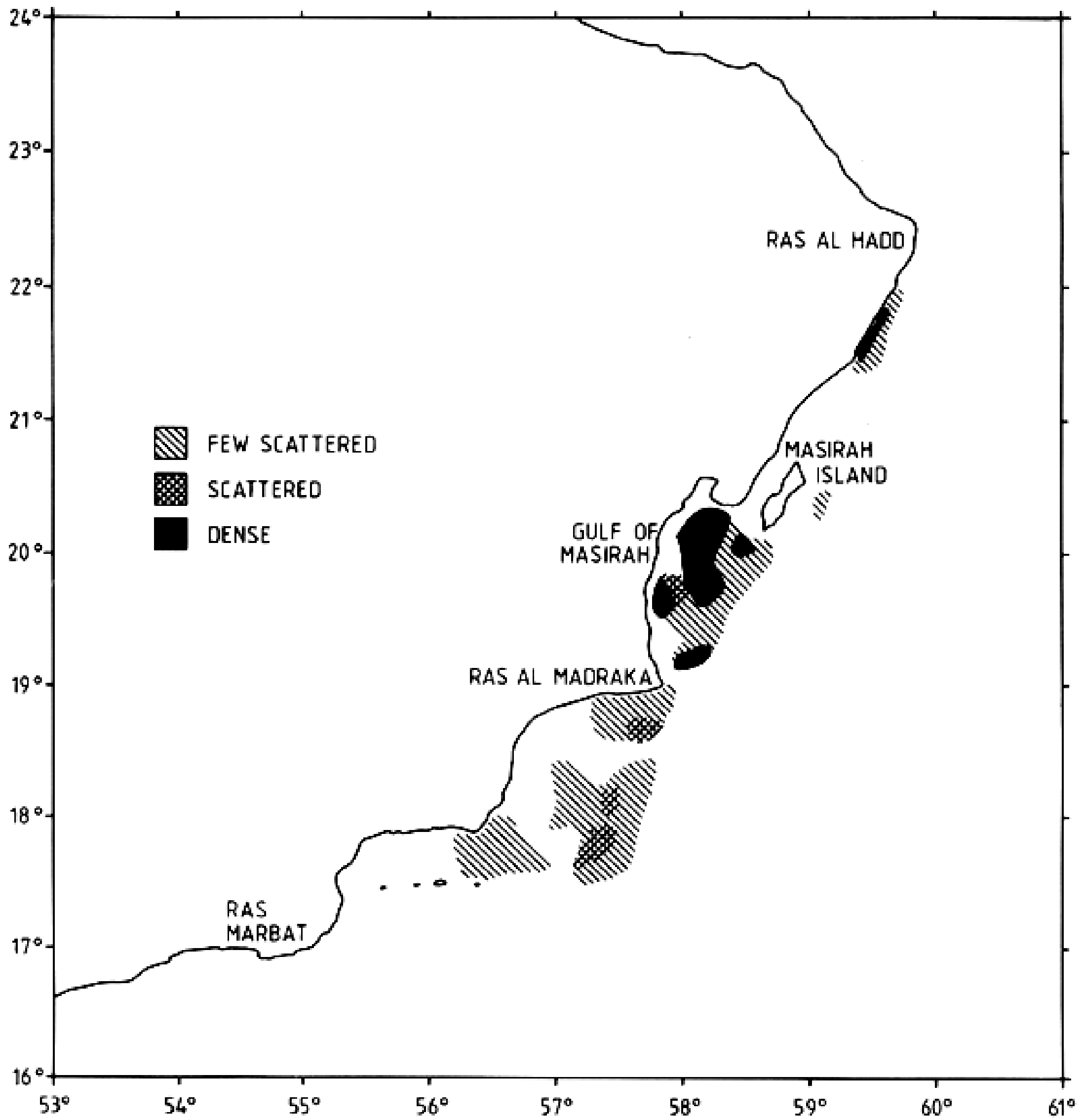

Figure 3.27 Distribution of small pelagic fish in the Arabian Sea off Oman in March 1983

Estimates of the biomass of small pelagic fish in the Arabian Sea, obtained by echo integration are presented in Table 3.36 for all surveys. All these estimates have been adjusted to a target strength of -34 dB/kg.

Table 3.36 Acoustic biomass estimates of small pelagic fish, all adjusted to a TS of -34 dB/kg, in the Arabian Sea off Oman, 1975–84

	Survey period	**Total biomass t**	**Mean density t/nmi²**	**Echosounder integrator used**
1	Apr-May 1975	250,000		EKS 38/QM
2	Oct-Nov 1975	2,600,000		EKS 38/QM
3	Feb-Mar 1976	1,800,000		EKS 38/QM
4	May-Jun 1976	1,500,000		EKS 38/QM
51 04	Aug-Sep 1976	1,700,000		EKS 38/QM
6	Mar 1983	1,000,000		EKS 38/QM
7	Nov 1983	1,300,000		EKS 38/QM
8	May 1984	1,400,000		EK 400 (38)/QD
	Subdivision May 84			
	Ras al Hadd-	140,000	60	

Masirah Isl.		
Masirah Isl. - Ras al Mandraka	810,000	270
Ras al Mandraka - Ras Marbet	420,000	70
Ras Marbet - Yemen border	30,000	47

Sources: 1975–76 Kesteven *et al.*, 1981 and Section 3.3
1983–84 Strø;mme, 1986

A part of the large variation must have been caused by survey sampling variation which is likely to have been higher in 1975/76 than in 1983/84 as the degrees of coverage were only about 7 to 10 in the first compared with about 20 in the recent, more detailed surveys. It seems appropriate to question the validity of the very low estimate from the first survey, which might have been the effect of malfunction of the instruments. However, the estimate of semi-demersal fish in this survey, based on simultaneous recordings was close to those obtained in three of the four later surveys, which supports the validity of the observation of the low biomass of small pelagics in early 1975. The mean of the biomass estimates of the four subsequent surveys (Nos 2 to 5) was 1.9 million t, which is somewhat higher than the levels in 1983/84 (1.0–1.4 million t).

A likely bias in surveys 6 and 7 in 1983 is an underestimate caused by saturation both in the EKS echosounder and in the QM analog integrator at high fish densities. This problem was significantly reduced with the EK 400 and QD system used in the last survey. All but some 10,000 t of the fish was located in the Arabian Sea.

In May 1984 the highest concentration of small pelagic fish was found in the sector Masirah Island to Ras al Madraka.

The possibility of large-scale fluctuations in the stocks of small pelagic fish in this region, perhaps related to interannual variability in the southwest monsoon, is discussed below.

The 1983/84 surveys provided data for describing the density distribution of the small pelagic fish on the southeast coast. Strø;mme (1986) shows that the main part of the biomass was found in aggregations of high density. The pattern varied little between surveys and the average proportions of density levels in % of total biomass were:

density level t/nmi^2	%
3–150	18
150–300	4
300–1500	49
> 1500	29

Fish concentrations at densities higher than 300 t/nmi^2 are considered to be suitable for industrial fishing.

Species composition of small pelagic fish

Aimed pelagic trawling for species identification gave high overall catch rates and thus seems to have been successful as a sampling method. Table 3.37 shows the mean catch rates for the hauls in the Arabian Sea and their composition by main families and species of pelagic fish. For all the surveys five families accounted for 91% of the total catches, of which Carangidae represented 80% and Clupeidae 8%.

Table 3.37 Composition by families and species of catches of aimed pelagic trawling in the Arabian Sea off Oman (% of total catch by weight).

Survey	March 83	November 83	May 84
No. of hauls	15	25	4
Mean catch kg/h	1,286	1,803	556
Carangidae	80.8	83.4	70.5
Trachurus indicus	*74.8*	*80.5*	*62.8*
Decapterus russelli	*5.5*	*2.6*	*0.6*
Clupeidae	13.9	3.3	8.0
Sardinella longiceps	*3.0*	*1.2*	*4.8*
Sardinella gibbosa	*6.3*	*2.0*	*2.1*
Etrumeus teres	1.0	0.1	0.0
Engraulidae	1.2	0	3.9
Scombridae	0.1	0.1	0
Sphyraenidae	0.2	2.8	4.9
Others	3.8	10.5	12.9

A small number of species dominated the catches of the mid-water trawl. The five species shown in Table 3.37 represented an average of 93% of the catch of the five pelagic families and 85% of the total pelagic catch. The Arabian scad (*Trachurus indicus*), which alone comprised 77% of the weight of the catches, was by far the most abundant species. A pelagic assemblage dominated by a few abundant species is characteristic for coastal upwelling systems. However, it seems likely that the often nearshore distribution of the Clupeidae and Engraulidae caused them to be under-represented in these data compared with the other pelagic families because the nearshore areas could not be covered.

The Carangidae, as the only pelagic family, also made a significant contribution to the bottom trawl catches, 40% of a mean catch of 1042 kg/h (27 hauls) in March/83 and 48% of a mean catch of 931 kg/h (38 hauls) in November/83. In these catches the species *Trachurus indicus* and *Decapterus russelli* appeared with roughly the same abundance in both surveys (Table 3.38). It seems, however, likely that the sampling with the pelagic trawl, which showed a large dominance of the Arabian scad, gave a better indication of the actual proportions of the two species.

Table 3.38 Species composition of catches of Carangidae in swept-area bottom trawl hauls (%)

Survey	March 83	November 83
No. of hauls	27	36
Mean catch kg/h	412	448
Trachurus indicus	46.4	44.9
Decapterus russelli	47.5	49.0
Carangoides spp	3.9	3.3
Others	2.1	2.8

The catches in the bottom trawl may also provide information on the distribution of the pelagic fish on the shelf in terms of distance from shore. Clupeids occurred nearly exclusively in bottom trawl hauls shallower than 20 m depth, while nearly all the high catch rates of *Trachurus indicus* and *Decapterus russelli* were from the depths of 50–100 m and 100–200 m. A similar pattern of distribution of small pelagic fish is found in other upwelling areas, e.g., the Benguela and Canary Currents, where clupeids are found mainly inshore and *Trachurus* sp. on the outer parts of the shelf and in the slope. This ecological difference must be seen in relation to the different position of these types of fish in the food chain, with Clupeidae closer to the inshore centres of upwelling and primary production and the small Carangidae offshore where there is a high secondary production of zooplankton.

Biomass estimates of demersal fish

Estimates of the biomass of the demersal fish for the southeast coast, Ras al Hadd to Ras Marbat based on the swept-area trawl survey method were as follows (Strø;mme, 1986, Table 8):

March 1983	335,000 t
November 1983	260,000 t
May 1984	335,000 t

The shelf of the Gulf of Oman was only covered in May 1984 and the biomass there was estimated at 42,000 t. The low estimate from November 1983 was related to greatly reduced catch rates from deeper waters which occurred in connection with the presence of oxygen-deficient water on the deeper shelf (Strø;mme, 1986).

The best estimate of the swept-area trawl surveys would thus seem to be 335,000 t for the area covered in the Arabian Sea. An adjustment for the Salalah sector which was not covered of 15,000 t and inclusion of the Gulf of Oman estimate of 42,000 t raises this to a total for the country of 390,000 t.

In addition to the usual uncertainty with swept-area estimations of the true effective fishing width of the trawl, there is probably a bias of underestimation connected with the semi-demersal behaviour of many of the species. The biomass of the semi-demersal fish was estimated with echo integration as follows (adjusted to -32 dB/kg for demersal fish):

March 1983	148,000 t
November 1983	38,000 t
May 1984	53,000 t

Acoustic estimates of the semidemersal fish from the first exploratory surveys (1975–1976) (Kesteven *et al.*, 1981) showed:

April-May 1975	230,000 t
October 1975	230,000 t
February 1976	80,000 t
April-May 1976	250,000 t
September 1976	250,000 t

Although showing high variability these data demonstrate that at times a considerable amount of demersal types of fish occur in mid-water on the Oman shelf. The most common of these semi-demersal fishes were probably the Japanese threadfin bream and hairtails. These species are likely to be under-represented in the swept-area estimates, but a quantification of this bias is not possible.

The swept-area estimate of biomass may also be biased if the mean density of demersal fish on the trawlable part of the shelf is different from that of the untrawlable rough-bottom part. Johannesson (1995) estimated the untrawlable bottom to represent 39% of the Oman shelf between the depth ranges 20–200 m. To correct for the possible bias from different mean densities he used observations of 'acoustic density' of fish in a 6 m layer next to the bottom which represented the vertical opening of the trawl used by the RASTRELLIGER. These data showed a mean fish density over hard bottom about double of that over soft bottom. An assumed similar higher fish density over hard bottom in the DR. FRIDTJOF NANSEN surveys would raise the swept-area estimate of 390,000 t quoted above to about 550,000 t.

Species composition of demersal fish

Table 3.39 shows the catch rates of main species groups by surveys using the bottom trawl. The data are mainly from the Arabian Sea. The very high rates for pelagic fish in the May 1984 surveys result from hauls directed at echo recordings for identification and sampling.

Table 3.39 Mean catch rates by main groups in bottom trawl hauls (kg/h)

Survey	March 83	November 83	May 84
Arabian Sea			
No. of hauls	27	36	30
Pelagic fish	430	453	4,780
Demersal fish	488	388	705
Sharks and rays	22	42	8
Cephalopods	9	8	33
Others	93	40	102
Total	**1,042**	**931**	**5,628**
Gulf of Oman			
No. of hauls		10	
Pelagic fish		335	
Demersal fish		249	
Sharks and rays		14	
Cephalopods		22	
Others		54	
Total		**674**	

Table 3.40 Composition of demersal fish in bottom trawl catches in the Arabian Sea off Oman (%)

Survey Arabian Sea	March 83	November 83	May 84
Ariidae (catfishes)	1.4	17.7	22.6
Synodontidae (lizard fish)	16.7	1.9	6.4
Serranidae (groupers)	2.2	4.8	3.6
Lutjanidae (snappers)	0.2	0.7	0.3
Nemipteridae (threadfin breams)	21.4	11.1	24.2
Pomadasyidae (grunts)	15.2	8.2	10.2
Lethrinidae (scavengers)	13.3	16.2	5.5
Sparidae (seabreams)	28.3	36.9	24.4
Sciaenidae (croakers)	0.6	0.2	1.0
Trichiuridae (hairtails)	0.7	2.3	1.2

The category pelagic fish represents the families Carangidae, Clupeidae, Engraulidae, Scombridae and Sphyraenidae analysed above. The category demersal fish consists for 90% of the ten most important families of demersal and semi-demersal teleost fish (see Table 3.40). In the Gulf of Oman, Psettodidae replace the Serranidae.

The distribution of demersal fish species by depth on the shelf varied between surveys. The Nemipteridae, Lethrinidae and Sparidae had the widest depth ranges through the surveys and the mean rates of the combined catches of these three families are shown by depth and surveys in Table 3.41. Changes in depth distribution may be related to the presence of the oxygen-deficient bottom water: In November 1983 it was found at only about 50 m depth, in March 1983 it occurred well below 100 m and in May 1974 it occurred between 75 and 100 m (Strø;mme, 1986).

Table 3.41 Mean catch rates by depth range of the combined catches of Nemipteridae, Lethrinidae and Sparidae, Arabian Sea off Oman (kg/h)

Survey	November	March	May
Monsoon	83 Post-SW	83 NE	84 Pre-SW
Depth m			
0–20	232	51	158
20–50	205	171	255
50–100	274	162	525
100–200	1	2,262	200

Because of the change of depth distribution of some of the families the mean composition in the catches will only represent the true proportions of the families if the sampling density is the same at all depth ranges and remains unchanged between the surveys. These conditions are roughly met for these data, but the number of hauls at some depths has been low thus increasing the likely survey variation. For this reason a single haul with the highly unusual catch of 10 t/h of Sciaenidae was omitted from the analysis.

In spite of these limitations the composition of the demersal group of 10 families (Table 3.40), was fairly consistent between surveys with five dominating families: catfishes, threadfin breams, grunts, emperors and seabreams. They represented 80%, 90% and 88% of the catches of the demersal group of 10 families in the three surveys respectively. However, it is unlikely that the catches showed the true composition of the demersal fish. The hard bottom fauna, especially snappers and groupers, and the typically semi-demersal fish such as hairtails and threadfin breams were probably significantly underestimated compared with the other demersal families.

The five families Ariidae, Nemipteridae, Pomadasyidae, Lethrinidae and Sparidae, were also reported to be among the taxa with highest biomass density in the extensive surveys carried out with the R/V RASTRELLIGER 1989–90 (Johannesson, 1995). There were, however, differences: Nemipteridae had a relatively much higher abundance, and the total catch composition included a high proportion of rays and porcupine fishes which had very low abundance in the DR. FRIDTJOF NANSEN surveys. At least part of these differences could be attributed to differences in the trawl gear used by the two vessels and in the sampling systems applied.

Species identification and assemblages of demersal fish

Most of the samples were identified to the species level. The dominating species for the most abundant families were as follows (see Strø;mme, 1986 Annex VI for more details):

Ariidae (catfishes): giant catfish (*Arius thalassinus*)

Nemipteridae (threadfin breams): Japanese threadfin bream (*Nemipterus japonicus*). It should perhaps be questioned if the catches reported as Japanese threadfin bream consisted of *Nemipterus japonicus* only, or as in Pakistan included an unknown proportion of the similar species described in 1986 as *Nemipterus randalli*. Other species of the same genus and of the genera *Scolopsis* and *Parascolopsis* occurred with low catch rates.

Pomadasyidae (grunts): striped piggy (*Pomadasys stridens*) and painted sweetlip (*Diagramma pictum*).

Lethrinidae (emperors): spangled emperor (*Lethrinus nebulosus*) and *L. lentjan*.

Sparidae (seabreams); king soldierbream (*Argyrops spinifer*), Santer seabream (*Cheimerius nufar*) and Arabian pandora (*Pagellus affinis*).

In analysing the demersal assemblages of the Oman shelf, Bianchi (1992b) found two groups in shallow water and a third in deeper waters, mostly in the Arabian Sea, the latter characterized by species such as *Trachurus indicus* and *Nemipterus japonicus* which are able to migrate to avoid oxygen-depleted waters. That the Japanese threadfin bream can also perform vertical migrations was confirmed by its occurrence in pelagic trawl hauls over the mid- and outer shelf in the November 1983 survey. Bianchi (1992b) related the high abundance of the third deeper water group to the high productivity of the area caused by seasonal upwelling.

Review of findings and of later research

The three 1983/84 surveys did not cover the monsoon seasons well; a planned fourth survey in September 1984, in the late southwest monsoon, had to be cancelled due to a breakdown of the main engine. However, the November 1983 survey showed the characteristic post-monsoon intrusion of oxygen-deficient water on the shelf in the Arabian Sea and supplementary hydrographical data from the 1975/76 surveys demonstrated the general scale of the wellknown upwelling in this region during the southwest monsoon.

Small pelagic fish were found in high density concentrations during all three surveys, most consistently in the sector off the Gulf of Masirah. The distribution of these fish was not limited to the shelf proper, but at times extended to the surface waters off the shelf edge.

The catches from aimed fishing with a pelagic trawl were dominated by Arabian scad (*Trachurus indicus*), while the pelagic fishes in the bottom trawl catches were a mixture of this species and the Indian scad (*Decapterus russelli*). Clupeidae were found inshore with Indian oil sardine (*Sardinella longiceps*) and goldstripe sardinella (*S. gibbosa*) dominant.

Table 3.42 Summary of estimates of biomass and mean density in Oman obtained from the 1983/84 survey data

	Arabian Sea		**Gulf of Oman**		**Total for Oman**	
	Biomass (t)	**Density (t/nmi^2)**	**Biomass (t)**	**Density (t/nmi^2)**	**Biomass (t)**	**Density (t/nmi^2)**
Pelagic fish	1,400,000	120	10,000	5	1,410,000	100
Demersal fish	350,000	29	42,000	19	390,000	28

Table 3.42 summarizes of biomass estimates and densities. Similar high levels of density of pelagic fish are found in other coastal upwellings such as the Canary and Benguela systems. It should be remembered that the shelf of the Gulf of Oman was surveyed only once and that therefore estimates for this part are less reliable. The much lower fish densities observed for this shelf compared with those found in the Arabian Sea upwelling region were, however, not unexpected and are most likely related to differences in ecosystems.

A set of comparable data on Oman's fish resources is available from the comprehensive programme of surveys executed from November 1989 to November 1990 with the RASTRELLIGER (Johannesson, 1995). The reported estimates of total biomass for pelagic and demersal fish were:

Acoustic estimate, pelagic fish	252,000 t
Swept-area trawl estimate, demersal fish	414,000 t

The acoustic estimate was only based on one survey in September 1990 when pelagic fish was found in some abundance in the Arabian Sea. In the other surveys much less pelagic fish was recorded. Thus this estimate appears particularly unreliable, and it would perhaps be better to use the sum of the mean observations made in each sub-area (Johannesson, 1995, Table 3) i.e. 163,000 t. For comparison with the DR. FRIDTJOF NANSEN data an adjustment is needed from an assumed TS of -29.4 dB/kg to a TS of -34 dB/kg (which represents an increase of the biomass with a factor of 2.88).

The comparable estimate then becomes

163,000 * 2.88 = 469,440 or 470,000 t.

For RASTRELLIGER's swept-area trawl estimate the geometric mean of the catch rates was used. Using the arithmetic mean as for the DR. FRIDTJOF NANSEN leads to a 30% increase. On the other hand the estimate should be reduced by 10%, because a “catchability coefficient” of 0.9 has been assumed for the RASTRELLIGER trawl gear, against 1.0 for the DR. FRIDTJOF NANSEN.

The comparable estimate then becomes:

414,000 * 1.2 = 496,800 or 500,000 t

Thus there was a much lower acoustic estimate of pelagic fish in the 1990 survey than in 1983/84. The lower abundance is also confirmed by the difference in the proportion of scads in the swept-area trawl catches: in March and November 1983 these species represented 40– 50% of the catches against only 6–7% in 1990.

Catch statistics of a small trawler fleet operating in deeper waters in the Arabian Sea off Oman, targeting hairtails and cephalopods (Anon., 1994) provide further evidence of a reduced abundance of scads in 1989–90; the by-catches of small pelagics were as follows: 1986 5.7%, 1987 3.3%, 1988 2.4%, 1989 0.4%, 1990 0.4%, 1991 0.3%, 1992 1.2% and 1993 4.8%.

The RASTRELLIGER estimate of demersal fish abundance is based on more than 400 trawl stations. The differences in the trawl gear used by the two vessels complicates the comparison of the biomass estimates. For example, there is a large difference in catch rates of rays, which is not a group expected to change much in abundance. In the March and November 1983 DR. FRIDTJOF NANSEN surveys the mean catch rates of rays in the Arabian Sea were 3 kg/h and 36 kg/h respectively compared with 125 kg/h in RASTRELLIGER's 1990 surveys. This difference is most probably caused by the rock-hopper ground gear used with the trawl of the RASTRELLIGER. In the absence of intercalibration between the trawls, there seems little point in detailed comparisons of the results of the two surveys. The correction proposed by Johannesson (1994) to adjust for the higher apparent fish density over the hard untrawlable bottom would increase the RASTRELLIGER's estimate of demersal fish by 28% to 640,000 t, and that of the DR. FRIDTJOF NANSEN to 570,000 t.

The main difference between the findings of the two sets of surveys is the low abundance of the pelagic fish in 1990 compared with 1983/84. As noted above, a similar observation of low abundance of pelagics was made in the first 1975 survey, while pelagic fish were found in high abundance in the four subsequent surveys from late 1975 to late 1976. Such fluctuations indicate a dependence of population size on a variable environment as has been found in the anchoveta - El Niño relationship in the Humboldt Current off Peru.

In a review of information on inter-annual variability in the Arabian Sea, Luther (1991) found that evidence exists of both bi-annual and decadal variability in the southwest monsoon winds and in the consequent open-ocean upwelling. This variability could be related to the amount of monsoon rainfall on the Indian continent and seems in a wider context to be part of a global fluctuation in climate. Thus a link has been shown between El Niño/Southern Oscillation (ENSO) events in the Pacific and monsoon variability, with a weak monsoon preceding a warm ENSO phase. Studies quoted by Luther (1991) showed a period of generally low rainfall and weak monsoons from the mid 1960s to the mid 1970s.

Variations in adult stock biomass of small pelagic fish caused by changes in the intensity and duration of upwelling is likely to lag 2–3 years behind the variations in the strength of the monsoon. Parthasarathy *et al.* (1992) reports Indian summer monsoon rainfall indices (ISMR) from 1871 up to 1990. The year 1972 had an anomaly of -49.5% in this index and ranked as the fifth driest year since 1871: this could explain the low abundance found in the first 1975 survey. The years 1985 through 1987 had negative anomalies with both 1986 and 1987 defined as dry years. The ISMR index for 1987 showed this to be the fourth dryest year since 1871. The weak monsoon of 1987 could thus have caused the low biomass of pelagic fish in 1989–1990 found in the RASTRELLIGER surveys.

It is uncertain whether the variability of the main monsoon and the open ocean upwelling is parallelled in the coastal upwelling off the Arabian Peninsula, however, until specific data for this region becomes available, it seems reasonable to consider the hypothesis that fluctuations also occur there and these are the most likely cause of the observed low stability of the stocks of small pelagics in Oman.

Fisheries development

The total landings of Oman's fisheries fluctuated around 100,000 t in the period 1980–86. There was an increase to over 160,000 t in 1988 brought about by a sharp increase in the landings of large pelagics (Spanish mackerels and tunas), but by 1989 the total landings were down to 118,000 t and remained at that level till 1993. About 80% of the 1993 landings were by the traditional small-scale fishery and the rest by small trawlers and longliners. The high abundance shown in the surveys of such species as Japanese threadfin bream and Arabian and Indian scads is not reflected in the landings, probably due to the undesirable small size of these fish. Sardines with their predominantly inshore distribution dominated the 42,000 t landings of small pelagics. The demersal landings of about 27,000 t were dominated by seabreams, emperors, croakers, groupers and hairtails which were all identifed as important families in the surveys. Large pelagic fish (tunas and Spanish mackerels) were not covered by the surveys. Since they are top predators, the landings of about 37,000 t of this group represent an indirect utilization of the abundant mesopelagic and small pelagic fishes. A comparison of the total landings with the findings of the surveys, as presented above, indicates that there is considerable room for expansion of Oman's fisheries.

3.7 YEMEN AND NORTHEAST SOMALIA, FURTHER SURVEYS, 1984

Survey objectives and effort

Yemen's coast in the Gulf of Aden and northeast Somalia had been shown to have a high abundance of small pelagic fish, and therefore these areas were also covered by two surveys under the new programme, in February-March and in August-September 1984 respectively, the first of which also included Socotra. The results were briefly described in preliminary survey reports (Blindheim, 1984 and Strø;mme, 1984b and c) and for northeast Somalia summarized and discussed by Strø;mme (1984d).

Table 3.43 shows the operational data for the surveys. Yemen's survey 1 included Socotra, while survey 2 also covered an offshore part. Yemen's shelf is narrow with a mean width of about 10 nmi, while the east coast of Somalia, north of Ras Mabber has a mean shelf width of 20 nmi. The degrees of coverage for the acoustic surveys were good. The timing of the surveys covered the two monsoon seasons, survey 1 the northeast and survey 2 the south-west monsoon.

Figures 3.28 and 3.29 show the coasts of Somalia and Yemen respectively and the survey routes and stations in the August-September 1984 coverage.

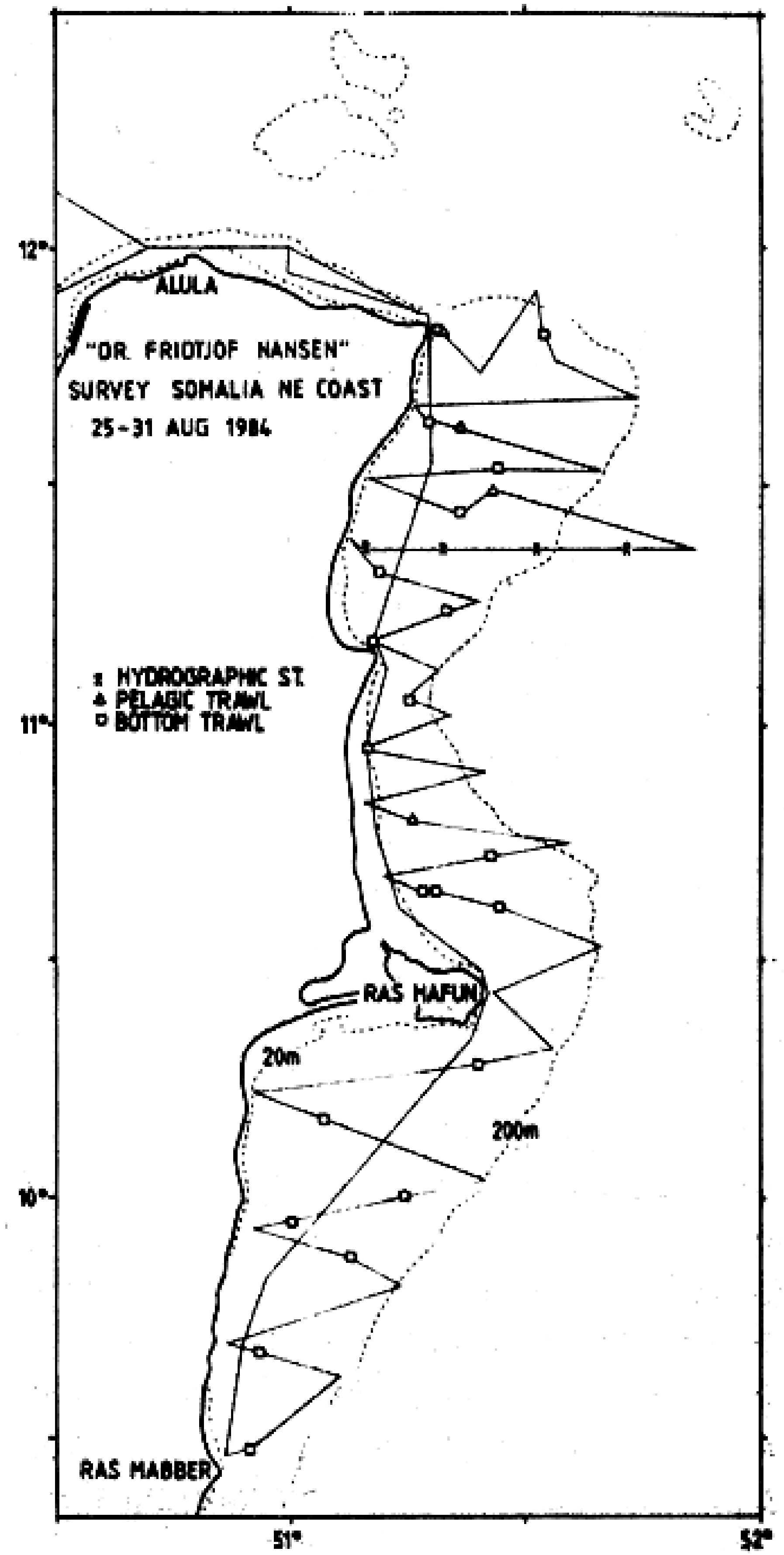

Figure 3.28 Somalia: Survey routes and stations, August-September 84

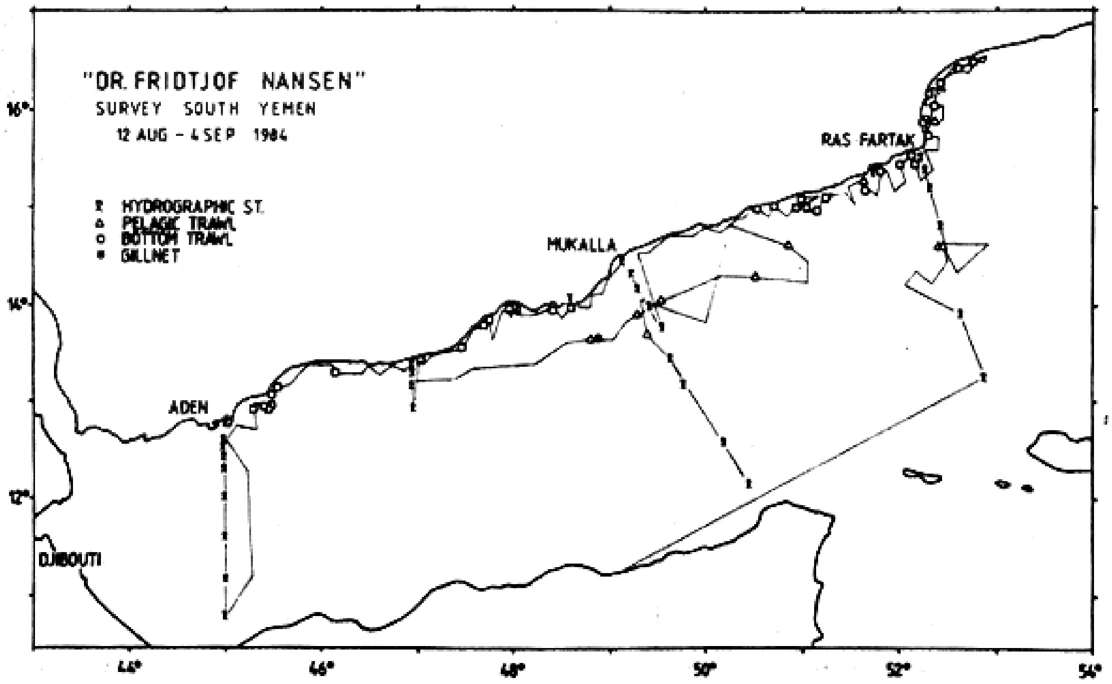

Figure 3.29 Yemen: Survey routes and stations in the August-September survey

Table 3.43 Yemen and northeast Somalia, operational details of the 1984 surveys

	Yemen		**NE Somalia**	
Survey Dates (1984)	**1** **14/2–28/2 1/9–4/9**	**2** **12/8–24/8**	**1** **28/2–4/3**	**2** **25/8–31/8**
Monsoon	NE	SW	NE	SW
Survey distance (nmi)	1,920	1,900	900	1,000
Survey area (nmi²)	7,900	8,400	3,600	3,600
Degree of coverage	22	21	15	17
No. of bottom trawl	44	36	18	20
No. of pelagic trawl	6	10	6	3

Hydrography

Sets of hydrographical stations were occupied in profiles across the Gulf of Aden and off Somalia in both surveys (IMR, 1984b; Strø;mme, 1984b and c). While the February data showed a situation of stable surface layers, the observations from August during the southwest monsoon showed clear evidence of coastal upwelling with low surface temperatures inshore along the Somali coast and the coast of Yemen east of about 47°E. On the coast of Yemen low oxygen water, less than 1 ml/1, was found shallower than 20 m depth compared with 150 m depth in the February survey. A similar seasonal rise of the oxycline was observed off Somalia. In addition to the effects of the upwelling process on the productivity of the region, the regular seasonal changes in environment influence the composition of the fish assemblages and cause major changes in their distribution (Bianchi, 1992b). These phenomena must be taken into account when interpreting the results of the surveys. The effects of the upwelling off Somalia includes at times mass mortality of fish as observed along a wide stretch of the northeast coast by the DISCOVERY expedition in August-September 1964 (Foxton, 1965).

Acoustic estimates of small pelagic fish

Charts of integrator outputs derived from small pelagics indicated a difference in distribution off the Yemen coast in the two surveys; in February the fish appeared to be restricted to the narrow shelf area, while in August aggregations were also found 30–60 nmi off the coast in the Mukalla-Ras Fartak region. The offshore distribution is likely to have been a response to unfavourable environmental conditions inshore during the southwest monsoon. Such findings were not reported from the five previous surveys of the DR. FRIDTJOF NANSEN in the Aden Gulf in 1975/76 nor from the special survey for mesopelagics in 1979.

The distribution of small pelagic fish as charted by the acoustic observations in the two surveys off northeast Somalia, believed to be typical for that well-known upwelling area is shown in Figure 3.30. Nearly all the fish was found between Alula and Ras Hafun. There was no time for an offshore coverage, but previous DR. FRIDTJOF NANSEN surveys had shown the small pelagics to be mainly confined to the shelf waters. Recordings made of the deeper slope and further offshore were shown to consist mainly of mesopelagic fish (Section 3.4).

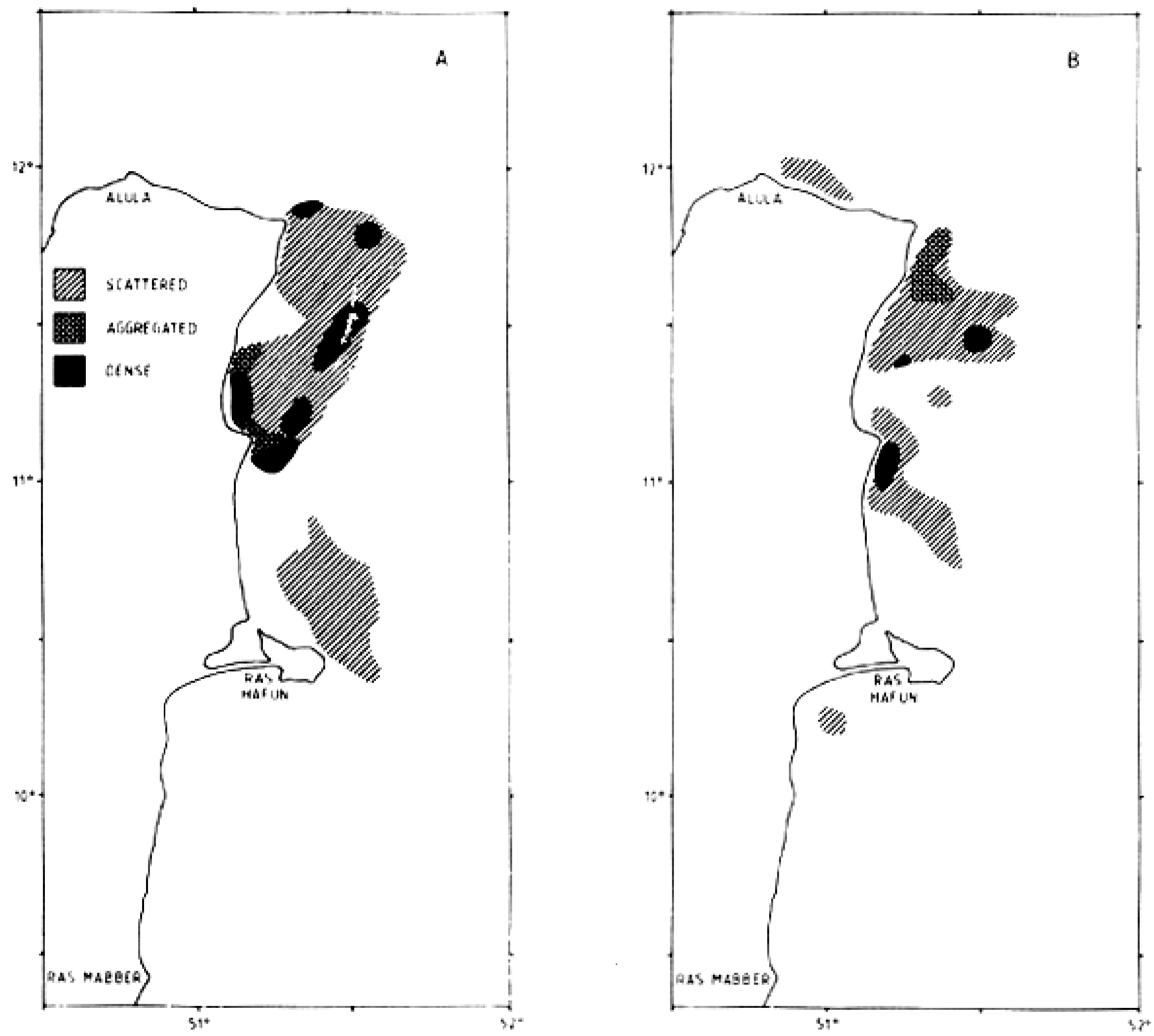

Figure 3.30 Distribution of small pelagic fish off northeast Somalia. A: Feb-Mar 1984; B: Aug 1984

There was a considerable variation in the biomass estimates of pelagic fish from the two acoustic surveys and it seems unlikely that this reflects a true change in the biomass of the stocks. The estimates from the surveys which were assumed to have given the best coverage could therefore be chosen (survey 2 for Yemen and survey 1 for Somalia):

Yemen	265,000 t
Somalia (Alula to Ras Mabber)	245,000 t

Species composition of small pelagic fish

Identification through sampling with pelagic trawl was not very successful. Survey 1 off Yemen had catches of *Sardinella gibbosa, Decapterus russelli*, and *Rastrelliger* *kanagurta* in the pelagic catches and *Sardinella longiceps* and *Megalaspis cordyla* in the demersal trawl. From the offshore aggregations in survey 2 small samples were obtained of *S. longiceps, Scomber japonicus* and various Carangidae.

Off Somalia the pelagic trawl samples included the Clupeidae *Dussumieria acuta, Etrumeus teres* and *Sardinella longiceps*, while Carangidae included *Decapterus macrosoma* and *D. russelli*. Small amounts of *Scomber japonicus* appeared in nearly all catches. These species also dominated the pelagic fish which appeared in the bottom trawl samples.

Biomass estimates of demersal fish

It was no doubt difficult to sample the demersals representatively on the narrow Yemen shelf with its changing environment between the surveys. Table 3.44 shows the mean catch rates on this shelf by main groups in semi-random hauls in the two surveys. There is a clear decline in the rates in the second survey with ponyfish presumably distributed in shallow water inside the survey coverage as a result of intrusion of oxygen-deficient water onto the shelf.

Table 3.44 Yemen: No. of hauls and mean catch rates by main groups on the shelf 10–200 m (kg/h)

Survey	February 1984	August 1984
No. of hauls	44	33
Demersal fish	144	138
Ponyfishes	272	0
Pelagic fish	96	15
Sharks & Rays	24	7
Squid	12	18
Others	132	138
Total	**680**	**316**

A swept area estimate of the fish biomass on the 6,700 nmi^2 shelf area using the mean densities of the February survey gave a total of 150,000 t of which the demersal group represented 32,000 t.

Also in east Somalia, Table 3.45, the mean total catch rate of the bottom trawl during the southwest monsoon season in August was less than half of that in February. The group of demersal fish, potentially commercial species, represented a higher proportion of the catches than in Yemen.

Table 3.45 Somalia: No. of hauls and mean catch rates by main groups on the shelf 10–200 m (kg/h)

Survey	February 1984	August 1984
No. of hauls	16	19
Demersal fish	917	217
Pelagic fish	254	164
Sharks & Rays	8	64
Squid	10	11
Others	57	117
Total	**1,246**	**573**

A swept area estimate of the biomass on the 3,600 nmi^2 shelf north of Ras Mabber using the mean densities of the February survey gave 150,000 t, of which 83,000 t represented the demersal group of potential commercial species.

Species composition of demersal fish

In Yemen the dominating species among the demersals were:

Threadfin breams:	*Nemipterus japonicus*
Grunts:	*Pomadasys maculatum, Diagramma pictum*
Emperors:	*Lethrinus nebulosus, L. elongatus, L. crocineus*
Snappers:	*Lutjanus bohar, L. rivulatus, L. sebae*
Groupers:	*Epinephelus undulosus, E. multinotatus*
Seabreams:	*Pagellus affinis*
Croakers:	*Otolithes ruber*
Catfishes:	*Arius thalassinus*

This assemblage reflects mainly the composition of the demersal fish group in the first survey. In the second survey a few high catch rates of *Nemipterus japonicus* dominated and most of the other species did not appear in the catches.

In Somalia the dominating species in the families of demersals were:

Emperors:	*Lethrinus nebulosus, L. lentjan*
Snappers:	*Pristipomoides filamentosus, Lutjanus sebae, L. coccineus*
Grunts:	*Diagramma pictum, Plectorhinchus pictus, Pomadasys olivaceum*
Groupers:	*Epinephelus tauvina, E. chlorostigma, E. acanthistius*
Threadfin breams:	*Scolopsis bimaculatus, Nemipterus nematophorus*
Seabreams:	*Pagellus affinis, Boops boops, Argyrops spinifer*

As pointed out by Bianchi (1992a) the seabream *Boops boops* common in the Mediterranean and off West Africa had not previously been reported from the Indian Ocean.

Review of findings and of fishery development

The surveys showed the well-known effect in this part of the Indian Ocean of redistribution of demersal fish caused by upwelling of oxygen depleted water during the southwest monsoon. Off Yemen also the coastal small pelagic fish seemed to have been dislocated by changes in the environment during the monsoon and surface aggregations of these fish were found outside the shelf area at some 30–60 nmi off the coast, a distribution not previously observed.

Using those surveys that are assumed to have given the best coverage of the target group, the following estimates of standing biomass were obtained:

	Yemen	Somalia
Small pelagic fish (acoustics)	265,000 t	245,000 t
Swept area trawl estimate (total)	150,000 t	150,000 t
Swept area “commercial fish” only	32,000 t	83,000 t
Total biomass density	62 t/nmi^2	110 t/nmi^2

These densities may be compared with the levels found in the Arabian Sea off Oman of 150 t/nmi^2 and thus confirm the relatively high productivity of the waters off Yemen and northeast Somalia.

In a discussion of the potentials of Yemen's resources Sanders and Morgan (1989) indicate that the official statistics of 70,000–90,000 t total landings in the period 1980–86 may represent an under-reporting particularly of the small-scale inshore fishery for oil sardine. There are uncertainties about the level of the industrial fishery for oil sardine during the 1970s. The FAO Yearbook of Fishery Statistics quote oil sardine landings of 80,000–90,000 t up to Vol 48 (1979), but only about 10% of that for the same years, from Vol 50 (1980) onwards.

The industrial fishery with large purse-seiners in any case ceased about 1980. The 1975–76 DR. FRIDTJOF NANSEN surveys gave estimates of about 0.5 million t of small pelagic fish for the Yemen coast, (Section 3.3). Results of exploratory fishing with purse-seines at the time (Ellingsen, 1975 quoted by Sanders and Morgan, 1989) tended to confirm a high abundance of small pelagics. The February 1984 acoustic survey showed a very low stock, while the 265,000 t estimate from August 1984 included an offshore distribution. Only part of this was, however, identified as oil sardine. These various data indicate a considerable variability in the stocks of small pelagic fish on the Yemen coast, perhaps affected by interannual variability in the monsoon through changes in the upwelling (as also seems to be the case in Oman).

An assessment of the oil sardine based on commercial fisheries data (Sanders and Bouhlel, 1984) showed a more limited potential, about 20,000 t annual yield, than perhaps indicated by the acoustic surveys. This assessment related particularly to the stocks available on a 90 nmi stretch of the coast near Mukalla. There may not be any discrepancy between this assessment and the survey data since these include a wider area as well as additional species.

In later years the stocks of small pelagics seem to have been only lightly exploited. Restraints other than resource availability limit an expansion of the fishery (Sanders and Morgan, 1989).

The considerable history of attempts and efforts to develop marine fisheries in Somalia in the 1970s and 1980s were reviewed by Anon., 1987. Although basic assessments of fishery resources had been provided by resource surveys at an early stage, sufficient information concerning commercially sustainable yields had been lacking. Various attempts had been made to obtain such information. As regards the resources of small pelagic fish two large Romanian factory trawlers were used in a simulation fishing programme off northeast Somalia in 1983–84 and had regular commercial size catches with a total production exceeding 6,000 t. The area fished was identical to that in which small pelagic fish was located in the 1984 DR. FRIDTJOF NANSEN surveys. An annual potential yield of 40,000 t was estimated by the Romanians for this area. Considerable environmental, technological and biological problems were, however, experienced and no follow-up resulted in terms of development of an industrial fishery.

Under a Fisheries Exploration/Pilot Project 1984–87 (Anon., 1991b) two purse-seiners were used for exploratory fishing of small pelagics in 1986–87. They were according to the report deployed in North Somali waters where the results led to the conclusion that "There was not enough off-shore fish to justify a major purse-seining method of harvesting small pelagic species." The programme included trials off Ras Hafun on the northeast coast where, however, purse-seine fishing is difficult in the period April-September due to wind and current conditions.

During a period of one year 1984–85 two large Japanese trawlers operated in a commercial bottom trawling feasibility study and caught well over 3,000 t of mixed demersal fish, for which, however, difficulties were experienced in finding international market acceptance (Anon., 1987). A Somalia/Egypt joint trawling venture with a smaller vessel and marketing in Egypt was economically more successful.

The problems of utilizing the marine fish production in Somalia are no doubt related to such factors as the remoteness of the northeast coast, the limited tradition in fisheries, the narrow shelf, the rough sea and wind conditions during the monsoon, the low fish consumption in the country. In these many constraints Somalia may represent a special case. The various unsuccessful efforts to develop the fisheries can on the other hand be seen as an apt illustration of the often complex process from base line resource studies to the stage of their commercial utilization.

4 SURVEYS IN THE NORTHEAST INDIAN OCEAN AND SOUTH CHINA SEA

Between August 1978 and August 1983 eleven surveys were conducted in the Eastern Indian Ocean and a small part of the South China Sea. These surveys were conducted in support of various projects and often as a supplement to trawl surveys conducted by local vessels. The waters around Sri Lanka were covered three times (1978–80), those of Myanmar and Bangladesh twice (1979–80) and those of peninsula Malaysia, West Thailand and northwest Indonesia/part of Sumatra) only once in 1980. Three years later a special survey was conducted in the Maldives, that has been not considered in this report.

4.1 SRI LANKA, 1978–80

Survey objectives and effort

The surveys off Sri Lanka formed part of a general programme of development co-operation between the Governments of Norway and Sri Lanka and were sponsored and coordinated by NORAD. They were planned and conducted jointly by the Fisheries Research Station, Colombo, and the Institute of Marine Research, Bergen.

The objective was to provide information on the distribution, composition and abundance of the fishery resources on the shelf and describe their environment. The main method was to be echo integration with fishing for identification, sampling and gear trials. A special bottom trawl survey was planned for the Pedro Bank to assess the potential of this ground for a possible trawl fishery. Rough bottom on large parts of the shelf represented a limitation for a general use of the swept-area trawl method with pre-positioned fishing stations for estimating the biomass of demersal fish.

Table 4.1 Sub-divisions of the Sri Lankan shelf

Area code	Area	Coastline length (nmi)	Area inside 200 m depth (nmi²)	Shelf width (nmi)
1	Northwest coast	110	1,500	14
2	Southwest coast	100	1,380	14
3	Hambantota Bank	80	940	12
4	East coast	120	1,300	11
5	Northeast coast	90	560*	6
6	Pedro Bank to 10° 15'N	40	1,020*	25
	Total covered area	540	6,700	
	Remaining northern shallow shelf, Palk Bay, Palk Strait etc. to mid-line		2,800	

* Outside about 20 m of depth

The Sri Lankan shelf is shown in Figure 4.1 with the tracks from the first survey. The subdivisions used to describe the survey results are indicated in this map and described in Table 4.1. The northwest coast includes the Sri Lankan part of the Gulf of Mannar. The shelf of Sri Lanka is very narrow with a mean width of less than 15 nmi except for the Pedro Bank and the northern part. The slope is very steep and only small parts in the Gulf of Mannar and off the Pedro Bank were found to be fishable with trawl. The northern shelf, Palk Strait and Palk Bay, was too shallow for navigation with the vessel and could not be included in the investigations.

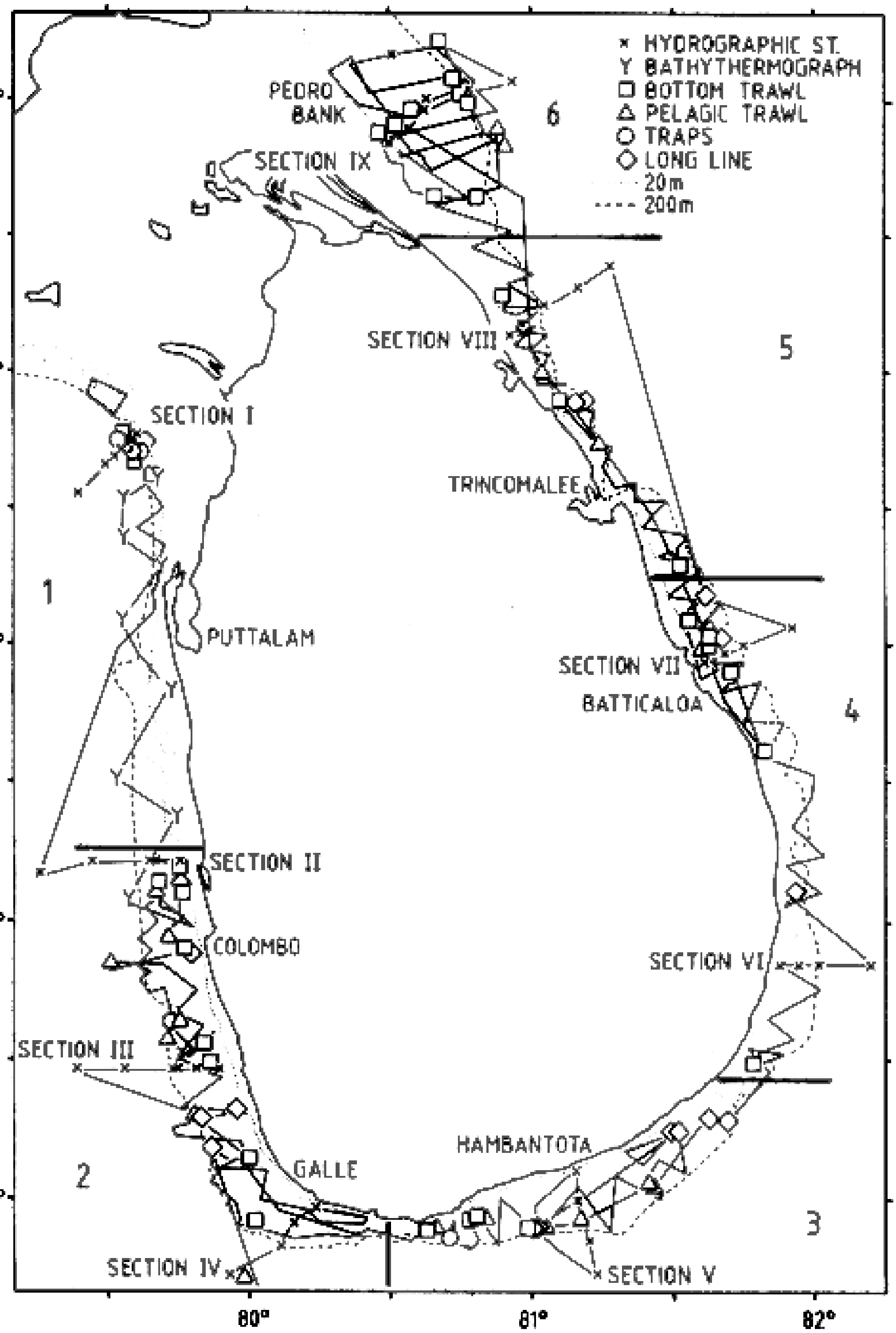

Figure 4.1 The Sri Lanka shelf with the sub-divisions used to describe the survey results and the tracks of the first survey

Table 4.2 gives some main data on the surveys. Survey I was at the end and survey II at the start of the southwest monsoon and survey III during the northeast monsoon. The pattern of survey tracks from survey I was repeated in the other surveys, but with more detailed coverage. Survey II included an additional programme of exploratory fishing in selected parts of the shelf.

Table 4.2 Sri Lanka: Review of survey information

Survey No	Dates	Distance steamed nmi	No. of fishing stations	Monsoon season
I	16/8–26/9 1978	3,400	84	Late SW
II	25/4–16/6 1979	5,800	147	Early SW
III	7/1–10/2 1980	4,300	133	NE

The historical review of the state of the acoustic instruments presented in Chapter 2 showed that the conversion factors used to estimate biomass from integrator deflection corresponded to a target strength level (TS) of -35 to -36 dB/kg (for 17 cm fish). This target strength is thought to be too low and in this review an approximately 2 dB higher level has been applied which was obtained by reducing the biomass estimates presented in the first survey reports by about one third.

The results of the surveys were presented in three summary reports, Sætersdal and de Bruin, (1978), Blindheim *et al.*, (1979) and Blindheim and Fø;yn, (1980).

Bottom topography

Based on interpretation of echosounder recordings a description of the bottom with regard to its suitability for trawling was made and presented in a chart which includes data from all coverages (Figure 4.2). Much uneven and rough bottom was found on the middle and outer shelf and especially from Colombo round the south coast beyond Trincomalee. Fishing with bottom trawl for identification and sampling had to be limited to smooth and not too uneven bottom and this may have caused bias as fish recordings off the bottom were often associated with rough bottom. Longlines were sometimes used for fishing trials on untrawlable bottom. The edge of the shelf was abrupt and the slope steep and unfishable in most parts.

Hydrography

The data showed a shift in the hydrographical environment around Sri Lanka with the monsoons. Figure 4.3 shows oceanographic conditions in two fixed profiles off the west (No. II) and southwest (No. IV) coast from each of the surveys: at the end of the southwest monsoon, at the start of the southwest monsoon and during the northeast monsoon. During the southwest monsoon the southward current brought surface water from the Gulf of Mannar and the southwest coast of India. The transitional layer lifted during the southwest monsoon and oxygen deficient water, less than 2–3 ml/l reached depths of less than 100 m on the shelf. During the northeast monsoon, in January-February the transition layer was found at more than 100 m depth, and the current was reversed with surface water moving west and northwest on the south and southwest coast.

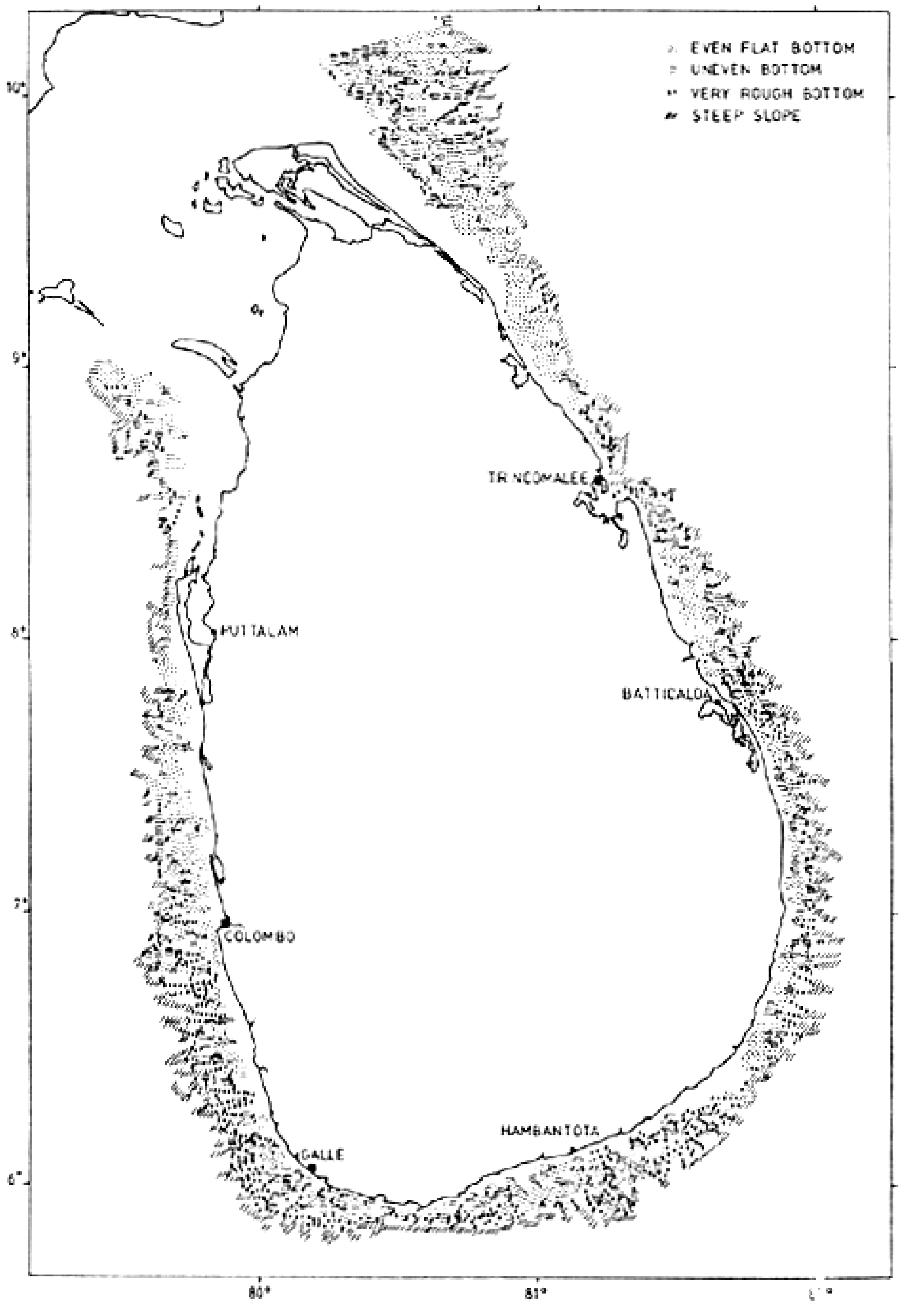

Fig. 4.2 Observations of the character of the bottom on the shelf and upper slope

Figure 4.4 shows hydrographic sections VI and IX from the east coast and the Pedro Bank during the three surveys. The lifting of the transition layer during the southwest monsoon was pronounced with bottom water of oxygen content of 1 ml/l found at about 50 m of depth in August-September. The shoreward tilting of the isopleths indicated upwelling on the northeast shelf. The shifts in the oxygen content of the bottom water may have affected the distribution of demersal fish.

Measurements of primary productivity during the IIOE summarized in Cushing (1971a) showed a relatively high production around Sri Lanka during the northeast monsoon. Observations in this area were lacking in the southwest monsoon season, but satellite images of phytoplankton concentrations in the Indian Ocean from September-October showed a belt of high levels from the southwest coast of India continuing in the Gulf of Mannar and past the west coast of Sri Lanka, see Figure 10 Chapter 10. The general productivity on the shelf and adjacent waters around Sri Lanka should thus be expected to be fairly high.

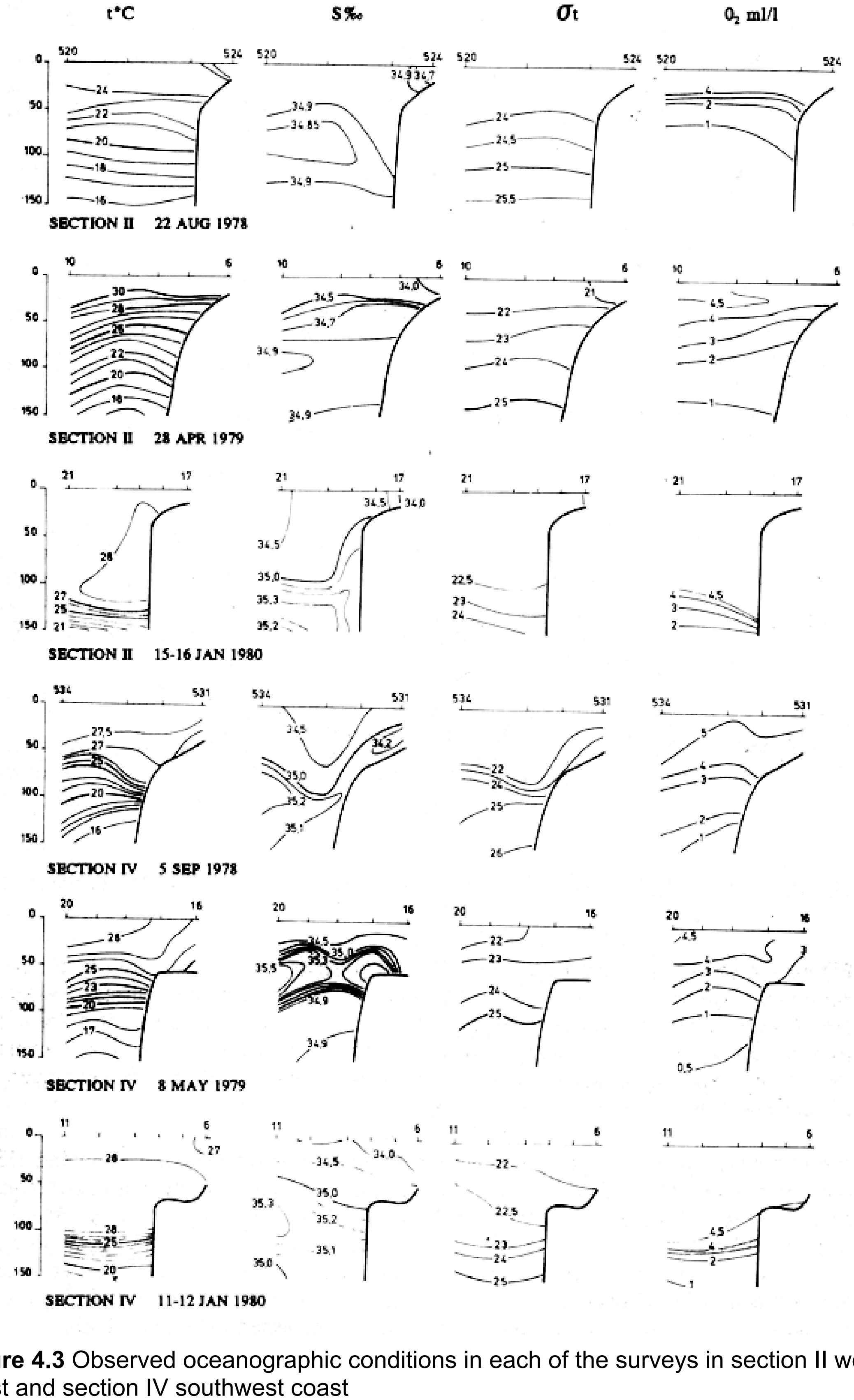

Figure 4.3 Observed oceanographic conditions in each of the surveys in section II west coast and section IV southwest coast

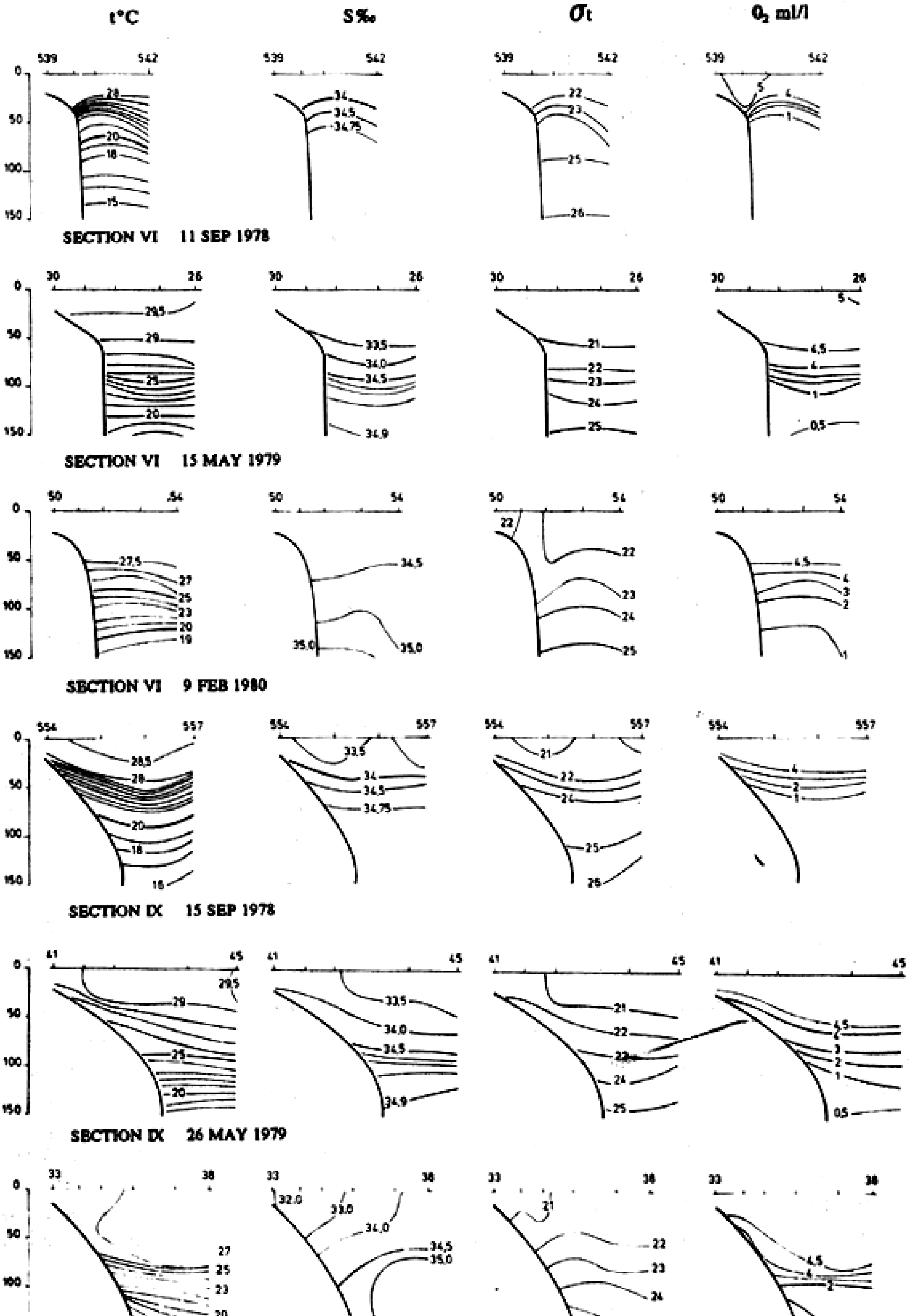

Figure 4.4 Observed oceanographic conditions in each of the surveys in section VI southeast coast and section IX Pedro Bank

The acoustic surveys

Based on general experience of identifying echograms and on identification by fishing during the surveys in Sri Lanka waters, the echosounder recordings of fish were classified as follows:

Type A:	Schools and aggregations of apparently larger fish near the bottom and in the lower part of the water column. These were ascribed to fish with semi-demersal or semi-pelagic behaviour such as snappers, breams, groupers, jack mackerels, etc.
Type B:	Single fish traces or small schools of bigger fish closer to the surface waters. These were thought to derive from Spanish mackerels, tunas and tuna-like fish.
Type C:	Recordings of true larger schools or dense layers mostly in the upper water column. These were ascribed to smaller sized pelagic schooling fish (Clupeidae and smaller Carangidae).

Figure 4.5 shows examples of the three types of echograms. Type A was by far the most common recording. Type B was less common and often thought to have been "lost" in dense plankton recordings near the surface. Type C was stated to be quite common particularly in inshore waters in the first survey, but scarce in the two following surveys. These differences will be reflected in the biomass estimates based on the echo integration data.

The identification of the common type A recordings as semi-demersal fish was confirmed in a convincing way in a test programme during Survey II, when density estimates by acoustic integration and bottom trawling were compared (see description under "Fishing trials with the bottom trawl" below). Recordings of semi-demersal fish were encountered in all surveys in the Indian Ocean, but only in Sri Lanka were these fish found to be the main acoustic target.

Oxygen depletion in bottom water on the slope and shelf is known to affect the fish distribution and fish behaviour in many parts of the Indian Ocean and the oceanographic observations indicate that this environmental effect may be important also in Sri Lanka.

Mid-water occurrence of demersal fish is in many cases known to be more pronounced during nighttime. A repeat survey during day and night was made of a set of course tracks on the Pedro Bank and this showed about 30% higher acoustic estimates by night. A set of comparisons of mean recordings from day and night surveying of the west and southwest coast during surveys II and III did not, however, confirm this trend: in three out of four comparisons the day-levels were highest. It must be concluded that mid-water occurrence is a common behaviour of semi-demersal fish also at daytime in Sri Lankan waters. The prevailing strong currents on the south and west coasts, where the semi-demersal fish is most abundant may be another environmental factor of importance for determining their behaviour.

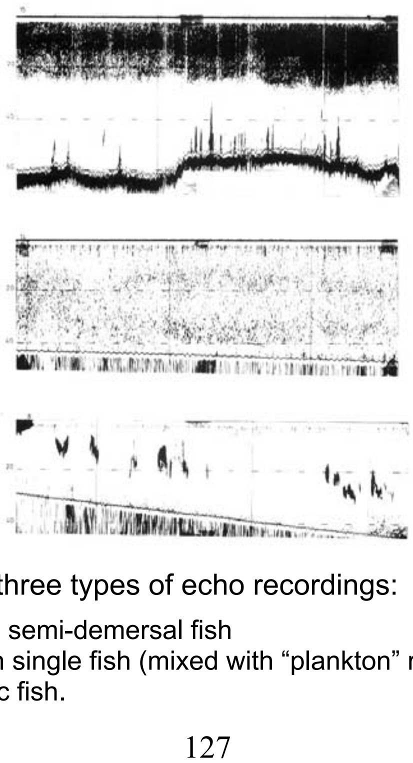

Figure 4.5 Examples of the three types of echo recordings:

Top:	Type A deriving from semi-demersal fish
Middle:	Type B, bigger fish in single fish (mixed with "plankton" recordings)
Bottom:	Type C, small pelagic fish.

Biomass of pelagic fish

The recordings of small and large-sized pelagic fish were not consistently distinguished in the surveys and therefore the biomass estimates are shown together in Table 4.3. On the west coast and the Pedro Bank mostly small pelagics were found, while large pelagics were found mainly along the east- and south coasts. The higher biomass from the post-monsoon survey (I) consisted mainly of small pelagics and may represent an effect of seasonal production. The pelagic trawl experiments for identification and sampling gave only low catches of small pelagic fish and the occurrence of this group in the catches from demersal hauls was also low thus confirming the generally low abundance of small pelagic in the parts of the shelf covered. Three species *Sardinella sirm, Rastrelliger kanagurta* and *Decapterus russelli* appeared in the catch records with about the same frequency.

The fish identified as large pelagics were assessed to have a biomass of some 40,000–60,000 t in the parts covered by the surveys. The source of these records was thought to be tunas and tuna-like fish and the distribution of the recordings, often on the offshore parts of the shelf indicated an oceanic continuation. The only type of these fish caught was Spanish mackerel (*Scomberomorus commerson*) which was probably the main representative of this group inside the shelf.

Table 4.3 Sri Lanka: Biomass estimates of pelagic fish by coastal regions and by surveys (1,000 t)

		Survey I Aug-Sep 78	**Survey II Apr-May 79**	**Survey III Jan-Feb 80**
1	NW coast	30	15	15
2	SW coast	15	15	15
3	Hambantota Bank	20	5	40
4	East coast	40	10	
5	Trincomalee-NW	35	5	10
6	Pedro Bank	10	5	20
	Total	150	55	100

Biomass of demersal and semi-demersal fish

Table 4.4 shows the biomass estimates of semi-demersal fish, while Figure 4.6 shows their distribution in each survey. The highest densities in August-September and January-February were recorded at the Hambantota Bank and up the west coast past Colombo, while the April-May distribution indicated a shift up the west coast, which may be the result of migrations related to the northward moving current during the northeast monsoon. The densities are lower on the east coast and Pedro Bank. There is some decline in the estimates from 1978 to 1980, but this may be within the range of survey variability.

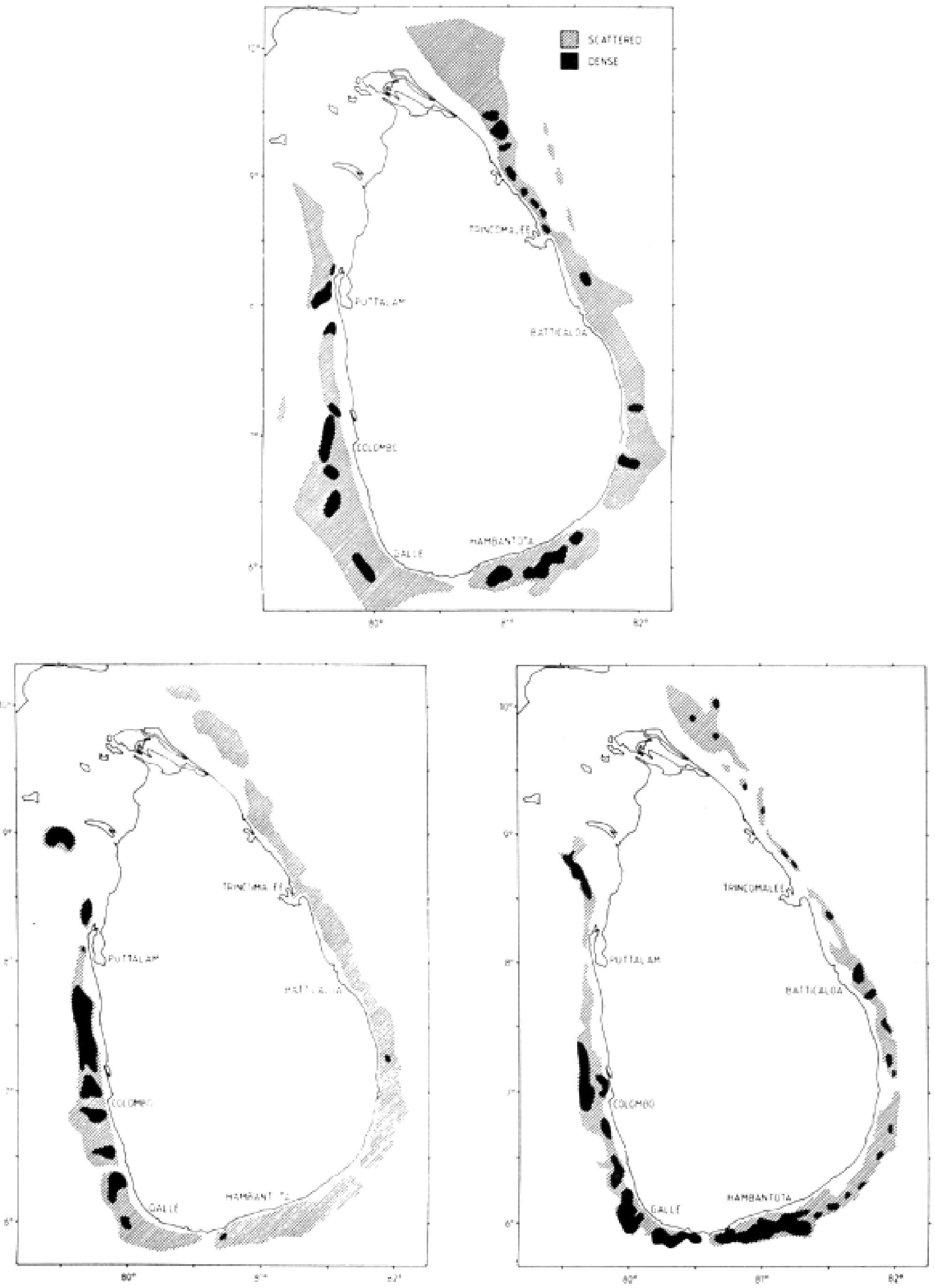

Figure 4.6 Distribution of echo intensity of semi-demersal fish.
Top: survey I, Aug-Sep 78; bottom left: survey II, Apr-Jun 79 and bottom right: survey III, Jan-Feb 80

Table 4.4 Sri Lanka: Biomass estimates of semi-demersal fish by coastal regions and by surveys (1,000 t)

Area code	Area	Survey I Aug-Sep 78	Survey II Apr-May 79	Survey III Jan-Feb 80
1	NW coast	-	70	25
2	SW coast	140	90	75
3	Hambantota Bank	50	20	40
4	East coast	40	30	20
5	NE coast	-	15	10
6	Pedro Bank	15	10	10
	Total	245	235	180

Species composition of demersal and semi-demersal fish

Although possibly biased towards true bottom dwellers, the catches in the bottom trawl were the only source of information available on the composition of the semi-demersal fish. Table 4.5 shows the composition by the main families in successful hauls on the west and south coasts and Table 4.6 on the east coast and the Pedro Bank. The fauna in all of these areas was dominated by species with a preference for hard and sandy bottoms. The most common families, both by occurrence and weight of catch were snappers, emperors, groupers and sweetlips. The emperors dominated the catches on the west coast. The east coast and the Pedro Bank had a more varied fauna, surgeon fish among the more common, and with large pelagic fish, Carangidae, barracudas and Spanish mackerel. There was thus an indication of a difference in the fauna of the demersal and semi-demersal fish between the west coast and Hambantota and the east coast and the Pedro Bank, although many species were the same. The west and south regions sustained by far the largest biomass and appeared to be the most productive.

Table 4.5 Sri Lanka: Composition of semi-demersal types of fish in bottom trawl catches. Incidence (%) and % of total catch by weight. West and south coasts, all surveys pooled

Area	**1 NW coast**		**2 SW coast**		**3 Hambantota**	
No. of hauls	18		28		15	
	Incidence %	**Weight %**	**Incidence %**	**Weight %**	**Incidence %**	**Weight %**
Lutjanidae	72	16	54	10	87	28
Lethrinidae	89	58	61	41	67	22
Serranidae	33	7	43	8	73	33
Pomadasyidae	61	14	18	3	47	11
Sparidae					20	2
Sciaenidae			4	11		
Carangidae	11	3	43	26	27	3
Sphyraenidae			7	1	20	1
Scombridae	11	2				

Table 4.6 Composition of semi-demersal types of fish in bottom trawl. Incidence (%) and % of total catch by weight. East coast and Pedro Bank, all surveys pooled

Area	**4 & 5 East coast**		**6 Pedro Bank**	
No. of hauls	21		30	
	Incidence %	**Weight %**	**Incidence %**	**Weight %**
Lutjanidae	76	23	80	19
Lethrinidae	71	14	77	20
Serranidae	71	10	70	17
Pomadasyidae	76	12	63	12
Acanthuridae	24	13	23	12
Sparidae	10	1	13	1
Sciaenidae	10	1	3	2
Carangidae	38	22	70	12
Sphyraenidae	10	2	40	2
Scombridae	14	2	20	2

The catches were only partly identified to species level. The following species were indicated as being the most common within the respective families listed in order of frequency of recording in the catch records:

Lutjanidae:	*Lutjanus argentimaculatus* (common), *L. rivulatus* (common), *L. sanguineus* (common), *L. lineolatus, Pristipomoides typus*
Lethrinidae:	*Lethrinus nebulosus* (very common), *L. elongatus, L. rhodopterus*, *L. miniatus*
Serranidae:	*Epinephelus undulosus* (common), *E. tauvina* (common)
Pomadasyidae:	*Plectorhinchus pictus* (very common)
Acanthuridae:	*Acanthurus strigosus*

Sciaenidae:	*Otolithes ruber*
Sparidae:	*Argyrops spinifer* (common)
Carangidae:	*Carangoides malabaricus, Alectes indicus, Selar crumenophthalmus*
Sphyraenidae:	*Sphyraena jello, S. barracuda*
Scombridae:	*Scomberomorus commerson* (common)

Most of these are commercial fish of high value, and many may attain a large size. The samples of size distributions from Surveys II and III are summarized in Table 4.7. Two regions of distributions were considered for purposes of weighting: the west coast and Hambantota Bank and the east coast and the Pedro Bank. The size distributions from each of these regions were weighted with a rough estimate of the family's proportion of the “acoustic biomass” in the regions.

Table 4.7 shows an abundance of large-sized fish of these generally slow-growing species and thus gives an impression of lightly fished stocks. These data may serve as a source of reference for later studies of the state of the stocks. The original more detailed observations are available in the NAN-SIS data base.

Table 4.7 Sri Lanka: Size compositions of selected species of demersal and semi-demersal fish of surveys II and III. Fork length (%)

	Lethrinus nebolosus		*Lethrinus miniatus*		*Plectorhinchus pictus*		*Epinephelus undulosus*		*Lutjanus argentimaculatus*	*Lutjanus sanguineus*	*Lutjanus rivulatus*
No.	516	142	156	96	306	111	86	62	81	118	55
Survey	II	III	II	III	II	III	II	III	II	II	II
cm											
10*	4	1		1							
15	5	6		2							
20		15		3							
25	1	12		3		10	1				
30	3	9	1	1		6	2	2			7
35	4	9	2	7		11	2	5	11		20
40	6	4	6		2	12	1	3	42	1	17
45	11	11	3		23	17	3	8	26	10	17
50	22	18	13	19	27	8	3	29	9	26	4
55	20	12	8	52	20	20	19	34		32	21
60	18	2	10	6	20	14	40	17	6	22	10
65	5	1	7	6	7	2	29	2	6	8	3
70	1		13		1					1	1
75			35								
80			1								
85			1								

* 10–14.9 cm etc.

Fishing trials with bottom trawl

For reference purposes, a review of catch rates in the bottom trawl is presented. The objective of the fishing was usually identification and sampling of fish recorded on the echosounder. Unsuitable bottom was often a limitation, preventing fishing on dense echo recordings. A swept-area survey was made of parts of the Pedro Bank.

Table 4.8 Gulf of Mannar: Catch rates with the bottom trawl from the deep-sea ground (kg/h)

	Survey I		**Survey II**		**Survey III**	
No. of hauls	7		2		6	
	Mean	**Max**	**Mean**	**Max**	**Mean**	**Max**
Lobster	55	140	170	230	260	570
Shrimp	170	600	180	250	40	150
Deep-sea fish	520	1,300	1,900	2,000	3,400	6,400

A small deep-sea trawling ground in the Gulf of Mannar around 8°45'N and 79°32'E, located in 1972 by the R/V OPTIMIST was tested in each of the surveys. The catch rates are shown in Table 4.8. The lobster was the whip lobster *Puerulus sewelli* which is also found off Somalia, SW India and the Tenasserim coast of Myanmar. The size was relatively small, 13– 14 cm total length for females and 11–13 cm for males. The shrimps were identified as *Aristeus semidentatus, Heterocarpus gibbosus, Parapandalus spinipes* and *Metapenaeopsis andamanensis*. *Chlorophthalmus agassizi* dominated the deep-sea fish.

Table 4.9 shows catch rates for fishing on the shelf of the northwest coast. Demersal and semi-demersal fish were as shown in Table 4.4, principally emperors, snappers and sweetlips. The catch rates were particularly high in the pre-monsoon survey II.

Table 4.10 shows the catch rates for the southwest coast. Emperors, represented mainly by the spangled emperor (*Lethrinus nebulosus*) dominated the catches of demersals as on the northwest coast with snappers and groupers following. The highest rates were from the post-monsoon season.

Table 4.9 Sri Lanka, northwest coast: Catch rates with the bottom trawl (kg/h)

	Survey I		**Survey II**	
No. of hauls	14		14	
Species groups	**Mean**	**Max**	**Mean**	Max
Demersal & semi-demersal	280	1460	11	240
Other commercial	110	550	70	380
Non-commercial	30		2	
Total	**420**		**83**	

Table 4.10 Sri Lanka, southwest coast: Catch rates with the bottom trawl (kg/h)

	Survey I		**Survey II**		**Survey III**	
No. of hauls	7		11		16	
Species groups	**Mean**	**Max**	**Mean**	**Max**	**Mean**	**Max**
Demersal & semi-demersal	270	1,700	110	500	100	470
Other commercial	230	1,400	150	720	80	500
Non-commercial	50		20		10	
Total	**550**		**280**		**190**	

Unsuitable bottom was a severe limitation for trawl fishing on the Hambantota Bank (Table 4.11). Tests with bottom longlines gave catch rates up to 200 kg/200 hooks. Snappers, emperors and groupers represented more than 80% of the catch.

The catch rates were lower on the east coast (Table 4.12), where sweetlips and surgeonfish were added to the fauna of demersal fish.

On the Pedro Bank catch rates were highest in Survey II (Table 4.13).

Table 4.11 Sri Lanka, Hambantota Banks: Catch rates with the bottom trawl (kg/h)

	Survey I		**Survey II**		**Survey III**	
No. of hauls	3		6		12	
Species groups	**Mean**	**Max**	**Mean**	**Max**	**Mean**	**Max**
Demersal & semi-demersal	40	110	100	260	100	570
Other commercial	30	40	40	110	20	90
Non-commercial	10				10	
Total	**80**		**140**		**130**	

Table 4.12 Sri Lanka, Batticaloa Banks: Catch rates with the bottom trawl (kg/h)

	Survey I		**Survey II**		**Survey III**	
No. of hauls	7		14		14	
Species groups	**Mean**	**Max**	**Mean**	**Max**	**Mean**	**Max**

Demersal & semi-demersal	80	150	80	570	40	270
Other commercial	80	340	130	460	60	370
Non-commercial			10			
Total	**160**		**220**		**100**	

The trawl coverage of the Pedro Bank in Surveys II and III allowed estimates of the demersal fish biomass by the swept-area method. Table 4.14 shows the summary data and biomass estimates based on a catchability coefficient of 1. The acoustic estimates of the semi-demersal fish on the Pedro Bank were about 10,000 t in each of the two surveys. These may have included fish out occurring at depths above the headrope of the bottom trawl.

Table 4.13 Sri Lanka, Pedro Bank: Catch rates with the bottom trawl (kg/h)

	Survey I		**Survey II**		**Survey III**	
No. of hauls	5		36		20	
Species groups	**Mean**	**Max**	**Mean**	**Max**	**Mean**	**Max**
Demersal & semi-dem.	5	15	140	1220	50	270
Other commercial	20	110	140	610	110	340
No-commercial			10			
Total	**25**		**290**		**160**	

Table 4.14 Sri Lanka, Pedro Bank: Summary of data on swept-area trawl survey inside 100 m of depth

	No. of stations	**Mean density (t/nmi²)**	**Area (nmi²)**	**Biomass (t)**
Survey II	32	10.8	575	6,200
Survey III	22	5.8	585	3,400

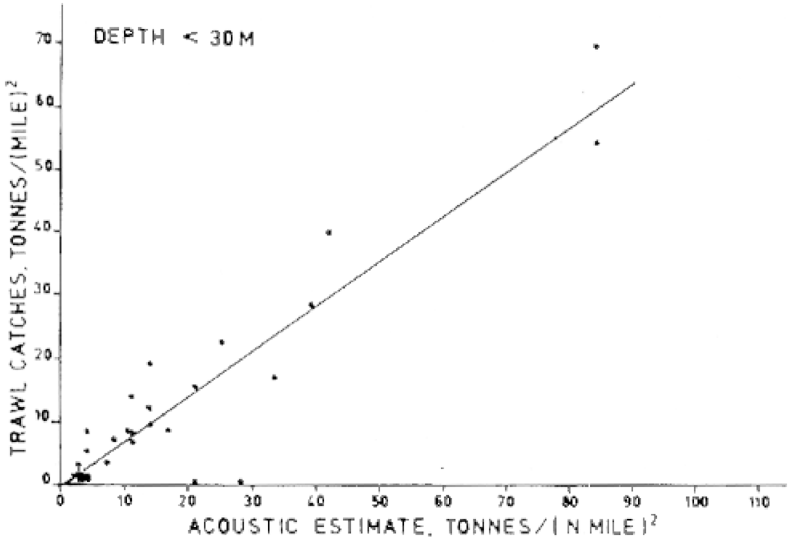

Figure 4.7 Relationship between estimates of densities of semi-demersal fish from catch rates in bottom trawl and acoustic integration of bottom channel. +: pelagic fish; o: demersal fish. Source: Blindheim *et al.*, 1979

A further comparison of trawl data and acoustic data was made in Survey II based on estimates of “acoustic density” from logging of integrator deflection in a 5 m bottom channel during towing and estimates of “trawl density” from catch rates and swept-areas. Figure 4.7 shows the plots from shallow hauls with a regression line estimated for the hauls in which recordings were identified as demersal fish, giving a correlation coefficient of 0.92. This relationship represents a strong confirmation of a correct identification of this type of recording.

Review of findings and later development in fisheries

The main results of the surveys as presented in the three summary reports and at a follow-up seminar in Colombo in August 1980 can be summarized as follows: the total biomass on the west, south and east shelf was 400,000–500,000 t with seasonal variation. The most important component of this was demersal and semi-demersal fish assessed at 250,000–350,000 t and consisting of emperors, snappers, groupers, sweetlips, Carangidae etc. The potential total yield from this group would be 50,000–70,000 t. Some three-quarters of these resources were located on the west and south coasts and it was recommended that they be exploited with gears other than trawls. These stocks seemed to be lightly exploited offering potential for expansion of the fisheries. The potential yield from a possible trawl fishery on the Pedro Bank was estimated at 2,000 t. The biomass of the small and large pelagics in the surveyed area was indicated at 100,000 t.

The shelf in the north - the very shallow Palk Bay and Palk Strait of about 2,800 nmi^2 could not be covered by the survey, but was reported to be productive with important shrimp resources and fish stocks dominated by ponyfish (Leiognatidae).

Sri Lanka's fisheries developed in the small scale sector in the years following the surveys with reported total marine landings increasing from about 150,000 t in 1979 to about 180,000 t in 1983 (FAO Yearb.Fish.Stat. Vol 50 and Vol 60). Demersal percomorphs formed part of this increase with reported landings growing from about 18,000 t to about 24,000 t. Available statistics from 1984 onwards show declining landings and changes in reporting by groups, trends which most likely must be related to political events in the country since 1983. The survey data may serve as references in future assessments of the state of the resources.

4.2 MYANMAR (BURMA), 1979–80

Survey objectives and effort

The plan of the UNDP/FAO Project BUR/77/003 “Marine Fisheries Resources Survey and Exploratory Fishing” submitted in March 1979 included approximately six months of surveys with the DR. FRIDTJOF NANSEN. The work programme for these surveys was developed jointly by representatives of The People's Pearl and Fisheries Corporation of Rangoon, FAO and IMR. The objective of the project, to which these surveys were expected to contribute, was to make an estimate of the marine fish biomass within the EEZ of Myanmar, and in particular, over its continental shelf. The estimate should serve as a basis for preliminary and tentative assessments of sustainable yields and, consequently, rational planning of further investment in the fishery industry (UNDP, 1979). The work programme as agreed in August 1979 specified the principal method as acoustic estimation of the biomass of demersal and pelagic fish, with fishing for identification and sampling purposes and for assessment of catch rates. Environmental work was to include recording of type of bottom, and hydrographical profiles from the coast to 500 m depth for temperature, salinity and oxygen.

The surveys were timed to cover two seasons, the post-southwest monsoon season in September-November 1979 and the pre-southwest monsoon season in March-April 1980. During each of these main surveys, the waters between the border with Bangladesh in the north and with Thailand in the south were covered twice. Figure 4.8 shows as an example the course tracks of the first coverage. The first and third cruises represented fixed-grid overviews, while the research efforts of the second and fourth cruises were concentrated in areas which in the preceding fixed grid survey were found to be of particular interest regarding fish abundance and distribution. The main fixed grid transects were spaced approximately 30 nmi apart and ran from a bottom depth of about 15 m seawards. During the third survey, the Coco Island region was also covered. The results were grouped by season and presented by three main areas: the Arakan coast

(I), the Delta (II), and the Tenasserim coast (III). The deep-sea grounds, at 200–400 m depth off the southern coast, are also presented separately.

Table 4.15 shows the extent of the shelf by sub-areas. Relatively wide shallow inshore parts could not be covered, especially in the Delta, because of the approximately 15 m depth limit needed for the safe operation of the vessel. More than 90% of the surveys were conducted inside the shelf with the rest on the southern deep-sea grounds, but hydrographic profiles were extended off the shelf. The mean survey intensity by coverage (measured as sailed distance over the square root of the area) was high for both surveys.

The main part of the shelf is shallow, less than 100 m, and this allowed use of the 120 kHz echosounder for acoustic integration which has limited depth range. The advantage of this choice was that this higher frequency permits (as explained in Section 2) an easier distinction between recordings from fish and recordings from spurious sources, plankton, etc. The results of the surveys in Myanmar were presented in preliminary cruise reports for each survey and in two summary reports, Nakken and Sann Aung (1980) and Strø;mme *et al.* (1981).

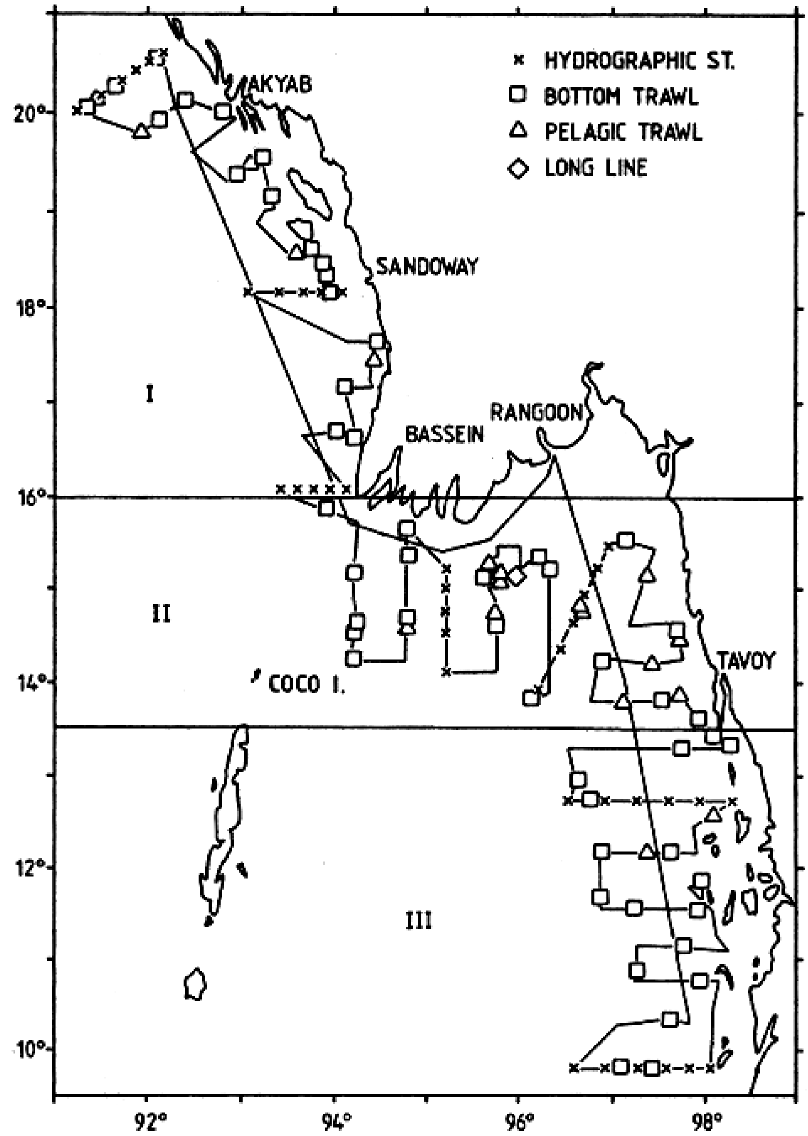

Figure 4.8 Survey tracks from the first coverage. Area I: Arakan coast; Area II: the Delta; Area III: the Tenasserim coast

Table 4.15 Myanmar: Shelf areas and parts covered; survey distances and acoustic degree of coverage

Sub-area	Shelf area nmi²	Areas of shelf covered	
		Sep-Nov 79	Mar-Apr 80
Arakan coast	11,400	9,400	9,400
Delta area	34,300	23,800	29,500
Tenasserim coast	21,000	15,300	17,800
Total	66,700	48,500	56,700
Survey distance, total		7,500 nmi	8,300 nmi
Survey distance, on shelf		6,900 nmi	7,900 nmi
Acoustic degree of coverage		16	17

The sea bottom

Based on the interpretation of echosounder recordings, a description of the bottom with special reference to its suitability for trawling was made and presented on charts which included data from all coverages (Figure 4.9).

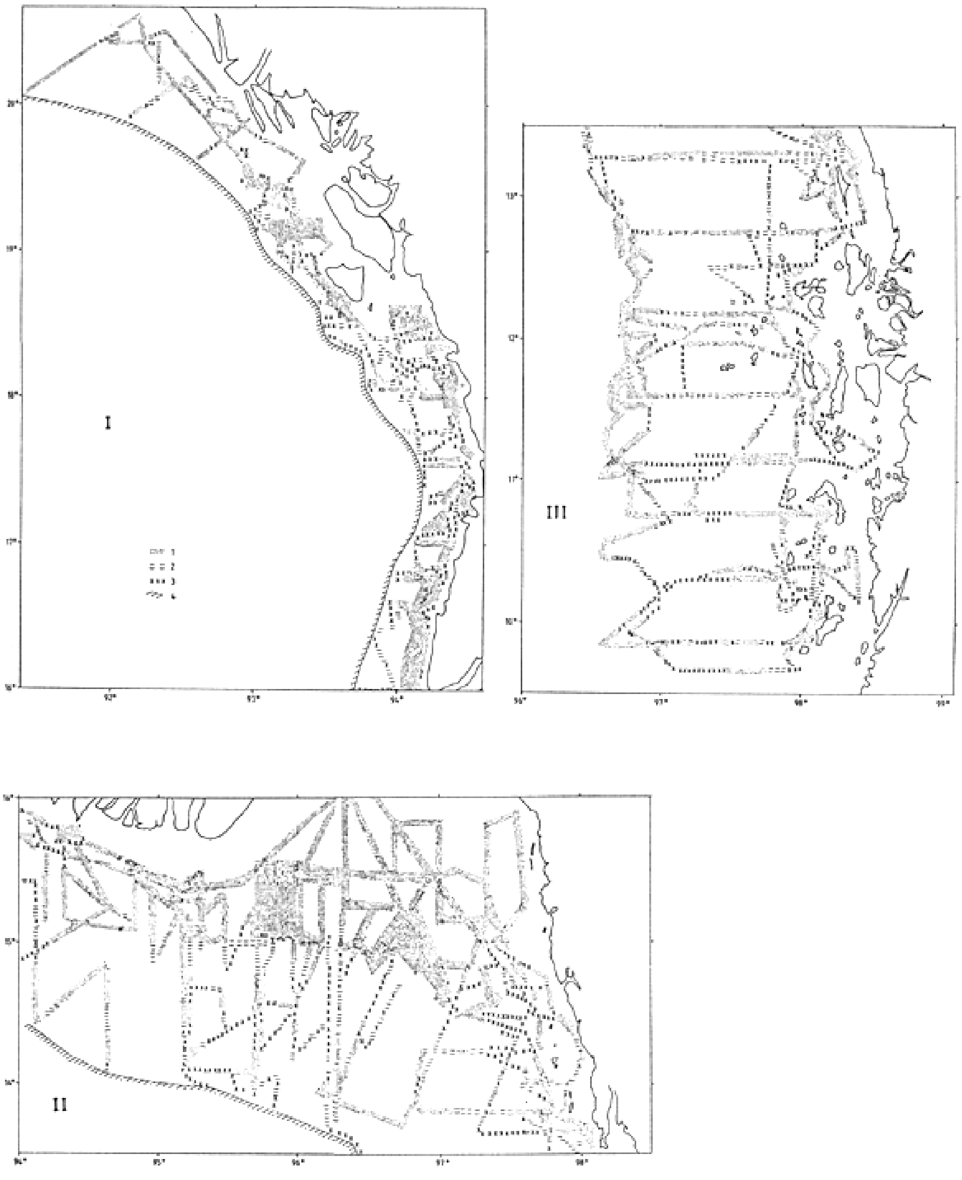

Figure 4.9 Bottom conditions by main areas.
Legend: 1 smooth even; 2 smooth uneven; 3 rough; 4 steep

The shelf off the Arakan coast has wide areas of smooth ground in the shallower parts, but these are in places interrupted by rocks, corals and sometimes mud volcanoes. The slope is steep, rough and generally unsuitable for trawling.

The Delta area is characterized by a wide band of shallow, smooth and gently sloping bottom created by silting from the Irriwaddy and Salween rivers. At about 15° N the bottom deepens more markedly from 20–30 m to about 100 m and in this region, which extends 40–60 nmi southwards, the bottom is variable with good trawling grounds interrupted by more uneven or even rough areas.

The wide shelf off the Tenasserim coast is more varied. Beyond the 200 m depth line which lies 60–100 nmi offshore, the slope down to about 400 m is not very steep, and a deep-water ground with generally smooth bottom extends over a wide offshore area from about 13°N southwards to the border with Thailand. There are also extensive areas of trawlable bottom further inshore towards the archipelago. Between the islands and in the inlets, conditions vary greatly between even, smooth bottoms and rocky grounds.

Hydrography

The great seasonal changes in the hydrographical conditions on the shelf caused by the shifts in the monsoons and in river discharges were clearly demonstrated by some of the hydrographical observations during the two surveys. As shown in Figure 4.10, in September-October the surface water off the Delta and Arakan coasts was extensively mixed with freshwater from the river runoffs, resulting in surface salinities of 20–30° over large areas in the Delta region and northwards along the Arakan coast, and indicating a westward and northward transport of the uppermost coastal water masses. In March-April the highest salinities were found inshore, an effect of the northeast monsoon.

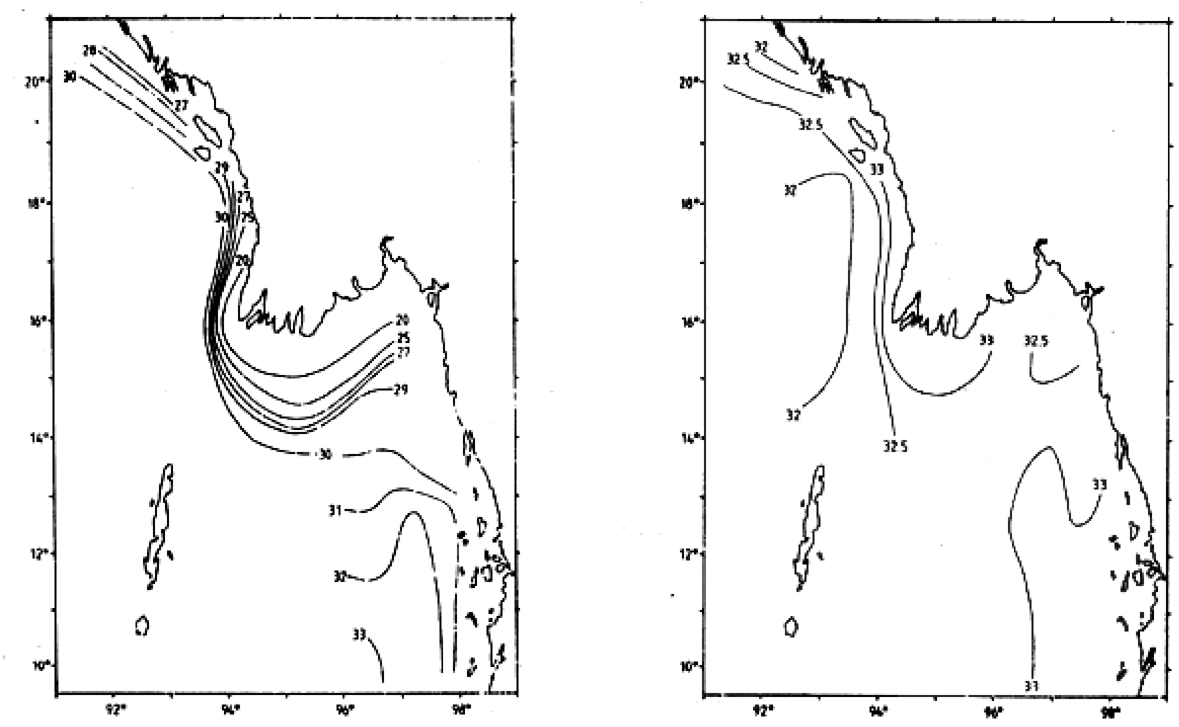

Figure 4.10 Salinity at 5 m depth 25 Sept-18 Oct 1979 (left) 5 March-1 April 1980 (right)

In the intermediate and deeper water masses distinct seasonal changes were evident from the distribution of temperature, salinity and oxygen in selected transects in September-October and March-April from the three parts of the coast (Figure 4.11). The main features were similar all along the coast: in September-November the transition layer between the upper homogeneous water masses and the deep water was found at depths between 70 and 150 m, while in March-April it was much shallower at 20 to 100 m depths. This lifting of the transition layer also brought poorly oxygenated water (between 1 and 2 ml/l) over large parts of the shelf. These observations confirmed previous evidence of upwelling during the northeast monsoon (Cushing, 1971b) with resulting enhanced primary production. In deeper waters, below 150–200 m, conditions were more stable. However, the difference in oxygen content between the deep water in the Bay of Bengal (Arakan) of: less than 0.2 ml/l, and that in the Andaman Sea (Delta and Tenasserim): not less than 0.8 ml/l should be noted.

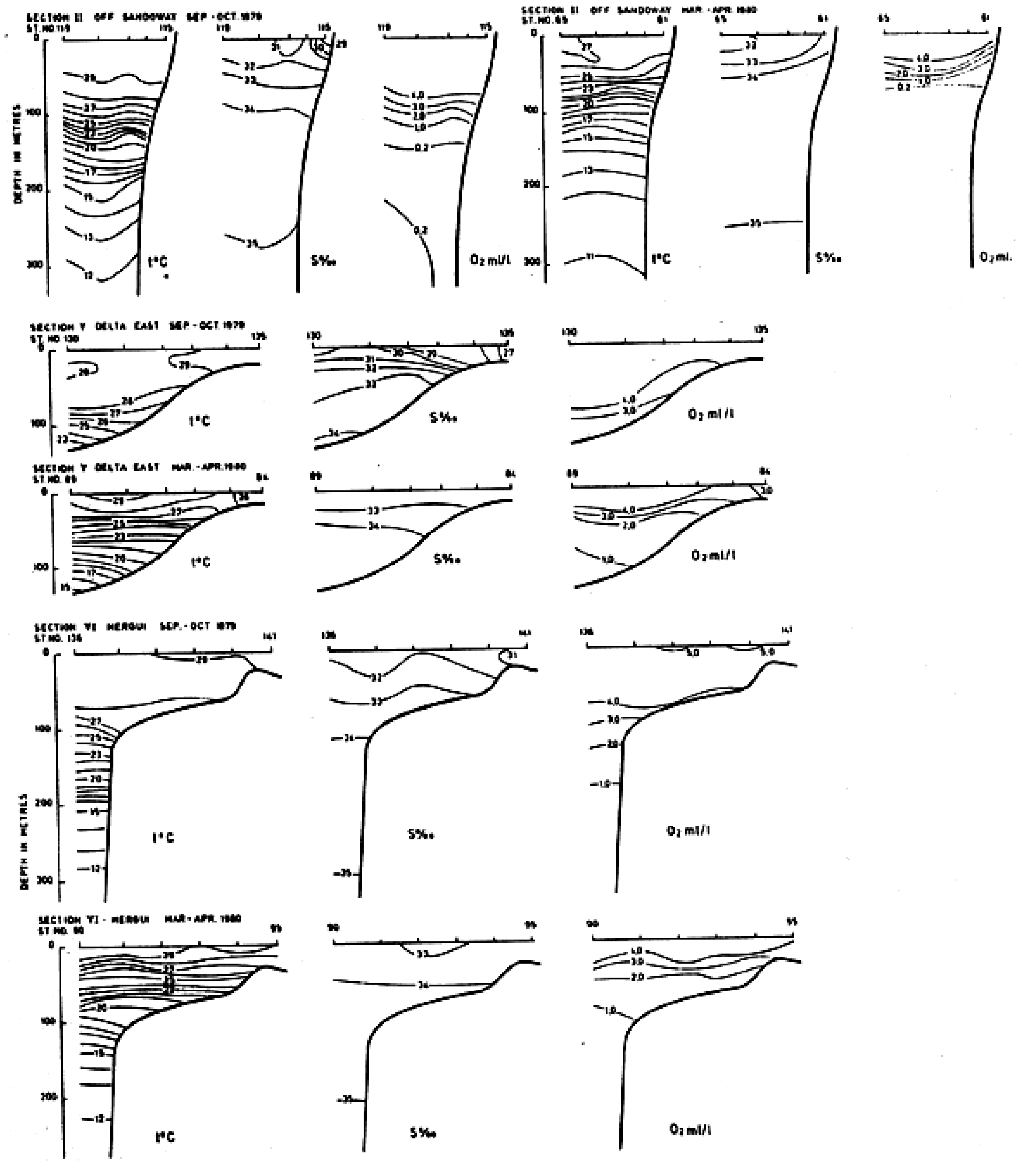

Figure 4.11 Distribution of temperature, salinity and oxygen in the hydrographical sections

In addition to the effect of seasonal upwelling on enhancing productivity it is also argued that the sea off Myanmar may receive additional contributions of nutrients from river discharges.

The acoustic surveys

The recordings of fish by the acoustic systems were classified into two types based on experience in identifying echograms and on identification from sample fishing during the surveys: Type A: recordings of true larger schools or dense layers mostly in the upper water, were identified as deriving from pelagic schooling fish usually of smaller size (e.g., Clupeidae, Engraulidae, Carangidae, but also including Trichiuridae). Type B recordings showed looser aggregations or smaller schools near or at least closer to the bottom. While type A was often found at high densities this was seldom the case for type B, which was ascribed to demersal or semi-demersal fish. The identification of species in this demersal group was indicated by the relative abundance of the various types of fish occurring in bottom trawl catches (Strø;mme *et al.*, 1981). This identification must be assumed to have been biased towards more strictly demersal fish, but indications of the more likely mid-water targets of this group are given below, in part based on a general knowledge of the behaviour of semi-demersal fish.

The historical review of the state of the acoustic instruments presented in Section 2 shows that the conversion factors used to estimate biomass from echo integrator deflection corresponded to a target strength level of -36 dB/kg (for 17 cm fish). Even if this early generation of echo integrators must be expected to have produced underestimates because of saturation phenomena in both the receiver and the integrator, a target strength of -36 dB/kg seems low and therefore an approximately 2 dB higher TS-level has been used in the present review, thus reducing the biomass estimates presented in Strø;mme *et al.* (1981) by about one third.

4.2.1 The Arakan coast

Pelagic fish

The distribution of the small pelagic fish differed little between the two surveys and the main part of the biomass was found on the southern inshore shelf (Figure 4.12). The biomass corrected estimates were also similar:

September-November 1979	125,000 t
March-April 1980	120,000 t

Appearance in the catches was the only source of information on the composition of this group although the varying catchability by size and species must be expected to have distorted these data. In these shallow waters small pelagic fish were caught both in pelagic and demersal trawls. Table 4.16 shows the occurrence of the pelagic fish by family in all trawl catches on this coast. Clupeidae and Engraulidae dominated especially by weight, followed by Trichiuridae and Carangidae.

Information on the species composition within each group was derived from their relative proportion in the weight of the catches of the three respective families in the pelagic trawl hauls (Table 4.17).

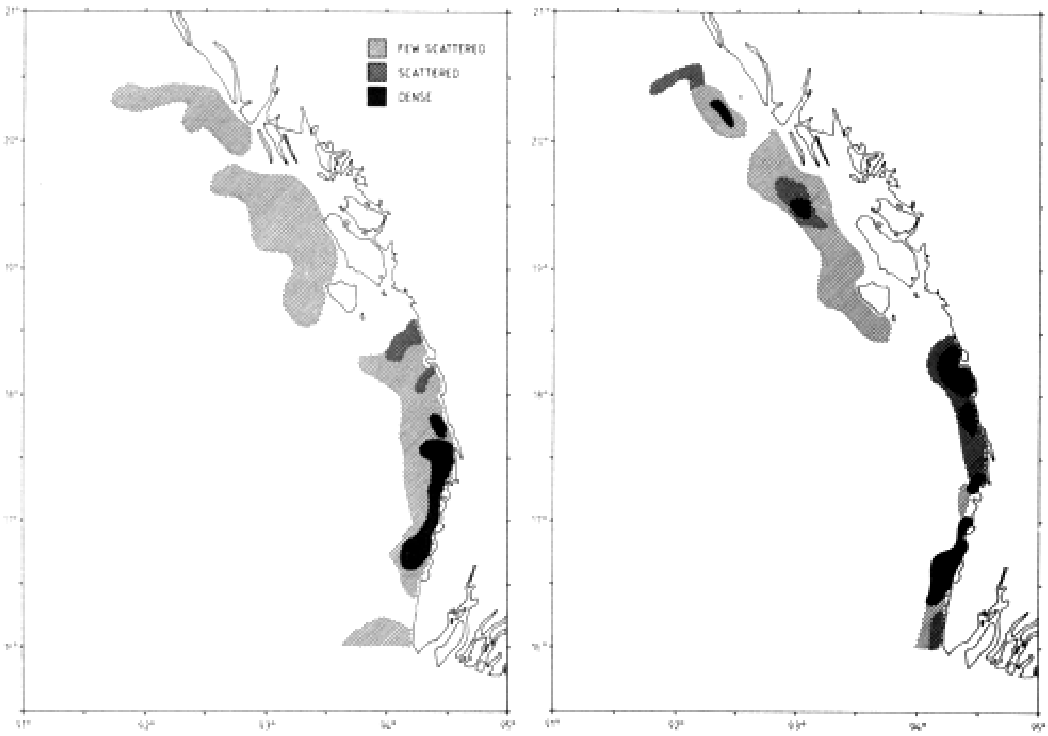

Figure 4.12 Distribution of small pelagic fish on the Arakan coast, September-November 1979 (left) and March-April 1980 (right)

Table 4.16 Arakan coast: Occurrence % in all pelagic and bottom trawl hauls of families of pelagic fish and their proportion by weight of total catch of pelagic fish (%)

	Sep-Nov 1979		**Mar-Apr 1980**	
No. of hauls	56		49	
	Incidence %	**% of total catch**	**Incidence %**	**% of total catch**
Clupeidae	54	38	43	52
Engraulidae	39	28	24	25
Trichiuridae	36	21	29	4
Carangidae	34	3	39	16
Sphyraenidae	38	9	22	2
Scombridae	27	1	18	1

Among the hairtails, *Lepturacanthus savala* was more common than *Trichiurus lepturus*. The Scombridae included *Rastrelliger kanagurta* as well as both *Scomberomorus guttatus* and *S. commerson* and two species of barracudas, *Sphyraena barracuda* and *S. obtusata* were caught.

Table 4.17 Arakan coast: Species composition of catches by pelagic trawl shown by proportion of total weight within families (%)

	Sep-Nov 1979	**Mar-Apr 1980**
Clupeidae		
Sardinella gibbosa	59	25
Dussumieria acuta	16	73
Sardinella melanura		2
Ilisha elongata	25	
Engraulidae		
Stolephorus indicus	59	100
Stolephorus bataviensis	41	
Carangidae		
Decapterus russelli	+	99
Megalaspis cordyla		2
+ = small numbers		

Table 4.18 Arakan coast: Occurrence (%) in all pelagic and bottom trawl hauls of families of demersal and semi-demersal fish and other groups and their proportion by weight of the total catch (%)

	Sep-Nov 1979		**Mar-Apr 1980**	
No. of hauls	56		49	
	Incidence %	**% of Total catch**	**Incidence %**	**% of Total catch**
Ariidae	32	8.4	24	3.0
Carangidae	36	1.4	67	1.4
Gerreidae	30	0.8	20	17.2
Lactariidae	30	5.8	18	2.1
Leiognatidae	70	7.5	39	19.0
Lutjanidae	25	1.9	16	0.6
Mullidae	43	1.1	33	2.8
Muraenesocidae	16	0.9	14	1.2
Nemipteridae	43	0.8	37	4.8
Pomadasyidae	52	21.4	45	10.4
Sciaenidae	38	33.4	35	4.5
Synodontidae	48	1.8	53	6.2
Sharks and rays	29	3.3	16	9.6
Squid	50	0.5	35	0.8
Shrimp	50	1.4	37	2.6
Miscellaneous		6.5		12.7

Semi-demersal fish

The corrected biomass estimates for this group on the Arakan coast were:

September-November 1979	90,000 t
March-April 1980	80,000 t

The information pertaining to the identification of this group was limited to the catch composition shown by family in all hauls in the area shown in Table 4.18, and to general information on the behaviour of species which tend to lift off the bottom.

From this it appears that the main contributors to the biomass identified as semi-demersal fish were species of the families Leiognatidae, Gerreidae, Synodontidae, Pomadasyidae, Nemipteridae and Lactariidae.

Fishing operations

An overview of catch rates recorded is presented in Table 4.19.

Table 4.19 Arakan coast: Summary of fishing operations

	Bottom trawl		**Pelagic trawl**	
	Sep-Nov 1979	Mar-Apr 1980	Sep-Nov 1979	Mar-Apr 1980
No. of stations	45	28	11	22
Mean catch (kg/h)	610	1,290	130	240
Max. catch rates (kg/h)	6,390	5,250	380	680

Part of the September-November operations related to a special shrimp survey near Sandoway; otherwise most of the fishing in this area was conducted for the purpose of identification and sampling and was of limited use for stock estimates.

A classification of the various species of fish into four economic categories was made by Strø;mme *et al.* (1981) based on local prices. About 80% of the catch was found to be of intermediate value, classes 2 and 3. Mean catch rates of these were fairly high, often exceeding 200 kg/h.

4.2.2 The Delta

Pelagic fish

Figure 4.13 shows the distribution of the pelagic fish recorded in the two surveys, with the main part of the biomass in a 40 nmi wide belt covering the bottom depth contours from about 15 to about 60 m. The estimates of biomass (almost doubling between the two surveys) were:

September-November 1979	260,000 t
March-April 1980	450,000 t

Table 4.20 shows the occurrence of the pelagic fish by family in all trawl catches in the Delta area. Trichiurids, Engraulidae and Clupeidae dominated, with Carangidae following. There is an increased proportion of Clupeidae in the second survey.

Table 4.21 shows the species composition as a percentage of total catch within each family. The effect of the shallow-water muddy delta was demonstrated by the higher number of both Clupeidae and Engraulidae, including the shallow water genera *Ilisha* and *Thryssa*. *Lepturacanthus savala* dominated the abundant Trichiuridae and *Decapterus russelli* the Carangidae. *Rastrelliger kanagurta* appeared in low quantities in both surveys. *Scomberomorus commerson* was more common than *S. guttatus* and *Sphyraena obtusa* more common than *S. barracuda.*

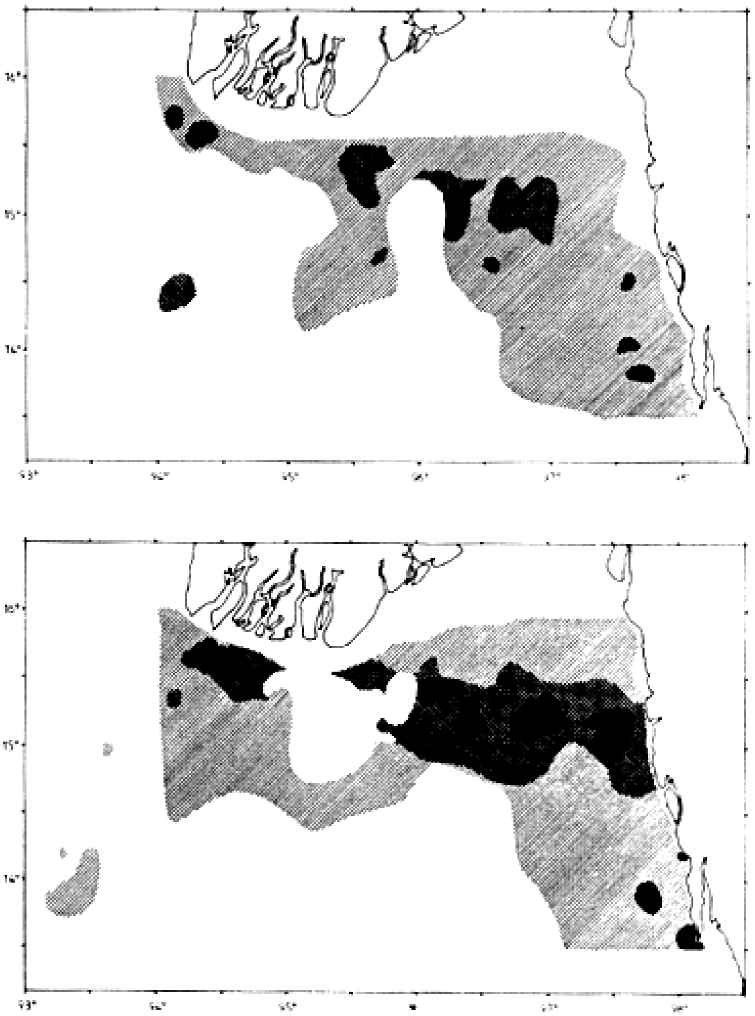

Figure 4.13 Distribution of small pelagic fish in the Delta area, September-November 1979 (upper) and March-April 1980 (lower).

Table 4.20 Delta area: Occurrence (%) in all pelagic and bottom trawl hauls of families of pelagic fish and their proportion by weight of total catch of pelagic fish (%)

	Sep-Nov 1979		Mar-Apr 1980	
No. of hauls	70		95	
	Incidence %	% of Total catch	Incidence %	% of Total catch
Clupeidae	44	11	35	24
Engraulidae	49	35	46	33
Trichiuridae	63	40	58	35
Carangidae	33	6	31	7
Sphyraenidae	17	7	11	1
Scombridae	17	2	5	1

Table 4.21 Delta area: Species composition of catches by pelagic trawl shown by proportion of total weight within families, (%)

	Sep-Nov 1979	Mar-Apr 1980
Clupeidae		
Sardinella gibbosa	18	26
Dussumieria acuta	13	36
Ilisha melastoma	22	35
Ilisha elongata	15	3
Ilisha megaloptera	32	
Engraulidae		
Stolephorus indicus	25	66
Stolephorus bataviensis	11	-
Stolephorus sp.	-	10
Thryssa dussumieria	13	22
Thryssa mystax	16	2
Thryssa sp.	35	
Carangidae		
Decapterus russelli		
Decapterus macrosoma	98	98
Megalaspis cordyla	2	2
Trichiuridae		
Lepturacanthus savala	69	100
Trichiurus sp.	31	

Semi-demersal fish

The adjusted biomass estimates of this group in the Delta area were:

September-November 1979	200,000 t
March-April 1980	500,000 t

The higher biomass in the second survey could be related to the seasonal lifting of the transitional layer which brought bottom-water of less than 2 ml/l of oxygen up to a depth of less than 50 m. The main part of the semi-demersal biomass was found at shallow depths in March-April. In part of the Delta area difficulties in interpreting echo recordings were experienced because of occurrence both in mid-water and near the bottom of small shrimp of the genus *Acetes*.

The composition of the demersal and semi-demersal fish in this area is given in Table 4.22. The Delta fauna differed in several respects from that of the coastal regions to the north and south. Noteworthy was the presence of threadfins (Polynemidae), pike congers (Muraenesocidae) and Bombay duck (*Harpadon nehereus*). Sciaenidae were more common, but ponyfish less frequent than in the other areas.

Table 4.22 Delta area: Occurrence (%) in all pelagic and bottom trawl hauls of families of demersal and semi-demersal fish and other groups and their proportion by weight of the total catch (%)

	Sep-Nov 1979		Mar-Apr 1980	
No. of stations	70		95	
	Incidence %	% of Total catch	Incidence %	% of Total catch
Ariidae	41	4.4	38	8.1
Carangidae	11	0.2	28	6.1
Gerreidae	26	1.3	11	1.0
Harpadontidae	11	2.2	19	20.5
Lactariidae	16	2.1	22	1.6
Leiognatidae	36	2.6	27	1.3
Lutjanidae	31	4.2	21	2.6
Mullidae	34	1.9	24	3.3
Muraenesocidae	29	5.6	22	1.4
Nemipteridae	37	2.6	26	2.9
Polynemidae	27	6.2	27	3.0
Pomadasyidae	26	0.9	40	2.7
Sciaenidae	47	18.5	25	9.7
Synodontidae	29	2.8	55	2.4
Sharks and rays	76	18.3	28	13.9
Squid	33	0.8	42	0.6
Shrimp	57	11.6		6.9
Miscellaneous		11.2		12.0

Fishing operations

An overview of catch rates recorded is presented in Table 4.23.

Table 4.23 Summary of fishing operations in the Delta area

	Bottom trawl		Pelagic trawl	
	Sep-Nov 79	Mar-Apr 80	Sep-Nov 79	Mar-Apr 80
No. of stations	44	57	26	39
Mean catch (kg/h)	415	513	232	559
Max. catch rates (kg/h)	2,260	1,380	1,140	5,340

Bottom trawling during the second survey formed part of a special survey of the eastern Delta to obtain bottom trawl estimates of demersal fish, especially the Bombay duck. The maximum catch rates quoted represent the mean of the three highest catches.

An economic analysis showed that the fish of the Delta area tended to be of higher value than off the Arakan coast, with nearly half the catch in the higher price categories classes 1 and 2, and yielding catch rates of about 200 kg/h.

4.2.3 The Tenasserim coast

Pelagic fish

Figure 4.14 shows the distribution of pelagic fish on this coast. During the second survey areas of high abundance formed a belt some 20 nmi wide in the waters of the archipelago. The adjusted estimates of biomass were:

September-November 1979	50,000 t
March-April 1980	360,000 t

Table 4.24 shows that Engraulidae formed the main part of the biomass, with some contribution from Clupeidae in the second survey. That the Engraulidae were by far the most abundant pelagic group was further demonstrated by the proportions in the pelagic hauls only. Of an overall total catch of Clupeidae, Engraulidae and Carangidae from this gear of about 9 t in March-April, Engraulidae (anchovies) represented more than 8 t.

Table 4.25 shows the species composition of the main families. The rainbow sardine (*Dussumieria acuta*) was the most common clupeid, and the Indian anchovy (*Stolephorus indicus*) by far the most common engraulid. *Rastrelliger kanagurta* was caught in small quantities in nearly all hauls. *Scomberomorus guttatus* was more common than *S. commerson* and *Sphyraena obtusata* more common than *S. forsteri* and *S. barracuda*.

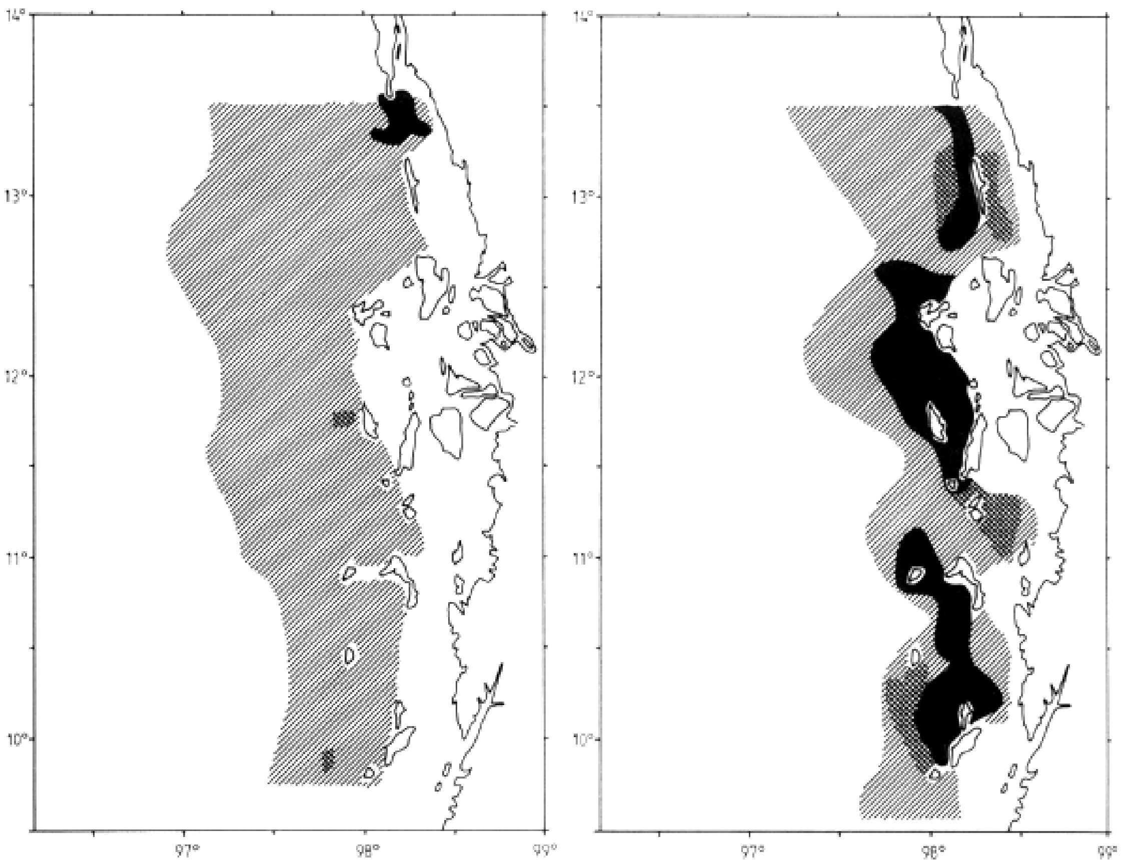

Figure 4.14 Distribution of small pelagic fish on the Tenasserim coast, September-November 1979 (left) and March-April 1980 (right)

Table 4.24 Tenasserim coast: Occurrence (%) in all pelagic and bottom trawl hauls of families of pelagic fish and their proportion by weight of total catch of pelagic fish (%)

	Sep-Nov 1979		**Mar-Apr 1980**	
No. of hauls	23		57	
	Incidence %	**% of Total catch**	**Incidence %**	**% of Total catch**
Clupeidae	35	1	46	14
Engraulidae	39	92	39	74
Trichiuridae	48	1	25	4
Carangidae	57	1	43	5
Sphyraenidae	36	3	27	1
Scombridae	17	1	27	1

Table 4.25 Tenasserim coast: Species composition of catches by pelagic trawl shown by proportion of total weight within families (%)

	Sep-Nov 1979	Mar-Apr 1980
Clupeidae		
Dussumieria acuta	48	80
Sardinella gibbosa	4	1
Ilisha melastoma	13	16
Ilisha elongata	35	3
Engraulidae		
Stolephorus indicus	99	92
Stolephorus commersoni		8
Thryssa spp	1	
Carangidae		
Decapterus russelli	82	95
Decapterus macrosoma	18	3
Megalaspis cordyla		2

The great increase in biomass from September-November to March-April was most probably brought about by a seasonal production of small pelagic fish, mainly the short-lived Indian anchovy, a production which seems likely to relate to the upwelling during the northeast monsoon.

Semi-demersal fish

The adjusted biomass estimates of this group off the Tenasserim coast were:

September-November 1979	80,000 t
March-April 1980	90,000 t

The densities of this group were considerably lower than in the northern regions. As shown in Table 4.26 the most common forms in the catches were ponyfishes (Leiognathidae), grunts (Pomadasyidae), lizardfishes (Synodontidae) and false trevallies (Lactariidae). The very high proportion of ponyfish in the last survey was caused by exceptionally high catches in shallow waters. More characteristic for the area was perhaps the relatively frequent occurrence of threadfin breams (Nemipteridae) and goatfishes (Mullidae).

Table 4.26 Tenasserim coast: Occurrence (%) in all pelagic and bottom trawl hauls of families of demersal and semi-demersal fish and their proportion by weight of the total catch (%)

	Sep-Nov 1979		Mar-Apr 1980	
No. of stations	23		57	
	Incidence %	% of Total catch	Incidence %	% of Total catch
Ariidae	35	2.7	21	5.4
Carangidae	26	2.1	26	2.3
Gerreidae	43	2.1	19	1.3
Lactariidae	26	12.0	19	4.0
Leiognatidae	61	15.5	25	56.9
Lutjanidae	35	1.7	18	2.9
Mullidae	43	4.8	39	2.7
Muraenesocidae	13	3.5	9	0.5
Nemipteridae	48	4.7	39	2.0
Pomadasyidae	39	6.4	32	6.5
Sciaenidae	35	12.7	16	0.9
Synodontidae	43	2.6	33	3.6
Sharks and rays	43	3.1	14	0.8
Squid	43	1.9	40	0.6
Shrimp	26	2.5	14	0.3
Miscellaneous		21.7		9.3

Fishing operations

An overview of catch rates is presented in Table 4.27.

Table 4.27 Tenasserim coast: Summary of fishing operations

	Bottom trawl		**Pelagic trawl**	
	Sep-Nov 79	**Mar-Apr 80**	**Sep-Nov 79**	**Mar-Apr 80**
No. of stations	16	26	7	30
Mean catch (kg/h)	890	1,040	80	300
Max. catch rates (kg/h)	4,000	5,100	500	1,100

The catch rates were relatively high, but since 60–80% of the catch was found to consist of species in economic class 3 the value of the bottom fish on the Tenasserim coast appears to be lower than in the northern parts.

Special trawl surveys of the deep-sea grounds

The gently falling slope in the Andaman Sea southwards from 13°N forms extensive grounds some 200 nmi long and 10–40 nmi wide within the depth range 200–500 m characterized by a predominantly even bottom suitable for trawling. Figure 4.15 shows the grounds and the distribution of fishing stations during the two surveys. Here the ambient conditions near the bottom with temperatures of 11–12° C and an oxygen content of about 0.8 ml/l were like those found on similar grounds off the southwest Coast of India and off Sri Lanka in the Gulf of Mannar, deep-sea shrimp and lobster have been found in quantities of commercial interest.

The gear used by the DR. FRIDTJOF NANSEN, an ordinary shrimp-cum-fish trawl equipped with bobbins, was likely to have had a relatively low efficiency for deep-sea shrimp and lobster. Table 4.28 shows the catch rates recorded for the 38 deep-water hauls.

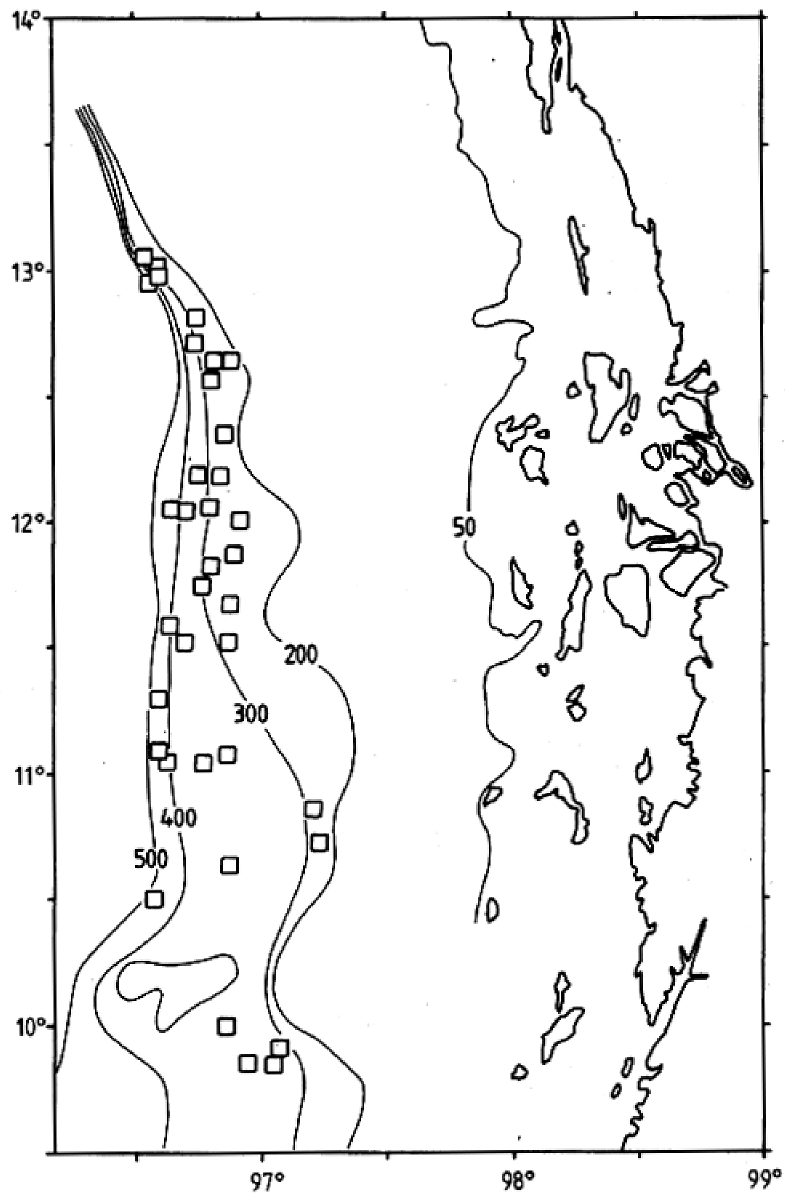

Figure 4.15 The coverage of the deep-sea grounds on the slope off the Tenasserim coast

Table 4.28 Catch rates on the deep-sea ground on the Andaman Sea (kg/h)

		Shrimp		Lobster		Fish	
	No. of hauls	**Range**	**Mean**	**Range**	**Mean**	**Range**	**Mean**
Oct-Nov 79	20	0–155	34	0–28	4	40–450	140
Mar-Apr 80	18	0–65	18	0–36	7	46–300	108

The shrimps were *Heterocarpus* sp., *Aristaeus semidentatus* and others. The lobsters were identified as *Puerulus sewelli*. Commercially these catch rates were not very promising and they were considerably lower than those obtained in the Gulf of Mannar, but the total area of distribution of lobster was very extensive and further fishing trials were recommended to see whether areas or seasons of higher concentrations might be found (Strø;mme *et al.*, 1981). Rawcliffe (1983) reported promising catches of deep-water lobster from further trials in this area.

4.2.4 Review of findings and of later research and development of fisheries

Biomass estimates by acoustic methods

The main findings were the biomass estimates summarized in Table 4.29. With totals of small pelagic and semi-demersal fish of 805,000 t in September-November 1979 and 1,600,000 t in March-April 1980. The doubling of the biomass between the two surveys, was probably related to the observed changes in the environment: enhanced production through upwelling during the northeast monsoon and the physical concentration of bottom and semi-demersal fish due to uplifting of oxygen-deficient bottom water. Obvious limitations of the surveys included incomplete coverage of extensive inshore shallow waters, and the deficiencies of the first generation echo integration system, both of which were likely to have caused underestimates.

Table 4.29 Myanmar: Estimated biomass for the shelf areas based on acoustic methods (1,000 t)

	Sep-Nov 1979	**Mar-Apr 1980**
Small pelagic fish		
Arakan coast	125	120
Delta	260	450
Tenasserim coast	50	360
Total	**435**	**930**
Semi-demersal fish		
Arakan coast	90	80
Delta	200	500
Tenasserim coast	80	90
Total	**370**	**670**

It should also be noted that the main objective of the survey was the investigation of fish with the echo integration method. The demersal fish on the shelf were thus incompletely covered since the programme did not include a general swept-area trawl survey. (A series of such surveys were carried out from November-December 1981 to March-April 1983, see below.)

Densities of fish measured as biomass per unit shelf area showed average values of 12 t/nmi^2 in September-November and 24 t/nmi^2 in March-April. These represented low to moderate levels, indicating only a moderate effect on the total production from the upwelling caused by the northeast monsoon and from the considerable river discharges. For comparison, a similar estimate of mean density of biomass measured by acoustics on the Malabar shelf (see Section 3.2.1) with its May-September upwelling during the southwest monsoon, was 67 t/nmi^2.

Taking the simple mean of the two biomass estimates as mean standing stock and yield fractions of 0.5 and 0.25 for small pelagic and semi-demersal fish respectively, theoretical potential annual yields of about 340,000 t and 130,000 t were obtained for the two groups respectively, a total of 470,000 t. Since the stocks are already exploited, the 1979 landings were reported to be 400,000 t, the total potential would be higher than the above estimate and can roughly be assessed at 600,000 t. A yield fraction of 0.5 used for the small pelagic fish may, however, not to be achievable for a predominantly small-scale fishery, since the highly seasonal biomass of small pelagics such as the anchovies cannot be expected to be fully utilized.

Biomass estimates from bottom trawl surveys

Table 4.30 shows a summary of the results of the fishing operations with the bottom trawl. It should be noted that these result from aimed fishing for identification and sampling. The rates may perhaps approach those of commercial fishing.

Table 4.30 Myanmar: Summary of fishing operations with the bottom trawl

	Sep-Nov 1979	Mar-Apr 1980
Arakan coast		
No. of stations	45	28
Mean catch (kg/h)	610	1,290
Max. catch rates (kg/h)	6,390	5,250
Delta area		
No. of stations	44	57
Mean catch (kg/h)	415	513
Max. catch rates (kg/h)	2,260	1,380
Tenasserim coast		
No. of stations	16	26
Mean catch (kg/h)	890	1,040
Max. catch rates (kg/h)	4,000	5,100

A special swept-area trawl survey of a section of the eastern part of the Delta in April showed a mean density of 21 t/nmi^2 over approximately 6,000 nmi^2, assuming a catchability coefficient of 1. The total biomass of 126,000 t may be compared with the acoustic estimate of 210,000 t for semi-demersal fish in the same area. In part of this area Bombay duck was important with a density of 15.7 t/nmi^2, corresponding to a biomass of 42,000 t over an area of 2,700 nmi^2.

Shallow-water shrimp

A proper survey of the shallow water shrimp resources would have required a different type of vessel, gear and survey design. Shrimp formed, however, part of the catch in a number of hauls in shallow waters in the Delta and on the Arakan coast and the catch rate data obtained are summarized in Table 4.31. In order to limit the study to areas where shrimp was reasonably abundant only those hauls with shrimp catches exceeding 10 kg/h were included in the analyses. Nearly all of these hauls were from the 10–24 m depth zone. The small "white" shrimp, mainly *Acetes* spp. were excluded. Apart from giving positive indications, the information was of limited value in view of the assumed low efficiency of the gear for shrimp. *Metapenaeus* spp. dominated the catches with *Penaeus* as the second most important genus.

Table 4.31 Myanmar: Analysis of catch rates of shallow-water shrimp

	Arakan		Delta		Tenasserim	
	Oct-Nov	Mar-Apr	Oct-Nov	Mar-Apr	Oct-Nov	Mar-Apr
No. hauls 10–24 m	8	11	7	35	3	10
No. hauls > 10 kg/h	8	10	10	12	0	1
Mean catch (kg/h)	28	60	73	65	12	0
Fish by-catch %	99	97	87	91	0	97

Surveys with other vessels

Further important information on Myanmar's marine fish resources was obtained during an extensive programme of bottom-trawl surveys during 1981–83 also organized under the FAO/UNDP Project BUR/77/003 "Marine Fisheries Resources Survey and Exploratory Fishing". The main objective of this programme was to supplement the acoustic surveys of pelagic and semi-demersal resources undertaken with the DR. FRIDTJOF NANSEN by determining the qualitative and quantitative distribution of the demersal resources (Rijavec and Htun Htein, 1984). More than 600 trawl hauls were made, distributed over four surveys: two in November-December of 1981 and 1982, two in April-May of 1982 and 1983.

The catch rates obtained from those trawl surveys are presented in Table 4.32 (from Rijavec and Htun Htein, 1984).

These results from the prepositioned semi-random sampling system executed by BUR/77/003 were, as expected, considerably lower than the catch rates from the aimed fishing with the DR. FRIDTJOF NANSEN, even though the fishing gear was roughly of the same size albeit of different design.

Table 4.32 Myanmar: Catch rates (kg/h) obtained in 1981–83 from a bottom trawl survey of project BUR/77/003

		Mean kg/h	Maximum kg/h
Rakhine coast (Arakan)	Nov-Dec 1981	188	1,018
	Apr-May 1982	396	1,704
	Nov-Dec 1982	192	1,171
	May-Jun 1983	497	7,758
Delta area	Nov-Dec 1981	168	1,212
	Apr-May 1982	168	1,308
	Nov-Dec 1982	151	1,673
	May-Jun 1983	147	750
Tenasserim	Nov-Dec 1981	161	925
	Apr-May 1982	174	781
	Nov-Dec 1982	128	1,477
	May-Jun 1983	131	508

Rijavec and Htun Htein (1984) used their data for a swept-area assessment of the demersal fish biomass, where the catchability coefficient q was assumed to have a value of 0.5. This assumption was based on considerations of the design of the gear, cut-out lower wings, rubber bobbins groundrope, and on the results of some comparative fishing trials. The resulting estimate was 750–800,000 t, on the basis of which the authors estimated a potential yield of demersal fish in the range of 300,000–550,000 using a range of M values of 0.4–1.0, and an estimate of existing landings of 300,000 t.

Their estimate was based on catch rates from daylight hauls only, which on average were 65% higher than the night hauls. The estimate of 750–800,000 t can be compared with acoustic estimates ranging from 370,000 to 670,000 t of semi-demersal fish (day and night observations) from the DR. FRIDTJOF NANSEN surveys. The limitation of acoustic observation of fish close to the bottom has been much discussed, but is difficult to quantify. The ratio between the estimates from these two surveys was at least not unreasonable.

In a review of the available information on the marine fish resources of Burma, Pauly *et al.* (1984) suggested a yield estimate based on an overall M value = 0.6, a total biomass of 800,000 t demersal fish (from the 1981/83 trawl survey) and 1 million t of pelagic fish (from the DR.FRIDTJOF NANSEN surveys). With an existing catch of 300,000 t this gave a potential annual total yield of 700,000 t. However, the authors present this estimate with reservation, relating both to the validity of the method used to calculate the potential from the biomass data, and to the feasibility of Myanmar's predominantly small-scale fisheries effectively exploiting the small pelagic fish stocks. The latter reservation may be related to the lack of success of experimental fishing for small pelagic fish during special programmes of the UNDP/FAO Project BUR/77/003 "Marine Fisheries Resources and Exploratory Fishing" (Anon., 1982). However, these trials did not cover the pre-monsoon season when the high densities of small pelagics were observed in the DR. FRIDTJOF NANSEN surveys.

Both of the above reservations might mean that the 700,000 t potential was an overestimate. On the other hand Pauly *et al.* (1984) found that the demersal resources of the shelf of Myanmar could not have been in a state of heavy exploitation. An analysis of the composition of main groups in four trawl surveys over the period 1953–83 showed no trends of change, in contrast to the fauna of the intensively fished Andaman coast of Thailand which comprises similar stocks.

The revised estimate of 700,000 t of small pelagic fish presented in this review would, with the assumptions used by Pauly *et al.* (1984), give a potential total yield of 600,000 t.

Unfortunately, the calculation of yield from biomass involves many uncertainties especially with the many different species of fish involved. The DR. FRIDTJOF NANSEN surveys provided, however, an extensive set of data describing the distribution, composition and abundance of the standing biomass of the main marine fish resources of Myanmar at a relatively early stage of development of light exploitation.

The reported marine fish landings of Myanmar were about 400,000 t in 1979 (FAO, 1984) and increased to nearly 600,000 t in 1990/91 (FAO, 1993). There thus seems indeed to have been a potential for increased catches. In studies of the effects of fishery development on the stocks, the results of the 1979–83 surveys may serve as important benchmarks.

4.3 SURVEYS OFF BANGLADESH, PENINSULAR MALAYSIA, WEST THAILAND AND NORTH SUMATRA, 1979–80

Survey objectives and effort

Brief assignments of exploratory nature were undertaken in the Eastern Indian Ocean and the South China Sea, supplementary to the more extensive work in Sri Lanka and Myanmar. These included Bangladesh (two coverages), the east and west coasts of Peninsular Malaysia, the west coast of Thailand and the north and west coasts of Sumatra. They formed part of the general programme of resource evaluations started by the IOP, while the assignments in the South China Sea and Malacca Strait were made in response to a request from the UNDP/FAO South China Sea Fisheries Development and Coordination Programme (SCSP). The findings of these surveys were reported as follows: Bangladesh by Saetre (1981), Malaysia by Aglen *et al.* (1981a), Thailand by Aglen *et al.* (1981b) and Indonesia by Aglen *et al.* (1981c). Because of the limited coverage of the surveys, the results as regards the magnitude of the resources and their distribution should only be regarded as indicative. They were, however, of interest in these areas which at the time were sparsely researched. The results regarding faunistic composition may be of interest in general and for indicating the state of exploitation at the time.

The particulars for each of the surveys are listed in Table 4.33. The coverage included the shelf waters from about 10 m to about 200 m depth and, where conditions permitted, also the upper slope. The uncovered shallow inshore parts were extensive, especially in Bangladesh, and also on the west coast of Thailand. Off the west coast of Malaysia the survey extended seawards to the medium line between Malaysia and Sumatra. The degree of coverage for the acoustic survey varied considerably, but demonstrated an adequate or even excessive effort. Unfavourable monsoon weather restricted work during part of the Thailand survey.

Table 4.33 Survey data for Bangladesh, Malaysia, Thailand and Indonesia

	Bangladesh		Malaysia		Thailand	Sumatra
Dates	1st cov.	2nd cov.	East coast	West coast	West coast	N&W coast
	25/11–12/12 1979	7–9/5 – 16–24/5 1980	10–25/6 1980	5–15/7 1980	16/7–3/8 1980	6–30/8 1980
Monsoon	NE	Pre-SW	SW	SW	SW	Post-S
Survey area nmi^2	12,000	12,000	4,000	18,000	12,000	25,000
Survey distance nmi	1,200	8,400	1,400	800	1,100	3,100
Degree of coverage	11	8	8	6	11	20
No. of trawl						

hauls:						
Bottom trawl	50	61	69	35	64	54
Pelagic trawl	16	7	20	3	16	22

Survey methods

Acoustic

As described in Chapter 2, the conversion factor C used in the acoustic method for estimating the biomass of fish from the observed integrator readings, was for all of these surveys based on a target strength of -36 dB/kg (for 17 cm fish). This represents a very low target strength and a 2 dB higher level, -34 dB/kg now seems more appropriate. This results in a reduction of the biomass estimates presented in the survey reports by Sætre (1981) and Aglen *et al.* (1981 a,b and c) by about one-third.

Trawl

For the swept-area estimates of demersal fish in Bangladesh, Sætre (1981) assumed a trawl efficiency coefficient of 0.5. In this review the coefficient is assumed to have been equal to 1 as was used for the corresponding estimates in all other surveys dealt with in this section.

Species identification was mostly based on Fischer & Whitehead (1974), Smith (1972), and Carcasson (1977). The records of the catch composition in the bottom trawl from the survey of Sumatra have been used by Bianchi (1996) in a study of the demersal fish assemblages in this area. Similar analyses of the corresponding data from Malaysia and Thailand are being prepared.

Bottom topography

Analysis of the echo recordings with reference to the suitability of the type of bottom for demersal trawling showed that the Bangladesh shelf was mostly smooth and even, but with a steep slope from 160–180 m onwards, and a steep canyon in the western part. The shallow shelves off eastern and western Malaysia were also generally smooth, but interspersed with rocks and corals at certain depth ranges. Off western Thailand the middle main shelf was found to be mostly smooth, but the shelf edge was rough and there were rocks and corals inshore. Off north and west Sumatra rough bottom with rocks and corals and steep slopes prevailed.

Hydrography

The most notable features of the hydrographic observations from Bangladesh were the low surface layer salinities, especially in November-December brought about by the river runoffs, and the lifting of the transitional layer from about 70 m depth in November to 30–40 m in May. It must be expected that the distribution of the demersal fish was affected by this change which brought oxygen deficient water up over the shelf to a depth of 20–30 m. The shoreward tilting of the isopleths in May indicates upwelling which may enhance the primary productivity in the Bay of Bengal.

Off the west coast of Thailand the thermocline was found at about 100 m depth and did not enter the shelf. Tropical surface water also covered the shelf off west and east Malaysia. The shelf off north and west Sumatra was fully tropical with the thermocline located at 100 m depth and more off the shelf edge.

4.3.1 Bangladesh, 1979–80

Figure 4.16 shows the survey area and the coverages in the 1979 survey.

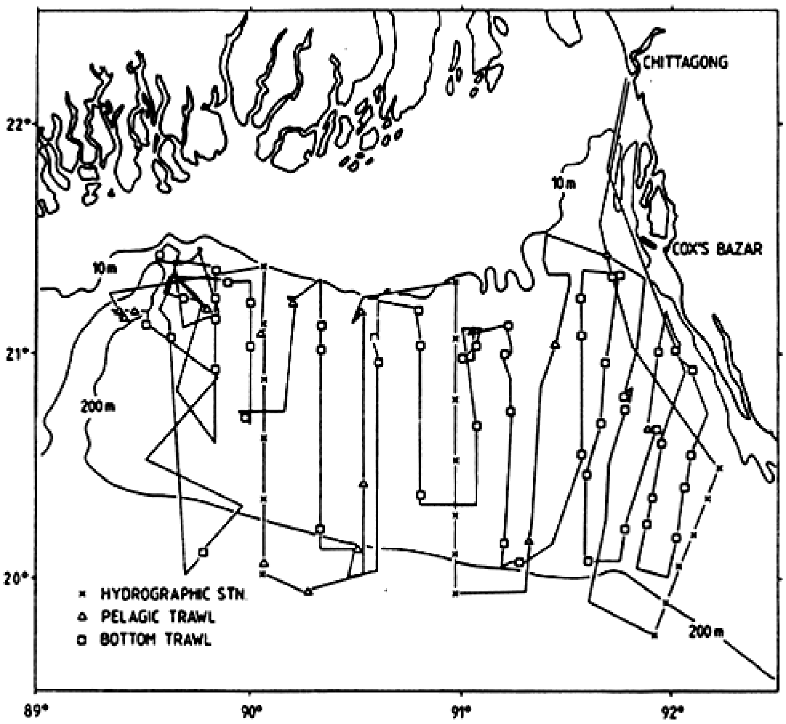

Figure 4.16 Bangladesh: Survey area, course tracks and stations in November-December 1979

Biomass estimates of pelagic fish

Two acoustic coverages, in November-December 1979 and May 1980 show no substantial concentrations of small pelagic fish over the part of the shelf covered. The general finding was a patchy and low-density distribution. Relatively high catch rates of clupeids and engraulids in the shallow depth range 10–24 m indicated, however, that the densities of these fish might have been higher in the extensive areas inside 10 m depth which could not be covered by the survey.

The acoustic estimates of the biomass of pelagic fish over the shelf covered were: 38,000 t in November-December 1979 and 76,000 t in May 1980. The part of the shelf in Bangladesh inside 10 m depth which could not be covered by the surveys is very extensive: about 7,000 nmi^2. If it is assumed that the density of pelagic fish here was the same as in the area between 10 and 100 m depth (about 9,400 nmi^2) where the pelagic fish was observed, then raised totals of 66,000 t in November-December and 133,000 t in May would represent the whole Bangladesh shelf. These are likely to be underestimates because of the generally negative bias of this first generation of acoustic equipment.

Seasonal changes in the biomass of short-lived small pelagic fish are well known. The biomass would be expected to be highest during and after the season of high primary production, which in Bangladesh would be associated with the northeast monsoon, and this thus fits the observations made. The surveys indicated that the exploitable stock of small pelagics was in excess of 130,000 t at its peak.

Only a few of the 23 hauls with the pelagic trawl had catch rates which indicated that the target fish had been successfully sampled. Pelagic fish appeared, however, in many of the catches of the bottom trawl even to the depth range 75–99 m, and the data from the 111 hauls with this gear represent a better source for evaluating their composition. Table 4.34 shows a largely similar pattern in each of the surveys, the scombrids, carangids and clupeids formed more than three-quarters of the catches of the pelagics. Indian mackerel (*Rastrelliger kanagurta*) gave the high scombrid catches, while round scad (*Decapterus* *maruadsi*) was the most common carangid. *Ilisha megaloptera and Sardinella fimbriata* dominated the clupeids.

Table 4.34 Bangladesh: Composition of pelagic fish by families. Mean catch rates in bottom trawl by surveys (kg/h)

Survey	Nov-Dec 1979	May 1980
No. of hauls	50	61
Ariommidae	7	17
Carangidae	21	57
Clupeidae	14	9
Engraulidae	9	4
Leiognathidae	6	9
Scombridae	49	83
Sphyraenidae	1	5
Total	107	184

Biomass estimates of demersal fish

The acoustic recording of semi-demersal fish showed only low densities and gave little information on their distribution over the shelf. The distribution of mean catch rates in the bottom trawl by depths, see Table 4.35, showed a marked difference between the surveys. In November-December 1979 relatively high catch rates of demersal fish were obtained down to a depth range of 75–99 m, while in May 1980 the rates were low beyond 25 m depth with an increase in the 10–24 m range. The overall mean catch rate of demersal fish in the May survey was less than half of that obtained in November-December. It seems likely that this change was caused by the observed of influx of oxygen-deficient water, present over a large part of the shelf in May 1980, an environmental effect which is well known from the Southwest Coast of India and other parts of the western Indian Ocean.

Table 4.35 Bangladesh: Mean catch rates in bottom trawl by depth ranges and surveys; Survey 1: Nov-Dec 1979; Survey 2: May 1980 (kg/h)

Depth range, m	10–24		25–49		50–74		75–99		100–149		Mean	
Survey	1	2	1	2	1	2	1	2	1	2	1	2
Pelagic fish	71	75	58	75	12	918	194	13	0	1	107	183
Demersal fish	174	363	185	74	538	68	259	63	14	50	264	127
Sharks/rays	18	59	4	11	7	1	3	+	0	0		
Crustacea	5	54	14	21	2	2	12	2	6	11		
Squids	1	1	5	1	2	6	5	0				
Total	**270**	**551**	**266**	**182**	**572**	**995**	**473**	**78**	**19**	**62**		
No. of hauls	10	13	10	11	11	10	14	15	5	12		

Table 4.36 Bangladesh: Depth distribution of most common families of demersal fish. Mean catch rates in bottom trawl by depth ranges and surveys; Survey 1: Nov/Dec 1979; Survey 2: May 1980 (kg/h)

Depth range, m	10–24		25–49		50–74		75–99		100–149		Mean	
Survey	1	2	1	2	1	2	1	2	1	2	1	2
Families:												
Ariidae	32	114	47	16	399	7	18	0	0	1	108	29
Gerreidae	1	+	16	10	4	1	12	+	0	0	8	2
Harpadontidae	15	69	0	2	0	0	0	0	0	0	3	15
Lutjanidae	2	14	+	0	37	3	4	0	0	+	10	3
Mullidae	2	+	21	2	14	2	2	0	0	0	8	1
Nemipteridae	+	0	5	1	4	13	169	41	5	+	50	13
Polynemidae	7	4	1	+	1	+	0	0	0	0	2	1
Pomadasyidae	11	4	2	2	11	1	1	0	0	0	5	1
Priacanthidae	0	0	0	0	+	1	19	13	6	0	6	11
Sciaenidae	64	109	50	23	13	11	6	5	+	1	27	31

Stromateidae	10	15	1	4	9	0	1	0	0	0	4	5
Synodontidae	6	+	21	2	6	9	19	2	2	2	12	3
Trichiuridae	8	20	5	2	21	0	1	0	0	0	7	4
Other families	17	14	17	11	18	19	8	1	1	8		

The mean catch rates by the more common families are shown for depth ranges in Table 4.36. Catfishes, croakers, threadfin breams and, in shallow water Bombay duck, represented about three-quarters of the demersal fish in both surveys. The lower catch rates beyond 25 m depth in the second survey are evident for most groups. Rates were low beyond 100 m depth also in the first survey, demonstrating the limit of the productive surface layer. Among the key species were the catfish (*Arius thalassinus*), the Bombay duck (*Harpadon nehereus*), the croaker (*Chrysochir aureus*) as the most abundant Sciaenidae and the threadfin bream (*Nemipterus japonicus*).

Table 4.37 shows the biomass of the fish identified as demersal (Table 4.36) estimated from the catch rates of the bottom trawl by the swept-area method. The reduction in the total estimates from 109,000 t to 47,000 t between the surveys was then presumably caused by the avoidance by the demersal fish of oxygen deficient bottom water. The high density in the 10– 24 m range in the May survey is additional evidence for this movement of the demersal fish.

Table 4.37 Bangladesh: Density and biomass of demersal fish by depth ranges

		Nov-Dec 1979		May 1980	
Depth range (m)	Area nmi^2)	Density (t/nmi^2)	Biomass (t)	Density (t/nmi^2)	Biomass (t)
10–24	2,500	7.8	19,500	11.2	28,000
25–49	1,400	7.6	10,600	2.3	3,200
50–74	1,600	22.1	35,400	2.1	3,400
75–99	3,900	10.7	41,700	1.9	7,400
100–149	3,000	0.6	1,800	1.6	4,800
Total			109,000		46,800

The abnormally high density in the 50–74 m depth range in November-December 1979 is due to a single 4 t/h catch. If this station is excluded, the biomass estimate for this survey is reduced to about 80,000 t. An adjustment should be made for the inshore part of the shelf not covered by the surveys. Assuming that the density in these shallow parts is the same as that observed in the adjacent depth range 10–24 m, the additional biomass would be 55,000 and 78,000 t in the first and second survey respectively. The total estimates then become roughly similar: 135,000 t and 125,000 t. If the average of these is accepted as the best estimate, the standing stock of demersal fish of 130,000 t for the shelf proper down to 100 m depth was observed to have a mean density of about 8 t/nmi^2.

Review of findings

An overview of biomass estimates by major groups is shown in Table 4.38. The total marine fishery resources of Bangladesh were thus estimated at 280,000 t with a density of 17 t/nmi^2 over the shelf to 100 m depth. The main uncertainty attached to these results relates to the extensive shallow inshore part of the shelf, representing 43% of the shelf area to 100 m depth, from which there were no observations and where fish densities were assumed to be equal to those of the adjacent outer shelf.

Table 4.38 Bangladesh: Overview of abundance estimates of pelagic fish from acoustic surveys and other resources from bottom trawl survey.

	Inshore <10 m		**Shelf 10–100 m**		**Slope 100–150 m**		**Total**	
	Density (t/nmi^2)	(t)	Density (t/nmi^2)	(t)	Density (t/nmi^2)	(t)	Density (t/nmi^2)	(t)
Pelagic fish	7.9	55,000	8.0	75,000			7.9	130,000
Demersal fish	9.6	67,000	6.7	63,000			7.9	130,000

Deep-water fish					1.7	5.000	1.7	5,000
Sharks, rays etc.	1.0	7,000	1.0	9,000			1.0	16,000
Total							17.1	281,000

4.3.2 East coast of Peninsular Malaysia, 1980

Figure 4.17 shows the area of investigation with course tracks and stations. The coastal area, defined as that of 10–25 m depth, is about 6,000 nmi^2 and the offshore area, 26–75 m depth, is 28,000 nmi^2.

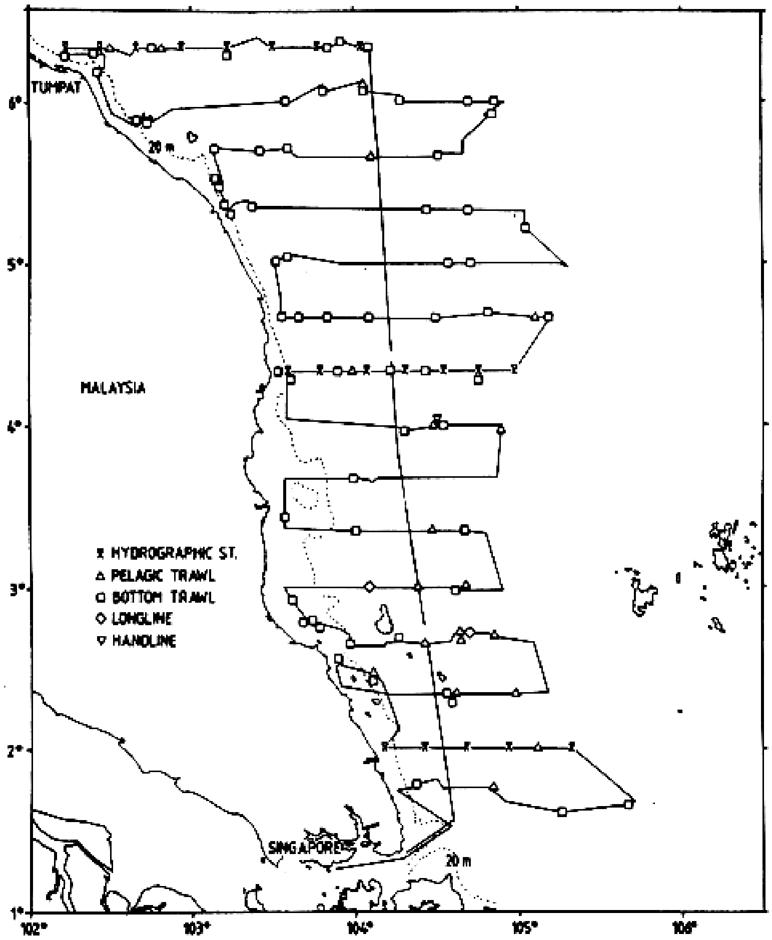

Figure 4.17 Malaysia, east coast, 10–25 June 1980: Survey area and course tracks and stations

Pelagic fish

In the acoustic survey small concentrations of pelagic fish were found near the shore at 10–25 m bottom depth, while the recordings in the offshore area were very scattered. In some areas much of the pelagic recordings were squid. Schools of pelagic fish were often seen close to the bottom and the trawl catches usually gave a mixture of pelagic and demersal fish.

Table 4.39 shows the catch rates of pelagic families in the bottom trawl and confirms their inshore distribution. The mean catch rates were low with carangids and the semi-demersal leiognathids dominating. The total species diversity was very high with for instance more than 20 species of carangids. Of these, yellowstripe trevally, (*Selaroides leptolepis*) dominated, while bigeye scad (*Selar crumenophthalmus*) was also common. Longfin mojarra (*Pentaprion longimanus*) was a common gerreid species.

Table 4.39 Malaysia, east coast: Mean catch rates of main pelagic families in bottom trawl by depth ranges (kg/h)

	10–25 m	26–50 m	51–75 m
No. of hauls	10	15	28
Families:			
Carangidae	62	8	6
Clupeidae	7	+	
Gerreidae	2	4	3
Leiognathidae	12	2	3
Scombridae	1	+	1
Total	84	14	13

Table 4.40 Malaysia, east coast: Mean catch rates of main demersal families and other demersal groups in bottom trawl (kg/h)

	10–25 m	26–50 m	51–75 m
No. of hauls	10	15	28
Ariidae	21	3	+
Balistidae	+	3	4
Lutjanidae	4	11	4
Mullidae	11	3	4
Nemipteridae	11	10	8
Pomacentridae	4	2	+
Priacanthidae	+	1	7
Siganidae	27	1	+
Synodontidae	5	5	5
Theraponidae	18	-	-
Rays	29	3	1
Other demersal fish	26	12	12
Crustacea	4	8	4
Cephalopoda	5	8	4
Total	165	70	53

Demersal fish

Acoustic recordings of fish identified as semi-demersal were low. The composition of the main families in the bottom trawl catches is shown by depth ranges in Table 4.40. There was a high diversity of species (about 110 identified species from 60 families). Catch rates were highest in the coastal area and reduced to about one-third offshore. Catfishes, snappers, goatfishes and threadfin breams were the most abundant. Catches of squid were common in the offshore area.

Biomass estimates

The acoustic estimates were based on mean integrator values and mean fish size for each of six sub-areas of the shelf. Table 4.41 shows the abundance of pelagic fish for the inner and outer parts of the shelf. The highest densities of pelagic fish and the main part of their biomass were found on the inner shelf. Semi-demersal fish were recorded with low densities in both parts.

Table 4.41 Malaysia, east coast: Abundance estimates and biomass of pelagic fish from acoustics and of demersal fish from swept-area trawl data

	No. of hauls	Area (nmi^2)	Density (t/nmi^2)	Biomass (t)
Pelagic fish				
Inner shelf		12,540	11.5	143,000
Outer shelf		21,840	2.6	57,000
Total		**34,380**	**5.8**	**200,000**
Demersal fish				
Coastal, 10–25 m	19	6,000	5.3	32,000

Offshore, 26–75 m	41	28,000	1.7	48,000
Total	**60**	**34,000**	**2.4**	**80,000**
All fish		34,000	8.2	280,000

Table 4.41 also shows that the densities of demersal fish estimated by the swept-area method from the bottom trawl hauls are by far highest in the coastal area, 10–25 m depth.

The total fish biomass estimated at the time of the survey was thus about 280,000 tonnes.

4.3.3 West coast of Peninsular Malaysia, 1980

Figure 4.18 shows the area of investigation and the course tracks covering the shallow shelf which hardly reaches more than 70 m depth.

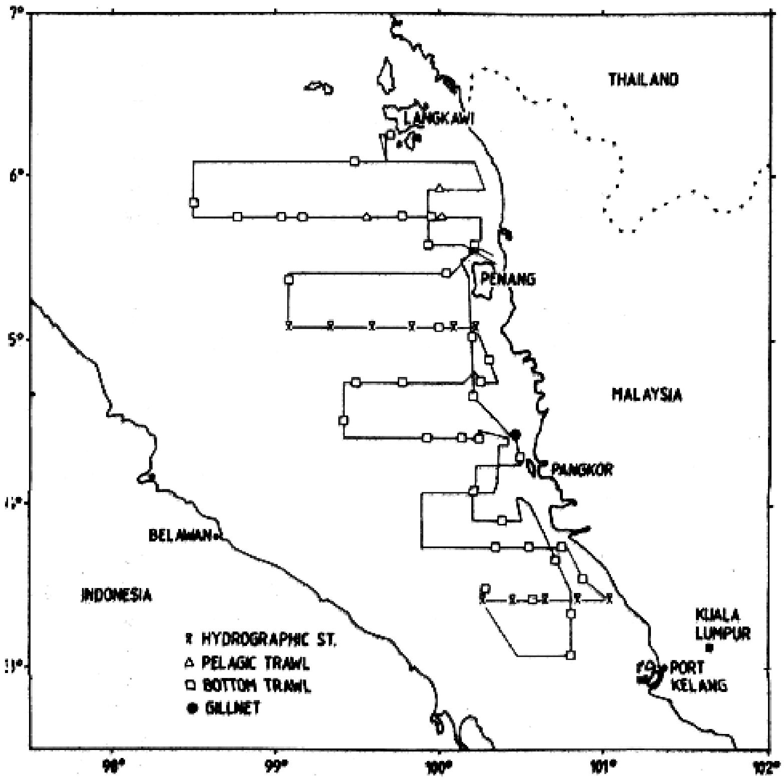

Figure 4.18 Malaysia, west coast, 5–15 July 1980: Survey area and course tracks

Pelagic fish

Pelagic fish were recorded over most of the shelf, but in low densities except for the coastal area north of Penang and smaller patches further south.

As on the east coast a considerable part of the bottom trawl catches consisted of pelagic fish. Table 4.42 gives the mean catch rates of the main pelagic families and shows that about two-thirds of the pelagic fish was caught inside 50 m depth.

Carangids dominated the true pelagics and, with 13 identified species only of this family, the diversity was also here high. The yellowtail scad (*Atule mate*) and the yellowstripe scad (*Selaroides leptolepis*) were the most common. Indian mackerel (*Rastrelliger kanagurta*) dominated the scombrids.

Table 4.42 Malaysia, west coast: Mean catch rates of main pelagic families in bottom trawl by depth ranges (kg/h)

Depth range	**10–25 m**	**26–50 m**	**51–75 m**	**76–100 m**
No. of hauls	7	13	13	2
Families:				
Carangidae	9	24	8	5
Clupeidae	4	2	+	
Gerreidae	-	+	1	13
Leiognathidae	20	5	1	
Scombridae	3	13	+	
Total	36	44	10	18

Demersal fish

The acoustic recordings of fish identified as semi-demersal were weak and showed little variation throughout the area. The composition of the main families in bottom trawl catches is shown in Table 4.43. With about 60 species representing 30 families the diversity of species was not as high as on the east coast. For most groups there was a reduction of mean catch rates with depth, but with one haul at 90 m giving an unusually high rate of big eye. Grunts, croakers and hairtails were the most common groups inshore and snappers, threadfin breams and bigeyes offshore.

Table 4.43 Malaysia, west coast: Mean catch rates of main demersal families and other groups in bottom trawl by depth ranges (kg/h)

Depth range	**10–25 m**	**26–50 m**	**51–75 m**	**76–100 m**
No. of hauls	7	13	13	2
Lutjanidae	+	5	4	4
Nemipteridae	+	9	9	18
Pomadasyidae	13	2	+	-
Priacanthidae	-	+	+	106
Sciaenidae	8	2	+	-
Synodontidae	1	6	2	1
Tetraodontidae	5	8	2	2
Trichiuridae	20	5	+	-
Rays	1	1	3	50
Other demersals	12	16	17	16
Crustacea	5	3	1	+
Cephalopoda	5	3	2	3
Total	70	60	40	200

Biomass estimates

The acoustic abundance estimates were based on mean integrator values and fish size calculated for 5 sub-areas. The mean biomass densities of pelagic fish were as shown in Table 4.44 highest on the inner part of the shelf ranging out to 30–50 nmi offshore. The acoustic recordings of semi-demersal fish did not show such a trend and were in general low.

Table 4.44 Malaysia, west coast: Abundance estimates of pelagic fish from acoustics and of demersal fish from swept-area trawl data

	No. of hauls	Area (nmi^2)	Density (t/nmi^2)	Biomass (t)
Pelagic fish				
Inner shelf		9,400	14.4	135,000
Outer shelf		7,300	6.6	48,000
Total		**16,700**	**11.0**	**183,000**
Demersal fish				
10–25 m depth	7	2,500	2.0	5,000
26–50 m depth	13	3,500	1.8	6,300
51–100 m depth	15	10,100	2.3	23,200
Total	**35**	**16,100**	**2.1**	**34,500**
All fish		32,800	6.6	218,000

The densities of demersal fish from swept-area calculations did not demonstrate any trend by depth. Sampling in shallow water was, however, sparce due to limitation on trawl operations caused by widespread commercial fishing.

The mean density of pelagic fish on the west coast shelf, 11 t/nmi^2 is somewhat higher than that found on the east coast, 6 t/nmi^2. Since the biomass of small pelagic fish is often found to have seasonal fluctuations, the difference in the observed densities may not represent differences in annual production. The density of demersal fish was about the same on both shelves.

4.3.4 West coast of Thailand, 1980

Figure 4.19 shows the survey area with cruise tracks and stations. Strong monsoon winds, rough bottom on parts of the shelf and commercial fishing inshore restricted some of the survey activities.

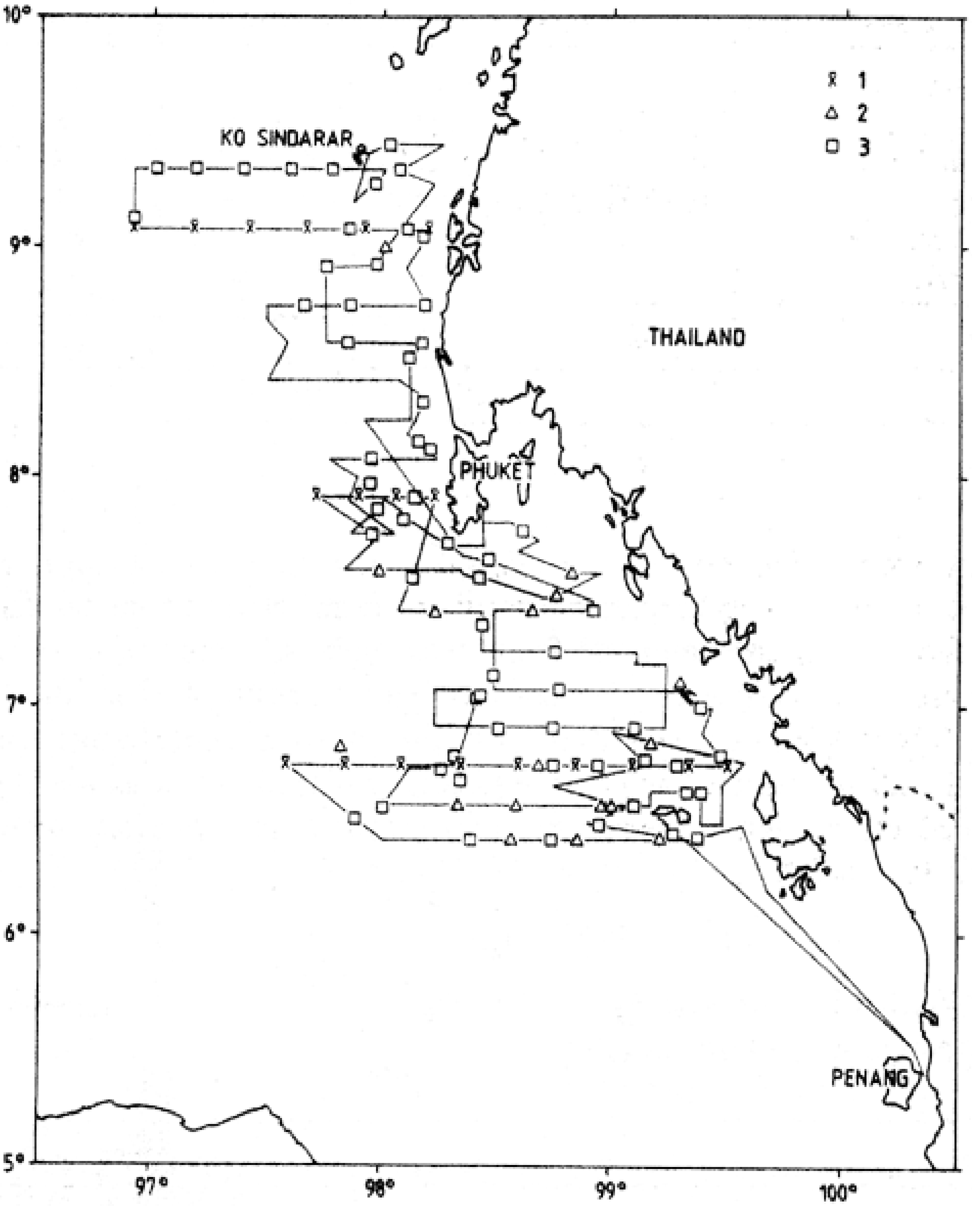

Figure 4.19 Thailand, west coast, 16 July-3 August 1980: Survey area and course tracks

Pelagic fish

The acoustic survey showed a patchy distribution of pelagic fish with moderate abundance in three areas: in the north near the Myanmar border, inshore south of Phuket and in the south near the border with Malaysia. The recordings showed that pelagic or semi-pelagic fish such as carangids were often found close to the bottom during daytime, while at night they occured as scattering layers in mid-water.

Four out of a total of 16 hauls with pelagic trawl had apparently successful catches of the target species, mostly engraulids and clupeids. Pelagic fish appeared in the bottom trawl catches in the proportions shown in Table 4.45. Some 25 carangid species were identified of which yellowstripe scad (*Selaroides leptolepis*) and Indian scad (*Decapterus russelli*) were the most common. Indian mackerel (*Rastrelliger kanagurta*) dominated the scombrids. It seems likely that engraulids and clupeids are under-represented in the bottom trawl catches.

Table 4.45 Thailand, west coast: Mean catch rates of main pelagic families in bottom trawl by depth ranges (kg/h)

Depth range	**10–25 m**	**26–50 m**	**51–75 m**	**76–100 m**
No. of hauls	3	20	16	14
Families:				
Carangidae	26	123	16	6
Clupeidae	2	4	2	-
Gerreidae	3	2	-	3
Leiognathidae	6	37	22	19
Scombridae	3	7	2	+
Total	40	173	42	28

Demersal fish

Semi-demersal fish were recorded in the same geographical areas as the pelagic fish. The composition in the bottom trawl catches of the main families of demersal fish is shown in Table 4.46. The diversity of the demersal fauna was high with more than 150 species from about 80 different families. Snappers, goatfishes, threadfin breams and hairtails were the most common families. The catch rates were highest in the 26–50 m depth range, but sampling in the shallow range 10–25 m was probably inadequate and biased. Some hauls at greater depths in the slope showed the presence, although in low abundance, of deep water shrimp and lobster as found further north off Myanmar (see Section 3.5).

Table 4.46 Thailand, west coast: Mean catch rates of main demersal families and other groups in bottom trawl by depth ranges (kg/h)

Depth range	**10–25 m**	**26–50 m**	**51–75 m**	**76–100 m**
No. of hauls	3	20	16	14
Ariidae	6	+	-	-
Lethrinidae	-	6	+	4
Lutjanidae	1	20	10	12
Mullidae	+	20	5	5
Nemipteridae	2	14	8	13
Pomadasyidae	4	4	+	+
Priacanthidae	-	3	10	8
Serranidae	+	2	4	+
Siganidae	1	18	+	+
Sphyraenidae	1	4	1	1
Synodontidae	+	2	2	4
Trichiuridae	+	40	6	+
Sharks	-	1	-	6
Rays	+	12	+	1
Other demersals	7	17	10	16
Crustacea	2	1	+	1
Cephalopoda	1	2	4	3
Total	25	166	60	74

Biomass estimates

The acoustic estimates were based on mean integrator values and mean fish size for a northern, central and southern parts of the shelf divided at the latitudes 8° 20' and 7° 20'. Table 4.47 shows that the density of pelagic fish was highest over the central shelf. The acoustic estimate of fish identified as semi-demersal was 26,000 t, the same as that obtained for demersal fish from the swept-area calculations. It seems likely that inadequate and biased sampling of the shallow waters (10–25 m depth) caused an underestimate of the demersal fish in this range.

The west coast of Thailand has extensive inshore areas of less than 10 m depth which could not be covered by the survey. These represent about 20% of the shelf area, and if it is assumed that the mean fish density here was the same as that estimated for the outer shelf, the survey's estimate of total biomass was about 125,000 t.

Table 4.47 Thailand, west coast: Abundance estimates of pelagic fish from acoustics and of demersal fish from swept-area trawl data

	No. of hauls	Area (nmi^2)	Density (t/nmi^2)	Biomass (t)
Pelagic fish				
Northern shelf		3,200	5.7	18,000
Central shelf		3,300	8.9	29,000
Southern shelf		5,100	5.0	26,000
Total		**11,600**	**6.3**	**73,000**
Demersal fish				
10–25 m depth	3	1,400	0.4	600
26–50 m depth	20	2,800	5.1	14,200
51–100 m depth	16	3,100	1.7	5,200
76–100 m depth	11	3,100	2.1	6,600
Total	**50**	**10,400**	**2.6**	**26,600**
All fish		11,000	9.1	100,000

4.3.5 North and west coast of Sumatra, 1980

Figure 4.20 shows the survey area, the course tracks and stations. The investigations were mostly limited to the generally narrow shelf (10–100 m) depth with some bottom trawling also in the deep slope (200–350 m). The shelf edge was often found to be marked with shallow grounds and coral reef peaks extending in some places almost to the surface. Particularly south of Kutanibong, reefs made navigation difficult and caused an uneven coverage. Rough bottom was in fact predominant over large parts of the survey tracks and the demersal fish fauna related to this type of bottom was no doubt undersampled.

Pelagic fish

Pelagic fish tended to stay close to the bottom during daytime and raised slightly and scattered at night. Real high densities of fish were not observed in any area, but the best recordings were made on the shelf inside the islands south of latitude 2°N.

The recordings of pelagic fish were seldom sufficiently above bottom to be identified by pelagic trawling, but catches in the bottom trawl provided clues to the identification. As shown in Table 4.48 the semi-pelagic ponyfishes dominated which may explain the proximity of the recordings to the bottom. There were also some carangids and scombrids. Species diversity was high with more than 20 carangid species among which Malabar cavalla, (*Carangoides malabaricus*) and bigeye scad (*Selar crumenophthalmus*) dominated.

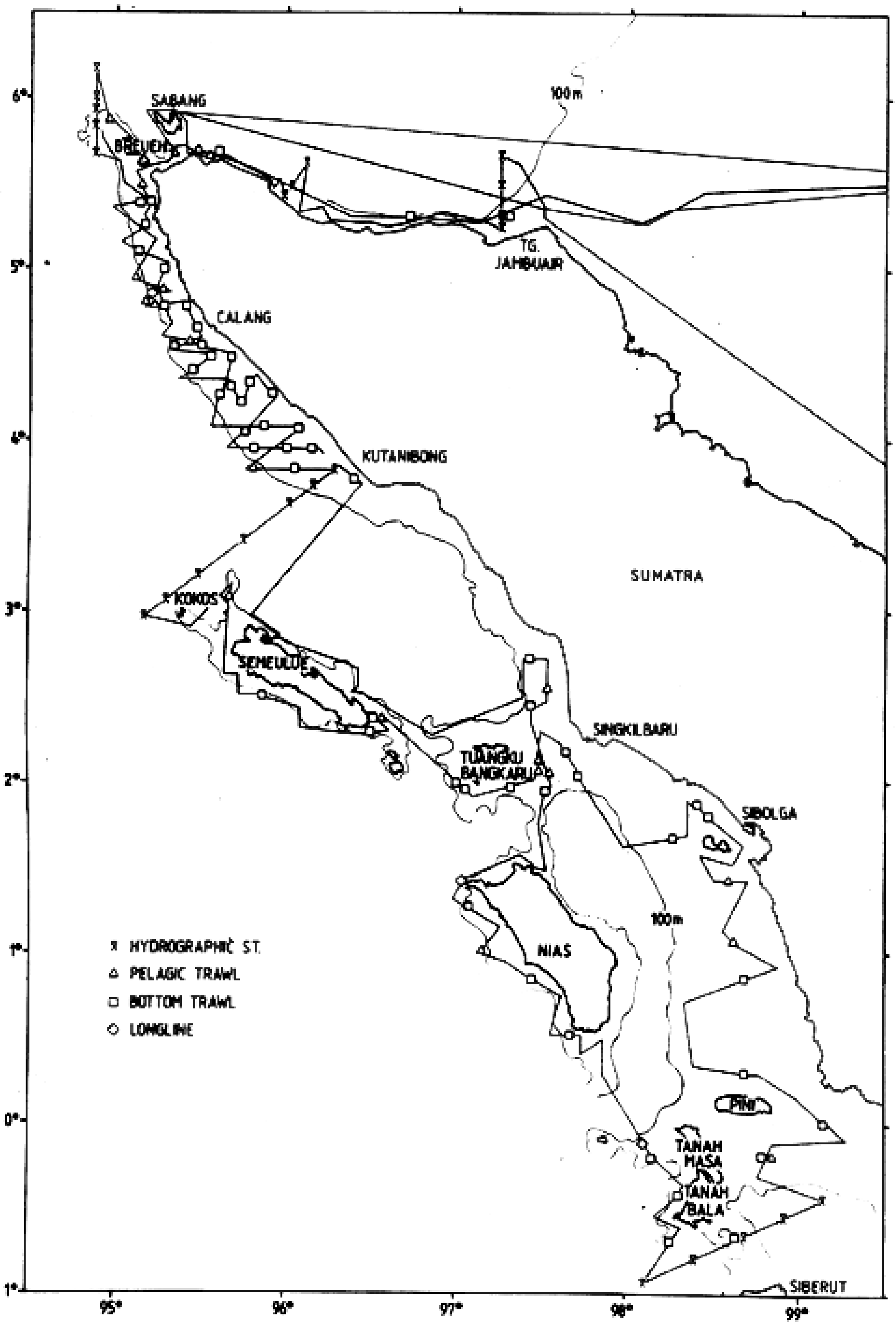

Figure 4.20 Sumatra, north and west coast, 6–30 August 1980: Survey area and course tracks

Table 4.48 Sumatra, north and west coasts: Mean catch rates of main pelagic families in bottom trawl by depth ranges (kg/h)

Depth range	**10–25 m**	**26–50 m**	**51–75 m**	**76–100 m**
No. of hauls	8	18	13	9
Families:				
Carangidae	7	19	11	1
Clupeidae	5	4	1	-
Gerreidae	+	7	2	+
Leiognathidae	26	151	4	+
Scombridae	10	5	1	+
Total	48	186	19	1

Demersal fish

The geographical distribution of the recordings of fish identified as semi-demersal was similar to that of the pelagic fish. The composition of the main demersal groups in the bottom trawl catches is shown in Table 4.49. The main part of the catch was taken at depth shallower than 75 m. Snappers, grunts, barracudas and hairtails were among the most important groups. The diversity of the bottom fauna was high with more than 160 species from about 80 families.

Table 4.49 Sumatra, north and west coast: Mean catch rates of main demersal families and other groups in bottom trawl by depth ranges (kg/h)

Depth range	**10–25 m**	**26–50 m**	**51–75 m**	**76–100 m**
No. of hauls	8	18	13	9
Harpadontidae	5	-	1	-
Lactariidae	2	7	1	-
Lutjanidae	-	11	20	13
Mullidae	14	3	1	-
Pomadasyidae	7	17	1	1
Sciaenidae	6	1	+	-
Sphyraenidae	2	21	2	1
Synodontidae	4	1	5	2
Trichiuridae	26	14	2	+
Sharks	2	4	3	6
Rays	+	3	13	1
Crustacea	5	1	+	+
Cephalopoda	2	+	1	1
Other demersals	7	18	14	1
Total	69	112	66	27

Biomass estimates

The acoustic estimates were calculated from mean integrator values and mean fish size in four areas: the north shelf; the northwest shelf to latitude 3° 30'N; the shelf around the islands; and the inner shelf south of Singkilbaru. The seaward limit was set at the outer limit of commercial fish recordings. Table 4.50 shows that the density of pelagic fish was highest on the inner shelf in the southern part of the survey area.

In the trawl survey the highest density of demersal fish was found in the 26–50 m depth range. Many parts of the shelf were, however, undersampled because of rough bottom and it seems likely that the density of demersal fish and their biomass was underestimated by the survey.

Four trawl hauls on the deep slope (230–350 m) showed a mean catch rate of 143 kg/h with bigeyes (Priacanthidae), greeneyes (Chlorophthalmidae), deep water sharks and shrimp dominating.

The total biomass within the surveyed area was estimated at about 225,000 t.

Table 4.50 Sumatra, north and west coast: Abundance estimates of pelagic fish from acoustics and of demersal fish from swept-area trawl data

	No. of hauls	**Area (nmi^2)**	**Density (t/nmi^2)**	**Biomass (t)**
Pelagic fish				
Northern shelf		6,700	5.2	34,000
Northwest shelf		3,800	4.5	18,000
Island shelf		6,100	6.4	39,000
Inner shelf 2°N-1°S		8,200	8.4	69,000
Total		**24,800**	**6.4**	**160,000**
Demersal fish				
10–25 m depth	8	7,350	2.1	15,000
26–50 m depth	18	9,800	3.7	37,000

51–100 m depth	13	4,900	2.2	11,200
76–100 m depth	3	2,450	0.9	2,000
Total	**48**	**24,500**	**2.7**	**65,000**
All fish		24,500	9.2	225,000

5 SURVEYS IN THE SOUTHWEST INDIAN OCEAN

In the 1970s and early 1980s, the development of marine fisheries in countries bordering the Southwest Indian was of great interest to donor agencies, such as NORAD and UNDP. After the termination of the strong co-operation with FAO and UNDP in the Arabian Sea, NORAD decided to deploy the DR. FRIDTJOF NANSEN in Mozambique, where it supported a number of long-term fisheries development programmes.

After the initial surveys in Mozambique, an interest was developed to also cover the adjacent states, usually in co-operation with FAO and local FAO/UNDP or NORAD projects.

A total of 16 surveys were conducted in the period 1977–90, of which seven in Mozambique, with 13 complete or partial coverages of the shelf areas, four in Kenya, three in Tanzania and one each in Madagascar and the Seychelles.

The survey in the Seychelles was incomplete, while the one off Madagascar was mainly for oceanographic purposes, covering only the southern part of the island. The results of the surveys in Kenya, Tanzania and Mozambique are described and discussed below.

5.1 KENYA, 1980–83

Survey objectives and effort

Surveys of the shelf of Kenya was part of the DR. FRIDTJOF NANSEN's East African Coast programme in the early 1980s to investigate small pelagic fish with acoustic methods and demersal fish with bottom trawling. The four surveys in Kenya, in December 1980, August and December 1982 and May 1983 covered together all trawlable parts of the shelf and the slope from about 10 m to 500 m. The shallow, more productive part of the shelf was covered in each of the surveys. The results were briefly described in cruise reports (IMR, 1982d; Nakken, 1981; Iversen, 1983) and summarized in a special report for the “NORAD-Kenya Seminar on the Marine Fish Stocks and Fisheries in Kenya” held in Mombasa in 1984 (Iversen, 1984; Iversen and Myklevoll, 1984b).

Table 5.1 shows the operational data of the four surveys. The degree of coverage for the acoustic investigations, was generally high and particularly so for the August 1982 survey. The trawl stations are those recorded as successful swept-area hauls, available in the NANSIS data bank with the exception of those from the 1980 survey.

Table 5.1 Details of the surveys in Kenya

Number	I	II	III	IV
Date	Dec 1980	Aug 1982	Dec 1982	May 1983
Survey distance (nmi)	1,300	2,360	1,040	810
Survey area (nmi^2)	6,000	4,500	3,500	2,300
Degree of coverage	17	35	17	17
No. of trawl stations	47	47	27	27

Figure 5.1 shows the shelf of Kenya, the sub-areas used in the trawl survey programme and the coverage in the August 1982 survey. Table 5.2 shows the areas of the depth strata by subarea (Iversen, 1984). Most of the southern area is very deep and this part was only covered in the December 1980 survey. The North Kenya Bank is narrow with a steep slope. The Malindi Bank-Ungama Bay area has the widest shelf with a generally smooth trawlable bottom. The bottom trawl investigations in the 1982/83 surveys were mostly confined to this area and to the southern part of the North Kenya Bank.

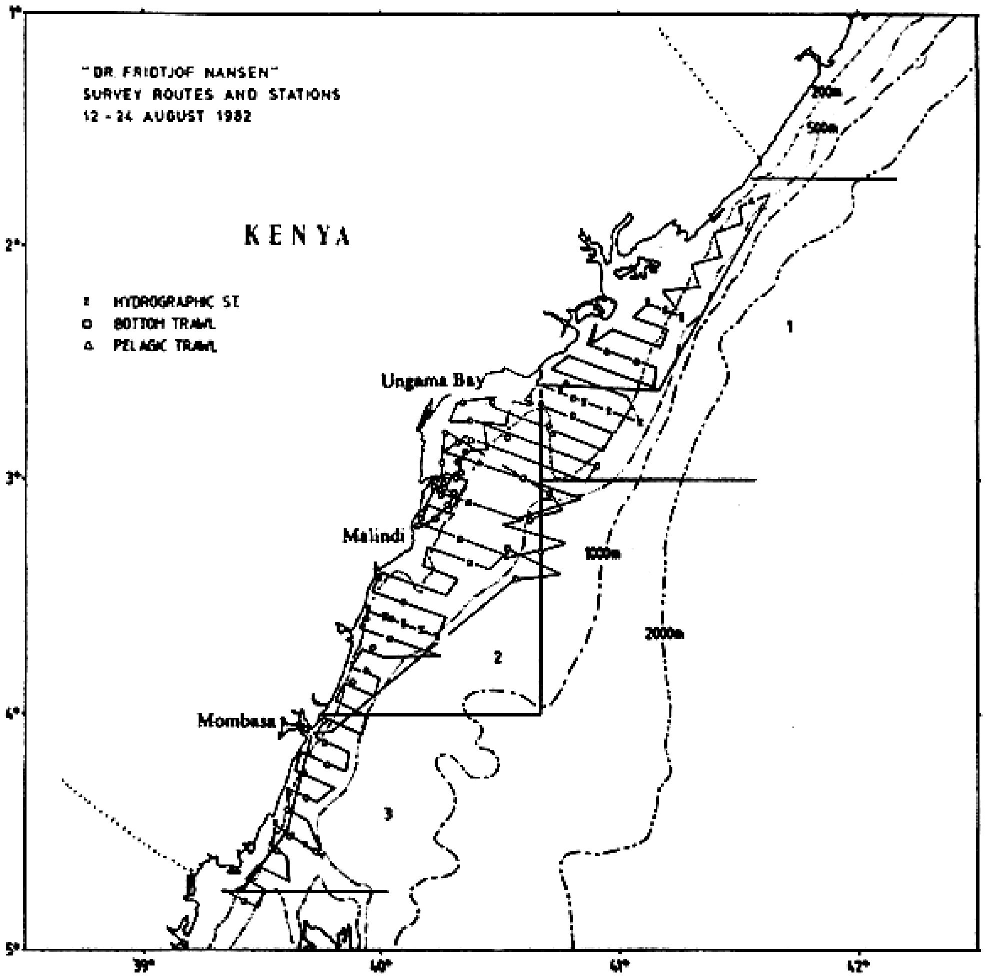

Figure 5.1 The shelf of Kenya: Course tracks in the August 1982 survey and the investigated areas. 1: North Kenya Bank; 2: Malindi-Ungama Bay area; 3: The southern area

Table 5.2 The shelf of Kenya by sub-areas and depth strata (nmi²)

Depth strata	< 20m	20–50 m	50–200 m	200–500 m	Total
1 North Kenya Bank	5	75	905	415	1,400
2 Malindi-Ungama Bay	235	125	210	925	1,495
3 Southern area	5	15	130	1,200	1,350
Total	245	215	1,245	2,540	4,245

The species diversity in this region is high and the task of identification was aided by the participation of Mr. S.C. Venema from FAO and Dr. P.C. Heemstra from the J.L.B. Smith Institute of Ichthyology in South Africa in the December 1980 survey during which some 260 species of special taxonomic interest were collected (Nakken, 1981). During this cruise the need for inputs of taxonomists was realized and it can be considered as the start of a close co-operation between the DR. FRIDTJOF NANSEN programme and FAO's Fish Identification Programme (Venema, 1981).

Hydrography

Hydrographical profiles worked off the southern, central and northern coasts showed no drastic changes in the seasonal environment over shelf. The temperature of the surface layer increased from 25°C in August 1982 to 27–28°C in December 1982 and was again about 28°C in May 1983. The thermocline was found at 100–150 m in August 1982, at 50–125 m in December 1982 and at 75–100 m in May 1983. The surface layer had high oxygen content, more than 4 ml/l, in all seasons.

Pelagic fish

Charts of the distribution of echo integrator outputs corresponding to density of fish recorded in mid-water (Iversen, 1984) showed that pelagic fish was present over wide parts of the shelf, but mostly scattered. The aggregations that were found were not of high density, and were confined to the central Malindi-Ungama Bay area in all surveys.

The biomass of the fish observed in mid-water was estimated with the acoustic integration method with the following results (Iversen, 1984):

December 1980	22,000 t
August 1982	29,000 t
December 1982	32,000 t
May 1983	18,000 t

These estimates include both small pelagics and semi-demersals such as ponyfish, but they do not represent the total biomass of these types of fish since the surveys did not include the shelf area from 0 to 20 m depth which is often a productive zone. The mean density in the shelf area observed between 20 and 200 m was, however, low with an average of about 15 t/nmi^2. No areas of high aggregations were found and the reports only mentioned occasional observations of surface schools.

Table 5.3 Kenya: Catch rates and incidence of pelagic fish in 42 hauls by bottom trawl between 10 and 50 m depth in the three 1982–83 surveys

	Mean rate (kg/h)	**Highest rate (kg/h)**	**Incidence (%)**
Clupeidae	75	826	76
Engraulidae	5	58	62
Carangidae	24	172	79
Scombridae	11	88	59
Sphyraenidae	10	148	57

Pelagic fish also formed part of the catches with the bottom trawl in shallow waters. As shown in Table 5.3 these data indicated that Clupeidae and Carangidae were the most common taxa, followed by Scombridae and Sphyraenidae.

There was a high species diversity. The most common pelagic species were:

Clupeidae:	*Pellona ditchela, Sardinella gibbosa, Ilisha melastoma*
Engraulidae:	*Thryssa vitrirostris, Stolephorus commersonii*
Carangidae:	*Decapterus russelli*, various *Carangoides* spp.
Scombridae:	*Scomberomorus commerson, Rastrelliger kanagurta*
Sphyraenidae:	*Sphyraena putnamiae, Sphyraena obtusata*

Demersal fish

The mean catch rates of demersal fish by depth ranges are shown in Table 5.4. The deep water areas (200–500 m) were covered in December 1980 and August 1982. The catches consisted mostly of various deep-water fish Zeniontidae, *Chlorophthalmus* sp. and *Diaphus* sp., sharks and squids, most of which would seem to be of little commercial interest. Small catches of deep-water lobster species (Palinuridae) were taken at 280–350 m depth. The catch rates varied from one to a few kilogrammes per hour in ten hauls and with one catch of 25 kg/h. More detailed information on deep-water crustacean resources off Kenya is available from other surveys as reported by Mutagyera (1984).

In the two last surveys the trawling was mainly restricted to the shelf inside 200 m depth off Malindi and the Ungama Bay. The most common families among the demersal fish were snappers, grunts, groupers and mullets, which have been included in the category demersal fish in Table 5.5. The semi-demersal ponyfishes were particularly abundant, while one-third of the catch consisted of pelagic fish with a species composition as described in Table 5.3.

Table 5.6 shows the biomass estimates by sub-area for each survey as summarized by Iversen (1984). The high estimate for the North Kenya Bank in the last survey is due to a single catch, blue-spotted jobfish (*Pristipomoides filamentosus*) which appears to occur in shoals in deep water. Otherwise, the highest biomass is found in the central Malindi-Ungama Bay area. Demersal fish of commercial interest formed, however, a small part of the catches in this area as shown in Table 5.5. An estimate of the composition of the biomass in this area in the 10– 200 m depth range based on the three 1982/83 surveys was as follows:

Commercial demersals	700 t
Ponyfishes	1,950 t
Pelagic fishes	2,150 t
Others	900 t
Total	5,700 t

Table 5.4 Kenya shelf: Total catch rates of bottom trawl hauls by depth strata (kg/h)

Depth strata	0–20 m	20–50 m	50–200 m	200–500 m	All hauls
Aug 82 catch rate	204	453	440	420	400
number of hauls	6	10	8	21	45
Dec 82 catch rate	87	904	100	119	215
number of hauls	8	4	13	2	27
May 83 catch rate	539	628	949	172	709
number of hauls	10	5	11	1	27

Table 5.5 Sub-area Malindi-Ungama Bay: Mean catch rates of bottom trawl hauls by survey of main species groups on the shelf 10–200 m (kg/h)

	Aug 82	Dec 82	May 83
Demersal fish	68	54	59
Ponyfishes	125	48	176
Pelagic fish	52	170	199
Sharks & rays	86	10	16
Squid	-	11	13
Others	74	31	79
Totals	405	324	542

Table 5.6 Kenya: Swept-area biomass estimates by survey and sub-areas

	Dec 80	Aug 82	Dec 82	May 83
North Kenya Bank	2,100	1,600	1,100	7,500
Malindi-Ungama Bay	11,900	5,400	9,000	5,800
Southern area	700	7,400	4,500	2,700
Total	14,700	14,400	14,400	16,000
Source: Iversen, 1984				

Summary of findings

The survey covered the shelf outside the inshore reef zone from a depth of 10–15 m to about 500 m. Most of the trawl hauls were in the 20–200 m depth range. The shallow grounds inside the reefs which in the central part are extensive and cover about 250 nmi^2 could not be covered by the vessel. The surveys did not include large pelagic fish, tunas and tuna like fish in offshore waters.

The estimates of fish biomass with the acoustic method showed a range of 18,000 to 32,000 t with a mean of 25,000 t. Samples showed a large variety of species of various typical pelagic families, but the estimates also included semi-pelagic ponyfish. Most of the fish was very scattered and located inside 200 m depth in the central Malindi-Ungama Bay area.

The swept-area estimates showed a range of 14,000–16,000 t total biomass. On the central shelf in the 15–200 m depth range about 70% of the bottom trawl catches consisted of pelagic fish and ponyfish and only about 12% were reas demersal species such as snappers, grunts, groupers and mullets.

The two methods of biomass estimation cover partly the same groups of fish. This is especially so for the pelagic families and ponyfish. A combined estimate may indicate a total standing biomass of about 35,000 t, of which by far the greatest part would be small pelagics and ponyfish. This represents a mean density over the shelf of about 20 t/nmi^2, a level consistent with the low-productive tropical environment. However, the inshore reef areas, which form the main grounds of the artisanal fisheries are likely to have a higher productivity. On the basis of the DR. FRIDTJOF NANSEN surveys, however, participants at the 1984 seminar drew the conclusion that the resources which had been identified and estimated did not warrant the development of industrial fisheries. Kenya's landings of marine fish have remained stable in the period 1982–92 at about 7,000 t.

5.2 TANZANIA, 1982–83

Survey objectives and effort

The Tanzanian shelf formed part of DR. FRIDTJOF NANSEN's East African Coast programme in the early 1980s to investigate small pelagic fish with acoustic methods and demersal fish with bottom trawling. In each of the three surveys, June-July 1982, November-December 1982 and May 1983 the trawlable parts of the shelf from the Zanzibar Channel south to the Rufiji delta (sub-areas 2 and 3) were covered by a bottom trawling programme. The whole shelf was also covered three times by acoustic surveys, except for the narrow shelf south of Kilwa Kivinje in the third survey. The surveys and their main findings were briefly described in cruise reports (Myklevoll, 1982b; IMR, 1982c and 1983a) and summarized in a special report for the “NORAD-Tanzania Seminar to Review the Marine Fish Stocks and Fisheries in Tanzania” held in Mbegani, Tanzania in March 1984 (Iversen and Myklevoll, 1984a and Iversen *et al.*, 1984).

Table 5.7 shows the operational data for the three surveys. The degree of coverage for the acoustic investigations was high in all surveys.

Figure 5.2 shows the Tanzanian shelf and the sub-areas used to analyse the trawl data. Table 5.8 shows the extent of the depth strata. The sub-areas 2 and 3 identified as “Zanzibar” and “Mafia” together comprise nearly 90% of the shelf inside 200 m depth and include the main trawlable parts, therefore the bottom trawl surveys were mainly confined to these sub-areas.

Like Kenya, Tanzania has also a high diversity of marine species and the taxonomic work was supported by the participation in the second survey of Ms Gabriella Bianchi of FAO's Department of Fisheries. This survey also provided a first opportunity to test drafts of the Species Identification Sheets for the Western Indian Ocean, produced by FAO (Fischer and Bianchi, 1984).

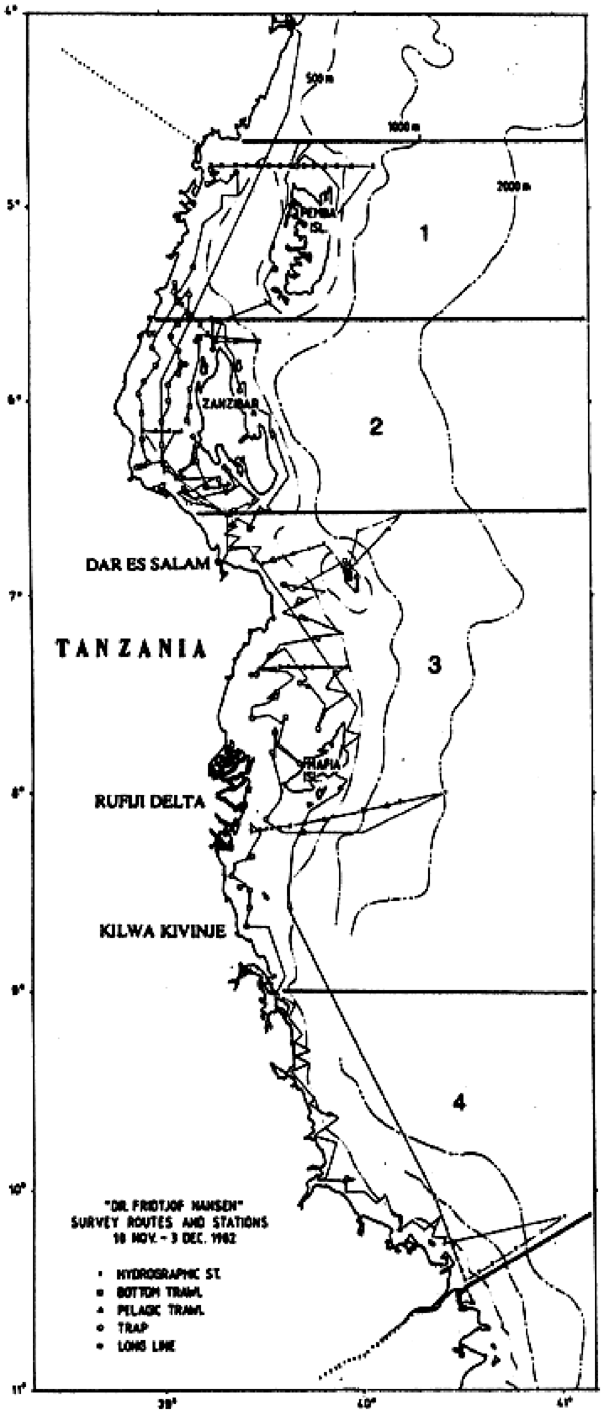

Figure 5.2 The investigated sub-areas of the Tanzanian shelf: 1) Pemba, 2) Zanzibar, 3) Mafia and 4) the southern area and survey routes of the November-December 1982 survey

Table 5.7 Details of the surveys in Tanzania

Number/Date	I Jun-Jul 82	II Nov-Dec 82	III May 83
Survey distance (nmi)	2,500	1,900	1,400
Survey area (nmi^2)	5,300	4,400	3,800
Degree of coverage	34	29	23
No. of trawl stations			
Bottom trawl	79	70	51
Pelagic trawl	20	18	4

Table 5.8 Estimates of the areas of the shelf of Tanzania by depth strata (nmi²)

Depth range	< 20 m	20–50 m	50–200 m	200–500 m
Sub-area:				
1. Pemba	100	150	200	850
2. Zanzibar	150	800	910	370
3. Mafia	600	600	770	2,150
4. Southern area	10	10	100	2,200
(Adapted from Iversen *et al.*, 1984)				

Hydrography

Sets of hydrographic profiles were worked from the coast in all surveys; the full data are presented and discussed in Iversen *et al.* (1984). The depth of the upper-mixed layer shows little change between surveys. The oxygen content of the shelf and slope waters was relatively high and is unlikely to have affected fish distribution. Surface salinity was low in May following high river runoffs at that season. The low-salinity water was restricted to inshore areas, an effect of the onshore surface transport set up by the southwest monsoon.

Pelagic fish

Charts of mean echo integrator outputs of the densities of fish in mid-water showed the highest values in localities close inshore and in the channels between the islands and within about 30 nmi of the shore in the central Zanzibar and Mafia areas. The densities of the aggregations were, however, overall low (IMR, 1982c and 1983a and Myklevoll, 1982b).

Acoustic estimates of the biomass of the fish observed in mid-water over the shelf north of 9°S (sub-areas 1, 2 and 3) were as follows: (data from Iversen *et al*., 1984 but adjusted to a target strength of -34 dB/kg for 17 cm fish)

June/July 1982	101,000 t
Nov/Dec 1982	66,000 t
May 1983	57,000 t
Mean	75,000 t

Semi-pelagics such as ponyfish were included in these estimates and may have represented a considerable part of the biomass.

Hauls with the pelagic trawl gave insignificant catches and did not represent a successful sampling method. Pelagic fish formed, however, part of the catches with the bottom trawl in shallow waters. As shown in Table 5.9 Carangidae and Clupeidae were the most common families, while Scombridae and Sphyraenidae appeared with high incidence, but with low catch rates.

Table 5.9 Tanzania: Catch rates and incidence of pelagic fish in 123 bottom trawl hauls, 10–50 m depth. Mean of all three surveys

	Mean rate (kg/h)	Highest rate (kg/h)	Incidence (%)
Clupeidae	20	326	49
Engraulidae	4	296	25
Carangidae	36	523	80
Scombridae	5	46	52
Sphyraenidae	7	235	46

The following species were among the most common of the pelagic families:

Clupeidae:	*Sardinella gibbosa, Pellona ditchela, Dussumieria acuta*
Carangidae:	*Decapterus russelli, D.kurroides, Atule mate*

Scombridae:	*Rastrelliger kanagurta, Scomberomorus commerson*
Sphyraenidae:	*Sphyraena forsteri, S. putnamiae, S. obtusata*

Demersal fish

Table 5.10 shows the mean catch rates in the bottom trawl for two sub-areas. The catches in the deep range (200–500 m) were generally low and consisted of various lizardfishes and deep-water fishes such as Myctophidae, *Chlorophthalmus* spp. and *Cubiceps* spp., apparently of little commercial interest. In a relatively narrow sector at 320–420 m on the slope off Dares-Salaam and a bit further south catches of deep-water shrimp and lobsters were obtained. The mean catch rates were low, but a few hauls gave rates up to 130 kg/h for deep-water shrimp and up to 15–16 kg/h for each of Nephropidae and Palinuridae.

The biomass in the depth range 10 to 200 m as estimated by the swept-area method was as follows, (t):

Sub-area	Jun-Jul/82	Nov-Dec/82	May/83	Mean
2. Zanzibar	13,000	17,100	21,600	17,200
3. Mafia	31,400	28,700	30,400	30,200
Total	44,400	45,800	52,000	47,400

Table 5.10 Tanzania: Mean catch rates of bottom trawl by depth range, sub-area and survey (kg/h)

Depth range		10–20 m	20–50 m	50–200 m	200–500 m	All hauls
2.	**Zanzibar**					
I	Jun-Jul 82	785	210	114	204	300
	No. of hauls	5	12	5	4	26
II	Nov-Dec 82	114	269	140	51	201
	No. of hauls	4	18	9	2	33
III	May 83	405	441	259	413	412
	No. of hauls	6	12	2	20	40
3.	**Mafia**					
I	Jun-Jul 82	356	1,160	43	191	520
	No. of hauls	5	10	2	14	3
II	Nov-Dec 82	340	319	613	146	319
	No. of hauls	4	11	4	7	26
II	May 83	203	649	521	-	414
	No. of hauls	11	8	4	0	23

On the shelf inside 200 m the most important demersal families of commercial interest were in order of abundance:

Sub-area 2 Zanzibar	**Sub-area 3 Mafia**
goatfishes	snappers
threadfin breams	goatfishes
grunts	grunts
snappers	groupers
groupers	emperors
emperors	threadfin breams

The most common demersal species in the catches are listed below by species groups families:

Snappers:	*Lutjanus bohar, L. malabaricus, L. rivulatus*, and especially in deep water: *Pristipomoides filamentosus*.
Goatfishes:	*Upeneus bensasi, U. sulphureus, U. moluccensis, U. vittatus*.
Grunts:	*Diagramma pictum, Pomadasys multimaculatum, P. kaakan*, *P. stridens*.
Threadfin breams:	*Nemipterus japonicus, N. bipunctatus, Scolopsis bimaculatus*.
Groupers:	*Epinephelus malabaricus, E. tauvina, E. areolatus*
Emperors:	*Lethrinus elongatus, L. variegatus, L. mahsena, L. rubrioperculari*s

These species are included in the group “demersal fish” in Table 5.11 which summarizes catch rates by main groups in all hauls made on the shelf.

The main species in the bottom trawl catches of the three DR. FRIDTJOF NANSEN surveys in Tanzania have been analyzed on by Yonazi (1985).

Table 5.11 Tanzania: Mean bottom trawl catch rates by species groups, sub-area and survey (kg/h)

Survey	**I Jun-Jul 82**	**II Nov-Dec 82**	**III May 83**
Zanzibar sub-area 2			
No. of hauls	22	31	20
Demersal fish	80	34	89
Ponyfishes	88	49	91
Pelagic fish	64	41	81
Sharks & rays	15	15	91
Squid	1	1	2
Others	70	72	59
Total	318	212	413
Mafia sub-area 3			
No. of hauls	17	19	23
Demersal fish	191	174	60
Ponyfishes	384	81	174
Pelagic fish	136	84	74
Sharks & rays	19	10	20
Squid	2	2	3
Others	58	35	83
Total	790	386	414

In the Zanzibar sector ponyfishes and pelagics formed on average 44 % of the catches, and in the Mafia sector as much as 59%.

Summary of assessments

The surveys covered the shelf from a depth of 10–15 m to about 500 m. Most of the survey effort was spent in the 15–200 m depth range. The shallow grounds inside the reefs which are extensive in the central part of the coast with an area of more than 1,000 nmi^2 could not be navigated by the vessel. Shallow-water shrimp resources were thus not covered by the surveys nor those of large pelagic fish, tunas and tuna-like fish in offshore waters.

The estimates of fish biomass in mid-water with the acoustic method in the central Zanzibar-and Mafia sectors ranged from 57,000 t to 101,000 t with a mean of 75,000 t. This represented pelagic fish, but included some semi-pelagics such as ponyfish.

The swept-area estimates based on bottom trawling ranged from 45,000 t to 52,000 t in the depth range 15–200 m in the sub-areas Zanzibar and Mafia, with a mean of 47,400 t. Taking into account that 30% of the pelagic fish and ponyfish biomass estimated by the swept-area method is also included in the acoustic estimate, then a combined estimate of the standing biomass is about 110,000 t for the shelf outside the reefs, and about 150,000 t for the whole central shelf if the productivity of the areas inside the reefs, not covered by the surveys, is assumed to be equal to that outside. These estimates correspond to a biomass density of 28 t/nmi^2, a somewhat higher level than that found for Kenya, but still demonstrating a modest productivity.

Iversen *et al.* (1984) concluded that the yield of Tanzania's marine fisheries of about 40,000 t might be increased if the fishing areas were extended beyond the reefs, but the prospects for this were perhaps not too good because of rather low fish densities and a predominance of ponyfish. The highest catch rates of both pelagic and demersal fish were, however, usually obtained at depths shallower than 50 m and most of this fish would probably already be available to the inshore fleet. Tanzania's marine landings are reported to have grown from about 27,000 t in 1982 to 55,000 t in 1991 (FAO, 1985 and 1993) through increases of catches of small pelagics, sardinellas and Indian mackerel, but also of demersals. These landings form a high percentage of the biomass as estimated by the DR. FRIDTJOF NANSEN.

5.3 MOZAMBIQUE, 1977–90

Survey objectives and effort

As a part of NORAD's long-term support of fisheries research and development in Mozambique, seven survey assignments with the DR. FRIDTJOF NANSEN were mounted in that country over a period of about 14 years. The particulars of these surveys are set out in Table 5.12.

Table 5.12 Data on surveys in Mozambique, 1977–90

Survey No.	Dates	No. of coverages	Objectives	Trawl stations Pelagic trawl	Trawl stations Bottom trawl	Areas
I	Aug 77-Jun 78	4	General, acoustics, trawl		272	Total shelf
II	Oct-Nov 80	3	Small pelagic fish Demersal fish Shallow-water shrimp	34	106	Sofala Bank Delagoa Bay
III	Sep 82	2	Small pelagic fish Demersal fish Shallow-water shrimp	39	60	Sofala Bank
IV	May-Jun 93	1	Small pelagic fish Shallow-water shrimp	4	53	Sofala Bank
V	Apr-May 90	1	Small pelagic fish Demersal fish	13	99	Sofala Bank Delagoa Bay
VI	Aug-Sep 90	1	Small pelagic fish Shallow water shrimp	1	52	Sofala Bank
VII	Nov-Dec 90	1	Deep-water shrimp		198	Shelf slope 17°S–27°S

The seven surveys taken together represent a full year of field operation of the vessel, a very considerable effort which delivered a great amount of information and data. This review deals only with the general findings concerning the distribution, composition and abundance of two groups of resources - small pelagic fish and demersal fish - and should be considered as a supplement to the information from many other research activities undertaken by IIP.

Hydrographical investigations, often extensive both in scope and coverage formed part of most of the surveys. However, the results of these investigations will not be included in this review as they are reported in detail in some of the survey reports as well as in special reports by oceanographers of the Instituto de Investigação Pesqueira (IIP), Maputo.

The shallow-water and deep-water shrimp surveys with the DR. FRIDTJOF NANSEN formed part of IIP's ongoing programme of investigations and assessment of shrimp resources. The results are well documented and have been discussed at special shrimp seminars organized in Maputo by the State Secretariat of Fisheries of Mozambique, therefore the findings of these surveys will not be reviewed here. However, in some cases these surveys also included observations of pelagic and demersal fish which may be of interest for this review.

The two research institutions involved in the surveys, IIP and IMR cooperated in survey planning and execution as well as in reporting. The seven surveys were described in cruise reports and analyzed in summary reports, as follows:

Survey No.	Dates	Cruise reports	Summary reports
I	Aug 77-Jun 78	IMR, 1977c, 1978b, 1978c and 1978d	Sætre and de Paula e Silva, 1979
II	Oct-Nov 80		Brinca *et al.*, 1981
III	Sep 82		Brinca *et al.*, 1983
IV	May-Jun 83		Brinca *et al.*, 1984
V	Apr-May 90	IMR, 1990b	
VI	Aug-Sep 90	IMR, 1990d	
VII	Nov-Dec 90	IMR, 1990f	

See Appendices I and II for full information.

Acoustics

In the review of the state of the acoustic instruments in the various assignments of the DR. FRIDTJOF NANSEN (see Section 2.3) it was concluded that the monitoring of the instruments during Survey I had been incomplete. No instrument reports were available for this period, but it was documented that the source level of the main echosounder had varied between the cruises (IMR, 1978c). The acoustic estimates from survey I are therefore considered less reliable than those from later surveys, therefore they have not been included in this review. The remaining acoustic surveys only cover three quarters of the year, from April to November.

Bottom conditions

The shelf of Mozambique is narrow (10–15 nmi), except in the central part, where it forms the wide Sofala Bank (Fig. 5.3). The much smaller Boa Paz Bank is situated in the northern part of the Delagoa Bay.

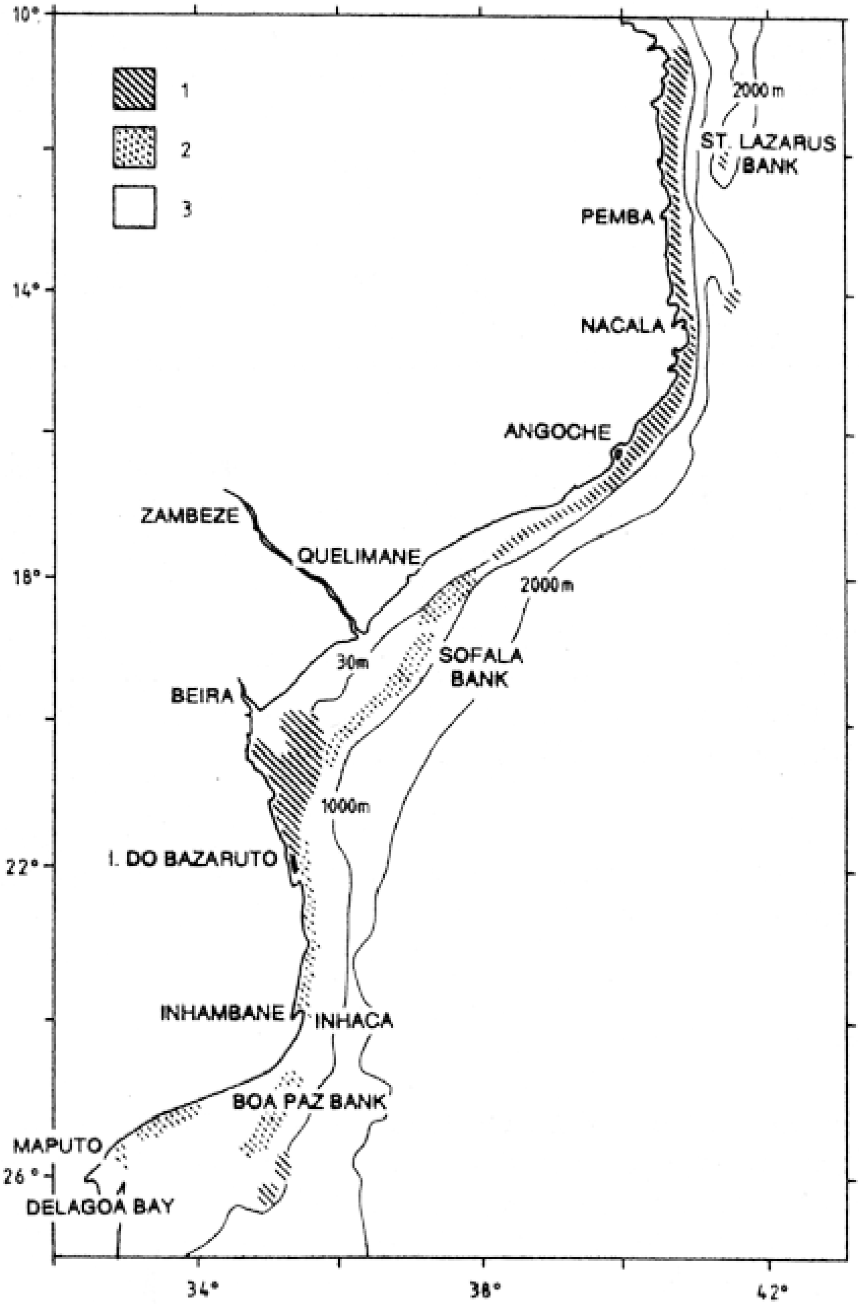

Figure 5.3 The shelf of Mozambique and its bottom conditions: 1) impossible to use bottom trawl; 2) possible with caution; 3) good trawl bottom. From Sætre and de Paula e Silva (1979)

The bottom conditions are important for the swept-area trawl method. Figure 5.3 shows that there are large areas of the shelf where bottom trawls cannot be used or must be used with caution. This created problems for representative sampling, and since many types of bottom fishes seem to aggregate on rough bottom, it is doubtful whether trawl catches from trawlable smooth bottom nearby will provide unbiased observations. The effect in a swept-area trawl assessment would be an underestimate of these types of fish.

Table 5.13 shows the area of the shelf by sectors and depth ranges (based on calculations from British Admiralty charts by Sætre and de Paula e Silva, 1979). Especially the Sofala Bank is shallow with about 80% of the area with less than 50 m depth.

Table 5.13 Mozambique: Shelf area by sectors and depth ranges. Recalculated from Sætre and de Paula e Silva (1979) (nmi^2)

Sector	Northern Border 17°S	Sofala 17 21°S	Bazaruto 21 24°30'S	Delagoa Bay-Inhaca 24°30'S Border	Total
Depth (m)					
10–50		11,140	1,240	1,420	
51–100		2,150	390	970	
101–150		140	280	420	
151–200		140	280	420	
10–200	1,800	13,570	2,190	3,230	20,790

The narrow shelf north of Angoche was only covered in survey No. I. Subsequent surveys were limited to the Sofala Bank and included twice the Delagoa Bay. In the last survey the slope of the shelf from 17°S southwards was covered to assess deep-water shrimp.

Species identification was, for the early surveys, mostly based on Smith (1972) and from surveys V-VII the special field guide for species identification prepared for Mozambique by Fischer *et al.* (1990). In surveys III through VII (1982–1990) records of the trawl stations and their catches are available in the NAN-SIS data bank.

Mainly because of bottom conditions most of the survey effort was expended in the Sofala Bank sector, with occasional extensions to other areas. Therefore, the majority of the results discussed below refer to the Sofala Bank only.

Acoustic estimates of pelagic fish

The degree of coverage for the acoustic investigations was estimated at 10 in survey V and 9 in survey VI. These surveys repeated the patterns of coverage from the previous surveys and the effort thus seems to have been adequate. Figure 5.4 shows, as an example, the survey routes and stations in the two surveys of the Sofala Bank in 1982.

Maps of the geographical distribution of small pelagic fish by integrator reading levels attributed to this group are available from surveys I, IV, V and VI. They show no recordings outside about 200 m depth and the highest densities were found at shallow depths (50 m and less), and mainly in the central part of the Sofala Bank between Quelimane and Beira.

Reliable estimates of the abundance of pelagic fish based on the echo integration technique are available from surveys II, III, IV, V and VI.

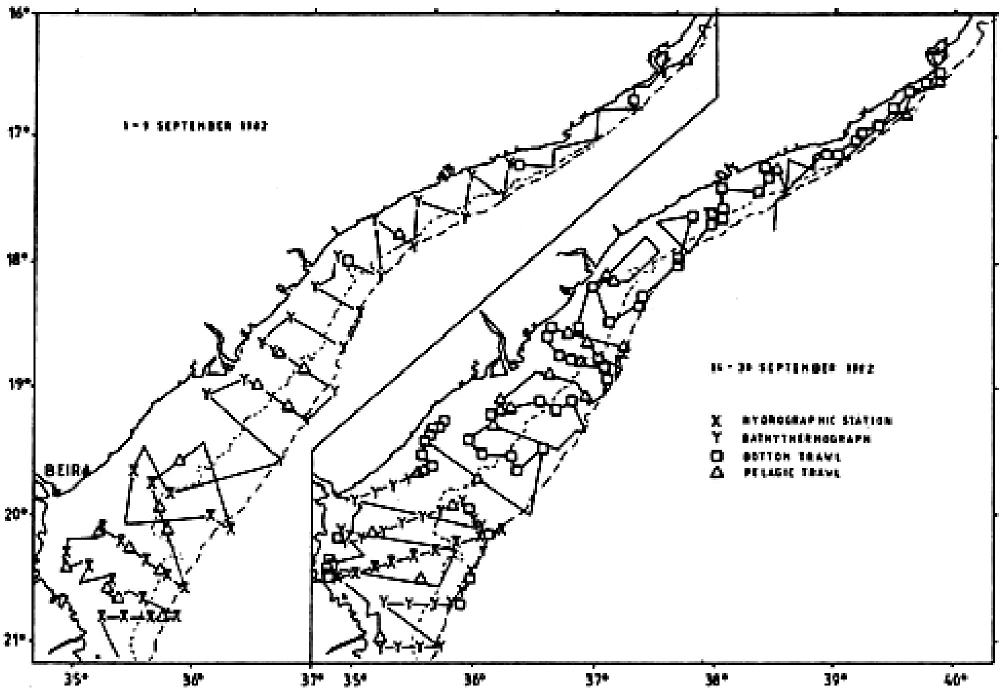

Figure 5.4 Survey routes and stations in the two 1982 surveys

As described in Section 3, the conversion factor C used in the acoustic method for estimating the biomass of fish from the observed integrator readings, was for survey II based on a target strength (TS) of -36 dB/kg (for 17 cm fish), for surveys III and IV on TS = -35 dB/kg and for surveys V and VI on TS = -34 dB/kg. In order to make the estimates comparable and since a TS level of -34 dB/kg now seems more appropriate, the biomass estimates reported from survey II have been reduced by 37% and those from surveys III and IV by 21%.

Table 5.14 Mozambique: Acoustic estimates of the biomass (t) of small pelagic fish adjusted to the same level of target strength, TS = -34 dB/kg

Survey		**Biomass (t)**
II	October-November 1980	100,000
III	September 1982	160,000
IV	May-June 1983	190,000
V	April-May 1990	210,000
VI	August-September 1990	130,000

Table 5.14 shows the adjusted estimates. A considerable part of the variation is likely to have been seasonal or inter-annual changes in stock sizes. The simple mean is 158,000 t and using the proportions by families derived from surveys III and V (see below) the deeper shelf group of Carangidae and Scombridae represents about 100,000 t and the shallow water assemblage of Clupeidae and Engraulidae about 58,000 t. The biomass of the latter group is likely to be underestimated because of the probable distribution of these species into the inshore waters not covered by the surveys. This group also showed large variations in biomass, viz. 70,000 t in survey III and 120,000 t in survey IV. In survey VI the acoustic coverage was extended to include the shelf south of the Sofala Bank, from Bazaruto to the Boa Paz Bank. The estimated biomass of small pelagic fish in that area was 24,000 t.

Species composition of pelagic fish

Information on the composition of the pelagic fish is available from the fishing trials. The composition by families in catches from aimed fishing with the pelagic trawl in surveys III and V, (Table 5.15) showed a predominance of Carangidae, Clupeidae and Engraulidae, but the catches especially in the 1990 survey were small and the results are unlikely to be representative of the true relative abundance of the groups.

Table 5.15 Mozambique: Mean catch rates of pelagic families in aimed fishing with mid-water trawl (kg/h)

Survey	**III**	**V**
No. of hauls	39	13
Carangidae	17	6
Clupeidae	26	6
Engraulidae	21	3
Scombridae	3	7
Sphyraenidae & Trichiuridae	5	3
Total	72	25

Pelagic fish formed also a substantial part of the catches in the bottom trawl as shown by the summary data of main groups in Table 5.16. The use of these more comprehensive data to analyse the composition of the group revealed (Table 5.17) a depth relationship as also discussed by Sætre and de Paula e Silva (1979) and Brinca *et al.* (1981): both surveys showed that Carangidae and Scombridae dominated the pelagic group in hauls deeper than 25 m, while Clupeidae and Engraulidae had the highest catch rates in the 10–25 m range.

Table 5.16 Sofala Bank: Mean catch rates of main species groups with the bottom trawl, 1982 and 1990 (kg/h)

Survey	**III**	**V**
No. of hauls	62	72
Pelagic fish	104	105
Demersal fish	82	109
Shrimp	5	4
Squid	2	9
Others	26	26
Total	220	253

Table 5.17 Sofala Bank: Catch rates of families of pelagic fish in bottom trawl by depth strata (kg/h)

Depth m	**10–25**	**26–50**	**50–75**	**75–100**
Survey III				
No. of hauls	40	15	7	0
Carangidae	9	119	17	
Clupeidae	43	2	1	
Engraulidae	26			
Scombridae	6	29	5	
Sphyraenidae	7	3	1	
Trichiuridae	8			
Survey V				
No. of hauls	34	20	15	3
Carangidae	16	44	135	97
Clupeidae	36	1	2	
Engraulidae	24			
Scombridae	11	27	13	18
Sphyraenidae	6			
Trichiuridae	11			

The bottom trawl catch composition in the range 10–25 m depth is similar to that of the pelagic hauls, of which a major part was from the inner shallow part of the shelf. This indicates that the catch rates in the bottom trawl hauls reflected the abundance of the various families of pelagic fish over the shelf area covered by this range. Assuming that this was the case also for the deeper parts of the shelf and using the areas of the Sofala Bank shelf reported in Brinca *et al.* (1981), the estimates of the composition of small pelagic fish shown in Table 5.18 were obtained. The two sets of data agree in showing that Carangidae and Scombridae which inhabit the deeper parts of the Sofala Bank represented about two-thirds of the biomass of the small pelagic fish, while Clupeidae and Engraulidae found predominantly on the inner parts, amounted to about 25%. The latter families may be under-represented in these estimates because they can be expected to be abundant also on the shallow shelf inside the 10 m depth limit of the survey. The short-lived anchovies are likely to have an annual production cycle and this may not have been covered by the two surveys analysed here. In the coverages of September 1977, April-June 1978 and May-June 1982 about half the total biomass of small pelagic fish was reported to be anchovies (*Stolephorus* spp.).

Table 5.18 Sofala Bank: Composition of small pelagic fish estimated from catch rates in bottom trawl by depth ranges and shelf areas (%)

Survey	**III**	**V**
Carangidae	51	49
Clupeidae	17	15
Engraulidae	10	10
Scombridae	14	19
Sphyraenidae	4	2
Trichiuridae	3	4

There is a large number of species of pelagic fish in the Mozambique fauna, but relatively few make up the main part of the biomass. The frequency of occurrence and the mean catch rates in bottom trawl for the dominating species of each family are shown in Table 5.19. Various *Stolephorus* spp. which occurred in about half of the pelagic hauls in each of the surveys (but represented only 16% and 3% of their total catches), should be added to the Engraulidae. With this addition the list of species shown in Table 5.19 is similar to the composition of main pelagic fish on the Sofala Bank reported from surveys I, II, and IV.

Table 5.19 Sofala Bank: Bottom trawl dominating species of pelagic fish, incidence (%) and mean catch rate (kg/h) by surveys

Survey	**III**		**V**	
	Incidence %	**Catch rate kg/h**	**Incidence %**	**Catch rate kg/h**
Carangidae				
Decapterus macrosoma	13	14	28	11
Decapterus russelli	19	12	52	32
Carangoides malabaricus	26	2	38	3
Clupeidae				
Pellona ditchela	42	17	15	15
Sardinella fimbriata	16	3		
Sardinella gibbosa	11	2		
Hilsa kelee	16	2		
Engraulidae				
Thryssa vitrirostris	44	17	17	10
Scombridae				
Scomberomorus commerson	35	6	51	10
Scomberomorus guttatus	23	2		
Rastrelliger kanagurta	26	4	38	5
Sphyraenidae				
Sphyraena chrysotaenia	18	5		
Sphyraena jello	11	2		
Trichiuridae				
Trichiurus lepturus	25	5		

Biomass estimates of demersal fish

The bottom trawl data from surveys III (1982) and V (1990) give the best coverage of the Sofala Bank and are available in the NAN-SIS databank. These data were analysed further in this review.

The trawl data may be used for estimates of the standing biomass. In surveys III and V the trawl stations were distributed randomly by pre-defined strata. For the purpose of estimation of fish biomass from swept-area calculations simple depth strata have been used based on the depth configuration shown by Brinca *et al.* (1983) with the fish densities from Tables 5.21 and 5.22. The effective trawl width is as discussed in Section 2.1 assumed to have been 18.5 m and the catchability coefficient 1. The results are presented in Table 5.20. The estimates for the pelagic fish are as anticipated, considerably lower than those obtained by the echo integration method. The relationship between the two types of biomass estimates will vary between areas depending on fish behaviour and bottom depth, but the ratio found here is not unreasonable.

Table 5.20 Mozambique: Biomass estimates from swept-area trawl surveys (t)

Survey	**III Sep. 1982**	**V Apr-May 1990**
Demersal fish	52,000	52,000
Pelagic fish	58,000	47,000
Others	17,000	16,000
Total	127,000	115,000

The estimate of 52,000 t for the demersal fish in the two surveys is similar to that which can be calculated from the densities of demersal fish reported from survey II, 1980. Weighted mean densities by depth ranges from Table 2 in Brinca *et al.* (1981) gave a total biomass estimate of 54,000 t. From a series of surveys with various vessels in 1977–78 Sætre and de Paula e Silva (1979) reported a demersal fish biomass on the Sofala Bank based on the swept-area method of 67,000 t in summer and 36,000 t in winter (with a mean of 52,000 t).

Previous estimates of a demersal fish biomass on the Sofala Bank of 100,000–120,000 t (Sætre and de Paula e Silva, 1979, Brinca *et al.*, 1983) were partly based on acoustics, partly on an assumption of an effective width of the trawl of only half of that used here.

Based on the simple assumption that the fish densities for the rest of the shelf of Mozambique inside the 100 m depth are the same as those estimated for the Sofala Bank, estimates for the whole shelf were obtained by raising those of the Sofala Bank by 44% resulting in about 220,000 t of pelagic fish and 97,000 t of demersal fish and other species.

Tables 5.20 and 5.21 show the densities by main families of demersal fish and other taxa and for depth strata, estimated from the mean catch rates. (Conversion to catch rates is obtained by multiplication by 30). Pelagic fish (defined as the families listed above) represented roughly half the catches, a level also reported from surveys I, II, IV and VI. Their proportion varies with depth and according to Sætre and de Paula e Silva (1979) also by season.

More than 40 families of demersal fish were identified in previous surveys (Brinca *et al.*, 1981), but only five to ten families make up the main bulk of the catch. From those listed in Tables 9 and 10 in Brinca *et al.*, 1981 and similar data reported from the other surveys it appears that goatfishes and lizardfishes are common over the whole shelf, while croakers, ponyfishes and grunts are typical for the shallow waters and threadfin breams and snappers for the deeper parts of the shelf.

The estimated mean density of pelagic fish was about the same in the two surveys, while the total for the demersal group appears to be about 30% higher in survey V. This is, however, only a sampling effect caused by a difference in the density of hauls in the various depth ranges. The estimates of biomass were, as will be shown later, the same for the two surveys.

The density of Cephalopoda was about five times higher in survey V than in survey III. This may be a seasonal effect, as the squids are known to have seasonal cycles in abundance. The other taxa appeared with about the same densities in the two surveys.

Table 5.21 Sofala Bank, survey III, 1982: Density of main demersal families and other taxa by depth ranges (t/nmi^2)

Depth range (m)	10–24	26–50	51–75	10–75
No. of hauls	40	15	7	62
Leiognathidae	0.52	2.91	0.04	1.05
Mullidae	0.55	0.76	1.02	0.67
Sciaenidae	0.66			0.43
Pomadasyidae	0.34	0.26	0.19	0.31
Sparidae	0	0.24	0.04	0.06
Nemipteridae	0	0.27	0.09	0.08
Synodontidae	0.05	0.10	0.07	0.07
Lutjanidae	0	0.11	0	0.02
Serranidae	0	0.09	0	0.0
Ariidae	0.04	0	0	0.03
Sum 10 demersal families	2.16	4.74	1.45	2.74
Sum 6 pelagic families	3.30	5.10	0.81	3.45
Cephalopoda	0.04	0.14	0.06	0.06
Sharks	0.12	0.04	0.06	0.10
Rays	0.05	0	0	0.03
Commercial shrimp	0.25	0.01	0	0.15
Others	0.75	1.14	0.27	0.75
Total	6.67	11.17	2.65	7.28

Table 5.22 Sofala Bank, survey V, 1990: Density of main demersal families and other taxa by depth ranges (t/nmi^2)

Depth range (m)	10–24	26–50	51–75	76–100	10–100
No. of hauls	34	20	15	3	72
Leiognathidae	0.33	0.01	1.35	0	0.44
Mullidae	1.13	0.78	1.41	4.07	1.21
Sciaenidae	0.6	0	0	0	0.30
Pomadasyidae	0.53	0.10	0.36	0	0.36
Sparidae	0	0.04	0.02	0	0.02
Nemipteridae	0.01	0.35	0.52	0.39	0.23
Synodontidae	0.26	1.25	1.32	0.14	0.75
Lutjanidae	0	0.49	0.29	0	0.2
Serranidae	0	0	0.11	0.23	0.03
Ariidae	0.21	0	0	0	0.10
Sum 10 demersal families	3.09	3.02	5.38	4.83	3.64
Sum 6 pelagic families	3.43	2.39	5.00	3.85	3.50
Cephalopoda	0.22	0.32	0.46	0.49	0.29
Sharks	0.13	0.04	0	0.03	0.07
Rays	0.09	0	0	0	0.04
Commercial shrimp	0.30	0	0.01	0	0.14
Others	0.58	0.34	1.81	0.34	0.75
Total	7.84	6.11	12.66	9.54	8.43

An important trawl fishery for penaeid shrimps takes place on the shallow parts of the Sofala Bank. The effort in this fishery was at a reduced level in a period in the 1970s, but increased from 1980 (FAO, 1981). The fish by-catch in the fishery was estimated at well over 20,000 t per year in the late 1980s. A substantial part of this was demersal fish of which croakers, grunts, goatfishes and ponyfishes formed important components (Brinca *et al.*, 1983).

Changes in the shrimp fishery over the period covered by the surveys may have affected the composition of the demersal fauna. In order to determine if this is the case, pertinent data have been compiled in Table 5.22. This table shows the estimated total densities of the main demersal families in shallow parts of the Sofala Bank and the densities of the typical by-catch families for the surveys for which these data are available, viz., surveys II through VI.

Sætre and de Paula e Silva (1979) found a seasonal variation in the density of demersal fish in the shallow waters at the Sofala Bank with the mean density in summer, October to March double that of the winter, April to September. The high densities of survey II may thus have been a seasonal effect. An alternative explanation is that a reduced shrimp fishery in the 1970s had allowed the demersal stocks, especially croakers and grunts to expand, but with increased fishing in the early 1980s they were reduced to the relative stable levels shown by the subsequent surveys.

At the species level there is, as might be expected, more variability in the density between surveys III and V for which data are available, but there was, as shown in Table 5.23 a general consistency in the domination of each family by relatively few species.

Table 5.23 Sofala Bank, demersal fish, shallow water: Estimated densities of all main demersals and of "by-catch families" (t/nmi^2)

		All demersal	Ariidae,	Sciaenidae,	Pomadasyidae,	Mullidae
Depth range (m)		**< 50**	**< 25**	**< 25**	**< 50**	**< 50**
II	Oct-Nov 1980	3.75	0.16	1.38	1.00	0.47
III	Sep 1982	2.16	0.04	0.66	0.32	0.60
IV	May-Jun 1983	2.48	0.07	0.65	0.25	0.81
V	Apr-May 1990	3.09	0.21	0.62	0.37	1.00
VI	August 1990	2.12	0.29	0.53	0.50	0.36

Data source: survey II Brinca *et al.* (1981), Table 3, otherwise NAN-SIS

In an analysis of demersal assemblages of fish on the East African continental shelf, Bianchi (1992a) found a fish fauna in Mozambique largely similar to that off Tanzania and Kenya. A homogeneous and well-defined group could be identified in shallow parts of the Sofala Bank, but in deeper waters the species represented groups similar to those found at corresponding depths in Tanzania and Kenya.

Table 5.24 Sofala Bank: Species composition of main demersal families in surveys III (1982) and V (1990). Proportion of total catch by weight of family (%)

Survey	**III**	**V**
Mullidae		
Upeneus vittatus	58	31
Upeneus bensasi	18	36
Upeneus moluccensis	13	4
Upeneus tragula	2	22
Upeneus sulphureus	7	4
Sciaenidae		
Johnius belangeri	51	70
Otolithes ruber	42	27
Leiognathidae		
Leiognathus elongatus	52	77
Leiognathus equulus	22	5

Secutor insidiator	20	18
Pomadasyidae		
Pomadasys maculatum	58	67
Pomadasys kaakan	26	17

The Delagoa Bay including the Boa Paz Bank was only covered with demersal trawl programmes in surveys I and V. Survey V showed an assemblage different from that of the Sofala Bank with dominance of sea breams and snappers in the depth range 25–50 m (Boa Paz Bank). Echosounder traces of semi-demersal fish were mostly found over rough stretches of bottom and it seemed therefore doubtful whether trawl catches provided unbiased observations of the composition and density of the demersal fish fauna (IMR, 1990b). (A similar bias will also have affected the observations further north since there are many parts of the Sofala Bank where rough bottom did prevent sampling by trawl.)

Review of findings

The Mozambique shelf was well researched in the period 1977–90 and the consistency of the main results confirms the adequacy of both the methods used and the execution of the programmes.

The standing stock of demersal fish was estimated at about 100,000 t for the entire shelf. There appeared to have been very little change in the mean density of this group over the period although some families at shallow depths, e.g., croakers and grunts, may have declined in the early 1980s as a result of increased effort in the shrimp fishery.

The variation of the biomass estimates of pelagic fish on the Sofala Bank between 100,000 and 210,000 t may well have been an effect of seasonal fluctuations in the stock of short-lived small pelagics.

It should be noted that neither the acoustic nor the trawl surveys covered the stocks of large pelagic fish, tunas and tuna-like species, which may be an important resource along the deeper shelf and in the adjacent waters outside.

The 1990 total catch was estimated at about 100,000 t, (source: DAP/SEP; IIP) well over half of which was shrimp by-catch and artisanal catch presumably consisting of small pelagic and small demersal fish. This might indicate a fair degree of utilization of the demersal potential, although surveys V and VI showed the presence of large-sized specimens of fish on hard bottom, seabreams, snappers and groupers suggesting a low rate of exploitation on these grounds.

The landings from directed fisheries for small pelagics: scads, mackerel, sardine and others were estimated at 10,000 to 15,000 t in 1990. With a standing stock estimate of small pelagics of more than 200,000 t there would seem to exist a considerable potential for increased utilization of this type of fish even if the group also form a considerable part of the shrimp by-catch and the artisanal catch.

Various attempts have been made by Mozambique's fishery administration to test the possibility of a higher utilization of this resource. A programme to determine if the stocks of small pelagics could be fished on an industrial scale was conducted in a joint activity between the Government of Mozambique and NORAD in 1985–87. A Norwegian fishing vessel of 21 m LOA (148 GRT) was used in a series of trial fishing experiments with purse-seine and mid-water trawl between August 1985 and September 1987. As reported by Sørensen *et al.* (1988), only low catch rates could be obtained with either gear although the fishing methods as such were judged to be effective. The failure of the trials were reported to be lack of areas with high densities of fish, although small schools and scattered fish were found. A commercial industrial fishery on these resources could thus not be recommended, but further trials were suggested with semi-pelagic pair trawls or high-opening bottom trawls on the Sofala Bank and small purse-seines and local boats in the Delagoa Bay.

This observation of lack of areas with high concentrations of pelagic fish is confirmed by an analysis of the distribution of acoustic observations of densities from surveys V and VI in 1990.

Table 5.25 shows the distribution of the biomass by ranges of density at which the pelagic fish was recorded. The general experience from other DR. FRIDTJOF NANSEN surveys is that only densities higher than 300 t/nmi^2 will represent areas where small pelagic fish aggregate in "school areas" suitable for commercial purse-seining. The data in Table 5.25 confirm the general impression obtained from the surveys of an absence of high density school areas suitable for purse-seining.

A fishery for scads and mackerel with bottom trawls was developed on the Sofala Bank and Boa Paz in the late 1970s and peaked in 1978 with a catch of 17,000 t and declined to 6,000– 7,000 t in the first half of the 1980s. In an analysis of the fishery by 1984–85 Gislason and Sousa (1989) recommended that fishing effort could be gradually increased. The acoustic estimates of biomass confirm a higher potential for these stocks.

Table 5.25 Sofala Bank: Distribution of biomass of small pelagic fish by density levels (%)

Density (t/nmi^2)	Survey V April 1990	Survey VI August 1990
2–6	10	29
7–20	29	33
21–60	36	35
61–200	25	3
Source: IMR, 1990d		

In general the productivity of the Mozambique shelf as measured from the estimated mean biomass of demersal and pelagic fish from the surveys over the period 1977–90 is at a moderate level for tropical areas with a mean density of 17 t/nmi^2. Limited areas of higher productivity may exist inshore. No information on the potentials of the open sea outside the shelf is available from these surveys.

6 SURVEYS IN THE ATLANTIC OCEAN OFF NORTHWEST AFRICA

From April 1981 to March 1992 the DR. FRIDTJOF NANSEN was deployed in various large-scale resource surveys off Northwest Africa. The activities formed part of the UNDP/FAO projects GLO/79/011 (Assessment and Development of World Renewable Marine Resources) and GLO/92/013 (Global Investigations of Fishery Resources) to which NORAD gave its support.

History of fisheries and research

Northwest Africa has a considerable history of artisanal and industrial fisheries and of fishery research. The large-scale industrial fisheries for the pelagic stocks off Northwest Africa date from the late 1960s. By the mid 1970s the total catch from FAO statistical area 34, the Eastern Central Atlantic, approached 4 million t, about 60% of which was taken by foreign distant-water fleets. The implementation of EEZs reduced foreign access and the total yield from the region declined for some time, to pick up again in the late 1980s, passing 4 million t again by 1990. Subsequent years showed, however, a trend of decrease in total catch caused mainly by a reduced participation of distant-water fleets in the fisheries for small pelagics.

The history of the fisheries over nearly three decades of industrial exploitation indicates that the pelagic stocks of the Canary Current upwelling system may have been more stable than those found in the three comparable systems, the Benguela Current in the

Southeast Atlantic and the California- and Humboldt Currents in the Eastern Pacific. Stock collapses such as those of the Namibian- and Californian sardines and the Peruvian anchoveta do not seem to have occurred in the large stocks of sardine and sardinellas off Northwest Africa. It can be speculated that this difference in stock variability is caused by more stable environmental conditions in the Canary Current system or by a more moderate fishing pressure or both.

Important contributions to knowledge of the region were made through the international Co-operative Investigation of the Northern part of the Eastern Central Atlantic (CINECA). Sponsored by ICES, FAO and IOC, the programme was based on field activities by a large number of research vessels over the period 1970–77. Results were presented and discussed at a symposium in 1978 (Hempel, 1982).

With a mixture of bilateral support and assistance from FAO/UNDP, fishery research centres were established in many coastal countries in the region during the 1960s and 1970s. Other countries, especially France, Spain and the former USSR made important investigations in the region and, in recognition of the potentials of the resources off Northwest Africa, FAO established in 1967 a Committee for the Eastern Central Atlantic Fisheries (CECAF). The work within CECAF has been supported by a series of regional programmes for fisheries development and management.

Hydrography

The investigations with the DR. FRIDTJOF NANSEN in this highly diversified region were as far as possible organized by ecologically defined sub-regions. The surveyed area (Figure 6.1), covers the coastal shelf and immediately adjacent waters and ranges from Safi, in Morocco, to Ghana (from about 32°N to 5°N) a distance of some 2,500 nmi.

Strong seasonal variability and a sharp contrast between the waters in the north and the south are the main characteristics of the Canary Current upwelling system. The upwelling generated by this east boundary current reaches its southernmost extent off Guinea, at about 10°N, in winter when trade winds are strongest, while during summer it is restricted to the region north of Cape Blanc (near Nouadhibou, 21°N), and then a northward flow dominates the surface and sub-surface layers south of Cape Blanc.

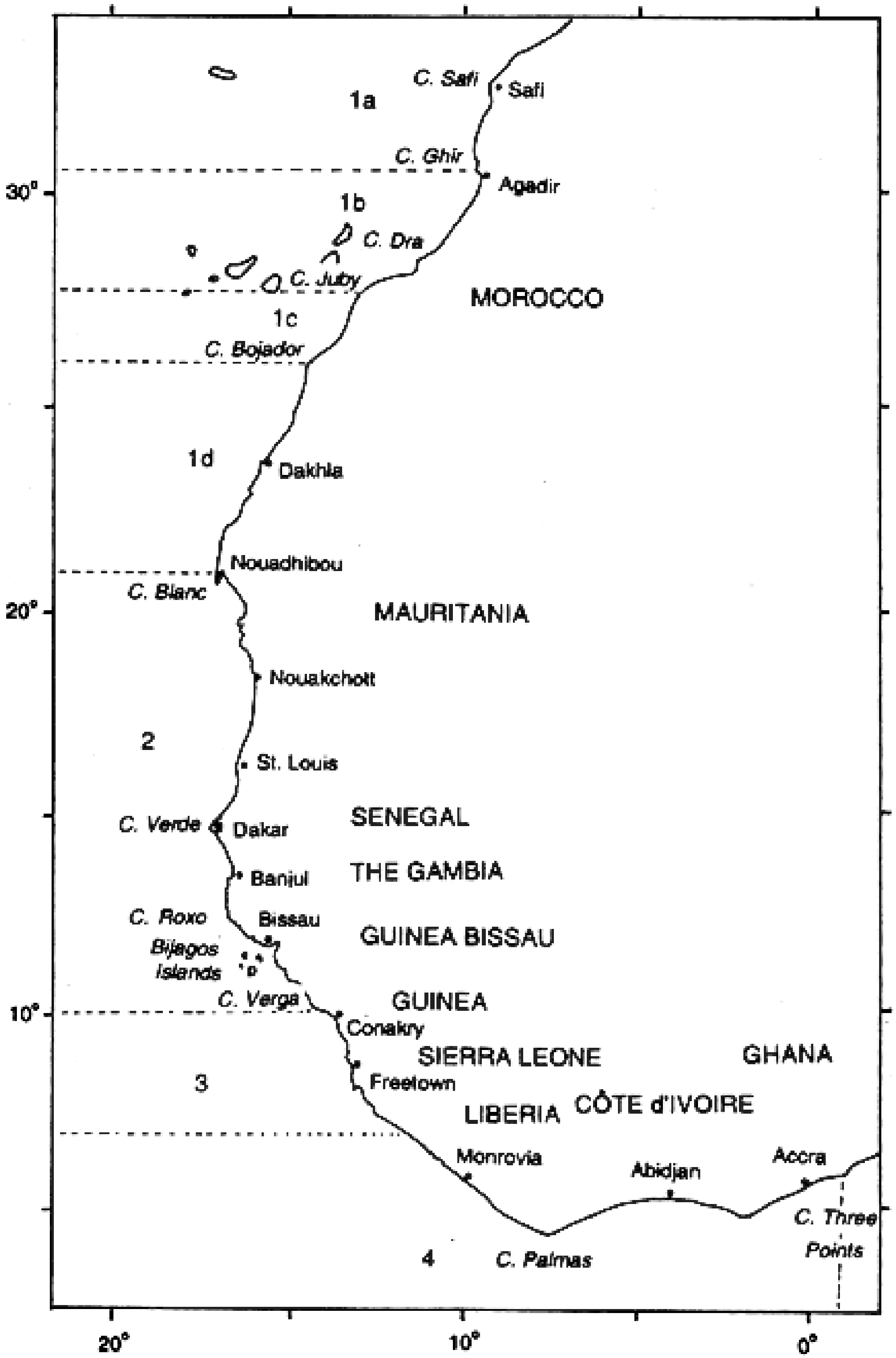

Figure 6.1 Map of coast from 32°N in Morocco to Ghana showing the shelf area and names of geographical sites used in this report

The seasonal shift in upwelling results in a coastal surface temperature front in the southern part of the system between cold, upwelled water to the north and warm tropical water to the south. This front is found near Cape Blanc (21°N) in August-September and south of Sherbro Island (6°N) in March, a seasonal shift of some 15 degrees or 900 nmi.

Speth and Detlefsen (1982) studied the seasonality of upwelling off Northwest Africa from an analysis of zonal temperature differences: coastal averages minus mid-ocean temperature. Figure 6.2 shows the mean differences by latitudes for the period 1969–1976. From this study three different upwelling regions can be distinguished:

1. between 20°N and 25°N upwelling exists throughout the year with peaks of activity in spring and autumn;
2. from 25°N and northwards past 30°N upwelling prevails during summer and autumn with a peak at 30°N;
3. from 20°N and southwards to 10°N upwelling takes place during late winter and spring.

Another type of upwelling is found along the coasts of Côte d'Ivoire and Ghana. It is not locally wind-driven, but the sea-surface temperature is seen to drop regularly by several degrees for 14-day periods during the northern summer. This is coupled with reversals of currents on the shelf, periodic lifting of the thermocline and advection of nutrient-rich water towards the coast. At the origin of this event are believed to be offshore depressions and bulges of the thermocline transplanted from the west eastward along the equator (Tomczak and Godfrey, 1994).

These characteristics of the environment must be expected to affect the composition and abundance of the resources. The conditions for the highest sustained biological production should be expected in the area from Cape Juby (28°N) to Cape Blanc (21°N).

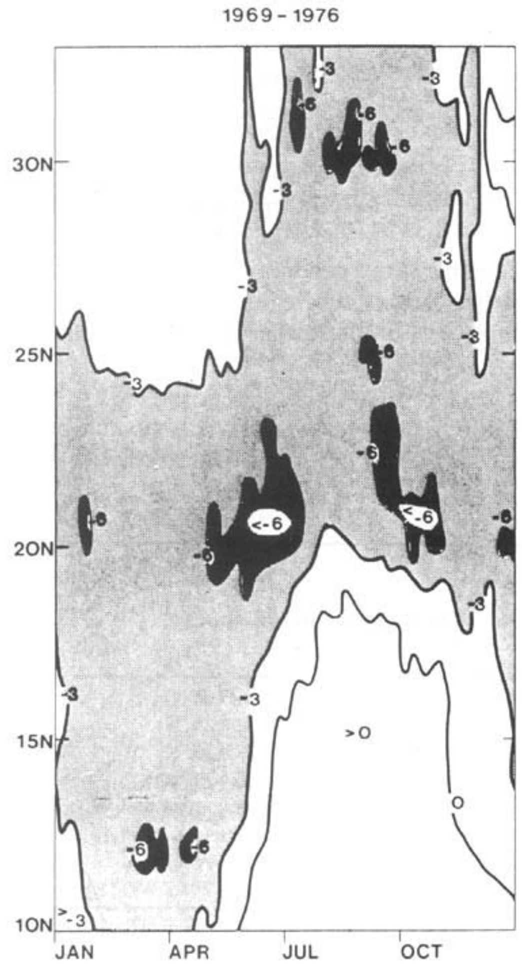

Figure 6.2 Seasonality of upwelling off Northwest Africa. Mean temperature difference between coastal areas and mid-ocean (K) for the period 1969–1976. Negative values indicate coastal temperatures colder than mid-ocean.

Source: Speth and Detlefsen (1982) Figure 14

Cape Blanc marks the division of the region into a northern, temperate regime and a southern, sub-tropical regime, thus creating two main sub-regions for assemblages of small pelagics, to the north mainly temperate species: European sardine (*Sardina pilchardus*), Atlantic horse mackerel (*Trachurus trachurus*) and chub mackerel (*Scomber japonicus*), and to the south mainly tropical species: round sardinella (*Sardinella aurita*), flat sardinella (*S. maderensis*), Cunene horse mackerel (*Trachurus trecae*), yellow scad (*Decapterus rhonchus*), other Carangidae as well as triggerfish (*Balistes capriscus*).

Survey objectives and operational data

The objectives of the assignments in this region were:

1. to provide information on the state of the main exploited resources, especially the abundant stocks of small pelagic fish;

2. to support the development of ongoing research, in particular to contribute to improved methodologies for acoustic surveys.

The time series generated was, however, discontinuous and with large differences in coverage of the various sub-regions. A review of all survey activities is presented by sub-regions in Table 6.1, while further operational details are given in seperate tables for each sub-region.

Table 6.1 Overview of months of coverage (1–12) of DR. FRIDTJOF NANSEN surveys off Northwest Africa by subregions, 1981–92 and of instruments used

No.	Sub-regions and Divisions	Survey No. Year					
		I	II	III	IV	V	VI
		1981	1982	1986	1986	1989	1992
1a	C.Safi-C.Ghir (32° -30°30'N)	-	-	-	-	9	1
1b	C.Ghir-C.Juby (30°30'-28°N)	-	3, 4	9	11	9	1
1c	C.Juby-C.Bojador (28°-26°N)	-	-	-	11	9	1
1d	C.Bojador-C.Blanc (26° -21°N)	12*	3*	9	11, 12	9	1
2	C.Blanc-Bijagos Archipelago (21° -10°N)	4, 5, 9	2, 3	8, 9	11, 12	-	2, 3
3	C.Verga-C.Mount (10°-7°N)	5, 6	2	8	-	-	-
4	C.Palmas-C.Saint Paul (7°45'W-1°E)	6	-	-	-	10	-
5	Ghana-Congo	8, 9	-	-	-	-	-
6	C.Verde Islands**	11					
	Echosounder	EKS	EKS	EK400	EK400	EK400	EK500
	Echo integration	QM	QM	QD	QD	QD	EK500

* Incomplete coverage, outside 12 nmi only
** The surveys of the Cape Verde islands have not been reviewed in this report.

Sub-region 1 has been divided into 4 parts:

1a Cape Safi-Cape Ghir (Agadir) (32° -30°30'N)
1b Cape Ghir-Cape Juby (30°30'-28°N)
1c Cape Juby-Cape Bojador (28° -26°N)
1d Cape Bojador-Cape Blanc (26° -21°N)

Division 1d, between Cape Bojador and Cape Blanc could not be covered adequately in the first surveys. For security reasons the vessel only covered the area outside the 12 nmi zone, and only with acoustic instruments.

In later years survey effort has been concentrated on pelagic stocks in the northern part, while sub-areas 3 (Guinea-Sierra Leone) and 4 (Côte d'Ivoire-Ghana) have received less attention. Sub-area 5 (Togo to Congo) and Sub-area 6 the Cape Verde Islands were surveyed only once and therefore have not been discussed in this report.

The main objective of all surveys was to describe the distribution, composition and abundance of the small pelagic fish based on the acoustic integration technique combined with trawl sampling for identification. The acoustic equipment used during each survey has also been indicated in Table 6.1.

The assessment of demersal fish, by bottom trawl surveys, was an additional objective in some areas from Senegal to Guinea Bissau in 1992, off the Gambia in 1986, on the shelf Bissagos Archipelago-Sherbro Island in 1986 and the Cape Verde Islands in 1981.

The surveys were briefly described in cruise reports, e.g. IMR, 1982, 1986g, 1986h, 1987a, 1987b, followed by summary reports:

1981–82:	Strømme, Sætersdal and Gjøsæter, 1982 Strømme, Sundby and Sætersdal, 1982 Strømme, 1983a (also Strømme, 1984e) and Strømme, Føyn and Sætersdal, 1983
1986:	Strømme and Sætersdal, 1987a and b.

Cruise reports of surveys made in 1989 and 1992 were more extensive, but real summary reports have not been produced. The relevant reports are:

1989:	IMR, 1989e and 1989f
1991:	IMR, 1992a, b, c and d.

The present review is limited to a brief description of the main findings by sub-regions and stocks of pelagic fish. These findings will be considered in the light of other information on the stocks and data from the fisheries in the hope that this may give insight into the distribution and fluctuations of the stocks in the region and their state of exploitation in the survey period. Due to the discontinuous nature of the programme, however, the resulting stock histories are far from complete.

6.1 SUB-REGION 1: CAPE SAFI TO CAPE BLANC (32°-21°N)

Survey effort

The operational data for the surveys in this sub-region are given in Table 6.2. The number of days' work gives a rough impression of the effort used. The degree of coverage (d) of the acoustic surveys was gradually increased in the northern area from 13 in 1982 and 14 in 1986, 17 in 1989, to 29 in 1992. Furthermore, in the later surveys the inner shelf, 10–50 m depth, the main area of distribution of sardine and anchovy, was more intensively covered than the outer part of the shelf (50–200 m) (Figure 6.3). Sampling for identification may have been inadequate in the first surveys and therefore the most reliable information is considered to be that based on the 1986, 1989 and 1992 surveys.

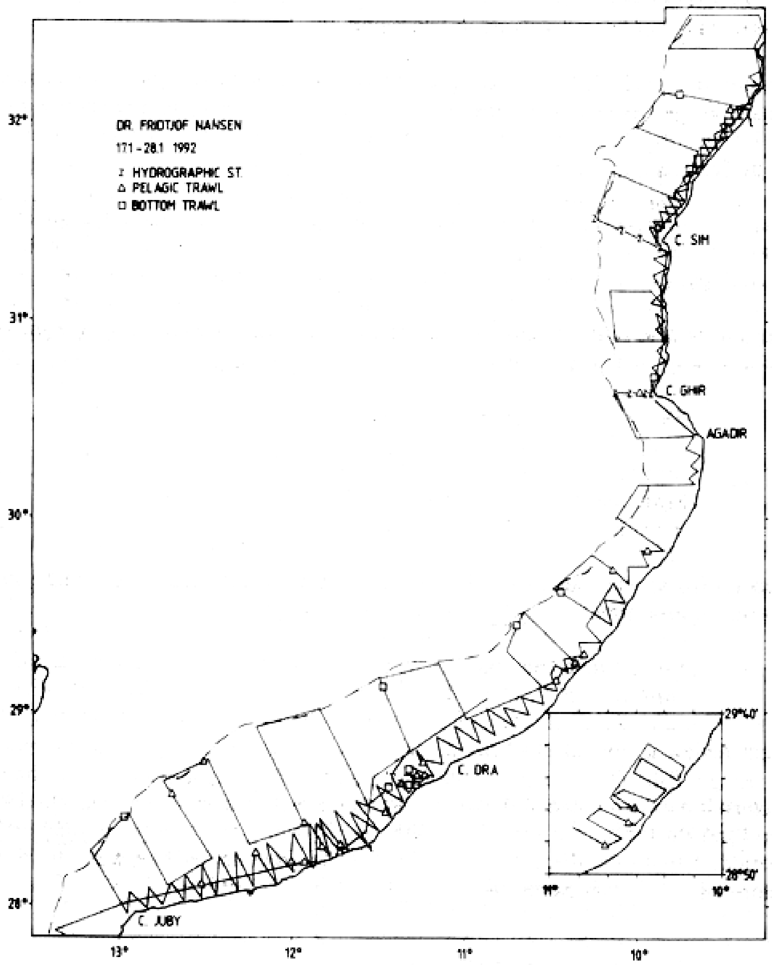

Figure 6.3 Course tracks and stations in divisions 1a and 1b, January 1992, showing higher survey density on inner shelf

Table 6.2 Operational data for surveys in sub-region 1

Survey No./ year	Divisions (1a-1d)	Month(s)	No. of survey days	No. of trawl stations	Remarks
Northern part (1a-1c)					
I/82	C.Ghir-C.Juby (1b) 31°-28°N	3, 4	10	9	
III/86	C.Ghir-C.Juby (1b) 31°-28°N	9	5	14	
IV/86	C.Ghir-C.Bojador (1b, c) 31°-26°N	11	10	30	
V/89	C.Safi-C.Bojador (1a, b, c) 32°-26°N	1	13	41	
Southern part (1d)					
I/81	C.Bojador-C.Blanc 26°-21°N	12	4	0	Outside 12 nmi only
II/82	C.Bojador-C.Blanc 26°-21°N	3	3	0	Outside 12 nmi only
III/86	C.Bojador-C.Blanc 26°-21°N	9	4	0	Open grid
IV/86	C.Bojador-Dakhla 26°-24°N	11	4	18	
IV/86	C.Blanc-Dakhla 26°-24°N	12	3	0	
V/89	C.Bojador-C.Blanc 26°-21°N	9	8	17	Full survey
VI/92	C.Bojador-C.Blanc 26°-21°N	1	11	29	Full survey

The three first surveys in the southern part, from Cape Bojador to Cape Blanc, were for security reasons only of a reconnaissance nature with a low degree of coverage (d) of about 5 and without sampling, while d was 18 in 1989 and about 15 in 1992, which seems adequate.

Most of the surveys were in the autumn or winter, while the late spring-summer season (May-August) was not covered. There is thus little opportunity for analysing possible seasonal changes in distribution, but there should be a good basis for inter-annual comparisons of the findings. The main pelagic stocks in this sub-region are sardine (*Sardina pilchardus*), Atlantic horse mackerel (*Trachurus trachurus*) and chub mackerel (*Scomber japonicus*).

Sardine

Distribution

Figure 6.4 shows the distribution of the acoustic recordings identified as sardine on the northern part of the shelf in November 1986, September 1989 and January 1992 respectively. The shelf from Cape Safi to Cape Ghir (Agadir) was not covered in 1986. The main features are similar in the three sets of data: the sardine is found on the inner part of the shelf, the main part within 20 nmi from the shore and with the highest densities between Cape Dra (28°44'N) and Cape Juby (28°N). The March-April 1982 survey showed a similar inshore distribution of small pelagic fish.

Figure 6.5 shows the distributions of sardine observed from Cape Juby southwards to Cape Blanc in the 1986, 1989, and 1992 surveys. On the broader shelf south of Cape Bojador the sardine is found further out, 40–60 nmi from the shore. In 1986 and 1992 the shelf south of Cape Blanc was also surveyed and the distribution of sardine was found to extend somewhat south of Cape Blanc, but not beyond 20°N. The Banc d'Arguin seems to form the southern limit for main sardine aggregations although the species may appear in low densities further south in Mauritania and even in Senegal.

With the low position in the food chain of Clupeidae and Engraulidae, their distribution in upwelling regions must be expected to be closely related to centres of active upwelling. Thus Thorne *et al.* (1977) found that the distribution of sardine between Cape Bojador and Cape Blanc was coincident with maximum abundance of small zooplankton and phytoplankton while that of horse mackerel was associated with a high abundance of large-sized zooplankton.

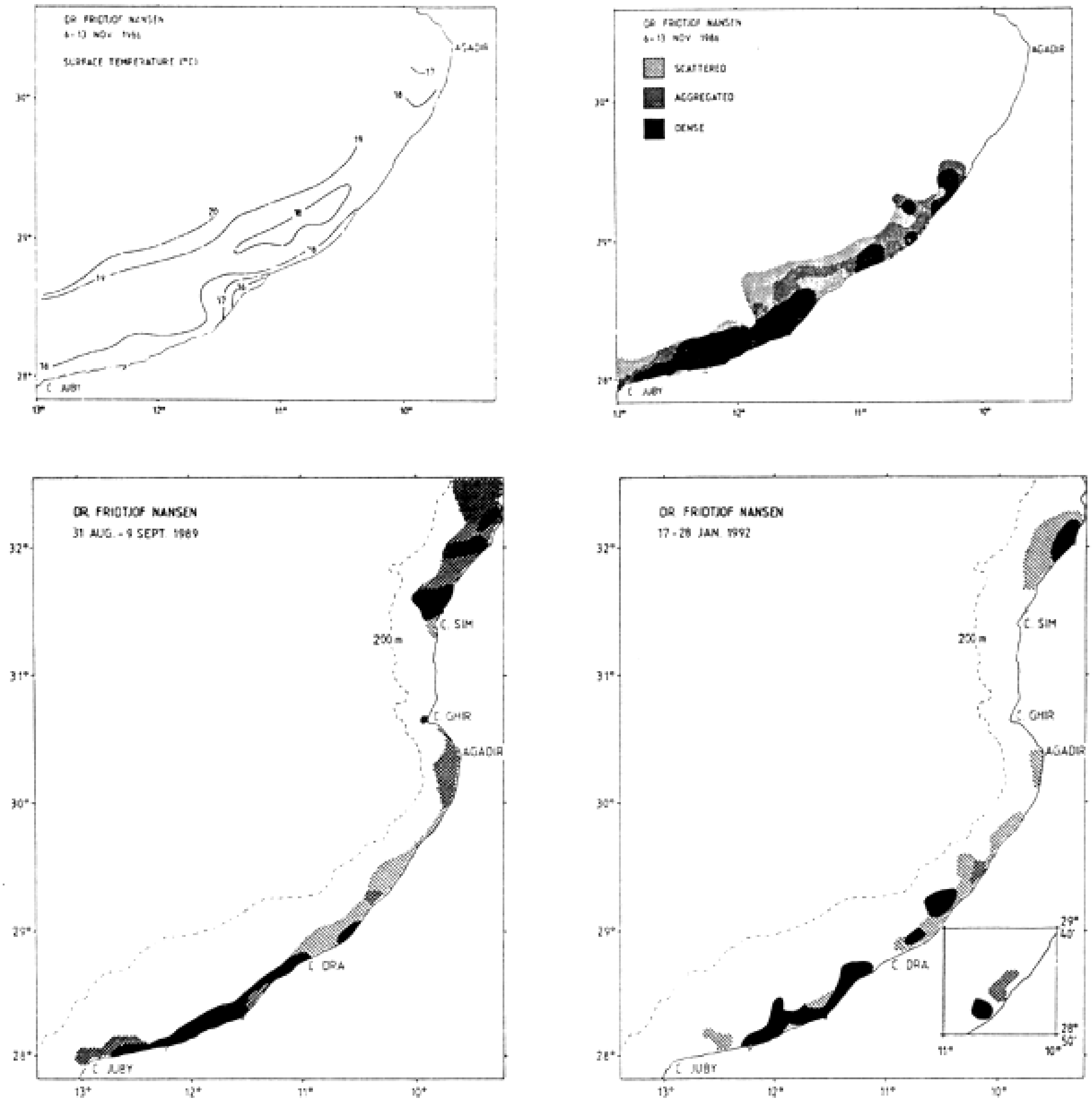

Figure 6.4 Distribution of sardine in divisions 1a and 1b (see Fig. 6.1) in 1986, 1989 and 1992 from echo integration data. Isotherms are shown for 1986

Although surface temperature observations during the survey period may have been affected by short-term changes in wind, the approximate positions of the prevailing upwelling cells are often disclosed by these observations. A comparison of sardine distribution during the various surveys and that of the simultaneous observations of surface temperatures, demonstrated as an example by the isotherms plotted in Figures 6.4, shows a close correspondence between the centres of cold surface water and fish aggregations. The aggregations south of Cape Dra (28°44'N) may thus be related to the area of local cold water in that region and the wide distribution of sardine on the shelf south of Cape Bojador corresponded with the extensive cold water masses found here in all surveys. The latter area lies within the latitudes 20° and 25°N where the most consistent upwelling of the Canary Current system is found.

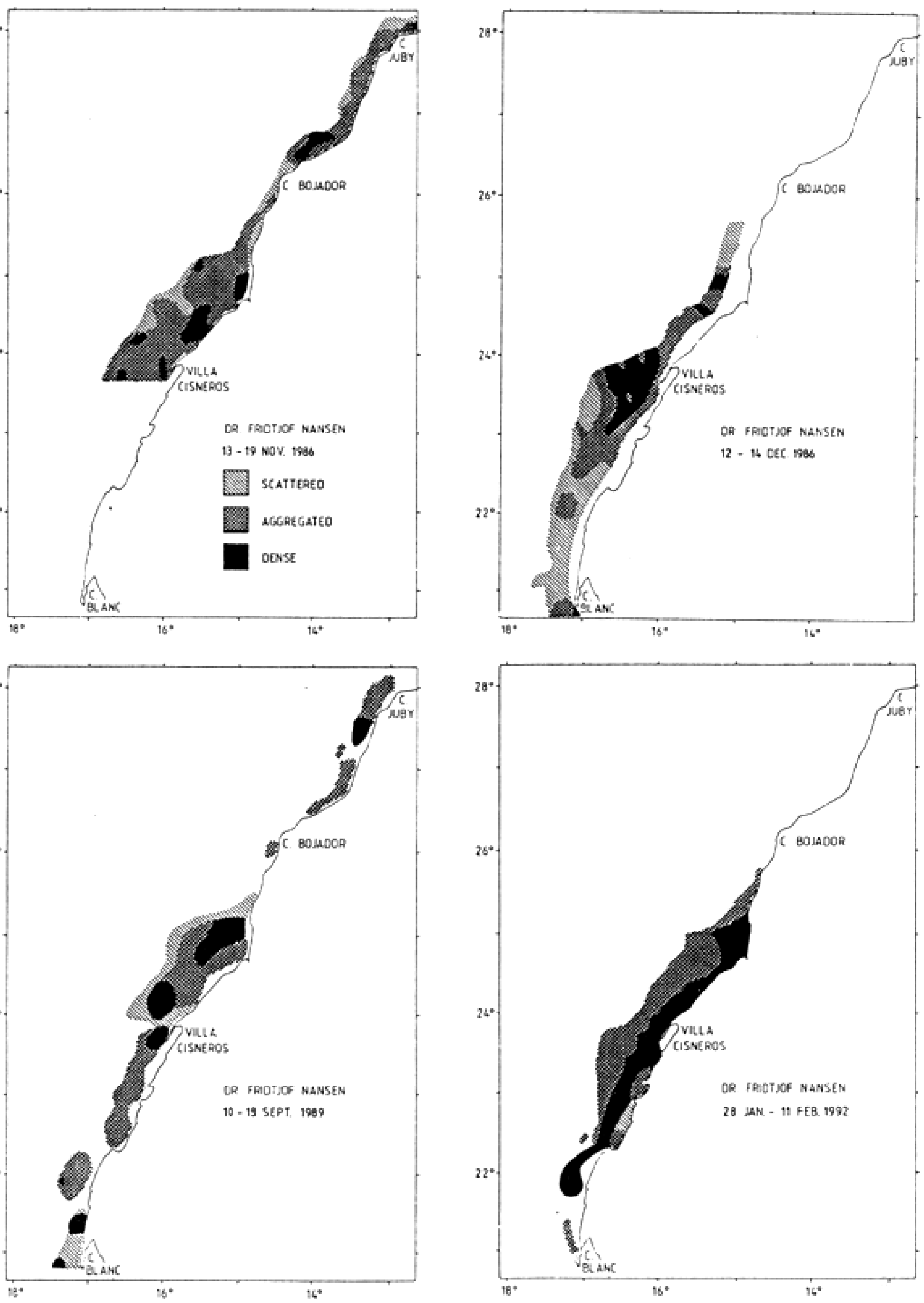

Figure 6.5 Distribution of sardine in divisions 1c and 1d (see Fig. 6.1) in 1986, 1989 and 1992 from echo-integration data

Biomass estimates

The details of the acoustic instruments and their operation are described in Chapter 2. The introduction of the EK500 in 1992 may to some extent have affected the comparability of the time series of stock estimates which the surveys provide. The possibility of underestimation by saturation in the previously used EK400 system existed especially where dense schools occurred close to the surface, which is a characteristic behaviour for sardine. In that case high values would be suppressed. This type of bias would be excluded by the wide dynamic range of the EK500 system. A comparison of the frequency distributions of integrator readings from the two systems may indicate whether or not saturation has occurred. Table 6.3 shows the frequencies by levels of integrator values from the 1986, 1989 and 1992 surveys. These represent the main areas of sardine distribution between Cape Bojador and Cape Blanc covering in each case about 90% of the total biomass. There is clearly a greater proportion of observations higher than 500 in the 1992 survey. This could be an effect of a change in the behaviour of the sardine to more densely packed aggregations in 1992 than in previous years, but the difference could also be explained by saturation in the EK400 at high signal levels. This analysis does not allow a direct quantification of a possible bias, but it would seem not to be of very great significance.

Table 6.3 Sub-region 1, Division 1d (Cape Bojador-Cape Blanc) 1986, 1989, 1992. Frequency distributions of integrator readings of the "pelagic I group", which includes sardine and other pelagics in 1986 and 1989 and sardines only 1992, and the percentage with levels above 500. Unit 0.1x m^2/nmi^2

Level of integrator reading	**Number of observations**		
	1986	**1989**	**1992**
0–100	65	48	53
100–200	32	20	47
200–300	32	18	14
300–500	31	5	19
500–1000	18	9	36
1000–1500	5	5	7
1500–2000	1	1	4
2000–2500	1	2	4
2500–3000			
3000–3500			1
Total	185	108	185
% > 500	14	16	28

The biomass estimates of sardine derived from the three surveys are shown by divisions in Table 6.4. As discussed in Chapter 2 and (IMR, 1992a to d) adjustments were made to the 1986 and 1989 data to correct for different assumptions regarding the condition factor of the fish.

There may be some reservations regarding the estimates from the 1982 surveys. For example, the 750,000 t found between Cape Ghir and Cape Juby represent all pelagic fish, about half of which was assessed to be horse mackerel and mackerel, a much higher proportion of the total biomass than found in subsequent surveys. Also, for security reasons no fishing was done between Cape Bojador and Cape Blanc and furthermore, the coverage there has been incomplete.

The sardine between Cape Safi and Cape Bojador (divisions 1a, b and c) is assumed to constitute the so-called "central stock" which is separated from the "southern stock" found south of Cape Bojador (division 1d) (Shotton, 1984). These two stocks migrate and the situation with regard to their intermixing is apparently not clear.

Sardine found in the Mauritanian part of sub-region 2 (south of Cape Blanc, 21°N) must form part of the "southern stock". The estimates for this part of the stock were about 500,000 t in 1986 and 20,000 t in 1992. In 1989 sub-region 2 was not surveyed, but observations off the Cape Blanc peninsula in that year indicated a continuation of the distribution of sardine further south.

When considering the time-series, the possibility of an underestimate in the 1986 and 1989 surveys caused by saturation in the EK400 system should be kept in mind. The biomass estimates have been grouped by stock in Table 6.5. The most notable feature is the low estimate of the central stock in 1992. Kifani and Gohin (1992) found that trends in the availability and distribution of this central stock could be related to changes in coastal temperatures and upwelling indices during the period from early 1960s to the late 1980s. Data are not available to determine if unfavourable environmental conditions may have caused the low stock in 1992.

Table 6.4 Sub-region 1: Biomass estimates of sardine by surveys and divisions (1,000 t)

Survey No.	Survey Year/month	Cape Safi - Cape Juby 1a + 1b	Cape Juby - Cape Bojador 1c	Cape Bojador - Cape Blanc 1d	Total Sub-region 1
II	1982, Mar	750*	n.c.	2,100**	(2,850)
IV	1986, Nov	610***	660	4,320	5,590
V	1989, Sep	1,200	450	3,050	4,700
VI	1992, Jan	320	0	4,050	4,370
	Mean	720	(370)	3,380	(4,380)

n.c.) not covered;
*) including other pelagics
**) incomplete coverage;
***) Cape Ghir-Cape Juby only
Source: IMR, 1992a to d

Table 6.5 Biomass estimates of sardine by stock in 1986, 1989 and 1992 (1,000 t)

Year	Central stock	Southern stock			Totals
	1a + 1b + 1c	1d	2	1d + 2	
1986	1,270	4,320	500	4,820	6,090
1989	1,650	3,050	(260)*	(3,310)	(4,960)
1992	320	4,050	20	4,070	4,390
Mean	1,080	3,870	(260)	4,070	(5,150)

* Average of estimates in 1986 and 1992

The estimates for the central stock vary more than those for the southern stock between Cape Bojador coast and Cape Blanc where upwelling occurs on a more stable year-round basis. It seems, however, that the central stock also has been more intensively fished. The combined reported catches by Spain and Morocco from FAO Statistical Area 34 which will mainly represent the yield from this stock increased from about 250,000 t in 1984 to about 450 000 t in the late 1980s, with a mean of 400,000 t in the period 1986–92, a considerable catch compared to a mean estimated biomass of 1.1 million t. For the southern stock, mean catches of 400,000 t in 1986–92 represented a much smaller part of the estimated standing biomass of over 4 million t, and therefore the rate of exploitation must have been relatively low for this stock.

Chub and horse mackerels

Distribution

Contributions to the integrator readings from Atlantic horse mackerel (*Trachurus trachurus*) and chub mackerel (*Scomber japonicus*) were estimated from their proportions in the trawl samples and from echo trace characteristics. In the 1989 survey no distinction was made between these two species in the integrator contributions. They were generally found in low densities, less than 10% of that of the sardine. Both species were, in contrast to the sardine, found to be distributed over wider and more offshore parts of the shelf and there were only a few cases of aggregations of high density. One such case was that of Atlantic horse mackerel found aggregated off the peninsula of Cape Blanc in 1989. Dense schools of adult fish near the shelf edge off Cape Blanc seem to be characteristic of the distribution pattern of this species, but the surveys were not designed to specifically cover these aggregations (IMR, 1989e).

According to Shotton (1984) the Atlantic horse mackerel moves outside the shelf in the hot season and may be found in the open sea. The horse mackerel of the Chile-Peru system has a substantial oceanic component, while DR. FRIDTJOF NANSEN surveys in Namibia and South Angola showed that the Cape horse mackerel could at times be found up to 5–10 nmi outside the shelf edge. The observation of the 1989 survey indicates that also the Atlantic horse mackerel may have a tendency to be distributed near the slope or even off the shelf.

The fishing areas of *Trachurus* spp. in the Eastern Central Atlantic include statistical division 34.2.0, the Northern Oceanic Division (FAO/CECAF, 1994) from which landings close to 100 000 t were reported by the USSR in 1982 and 1983. This indicates that the horse mackerel in the northern part of the CECAF area may have an oceanic component and that therefore the biomass estimates of the Atlantic horse mackerel obtained from surveys limited to the shelf area may be too low.

Biomass estimates

Table 6.6 shows the combined estimates of these two species by surveys. Separate estimates were only attempted in 1986 and 1992 when the proportions chub mackerel/horse mackerel were 17 to 10 and 19 to 50 respectively. The 1992 estimates were very low in all sub-areas.

The reported total catches of horse mackerels in FAO statistical area 34.1.3, Sahara coastal and chub mackerel in FAO statistical area 34 (FAO/CECAF, 1994) in the period of the survey are presented in Table 6.7.

Table 6.6 Biomass estimates of chub and horse mackerel by surveys and sub-areas. (1000 t)

Survey No.	Survey Year/month	C.Safi-C.Juby 1a + 1b	C.Juby-C.Bojador 1c	C.Bojador-C.Blanc 1c	Total Sub-region 1
I	1982, Mar	340*	-	-	-
IV	1986, Nov	240*	60	220*	(520)
V	1989, Sep	320	125	*	925
VI	1992, Jan	100	0	480 70	170
MEAN	(1986–92)	220	62	(257)	(539)

* Division Ia, Cape Safi-Cape Ghir not surveyed
** To Dakhla only

Table 6.7 Reported total catches of horse mackerels in FAO statistical area 34.1.3, and chub mackerel in area 34 from 1982 to 1991 (in 1,000 t)

Year	Chub mackerel	Horse mackerel
1982	200	203
1983	180	181
1984	212	185
1985	155	(181)*
1986	215	(187)*
1987	118	209
1988	326	181
1989	314	174
1990	172	150
1991	137	124

* adjusted to include the USSR catch
Source: FAO/CECAF, 1994

It is assumed that the main part of the chub mackerel was caught in the survey area. The combined landings of the two species represented 77% and 53% of the biomass estimates in 1986 and 1989 respectively. In general, the biomass estimates seem too low for the level of the landings. This indicates that the surveys have underestimated one or both stocks. For the Atlantic horse mackerel lack of detailed coverage of fish aggregations on the shelf edge and over the slope off Cape Blanc, as reported to have occurred in 1989, and a possible oceanic distribution may have caused an underestimate.

On the other hand, the low landings in 1990 and 1991 could indicate the start of declining stocks as demonstrated by the low 1992 survey estimate (Table 6.6).

Review of biomass estimates and densities

The mean estimates for the surveys 1986, 1989 and 1992 which are thought to have given more reliable and complete data than the 1981/82 surveys, are shown in Table 6.8 by the divisions Cape Safi to Cape Bojador and Cape Bojador to Cape Blanc. The density estimates will also be used as indices of fish productivity of the upwelling system and for this purpose it is thought better to base them on a combination of catches and biomass rather than on biomass alone.

Table 6.8 Sub-region 1: Cape Safi-Cape Blanc. Mean estimates of standing biomass and corresponding of small pelagic fish from surveys in 1986, 1989 and 1992, mean annual reported (1,000 t). Densities by shelf area and coastline

Sub-region	**Cape Safi-Cape Bojador 1a, 1b, 1c**		**Cape Bojador-Cape Blanc 1d**		**Total**	
Shelf area (nmi^2)	12,300		16,000		28,300	
Coastline (nmi)	515		375		890	
	Standing Biomass	Landings	Standing Biomass	Landings	Standing Biomass	Landings
Sardine	1,080	400	3,800	400	4,880	800
Horse mackerel & mackerel	280	200	300	200	580	400
Total	1,360	600	4,100	600	5,460	1,200
Total densities by:						
Shelf area (t/nmi^2)	160		295		235	
Coastline (t/nmi)	3,800		12,500		7,700	

Division 1d, Cape Bojador to Cape Blanc, where upwelling is reported to be most persistent had by far the highest density with 295 t/nmi^2, nearly double that of the northern divisions (1a-1c), Cape Safi to Cape Bojador with 160 t/nmi^2. Measured in terms of coastline the density in the southern region with 12,500 t/nmi was more than three times higher than that between Cape Safi and Cape Bojador. These densities are high compared with those estimated for small pelagic fish by DR. FRIDTJOF NANSEN surveys in other upwelling systems, for example: Somalia 70 t/nmi^2, Oman 120 t/nmi^2 and northern Namibia 171 t/nmi^2 and 5,080 t/nmi coastline.

The final conclusion is that the area between Cape Bojador and Cape Blanc (division 1d) still has a considerable potential for the development of fisheries for small pelagics.

6.2 SUB-REGION 2: CAPE BLANC TO BISSAGOS ARCHIPELAGO (21°N-11°N)

Survey effort

The operational data for the surveys in this sub-region are reviewed in Table 6.9. Three surveys I/81, II/82 and V/92 took place in spring when the coastal surface temperature front was located in the south and upwelling is taking place along most of the coast. The other three surveys in the in the south and upwelling is taking place along most of the coast. The other three surveys in the autumn, September-December, represented the season when the front was in northern Mauritania and warm surface water of 25°–30°C extended along the coast southwards.

Table 6.9 Sub-region 2: Operational data for the surveys (21°N-11°N)

Survey No./year	Months	Days of work	No. of trawl stations
I/81	Apr-May	24	106
I/81	Sept	20	78
II/82	Feb-Mar	27	70
II/86	Aug-Sep	21	102
IV/86	Nov-Dec	19	76
VI/92	Feb-Mar	28	199

Figure 6.6 shows the survey area with the course tracks of the 1992 survey (VI). This survey had the highest effort with a degree of coverage of 29, but the survey effort was also high in the other surveys as shown by the number of days of work. Degrees of coverage for these varied from 20 to 26. Some swept-area trawl programmes were included in the 1986 and 1992 surveys.

General distribution of pelagic fish

Although the coverage of the surveyed area was good, there are important inshore shallow areas in this sub-region which could not be surveyed. These shallow water areas would add approximately the following proportions to the surveyed parts of shelf: Mauritania 50%, Senegal-The Gambia 27%, and Guinea Bissau 70% (Strømme, 1984e). The validity of the observations of the surveys regarding the shallow water fauna is thus limited. For the small pelagic fish this is thought especially to have affected the juvenile stages of most species and the adult stages of anchovy (*Engraulis* spp.) and to some extent flat sardinella (*S. maderensis*) and bumper (*Chloroscombrus chrysurus*). Adult horse mackerels (*Trachurus* spp.) and scads (*Decapterus* spp.) were usually found on the outer shelf, and were therefore less affected.

A characteristic of the distribution of small pelagic species which affects survey and sampling techniques is that where they occur in relatively high abundance they are usually found in school areas, aggregations of higher densities of schools over a smaller part of the shelf. This type of distribution was found to be pronounced on the Mauritania to Guinea-Bissau shelf. The school areas would extend from 10 to 30 nmi in the alongshore direction and from 5 to 10 nmi across the shelf. The composition within the school areas tended to be by species, but a mixture of species also occurred, especially inshore. The 1992 survey indicated that for the sardinellas the size of the individual school areas increases with increasing stock size. It was also noted that the density within the schools was very high for adult sardinella, higher than for most other species. There was thus a higher probability of saturation in the EK400 system when estimating the biomass of sardinellas and therefore a higher possibility of underestimating the biomass of sardinellas than for the other species.

Figure 6.7 shows as an example the distribution of sardinellas found in February-March 1992.

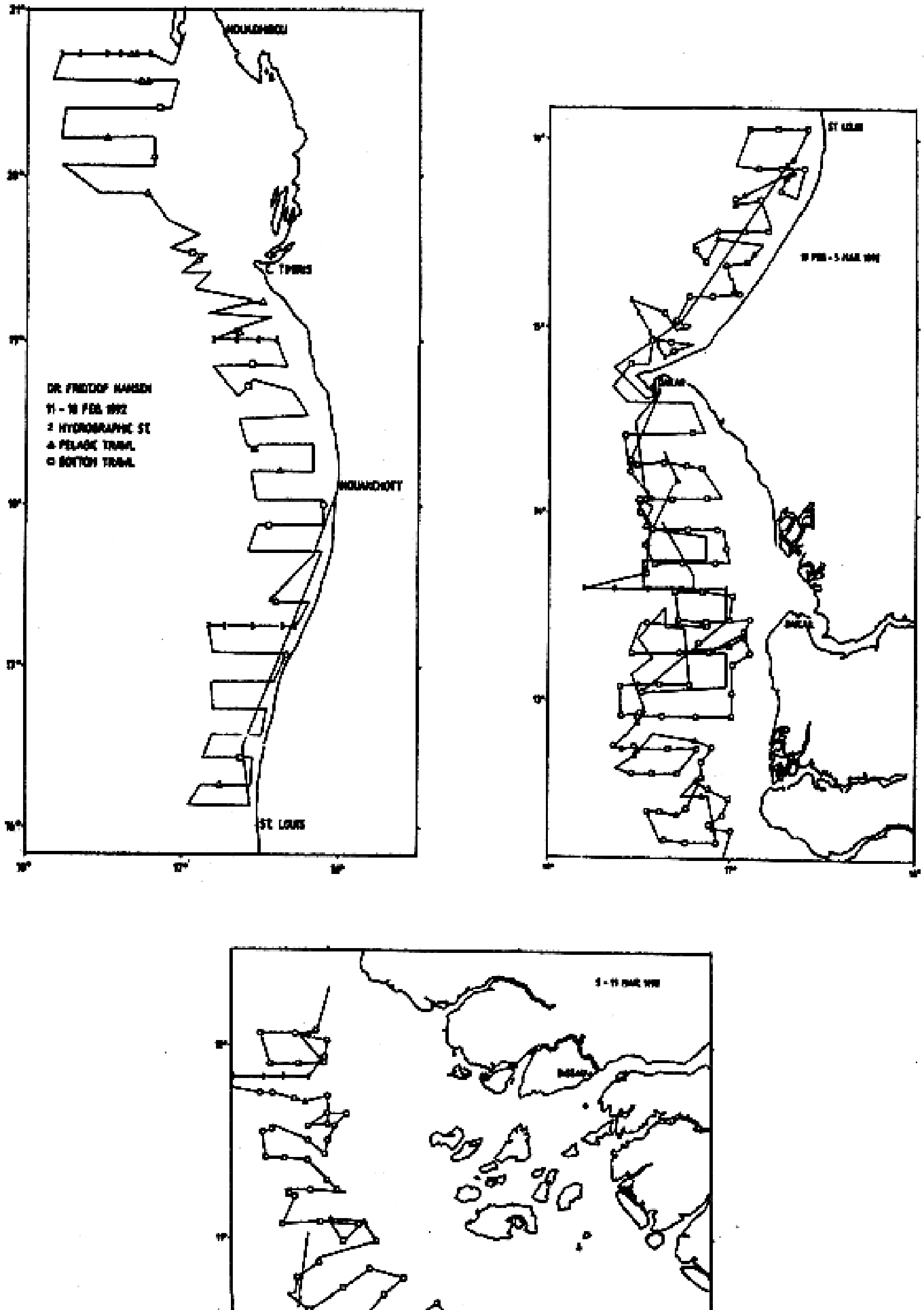

Figure 6.6 Survey tracks and stations in subregion 2, February-March 1992 survey

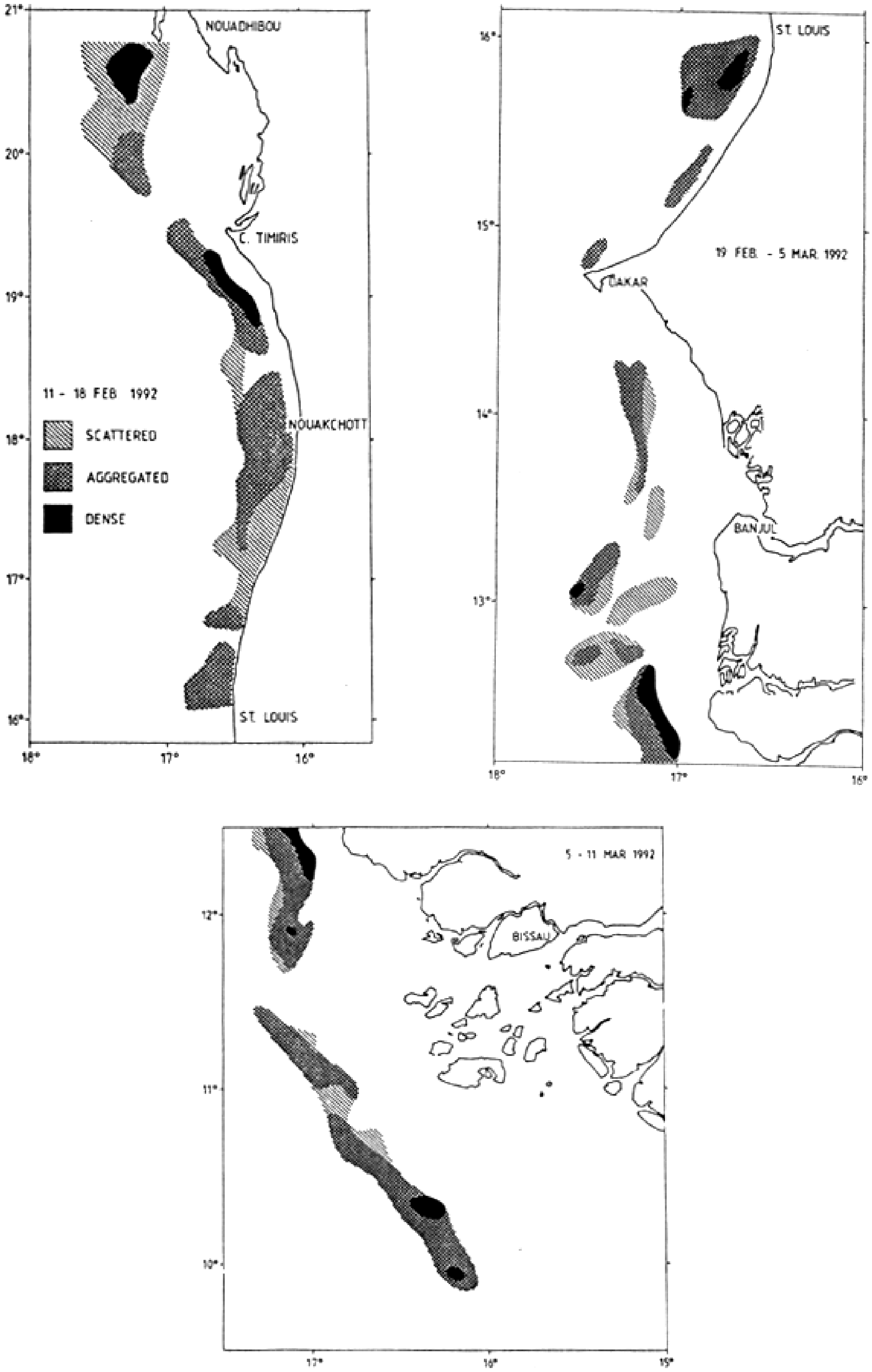

Figure 6.7 Distribution of sardinellas in subregion 2, February-March 1992 survey

The fauna of small pelagic fish in this region is well known. For the stocks of sardinellas, the round sardinella (*Sardinella aurita*) and the flat sardinella (*Sardinella maderensis*), the region is a main distributional area although these species may also be found north of Cape Blanc and southwards on the shelf off Guinea and Sierra Leone.

Cape Timiris (19°23'N) in Mauritania represents the southern boundary for the European horse mackerel (*Trachurus trachurus*), and the northern boundary for the Cunene horse mackerel (*Trachurus trecae*). The false scad (*Decapterus rhonchus*) has a distribution similar to that of the Cunene horse mackerel, while the round scad (*Decapterus punctatus*) is less abundant and is found further inshore in the southern part of the sub-region. Among the other Carangidae the bumper (*Chloroscombrus chrysurus*) is common in the central part of the subregion, sometimes mixed with lookdown (*Selene dorsalis*).

The triggerfish (*Balistes capriscus*) appeared in the trawl catches as far north as Mauritania in the early surveys. Its main distributional area was, however, much further south from Guinea-Bissau to Sierra Leone.

The drastic environmental changes in this sub-region, with cold, temperate water and upwelling extending southwards past Guinea-Bissau in early spring and tropical water reaching up past Cape Verde (Dakar, 14°40'N) in the autumn, must be expected to cause seasonal changes in fish distribution. Migrations related to the movement of the temperature front are described for the main species by Garcia (1982).

Evidence from the DR. FRIDTJOF NANSEN surveys, which represent a good coverage of the various seasons, indicated that the alongshore seasonal shifts in distribution, although clearly present, had perhaps more characteristics of displacements within a limited range along the coast than of long-distance migrations.

Sardinellas

Distribution

Important parts of the total biomass of sardinellas were still retained between Cape Verde (14°40'N) and Cape Roxo (12°20'N), in September 1981 more than 50% and, in November-December 1986 about 40% (Strømme, 1984e and IMR, 1987a and b). Table 6.10 shows the distribution of the total biomass of sardinellas by countries. There is a clear shift in the distribution towards Guinea-Bissau in spring, but otherwise there were no clear seasonal trends.

The surveys also provided information on the relative abundance of the two sardinella species, round sardinella (*S. aurita*) and flat sardinella (*S. maderensis*). For the 1981–82 surveys the occurrence of each species in all trawl stations was weighted with a factor proportional to the size of the catch thus giving a mean abundance index for each survey and sub-area (Table 9 in Strømme, 1984e). The averages of these indices for the whole survey period were very similar for the two species, 49% for the flat sardinella and 51% for the round sardinella, expressed as proportions of the total abundance. The analysis of the 178 fishing stations in the 1986 surveys showed a similar incidence for the two species, 26% for flat and 23% for round sardinella, but with higher mean catch rates for the flat sardinella (about 75%) (Strømme and Sætersdal, 1987a). A higher rate of sampling in the 1992 surveys allowed an estimation of the biomass of the two species separately by sub-areas. Of a total biomass of about 4 million t 58% was estimated to be round sardinella. This species had its highest concentration of biomass in Mauritania, while the flat sardinella was most abundant in Senegal-The Gambia. The accuracy of the method of allocation of biomass between the two species is, however, not thought to be very high and it may be concluded that the survey data indicate that the two species occurred at roughly the same level of abundance in the subregion at the time of the surveys. Since there were considerable variations in the total abundance of both sardinellas over the period of the surveys this indicates that the fluctuations in stock size of the two species must have been largely similar.

Table 6.10 Sub-region 2: Biomass estimates of sardinellas by surveys and divisions, 1981–92

Divisions		21°N-16°N Mauritania		16°N-12°20'N Senegal-The Gambia		12°20'N-11°N Guinea-Bissau		21°N-11°N Total
Survey		(1,000 t)	%	(1,000 t)	%	(1,000 t)	%	(1,000 t)
I	81 Apr-May	20	7	210	75	50	18	280
I	81 Sep	75	17	360	79	20	4	455
II	82 Feb-Mar	50	32	40	25	70	44	160
IV	86 Nov-Dec	300	45	330	50	30	5	660
VI	92 Feb-Mar	1,970	49	1,530	40	535	11	4,035

Sources: Strømme, 1984e, IMR, 1987a and b and IMR, 1992a to d

Biomass estimates

Table 6.10 shows the combined biomass estimates of the two sardinella species by surveys and sub-areas. The highly variable total estimates from the 1981–82 surveys were probably caused by inadequate coverage of the shallow inshore parts of the shelf. An interpretation of the survey findings could be that they show stock levels of about 500,000 t in 1981–82, 700,000 t in 1986 and 4 million t in 1992.

These variable stock levels are not in disagreement with the reported landings from the period. From the 1993 meeting of the sardinella Working Group of CECAF (Figs. 20 and 21 in Do Chi, 1994), it appears that the reported landings of both sardinella species were low in the early 1980s, with a total of about 150,000 t, well over 200,000 t in 1986 and exceeding 300,000 t in the early 1990s. Reviewing the findings of various surveys as well as other information, the Working Group found that the biomass had been increasing after 1987. However, the Working Group thought that the 4 million t estimate of the DR. FRIDTJOF NANSEN 1992 survey would need confirmation as it very much exceeded all other estimates of these stocks.

The sharp increase in the acoustic biomass estimate in 1992 may, as discussed above for sardine, to some extent be an effect of the increased dynamic range of the EK500 system that was used in this survey. Sardinella schools are often densely packed and would be susceptible to the effects of saturation in the EKS and EK400 systems. However, there is little doubt that there has been a real increase in the biomass. As shown in Table 6.11, the 1992 estimate of the stocks of Carangidae does not deviate markedly from those of previous surveys, a fact which indicates a consistency in the measurements and therefore a confirmation of the veracity of the sardinella estimate.

Horse mackerels

The Cunene horse mackerel (*T. trecae*) was mainly found between Cape Blanc (21°N) and Cape Roxo (12°20'N). The distribution of the total biomass of Carangidae along the coast (Table 6.11 indicated a northward shift with the temperature front. In the autumn surveys of 1981 and 1986 most of the stock was located north of Cape Verde (14°40'N). Figure 6.8 shows an example of the spring distribution from February to March 1992.

The Atlantic horse mackerel (*T. trachurus*) was largely limited to the shelf north of Cape Timeris (19°23'N) and as an average for all surveys only contributed about 20% to the total biomass of horse mackerels in the sub-region.

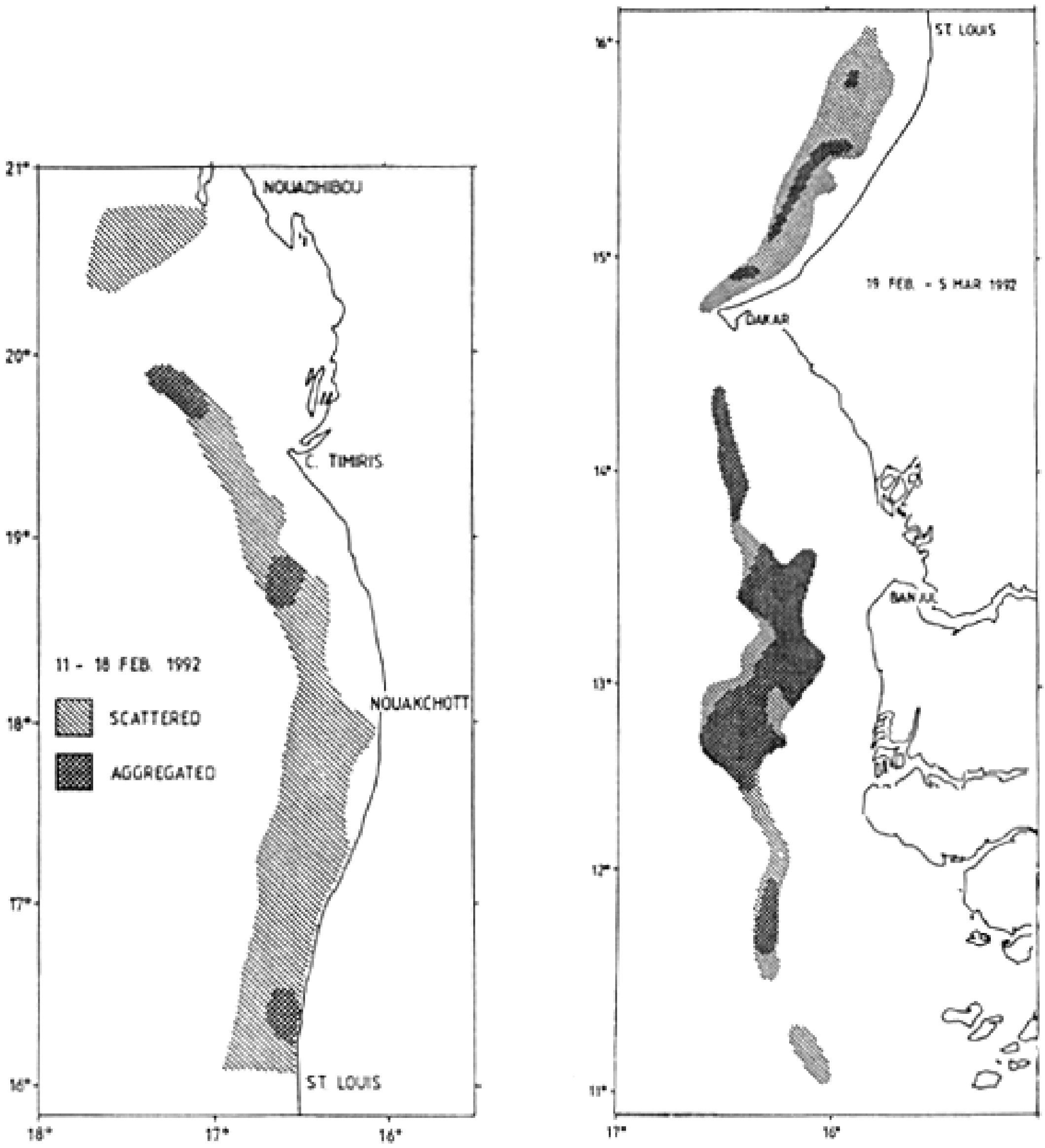

Figure 6.8 Distribution of Cunene horse mackerel in subregion 2 as shown by the February-March 1992 survey

False scad

The false scad (*Decapterus rhonchus*) was reported to have about the same distribution as the Cunene horse mackerel in the 1981–82 surveys, but a more southerly one in August-September 1986, when it was found in highest abundance from The Gambia south past the Bissagos Archipelago. In the 1992 survey it was found in highest abundance off Casamance, the southern part of Senegal.

Biomass estimates

Table 6.11 shows the estimates of the total biomass of the Carangidae for the surveys with good continuous coverages of the shelf. The group totals vary only between 850,000 and 980,000 t, with Cunene horse mackerel being the largest and most stable component as shown in Table 6.12. The total reported landings of horse mackerels from the corresponding statistical area 34.3.1 were 100,000–120,000 t in the survey period with no distinct trends (FAO/CECAF, 1994). This appears not to be inconsistent with the biomass estimates. The group "other pelagics" includes bumper, lookdown, other Carangidae, barracudas, Spanish mackerels and others. This group had a markedly reduced abundance in 1992.

Table 6.11 Sub-region 2: Biomass estimates of Carangidae by surveys and divisions

Divisions Survey	Mauritania (1000 t)	%	Senegal-The Gambia (1000 t)	%	Guinea-Bissau (1000 t)	%	Total (1000 t)
I 81 Apr-May	370	38	570	58	40	4	980
II 82 Feb-Mar	470	49	90	9	400	42	960
IV 86 Nov-Dec	540	64	170	20	140	16	850
VI 92 Feb-Mar	190	21	690	76	30	3	910
Sources: Strømme, 1984e, IMR, 1987a and b and IMR, 1992a to d							

Table 6.12 Sub-region 2: Biomass of some Carangidae species and of a mixture of other pelagics (1,000 t)

Species Survey		*Trachurus trachurus*	%	*Trachurus trecae*	%	*Decapterus rhonchus*	%	Other pelagics		Total
I	81 Apr-May	50	5	615	63	315	32	*	0	980
II	82 Feb-Mar	170	18	440	46	140	14	210	22	960
IV	86 Nov-Dec	0	0	480	56	170	20	200	24	850
VI	92 Feb-Mar	70	8	560	61	210	23	70	8	910
* Group not identified, see text										

Review of biomass estimates and densities

Table 6.13 shows the simple means of the biomass estimates from each of the surveys, rough averages of the annual catches in the period and estimates of densities by unit shelf area and coastline. As expected the densities were much lower than in the areas of high upwelling further north, between a quarter and a third of the densities found in sub-region 1d between Cape Bojador and Cape Blanc. Measured by unit of coastline the density from Cape Blanc to Bissagos was about the same as that found between Cape Safi and Cape Bojador. By unit shelf area the density in sub-region 2 was only about half of that found on the narrower northern shelf in sub-region 1.

Table 6.13 Sub-region 2, 21°N-11°N. Mean estimates of standing biomass of small pelagic fish from surveys in 1981, 1982, 1986 and 1992 and corresponding mean annual reported landings (1000 t). Densities by shelf area (t/nmi^2) and coastline (with and without landings)

Shelf area (nmi^2)	32,000	
Coastline (nmi)	720	
	Standing Biomass	Landings
Sardine	100?	
Sardinellas	1,120	200
Horse mackerel etc.	930	100
Total	**2,150**	**300**
Total densities by:		
Shelf area (t/nmi^2)	67	77
Coastline (t/nmi)	2,986	3,400

6.3 SUB-REGION 3: CAPE VERGA TO CAPE MOUNT (10°N-7°N)

Survey effort

Of the three surveys in this sub-region (Table 6.14) only that in February 1982 covered the southern upwelling, which takes place during late winter and spring.

Table 6.14 Sub-region 3: Operational data for the surveys off Guinea-Sierra Leone (10°N-7°N)

Survey No.	Months	Days of survey	No. of trawl stations
I/81	May-June	11	43
II/82	February	8	16
III/86	August	7	52

Figure 6.9 shows the course tracks and stations in the 1986 survey.

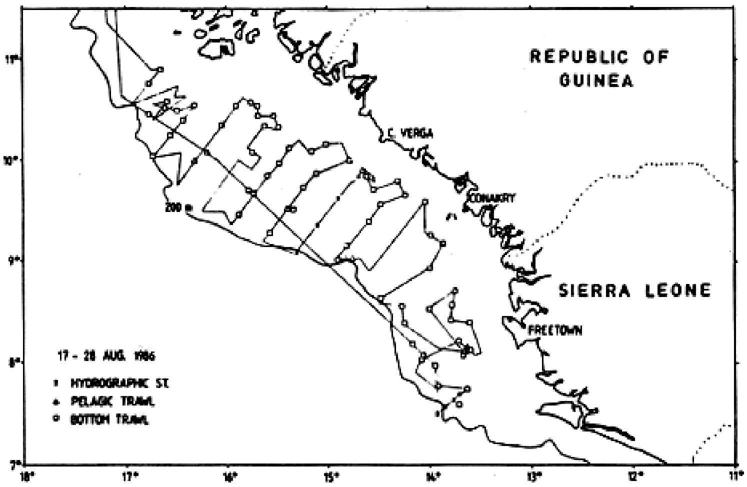

Figure 6.9 Survey tracks and stations on the shelf of sub-region 3, off Guinea-Sierra Leone, August 1986

All species

Distribution

The triggerfish (*Balistes capriscus*) was the dominating species in the pelagic regime in this region. The distribution and abundance of this species will be described in Section 6.5. Small pelagic fish were found in more scattered distributions and at lower densities over this shelf than further north. Aggregations of sardinellas were found near Sherbro Island in each of the surveys. The round scad (*Decapterus punctatus*) was the main species of the Carangidae.

Biomass estimates

The biomass estimates of the small pelagic fish (Table 6.15) were low. The biomass of sardinellas, found mainly near Sherbro Island, was judged to be underestimated due to their occurrence in shallow waters which could not be surveyed. The absence of Cunene horse mackerel (*T. trecae*) on the outer shelf may be related to the relatively high abundance of triggerfish here. Presumably these two species would be food competitors.

Table 6.15 Sub-region 3: Biomass estimates of small pelagics by surveys and divisions (1,000 t)

Survey No.	Divisions	Sardinellas	False scad	Round scad	Others	Total
I/81	Guinea	70	15	15	30	130
	Sierra Leone	80	0	120	20	220
II/82	Guinea	30	10	0	10	50
	Sierra Leone	15	0	5	40	60
III/86	Guinea	2	54	0	61	117
	Sierra Leone	24	2	0	5	31

6.4 SUB-REGION 4: CAPE PALMAS TO CAPE SAINT PAUL (7°45'W-1°E)

Survey effort

Only two surveys were made in sub-region 4 (Table 6.16), one in June 1981 at the start of the local upwelling season and the other in October 1989 at the end. Figure 6.10 shows the course tracks and stations in the 1981 survey. The shelf off Côte d'Ivoire is narrow (10–20 nmi) while that off Ghana is up to 60 nmi wide at certain points. The degree of coverage was somewhat less in 1989 than in 1981.

Table 6.16 Sub-region 4: Operational data for the surveys off Côte d'Ivoire and Ghana

Survey No.	Season	Days of work	No. of trawl stations
I/81	June	10	34
V/89	October	9	24

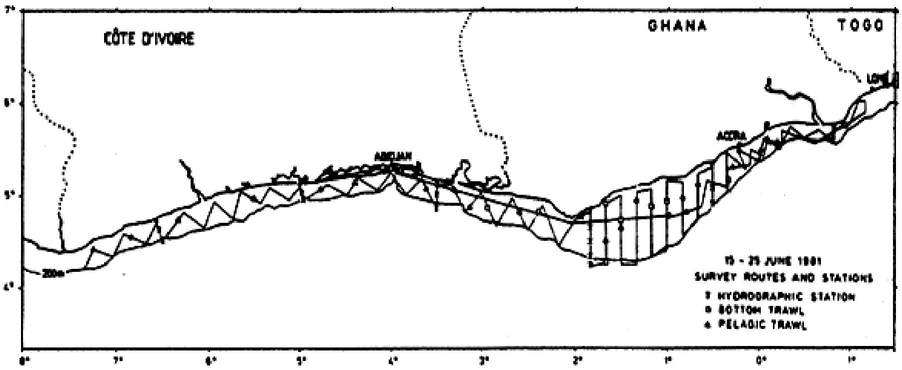

Figure 6.10 Survey tracks and stations on the shelf off Côte d'Ivoire-Ghana in June 1981

Pelagic fish

In the 1981 survey well over 80% of the biomass as estimated by the acoustic method was allocated to triggerfish (see Section 6.5) and since this species was found together with the small pelagic fish, the precision of the estimates of small pelagics was low.

The small pelagics tended to occur in school areas with the Clupeidae predominantly concentrated on the inner shelf. The estimates of sardinellas (*S. aurita* and *S. maderensis*) include some anchovy (*Engraulis encrasicholus*).

Table 6.17 shows the biomass estimates by species or groups of species of small pelagics and includes also estimates from the August 1986 survey by the Spanish research vessel CORNIDE DE SAAVEDRA as reported by Oliver and Miquel (1987). The acoustic system of this vessel was inter-calibrated with that of DR. FRIDTJOF NANSEN off Senegal in August-September 1986 (Anon., 1986).

Table 6.17 Sub-region 4: (Côte d'Ivoire-Ghana). Biomass estimates by species groups and divisions from DR. FRIDTJOF NANSEN surveys in 1981 and 1989 and a survey by the CORNIDE DE SAAVEDRA in 1986 (1,000 t)

		Sardinellas & anchovies	Cunene horse mackerel	Other small pelagic	Total small pelagic
DR. FRIDTJOF NANSEN					
June 81	Côte d'Ivoire	45	0	3	48
	Ghana	43	0	24	67
	Total	88	0	27	115

CORNIDE DE SAAVEDRA					
Aug 86	Côte d'Ivoire	78	0	13	91
	Ghana	53	0	43	96
	Total	131	0	56	187
DR. FRIDTJOF NANSEN					
Oct 89	Côte d'Ivoire	6	26	7	39
	Ghana	41	46	11	98
	Total	47	72	18	137

These estimates of the standing biomass of sardinellas are low compared with reported landings by the two countries of 47,000 t in 1981 and about 100,000 t in 1986 and 1989. The discrepancy becomes even bigger if Ghana's considerable landings of anchovy are included in the comparison. A possible explanation is that the surveys did not cover inshore aggregations of these species.

The horse mackerel (*Trachurus trecae*) which with an estimated biomass of 72,000 t in 1989 was the most abundant species of small pelagics in that survey, was not present in the two previous surveys. The mean catch rates of the Carangidae species in the 1981 and 1989 surveys are not comparable because the sampling in 1981 was mainly based on pelagic trawling, while bottom trawl was the main gear used in 1989. The relative proportions of the main Carangidae species (Table 6.18) show, however, the dominance of the Cunene horse mackerel (*T. trecae*) which occurred in 12 of the 24 hauls in 1989 including pelagic trawls, but in none of the 34 hauls in 1981. Ghana's reported landings of *Trachurus* spp. increased from a few hundred tonnes per year during 1981–89 to 3,000 t in 1990 and down again to 1,800 t in 1991 (FAO/CECAF, 1994). The increase of the horse mackerel stock took place after the decline of the stock of triggerfish of which none were found in 1989.

Table 6.18 Sub-region 4: Composition (%) of Carangidae in sampling hauls in 1981 and 1989 surveys

Survey	**1981**	**1989**
No. of hauls	34	24
Species		
Trachurus trecae	0	86
Decapterus punctatus	35	1
Chloroscombrus chrysurus	31	7
Selene dorsalis	20	2
Selar crumenophthalmus	14	4

The group “other pelagics” included scads, chub mackerel, Spanish mackerels and barracudas. The reported total landings of these fish by Côte d'Ivoire and Ghana in 1989 amounted to 38,000 t and these species were thus severely underestimated in the surveys.

6.5 TRIGGERFISH

The occurrence of the grey triggerfish (*Balistes capriscus*) in high abundance in the 1970s and 1980s in sub-regions 3 and 4 (Sierra Leone-Guinea Bissau, western stock and Ghana-Côte-d'Ivoire, southern stock) is probably an unusual phenomenon. Most members of the family Balistidae are slow-moving solitary reef-dwellers (Moyle and Cech, 1992) and this seems to be the more normal behaviour and habitat also of the grey triggerfish. However, the stocks in the Eastern Central Atlantic were able to expand their populations to a remarkable and unusual size, probably by utilizing the relatively high productivity of the still tropical regimes of the shelf waters of the Western Gulf of Guinea and the coastal upwelling system south of Senegal. The DR. FRIDTJOF NANSEN surveys in 1981–82 coincided with the culmination of the triggerfish stocks, while those in 1986 and 1989 with their decline and collapse.

The triggerfish was found in layers and schools in mid-water and near the bottom and was a convenient target for acoustic investigations and also easily sampled with mid-water and bottom trawls. Figure 6.11 shows the distribution in June 1981. The two separate areas of distribution seem to have represented sub-stocks with little or no mixing (Strømme, 1984e). In September 1981 the western stock was recorded scattered past Cape Roxo (12°20'N) towards Cape Verde (14°40'N), but in all surveys the highest densities in the west were found between Sherbro Island and the Bissagos Archipelago. A distribution over the outer shelf, with the highest densities in waters with a bottom depth of about 100 m, was a characteristic feature found in all surveys.

Biomass estimates of triggerfish from the relevant DR. FRIDTJOF NANSEN surveys are shown in Table 6.19 together with available data from other similar surveys. The eastern stock was about 0.5 million t in 1981 and had declined to 140,000 t by 1986 and to virtually nil in 1989. For the western stock there seems to have been a rapid growth from about 0.4 million t in 1978/79 (Marchal *et al.*, 1980) to about 1.4 million t in 1982 and a decline to only 0.2 million t in 1986.

The DR. FRIDTJOF NANSEN survey in 1992 was limited to the Guinea-Bissau shelf, which was a main distributional area for the western stock of triggerfish in 1981/82 and 1986. Since no triggerfish was found it seems likely that the western stock had disappeared by that time.

There is less information on the eastern stock in sub-region 4.

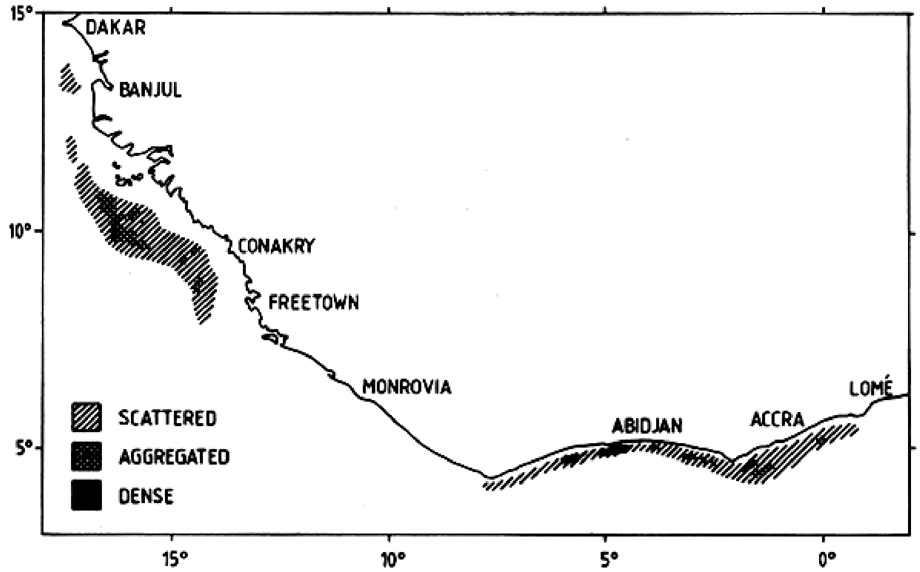

Figure 6.11 Distribution of triggerfish from acoustic observations in the June 1981 survey. Source: Strømme, 1984e

Table 6.19 Biomass estimates of triggerfish from acoustic surveys (1,000 t)

Vessel	Period	Western stock	Eastern stock
CAPRICORNE	Nov-Dec 78	440	n.c.
CAPRICORNE	March 79	440	n.c.
CORNIDE DE SAAVEDRA	August 80	760	n.c.
DR. FRIDTJOF NANSEN	May-Jun 81	1,050	500
DR. FRIDTJOF NANSEN	February 82	1,350	n.c.
DR. FRIDTJOF NANSEN	Aug-Sep 86	220	n.c.

CORNIDE DE SAAVEDRA	Aug 86	n.c.	141
DR. FRIDTJOF NANSEN	October 89	n.c.	0
DR. FRIDTJOF NANSEN	February 92	0*	n.c.

* only Guinea Bissau was covered
n.c. = not covered
Sources:
For CAPRICORNE Marchal *et al.*, 1980
For CORNIDE DE SAAVEDRA, 1980: FAO/CECAF, 1981
For CORNIDE DE SAAVEDRA, 1986: Oliver & Miquel, 1987

According to Ansa-Emmim (1979) triggerfish was practically absent from the continental shelf of Ghana prior to 1969. A sudden increase of the biomass of the species was observed from 1970.

The stocks were fished by Ghana from 1972 on (presumably the eastern stock) and by a distant water fleet from USSR in the west from 1980 to 1987. The mean annual reported landings by four-year periods are given in Table 6.20.

Table 6.20 Landings of triggerfish from the Gulf of Guinea area, 1972–91. Means over four-year periods (t)

	Ghana	USSR	Mean total per year	Total per four years
1972–1975	5,340	-	5,340	21,360
1976–1979	10,335	-	10,335	41,340
1980–1983	6,770	77,000	83,770	335,080
1984–1987	12,497	28,034	40,531	162,124
1988–1991	913	-	913	3,652
Grand Total				563,556

Source: FAO, 1977; FAO, 1981 and FAO/CECAF, 1994

The total yield over the period of the fishery was thus well over 0.5 million t, of which the main part was taken from the western area. Since little is known of the population parameters for this type of fish it is difficult to assess which effect the fishery may have had. It does not seem likely, however, that the disappearance of the eastern stock in 1989 can have been caused by the relatively modest catches in this area, and the growth and decline of these stocks is probably a phenomenon of natural ecosystem variability.

7 SURVEYS IN THE ATLANTIC OCEAN OFF SOUTHWEST AFRICA

After having surveyed the important upwelling areas associated with the Somali Current and the Canary Current, the DR. FRIDTJOF NANSEN started surveys of the area associated with the Benguela Current in 1985. The programme started in Angola, Congo and Gabon in 1985 and was extended into Namibia in January 1990 shortly before the independence of that country. Southwest Africa has also become the main area of work for the new DR. FRIDTJOF NANSEN in 1994, however, this review only covers the surveys done with the old DR. FRIDTJOF NANSEN until mid 1993. In order to facilitate the discussion of shared resources the results will be presented following the direction of the Benguela Current, from south to north. Emphasis has also been placed on describing the historical developments of the important fisheries in Namibia and Angola.

7.1 NAMIBIA, 1990–93

A comprehensive and long-lasting series of investigations started in January 1990 with the DR. FRIDTJOF NANSEN immediately prior to the achievement of independence for the country. Following independence, an EEZ was declared and Namibia's jurisdiction over the shelf and its rich fish resources was established. Important fisheries had, however, been developed during the previous state of open access of the Namibian shelf, and an account of the history of these pre-independence fisheries is desirable as a background for the description of the surveys and their results.

7.1.1 History of the pre-independence fisheries, 1951–89

Two major industrial fisheries were established off Namibia in the 1950s and 1960s, an inshore pelagic fishery for pilchard and anchovy conducted by a Namibian based purse-seine fleet and an offshore trawl fishery for hake and horse mackerel mainly conducted by distant water fleets from a number of nations. From the 1970s, a limited number of Namibian based vessels participated in the trawl fishery for hake and other groundfish species and with increasing effort in the 1980s. The responsibility for management of the resources and regulation of the fisheries up to independence was divided between the Republic of South Africa's administration in Windhoek (inshore fisheries), and the International Commission for the Southeast Atlantic Fisheries (ICSEAF) (offshore fisheries).

ICSEAF was established by a convention signed in Rome in 1969 and ratified by well over a dozen countries during the 1970s, and ceased functioning in 1990 following the establishment of the Namibian EEZ.

Although ICSEAF's reference area also included the seas off Angola and the Republic of South Africa, its main activities related to the resources and the fisheries off Namibia. This was in fact one of the few rich coastal fishing areas for which an EEZ had not yet been introduced. ICSEAF formed a forum for co-operation among the many fishing countries whose fleets operated in the area with the overall objective of preservation of the resources through regulation of the fisheries.

The catches were reported to ICSEAF by statistical divisions which are no longer used, but are still helpful for describing the history of the offshore fisheries. These divisions start at the northern border of Angola at 5°S and consist of blocks of 5° latitude. Figure 7.1 shows statistical divisions 1.3, 1.4 and 1.5 off Namibia.

The dimensions of the fisheries towards the end of the ICSEAF period can be roughly assessed from the catch statistics. The mean total annual catch from Divisions 1.3, 1.4

and 1.5 over the three-year period 1986–88 as reported to ICSEAF from the various participating countries, was close to 1.3 million t, of which hake 330,000 t, horse mackerel 500,000 t, pilchard and anchovy 230,000 t and others about 230,000 t.

These catches derived from the fishing grounds that now are part of the Namibian EEZ, except for some catches of horse mackerel and other species from southern Angolan waters and small catches by South Africa in the Southern part of Division 1.5.

The main participants in the offshore fisheries in the late 1980s, as demonstrated by reported catches of hake and horse mackerel in Divisions 1.3, 1.4 and 1.5, are shown in Table 7.1. USSR and Spain reported the largest landings followed by Rumania, Bulgaria, Portugal, Cuba and Poland.

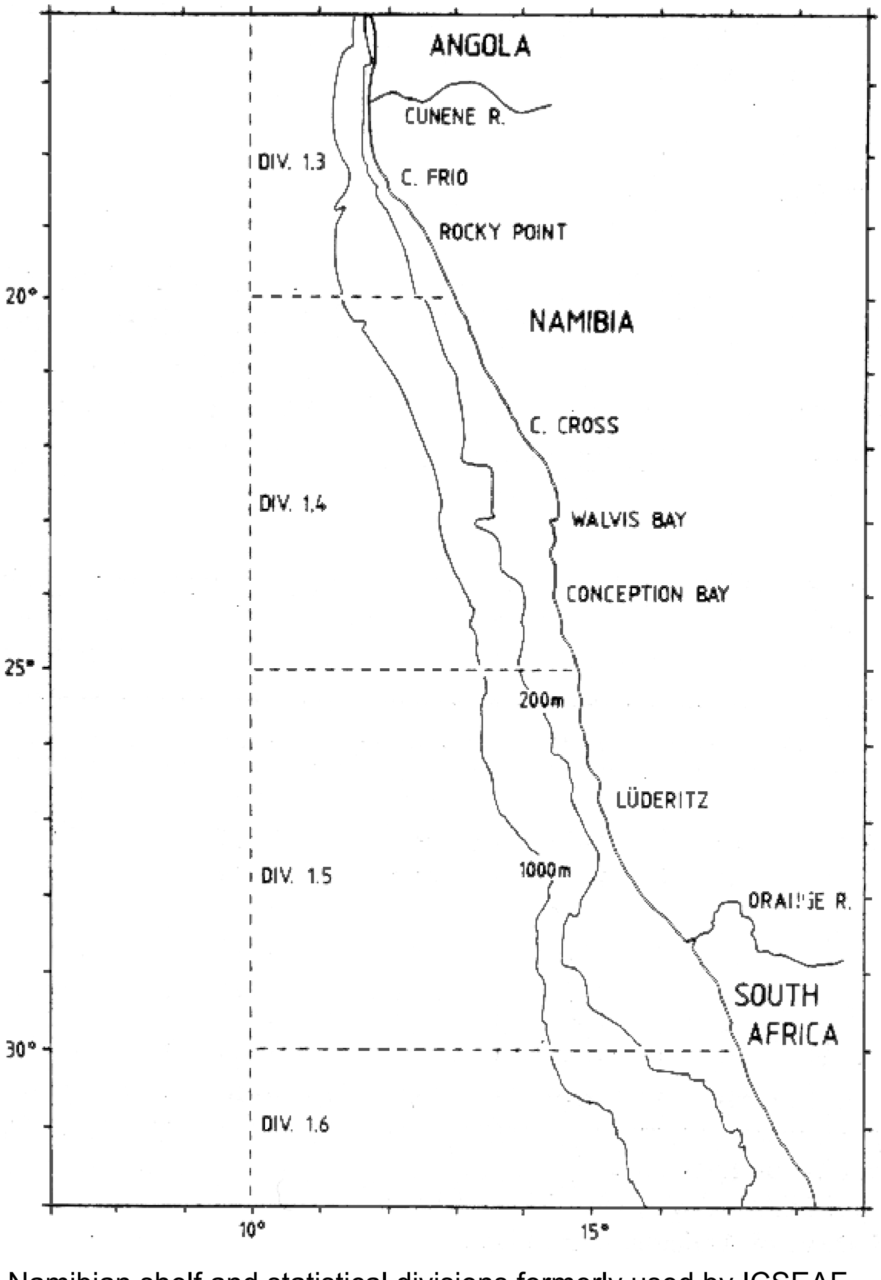

Figure 7.1 Namibian shelf and statistical divisions formerly used by ICSEAF

Table 7.1 Main participants in the offshore fishery off Namibia 1986–88 as shown by catches of hake and horse mackerel in ICSEAF Divisions 1.3, 1.4 and 1.5. Mean annual catch (1,000 t)

Hake		Horse mackerel	
Spain	150	USSR	231
USSR	118	South Africa	96
Portugal	29	Rumania	70
South Africa	29	Bulgaria	47
Others	6	Poland	15
Rumania	4	Others	18
Poland	4	Cuba	18
		Spain	18
Total	**340**	Total	**511**

Source: ICSEAF Stat.Bull. 1986 and 1987 and SAC/89/Doc. 12.

The management measures introduced by ICSEAF included global TACs for horse mackerel, chub mackerel and snoek, TACs allocated by country for the hake stocks, a minimum trawl mesh size, an inshore prohibition zone for trawling, and a maximum percentage bycatch of hake in the horse mackerel catches.

The inshore pelagic fishery: Pilchard and anchovy

The fishery for Southern African pilchard (*Sardinops ocellatus*) and Southern African anchovy (*Engraulis capensis*, also named *E. encrasicolus*) was based in Walvis Bay, and in some years included also factory ships. Following a period of rapid development of the fishery for pilchard in the early 1950s the yields remained quite stable until the early 1960s due to a policy of strict regulation of both landing quotas and processing capacity (Table 7.2).

Table 7.2 Landings of pilchard in Namibia. Catches by factory ships included. (1,000 t)

Year	Landings	Year	Landings	Year	Landings
1951–55	273	1972	562	1981	374
1956–60	248	1973	561	1982	408
1961–65	540	1974	452	1983	44
1966	801	1975	200	1984	56
1967	926	1976	46	1985	54
1968	1,387	1977	34	1986	53
1969	1,110	1978	11	1987	67
1970	514	1979	52	1988	63
1971	325	1980	51	1989	76

Sources: 1951–66 (Newman, 1970);
1967–82 (ICSEAF, 1983), 1983–86 (Le Clus *et al.*, ICSEAF),
1987–89 Dept. of Agriculture, Namibia.

From 1959 onwards, the policy of strict regulation was abandoned. Quotas rapidly increased and during the mid-1960s the fishery greatly expanded. The boom culminated in 1968 with a total catch of pilchard in Namibian waters, including that of South African factory ships, of nearly 1.4 million t. Thereafter, the catch fell drastically because of fish scarcity until 1972 when, due to improved recruitment in the stock, the decline was temporarily halted and was even reversed for a couple of years. After 1976 the downward trend accelerated to the average low level of about 50,000 t during 1978–90.

As a consequence of the decline in the stock the fleet was reduced to less than half its previous size and large segments of the processing industry were closed down.

To counterbalance the dwindling supply of pilchard for the processing industry, the fleet directed its attention towards other pelagic resources which can be harvested by purse-seine, primarily anchovy, round herring or redeye (*Etrumeus whiteheadi*) and horse mackerels (Cape horse mackerel, *Trachurus capensis*, and Cunene horse mackerel, *Trachurus trecae*.) These species are found in the same inshore fishing localities as the pilchard, and the occurrence of fishable aggregations of all three species may overlap considerably both with regard to locality and season. There was thus a problem of by-catch of pilchard, especially juveniles, in the fisheries directed towards these other pelagic species.

The fate of the pilchard stock during the 1960s and 1970s must be described as a collapse caused by depletion through excessive fishing. Over 12 years, 1967–78, the estimated total biomass of the stock declined from some 6 million t to about 100,000 t.

Several other large pelagic stocks were depleted around this period (North Sea and Atlanto-Scandian herring, Peruvian anchoveta) and in retrospect it must be recognized that fishery science was by that time perhaps not sufficiently developed to enable a proper management of these types of fish stocks. In particular, it is now realized that catch rates for typically schooling species are not a reliable measure of the abundance of the stock.

ICSEAF's Scientific Council reviewed the pilchard stock annually from 1976 to 1989. For 1978 a recommendation was passed to set the quota "as low as possible to maintain a viable fishery based on alternative stocks". In 1979 and at a number of later sessions recommendations for stringent regulatory measures were submitted, including that of a total ban on fishing adult pilchard and limitations on the bycatch of juvenile pilchard in the anchovy fishery. In later years, however, the reports from the Council must be interpreted as following a policy of recommending catch levels which would maintain the stock at its very low level. Thus for the 1988 season it was suggested that the TAC be set at between 20% and 25% of the projected standing biomass and for 1989 it was proposed that the TAC should not exceed 40,000 t.

The anchovy fishery started in 1968 when small-meshed purse-seine nets were introduced. This short-lived fish showed large natural year-to-year fluctuations of yield and stock abundance from the start of the fishery, and annual catches varied between 83,000 t and 355,000 t until 1983, (Table 7.3). By the early 1980s, however, a general decline of adult stock biomass was recorded and the fishery came to depend on higher proportions of juveniles. The low catches during 1984–86 demonstrated a depleted stock. An unexpected large increase of yield took place in 1987. This was concurrent with a record increase of stock size and catch of the South African anchovy and South African investigations have indicated the possibility of a relationship between the recovery of the Namibian anchovy stock and that of the South African stock. Whether this happened remains uncertain, but afterwards the Namibian anchovy stock and the landings again declined.

Table 7.3 Landings of anchovy in Namibia (1,000 t)

Year	Landings	Year	Landings
1968	161	1979	277
1969	226	1980	190
1970	189	1981	199
1971	185	1982	83
1972	137	1983	184
1973	296	1984	14
1974	249	1985	51
1975	186	1986	16
1976	88	1987	376
1977	133	1988	117
1978	355	1989	79

Sources: ICSEAF, 1983, Le Clus *et al.*, 1986.
1987–89: Department of Agric., Namibia

The trawl fisheries

The existence of large offshore demersal and semi-pelagic resources in the Benguela Current system was proved by surveys in the late 1950s. Exploitation of these resources began in the early 1960s with long-distance trawlers and by 1965 had developed into a 500,000 t multinational fishery.

This development coincided with a rapid general build-up in many countries of modern stern-trawler fleets, which resulted in heavily increased fishing pressure and subsequently reduced catch rates in the North Atlantic demersal fisheries. The deep-sea fisheries development off Southwest Africa was, therefore, basically a much needed redeployment of excessive catching capacity from the North Atlantic, a need further enhanced by the introduction of the EEZ regime in the mid-1970s by most coastal States.

In the beginning, fishing was concentrated on hakes (Cape hake, *Merluccius capensis* and deep-water Cape hake, *Merluccius paradoxus*) but, during the 1970s horse mackerels became increasingly important, particularly after 1976 when hake catches started to decline rapidly.

Hakes were primarily fished with a standard bottom trawl, fairly similar in all fleets, although differing somewhat in details of net construction and rigging. The minimum codend mesh size for hake was stipulated by ICSEAF regulations as 110 mm. However, when trawling for horse mackerels with bottom trawls, some hake were often taken as bycatch and, since this gear had a smaller codend mesh size (60 mm), some quantities of juvenile hake may have been caught.

From the mid 1970s, directed fishing for horse mackerel was carried out with pelagic trawls, sometimes also operated in a semi-pelagic mode. This technology was closely related to that developed for blue whiting and mackerel in the North Atlantic, i.e., pelagic trawls with a very large opening and with the front part and wings made of very large meshes and/or longitudinal ropes.

In the late 1980s the majority of the foreign fleet vessels fishing off Namibia, were large long-range freezer trawlers (≥ 1,000 t), many also equipped for further processing of the catches on board (factory vessels).

The state of the hake stocks

The two species, Cape hake and deep-water Cape hake are not distinguished in the commercial fishery in Namibia, but were identified in the sampling during surveys with the DR. FRIDTJOF NANSEN. Cape hake is found along the entire Namibian shelf, while deep-water hake has its main distribution south of 25°S.

Therefore, the validity of ICSEAF's views of the stock structure of the Namibian hakes with a northern and a southern stock divided at approximately 25°S is doubtful, but for the purpose of this historical description, reference to this stock structure has been maintained.

The stocks were monitored from the early 1970s by ICSEAF scientists. There was a rapid build-up of fishing effort on the northern stock from the mid 1960s to the early 1970s, with catches increasing to a peak of about 606,000 t in 1972 (Table 7.4). The effort remained at a high level towards the end of the 1970s but with declining catches and catch rates.

The history of the fishery on the southern Division 1.5 stock shows much the same picture of high catches in the late 1960s and early 1970s followed by a sharp trend of decline until the early 1980s.

Table 7.4 Catches of hake off Namibia (1,000 t)

Year	Northern stock Division 1.3 + 1.4	Southern stock Division 1.5	Total
1965	93.5	99.7	193.2
1966	212.4	122.2	334.6
1967	195.0	199.4	394.4
1968	382.7	247.7	630.4
1969	320.5	206.2	526.7
1970	402.5	224.7	627.2
1971	365.6	229.7	595.3
1972	606.1	214.0	820.1
1973	377.6	290.3	667.9
1974	318.8	195.7	514.5
1975	309.4	178.7	488.1
1976	389.0	211.9	600.9
1977	275.9	154.5	430.4
1978	254.2	125.1	379.3
1979	170.0	140.1	310.1
1980	97.2	71.6	168.8
1981	90.3	120.6	210.9
1982	176.4	130.1	306.5
1983	216.1	123.3	339.4
1984	228.5	141.8	370.3
1985	211.4	200.1	411.5
1986	231.1	149.8	380.9
1987	136.4	162.6	299.0
1988	211.7	123.2	338.2
Source: ICSEAF, 1983, 1986, 1987, 1989			

The hake stocks became seriously overexploited already by the mid 1970s and remained in that state in spite of the efforts on the part of the ICSEAF countries to manage these resources by various regulations of the fisheries. Table 7.5 summarizes the history of ICSEAF's efforts to manage the fisheries on the Namibian hake stocks with an outline of the scientific diagnosis of the state of the stocks, the management advice submitted to the Commission, the regulations adopted and the reported total catch in the year to which the regulation applied.

A mesh increase to 110 mm was introduced in 1975. By that time the scientists had already concluded that the stocks were heavily fished and they recommended a limitation of total catches in 1976. Such limitations were adopted from 1977 onwards, but the effects of these measures can only have been limited since the adopted TACs exceeded the actual catches by more than 100,000 t for the years up to 1980.

Towards 1980, the effort in the hake fisheries declined; this was not the effect of management measures but the reaction of the fleets to declining stocks and catch rates. Recruitment to the stocks was, however, greatly improved in the early 1980s especially the 1982 and 1983 year classes. Fishing then soon revived with considerably increased ICSEAF quotas and in two years, 1983 and 1984, the total catches approached the level of the quotas. It quickly became apparent, however, that no use had been made of the high recruitment in the early 1980s to rebuild the adult stock. From 1985 on the total annual catches were about 100,000 t below the adopted TACs (Abello *et al.*, 1988; Macpherson *et al.*, 1985 and 1986).

It seems evident from the stock history from the mid 1980s that the ICSEAF scientists' assessments based on total production models exceeded the potentials of the stocks and it is reasonable to conclude that either the data or the model used must have been at fault. Assessments of the stocks in 1986 based on a Virtual Population Analysis (VPA) (Schumacher, 1987) deviated significantly from other results and indicated an exerted level of fishing mortality at more than the double of F_{max}, whereas the assumption had been that the stocks were fished at a moderate level. The assessment also showed that the fishing mortality of two-year old was excessive, particularly in the years 1982–84. Later developments in the fishery confirmed the diagnosis of over-fished stocks with declining catch rates and low recruitment.

According to the VPA assessment the level of the exploitable stock biomass in the early period of the fishery (1968–76) was about 800,000 t based on data from ICSEAF Divisions 1.3 and 1.4, while including Division 1.5 it would probably be 1.2 million t. This could be considered as an approximate target for standing stock biomass for a long-term optimal exploitation of the hakes referring to the exploitable part of the stocks in these divisions. It would represent an annual sustainable catch level of about 400,000 t. The mean reported annual landings in the period 1968–77 were 590,000 t, but this would include yields from an accumulated stock. On the other hand, the mean annual catch in the period 1978–87 when the stock was reduced by over-exploitation was only 318,000 t.

Table 7.5 Management history record for the Namibian hake stocks Source: ICSEAF, 1972–1988

Year	Scientific diagnosis	Scientific advice given	Management regulations adopted and TACs set	Total catch corresponding with TAC
1973	Small mesh size wasteful	Increase mesh to 110 mm	110 mm mesh size from 1/1 1975	667,900 t ('73)
1974	Hake stocks heavily fished risk of decline of total yield	Prevent further substantial increase in amount of fishing	None	514,500 t ('74)
1975	Hake stocks fully exploited yield from two stocks 650,000 t	Prevent that catches in divisions 1.3, 1.4, 1.5 and 1.6 exceed 800,000	None	488,100 t ('75) 600,900 t ('76)
1976	Revised assessment for two stocks 550,000	Not to exceed 480,000 t for both stocks (300 + 180)	1977 TAC of 536,000 t with allocation by countries	435,000 t ('77) (277 + 158)
1977	Further revision of assessment recommend a 10% decrease in F_{MSY} TACs in 1976 and $f_{0.1}$ = 360,000 t	Not to exceed 410,000 t for both stocks	1978 TAC: 480,000 t	382,000 t ('78) (258 + 124)
1978	1977 measures inadequate for stock recovery; decline not halted	Not to exceed 300,000 t (200 + 100)	1979 TAC: 415,900 t	302,000 t ('79) (172 + 130)
1979	$f_{0.1}$ in present stock conditions may be higher than $F_{0.1}$ or F_{max} of analytical model		1980 TAC: 320,000 t	160,000 t ('80) (90 + 70)
1980	Stock in 1.3 and 1.4 further signs of severe deterioration, stock in 1.5 more stable	TAC for 1.3 + 1.4 not to exceed 90,000 t and for 1.5: 100,500 t	1981 TAC: 210,000 t (110 + 100) Closure of inshore zone	208,000 t ('81)
1981	Notable reduction of effort in fisheries. Regretable lack of data for virtual population analysis	North: $f_{0.1}$ = 217,000 t South: $f_{0.1}$ = 135,000 t	1982 TAC: 352,000 t	305,000 t ('82)
1982	Stock recovering slightly as result of decreased effort since 1980	North:$f_{0.1}$ = 270,000 t South: $f_{0.1}$ = 143,000 t	1983 TAC: 413,000 t	339,000 t ('83)
1983	Recovery of stocks levelled out in 1982	North: $f_{0.1}$ = 253,000 t South: $f_{0.1}$ = 138,000 t	1984 TAC: 391,000 t	370,300 t('84)
1984	Stock in recovery but concern over heavy rate of exploitation on recruiting fish	North: TAC = 266,000 t South: TAC = 163,000 t	1985 TAC: 429,000 t	411,500 t ('85)
1985	Estimated increase of catch rates in northern stock but not in south	North: TAC = 318,000 t South: TAC = 163,000 t	1986 TAC: 481,000 t	381,000 t ('86)
1986	New VPA shows	North: TAC	1987 TAC: 411,000	299,000 t ('87)

	present F double F_{max} for northern stock but production models show state of moderate exploitation	253,000 t South: TAC 158, 000 t	t	
1987	Models considered to give overoptimistic estimate. Direct measures show trends of decline	North: TAC 253,000 t South: TAC = 158,000 t	1988 TAC: 411,000 t	335,000 t ('88)
1988	Models indicate TAC at about previous levels, but scientists concerned about declining catch rates and low recruitment	North: TAC = 253,000 t South: TAC = 158,000 t	1989 TAC: 411,000 t	

The state of the stock of Cape horse mackerel

Catches of Cape horse mackerel (*T. capensis*) since 1966 are shown in Table 7.6. Some, usually minor, amounts derive from fishing in southern Angola. The fishery on this stock expanded greatly with catches below 100,000 t until 1970, then at about 200,000 t till 1975 and fluctuating around 500,000 t from 1976 to 1980. Catches peaked in 1982 with 660,000 t, and later declined. It is possible, however, that the highest catch of this species, about 800,000 t, was obtained already in 1978 when for a few years very high catches of what was assumed to be Cunene horse mackerel (*T. trecae*) were reported from Division 1.3. The major part of these may in fact have been Cape horse mackerel (*T. capensis*) since there is some confusion over the separation of the two species in this area where they both occur.

Table 7.6 Catches of Cape horse mackerel reported from divisions 1.3, 1.4 and 1.5 in 1966–89 and ICSEAF TACs 1980–88. (1,000 t)

Year	Catch	Year	TAC	Catch
1966	99.6	1980	500	544
1967	72.4	1981	500	590
1968	69.2	1982	500	660
1969	46.5	1983	643	606
1970	50.4	1984	647	530
1971	214.5	1985	630	435
1972	72.2	1986	485	448
1973	271.4	1987	440	548
1974	193.1	1988	472	539
1975	242.2	1989	497	
1976	456.2			
1977	352.1			
1978	516.2			
1979	401.6			

Source: ICSEAF, 1983, 1986, 1987;
FAO Yearb. Fish.Stat. Vol. 60

It proved difficult for the ICSEAF researchers to obtain precise and reliable assessments of this stock, one reason being the problem of obtaining meaningful indices of abundance from catch rates in a directed fishery for this schooling species. Since the mesh size of the trawl gear used for horse mackerel must be smaller than the minimum mesh of 110 mm used in the hake fishery, the bycatch of small hake in the horse mackerel catches was a management problem. An ICSEAF provision stipulated a maximum bycatch level of 20% of hake.

With the objective of limiting the total fishing effort in the horse mackerel fishery, ICSEAF adopted a global TAC each year from 1980 to 1989 (Table 7.6), together with a catch reporting scheme to the Secretariat to permit closure of the fishery when the quota was reached. However, the catches often exceeded the global TACs.

In evaluations in the late 1980s ICSEAF scientists considered the Cape horse mackerel stock to be in a healthy state. In a general way the results of the fishery seem to have confirmed this diagnosis.

Other exploited resources

Various other species of demersal fish were taken mostly as subsidiary catches in the offshore trawl fisheries for hake and horse mackerel. Kingklip (*Genypterus capensis*) was caught both as a by-catch in the trawl fisheries and in directed long-lining. Total catches were around 15,000 t of which somewhat less than one-third in Namibian waters. Anglerfish (Cape monk, *Lophius vomerinus*, synonym: *L. upsicephalus*) was mainly taken as bycatch in the hake fisheries, with catches in the late 1980s of about 15,000 t of which roughly two-thirds came from Namibian waters. Catches of large-eye dentex (*Dentex macrophthalmus*) exceeded 25,000 t in the late 1970s, but declined to 6,000–8,000 t in the 1980s.

In the group of other pelagic fish snoek (*Thyrsites atun*) was the most important species. Catches by long-line alone at a level of 5,000–20,000 t, increased to 80,000 t with the start of a trawl fishery in the late 1970s. A major part of the catches came from Namibian waters. A global TAC of 34,000 t was adopted by ICSEAF in 1985 and maintained at about this level, but catches during 1987 and 1988 only reached some 25,000 t.

Chub mackerel (*Scomber japonicus*) showed varying catch levels, in the latest years about 30,000 t.

Squids were caught at a level of about 10,000 t over the 1980s, most of this catch coming from Namibian waters.

7.1.2 Surveys with the DR. FRIDTJOF NANSEN, 1990–93

Survey objectives and operational data

In the Southwest African People's Organization's (SWAPO) plan for the reconstruction and development of independent Namibia (UNIN, 1986), the recovery of depleted and overexploited fish stocks was described as one of the foremost objectives of the country's fisheries policy, and this priority was adopted by Namibia's first Government in its fisheries sector plan. Since the offshore fisheries as well as all ICSEAF-sponsored activities ceased following Independence, this traditional source of information on the state of the fish stocks was not to be available for guiding the future management of the sector. Direct observations of the stocks obtained through surveys by fishery research vessels can, however, provide most of the information needed for fishery management and the DR. FRIDTJOF NANSEN programme in Namibia was perceived as one of the tools of such an approach.

The survey objectives were accordingly defined simply as being descriptions of the distribution, composition and abundance of the most important resources of fish and shellfish (although little information was expected to be obtained on lobster). The pelagic fish - horse mackerel, pilchard and anchovy - would be investigated by the acoustic integration method combined with sampling with mid-water and bottom trawls, while a swept-area trawl survey programme would be used for the demersal stocks, mainly hakes.

Environmental studies would include recording of surface temperature on a continuous basis and occupation of hydrographic stations in a series of fixed profiles.

These main objectives were maintained throughout the survey period, 1990–93. More specific tasks were added as required, for example: survey 3/90 and 2/91 to use the acoustic system to observe and assess hake in mid-water; survey 2/91 trawl selectivity experiments for hake with metal frame separator; survey 1/92 collection of taxonomic data for preparation of a species guide in co-operation with the FAO Species Identification Programme (Bianchi *et al.*, 1993).

It proved practical to separate the planning and execution of the surveys of demersal resources from those of small pelagics. The first needed a fairly synoptic coverage of the whole shelf from about 150–500 m depth, while the surveys for the pelagic fish, especially pilchard and anchovy could be limited to the middle and inner shelf from central Namibia northwards.

Table 7.7 gives the timing and some data on the survey effort. There were two surveys per year for each group, mostly in the summer (January-March) and late spring (October-December). The demersal trawl stations were positioned in a semi-random manner along course tracks, and after more data had been obtained the density of the stations was adapted to the expected fish densities. The balance between the effort expended and the need for precision of the hake estimates was thought to have been found with 180–190 trawls stations in a 35–40 day survey. Problems of survey methodology, especially that of the occurrence of hake in mid-water above the headline of the trawl, are described and discussed below. Figure 7.2 shows an example of course tracks and stations in one of the later hake surveys, survey 2/1992.

The survey intensity in the investigations of pelagic fish varied, but was generally very high in inshore pilchard areas and was further increased when the pilchard stocks diminished in 1992–93. The extreme inshore distribution of the pilchard schools was a constraint on a full coverage of the resource in several surveys, while other methodological problems were also experienced. Therefore repeat surveys under different conditions were often made. Complementary and co-operative surveys with the Namibian research vessel BENGUELA added to the effort spent in the pelagic investigations from late 1991 on, as did scouting activities by commercial purse-seiners jointly with or prior to the surveys. The total effort in these surveys in the period 1990–93 must be assessed to have been very high. Figure 7.3 shows an example of repeat coverages for pilchard under different conditions in survey 2/93.

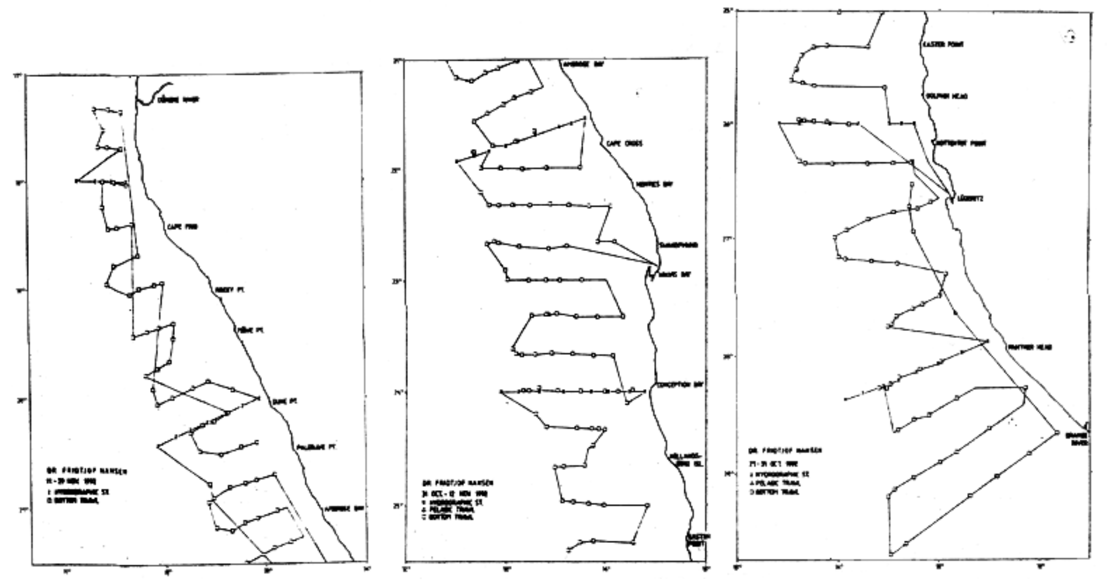

Figure 7.2 Example of the course tracks and stations of one of the later hake surveys (survey 2/92)

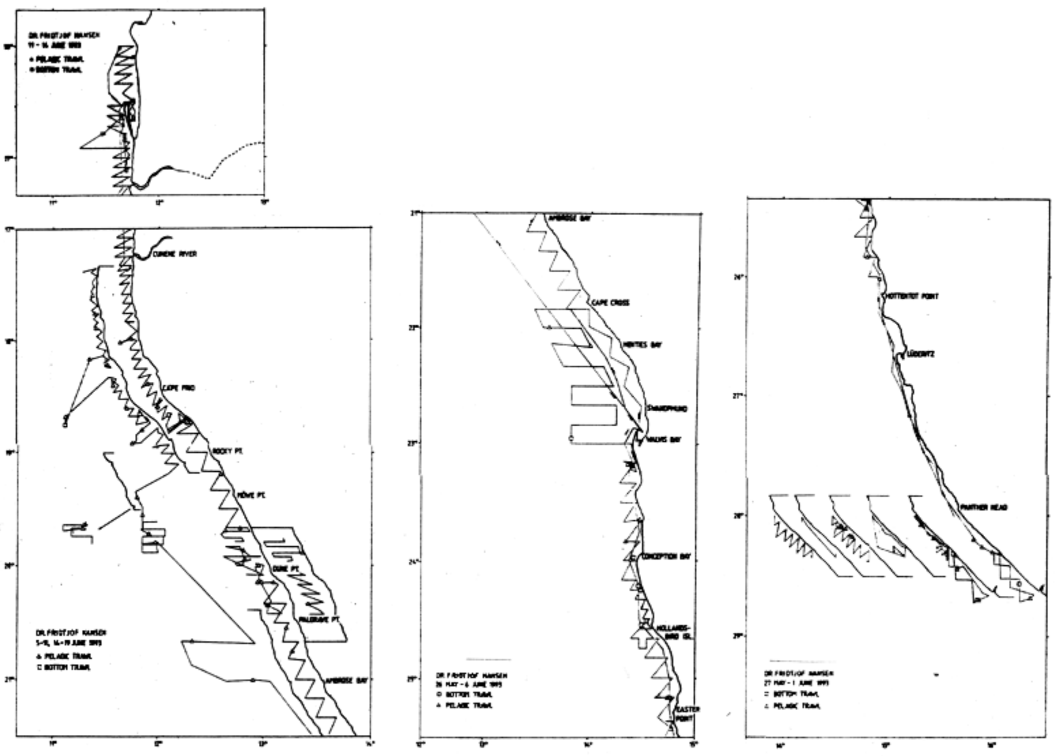

Figure 7.3 Example of repeated coverages of pilchard under different conditions of fish behaviour (survey 2/93)

Table 7.7 Operational details of the surveys in Namibia, 1990–93

			Objectives		No. of days work		No. of fishing stations	
	Survey	Dates	Demersal fish	Pelagic fish	Demersal and pelagic		Demersal and pelagic	
I	1/90	25/1-10/3	X	X	44		169	
II	2/90	27/5-20/6		X	23		96	
III	3/90	11/9-6/10	X		26		129	
					Demersal	**Pelagic**	**Demersal**	**Pelagic**
IV	1/91	15/1-22/3	X	X	34	20	174	69
V	2/91	23/10-16/12	X	X	29	24	170	102
VI	1/92	23/4-21/6	X	X	30	29	164	102
VII	2/92	20/10-16/12	X	X	42	14	192	43
VIII	1/93	20/1-19/3	X	X	37	23	184	45
IX	2/93	21/4-19/6	X	X	35	24	208	88

Responsibility for planning and execution of the surveys was shared between the Ministry of Fisheries and Marine Resources of Namibia, in particular the research unit in Swakopmund and the IMR, Bergen. Representatives of FAO Marine Resources Service participated in taxonomic work.

Cruise reports were issued after each survey, (IMR, 1990a, 1990c, 1990e, 1991a, 1991d, 1992e, 1992g, 1993a, 1993b). A summary report covering this period has not been produced, however IMR, 1994b contains an overview of work done with the old

DR. FRIDTJOF NANSEN, see Appendices I and II). All biological data were entered in the NAN-SIS databank during the surveys.

The shelf and the slope

The coastline is about 800 nmi from the mouth of the Orange River (28°38'S) in the south to that of the Cunene River (17°15'S) in the north. The depths over the shelf and the slope and the quality of the bottom were incompletely described in the available nautical charts. Observations of depths from the DR. FRIDTJOF NANSEN surveys were used to prepare the bathymetric chart presented in Figure 7.4. Echosounding also provided information on the type of bottom, smooth and even or uneven, and rough and hard or soft.

From the Orange River to Panther Head (27°55'S) the shelf is wide with 200 m isobath at 70–80 nmi offshore. The slope is relatively steep and the 500 m isobath lies about 90 nmi offshore. Considerable parts of the bottom are uneven and rough, especially inshore. Hard and rough bottom was also found on the slope, especially around the 300 m range. From Panther Head up past Lüderitz (26°35'S) the 200 m isobath approaches the coast to about 20 nmi, but the slope is gentler and the 500 m isobath lies 50–60 nmi or more off the coast. Rough and uneven bottom is common over the inshore parts. In the northern part of the ICSEAF Division 1.5 up past Easter Point (25°18'S) the shelf is wide with the 500 m isobath at about 70 nmi from the coast and with more than half of that width consisting of a gently deepening slope from 200 to 500 m. Rough, uneven bottom dominates the innermost parts of the shelf up to 20–30 nmi from the coast and there is also rough ground offshore especially off Dolphin's Head (25°40'S) at 200–300 m depth.

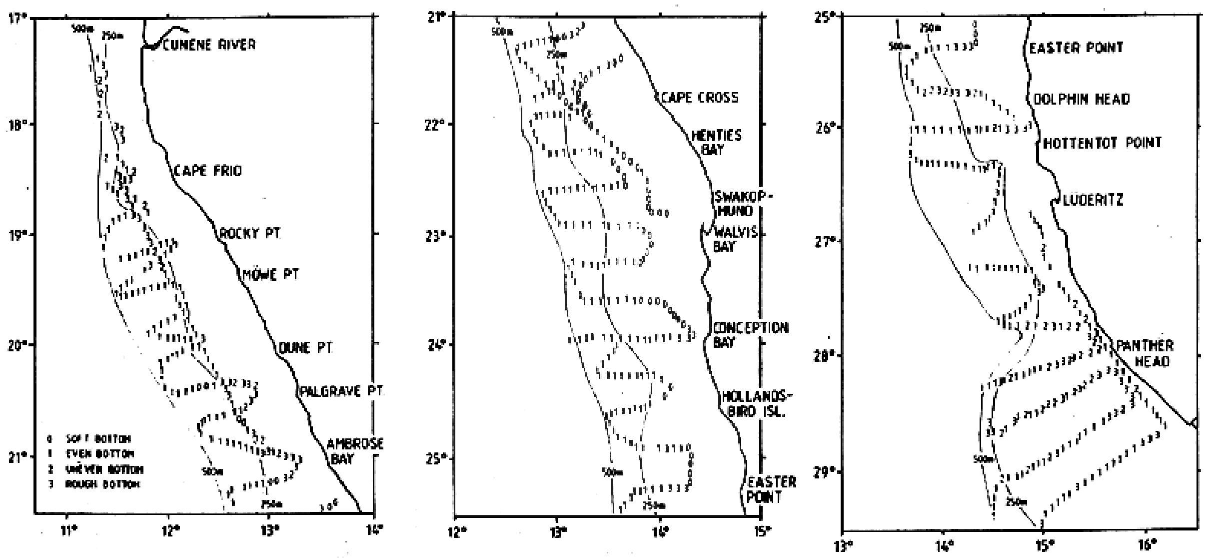

Figure 7.4 Bathymetric chart of the Namibian shelf based on echosounder observations from the DR. FRIDTJOF NANSEN surveys 1990–91. Type of bottom indicated

The broad shelf continues from Easter Point (25°18'S) northwards towards Ambrose Bay (21°S) with a generally gentle slope from 200 to 400 m depth. Most of the bottom is smooth with few and limited rough parts. An inshore belt extending out past 100 m depth, in some places to 150 m has very soft muddy bottom. At times, indications of anoxic conditions were found in this type of bottom and catches were absent or low. In some hauls from this zone the trawl contained large numbers of fish bones, and in other cases large amounts of dead mussels. Frequently the trawl got stuck after a short tow, being filled with mud. This mud layer is mainly of biogenic origin and derives from the intensive organic production caused by upwelling. Anoxic conditions associated with upwelling at times causes mass mortalities of fish and shellfish.

From Ambrose Bay up towards Cape Frio (18°30'S) the shelf maintains a width of about 70 nmi to the 500 m depth line, of which about half consists of a gentle slope from 200 m outwards. From Cape Frio to the Cunene River (17°15'S) the shelf narrows to about 25 nmi with a steep slope from the 200 m depth line.

Table 7.8 shows the approximate extensions of the areas between various depth ranges along the coast based on the depth chart shown in Figure 7.4. The total shelf area to 250 m is 25,000 nmi^2 and the slope from 250 to 550 m about 19,000 nmi^2.

Table 7.8 Coastline (nmi) and areal extension of shelf and slope by depth strata (nmi^2)

	Coastline nmi	0–250 m nmi^2	250–350 m nmi^2	350–450 m nmi^2	450–550 m nmi^2
Orange River - 25°S	240	12,000	3,300	3,000	1,700
25°S - 21°S	250	8,300	3,700	1,700	700
21°S - Cunene River	250	5,100	2,700	1,600	800
Total	**740**	**25,400**	**9,700**	**6,300**	**3,200**

Hydrography

The hydrographic conditions during each survey as observed by the oceanographic programme are described in each of the preliminary survey reports. No collective analysis has as yet been made of these data, the main problem being the very limited representativity in time of surface layer observations. Nearly all surveys experienced the effects of a few days gale in changing the surface layer conditions. The data may, however, be of value in supplementing satellite observations and in studying deeper layers. Thus, simple inspection of the observed dissolved oxygen in the profiles indicates a prevalence in many surveys of low oxygen near the bottom of the inner shelf in the central region from Conception Bay to Cape Cross.

The coastal hydrography of Namibia is well described in the literature. The waters form part of the Benguela Current system, one of the four major eastern boundary systems of the world. The surface current in general flows northwards, roughly following the isobaths between latitudes 34°S and 23°S, while north of 23°S (near Walvis Bay) it tends to veer away from the coast (Parrish *et al.*, 1983). In the north a front of Angola warm surface water moves latitudinally with the season and reaches its southernmost position in the autumn (November).

There is a southward undercurrent flowing parallel to the coast west off the shelf edge and penetrating to the coast south of Lüderitz (Shannon, 1985). This undercurrent is at times characterized by a low dissolved oxygen content, typically between 1 and 2 ml/l.

Upwelling intensity varies in space and time following changes in the wind regime and because of coastline and shelf topography. Major centres of upwelling in Namibia are near Cape Frio (18°30'S) and from Lüderitz to the Orange River estuary (26°35'S to 28°38'S). The latter is believed to effectively divide the Benguela Current system into two regions, acting as an environmental barrier for some key species.

Upwelling is perennial off Namibia, but less intensive in the north in summer, while inter-annual variability is important. Although there have been several warm and cool periods in the Benguela Current from the early 1950s to 1985, according to Shannon (1985) only two events come close to major El Niño type situations viz. in 1963 and 1984. In these events warm highly saline Angolan water intruded southward and temperatures of 2–4 degrees above normal were recorded in the upper 50 m off Namibia. The most important biological effect is probably an accompanying reduced primary productivity.

7.1.3 Pelagic fish

The species covered by these investigations were pilchard, anchovy, round herring (*Etrumeus whiteheadi*) and Cape horse mackerel, of which pilchard and anchovy had the highest priority. The distribution of horse mackerel was covered in most cases mainly over the inshore and middle shelf.

Several methodological problems were encountered in the attempts to describe the distribution and abundance of the stocks by echo integration surveys. Especially two features of pilchard behaviour created difficulties: an extreme inshore distribution in some surveys particularly in the Cape Frio area and a distribution at the surface at night which took most of the biomass above the reach of the transducer. During daytime the pilchard in a particular area would at times aggregate in a few very large schools causing high variance of the estimates. Attempts to overcome these problems of method were made by repeating surveys in areas where fish concentrations had been located. Identification to species level based on acoustic observations of such characteristics as school form and density was at times not possible and therefore trawl sampling was intensive although at times complicated by high densities of jellyfish.

In conclusion it is thought that the methodological problems were largely overcome by the very high effort put into the investigations through the combined use of the DR. FRIDTJOF NANSEN, BENGUELA and the commercial vessels. The findings show trends in stock biomass over time and can in general be said to be consistent with the outcome of the fishery.

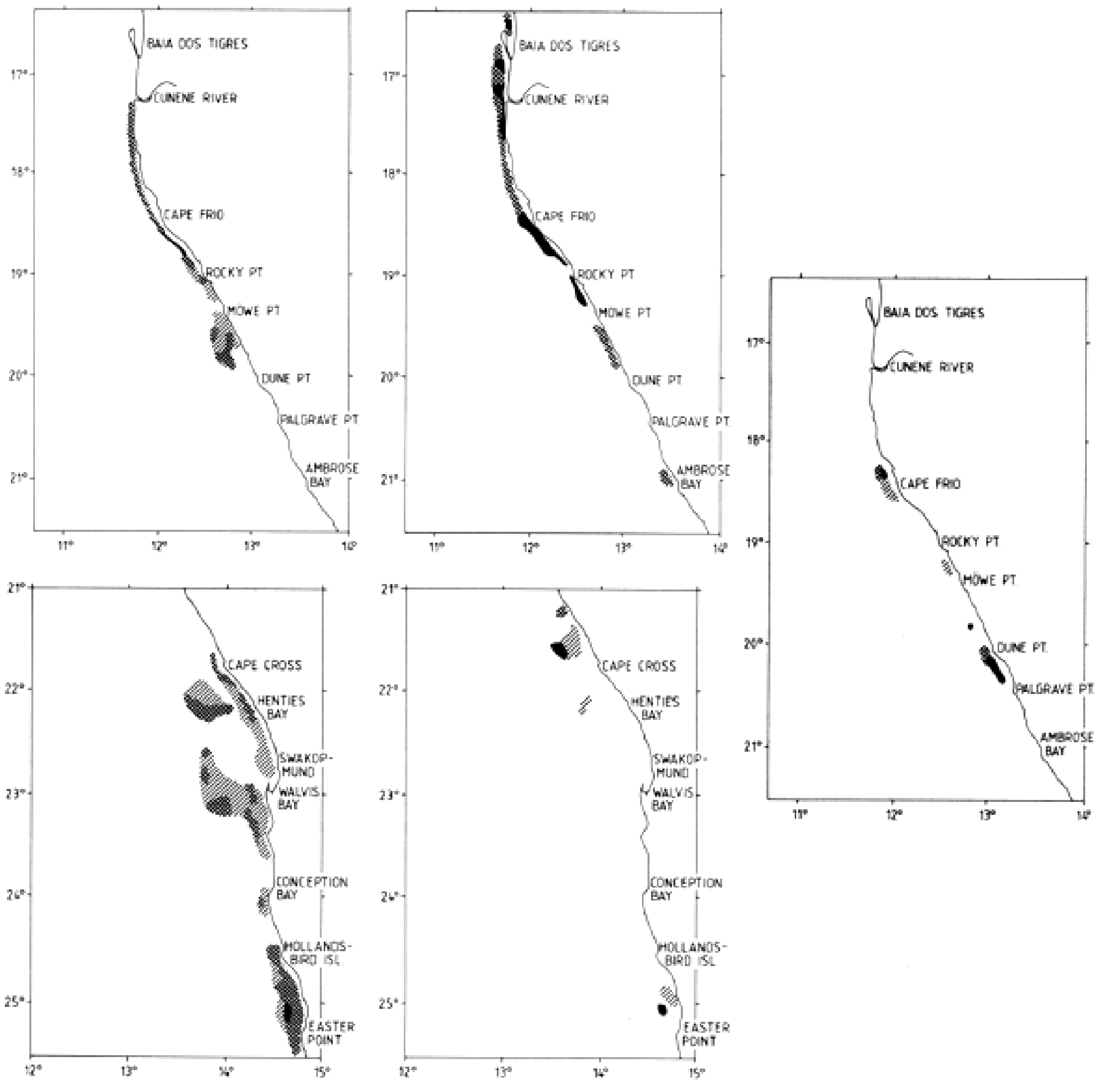

Figure 7.5 Distributions of pilchard, with some anchovy and round herring. May-June 1990 (2/90) (left top and bottom); Nov-Dec 1991 (2/91) (right top and bottom) and March 1993 (1/93) far right, bottom)

Pilchard

Distribution

With its original large stock size in the 1960s, pilchard was distributed from south of Lüderitz northwards into Angola. The fisheries were based in Walvis Bay, Lüderitz and Moçâmedes (now Namibe, 15°10'S). Pilchard tagged in Walvis Bay were recaptured in Angola and Lüderitz, but only very few in the South African western Cape fishery (Newman, 1970) demonstrating the structure of a Namibian stock. Aerial spotting in the early 1970s showed that fish occurred fairly evenly along the coast between 19°S (Rocky Point) and 25°S (Easter Point) during summer, but mainly from Walvis Bay northward in winter (Agenbag, 1980). The pelagic fish was found in an intermediate zone between inshore waters of dense phytoplankton and offshore waters of dense zooplankton. Offshore distribution (to 50 nmi) declined more rapidly in summer than in winter.

Pilchard shares the inner shelf with anchovy and round herring, classified together as "Type 1 pelagic fish" in the terminology of acoustic surveys. In many of the DR. FRIDTJOF NANSEN survey reports the distribution of these species was shown together, although the important aggregations were identified by trawl sampling to species level. In addition, young Cape horse mackerel was common on the inner shelf from about Walvis Bay northward.

Figures 7.5a through c, show the distribution of pilchard with some anchovy and round herring for a selection of the surveys over the period, viz., 2/90, 2/91 and 1/93. Of the total of eight surveys three were from summer February-March, three from autumn May-June and two from late spring November-December. An inspection of the distributions shows no clear latitudinal shift with the season along the Namibian coast. As described in Section 7.2 below, the occurrence of pilchard in southern Angola appeared to have a seasonal cycle with a maximum in winter. Some of the pelagic surveys from Namibia also covered the Angolan shelf to Tombua, in a co-operation with IIP Luanda.

The data presented in Table 7.9 seem to confirm that pilchard undertakes northward seasonal migrations towards the Cunene-Tombua shelf in August.

All three Namibian May-June surveys showed a distribution of pilchard south of Walvis Bay and it seems likely that these north-south migrations affect the whole stock as observed before the collapse of the stock (Agenbag, 1980).

An inspection of the distribution charts in sequence gives the impression that a higher proportion of the pilchard is found in the north over the survey period. It should also be noted that the stock as a whole tended to be found progressively more inshore, perhaps an effect of the narrow shelf from Cape Frio (18°30'S) northwards.

Biomass estimates

Biomass estimates were based on target strength for pilchard assumed to be similar to that of the North Sea herring. From survey 2/91 on a change was made in the assumption of the condition factor for the pilchard necessitating a reduction of 25% in the biomass estimates reported from previous surveys. Table 7.9 shows the time-series of the estimates.

Table 7.9 Biomass estimates of pilchard 1990–93 by areas and surveys. Data from Angola surveys included (1,000 t)

Season	Survey	Angola	Namibia		Total	Namibia (S)
		Tombua-Cunene	Cunene-Ambros Bay	Ambros Bay-Easter Point	Tombua-Easter Point	Panther Head-Orange River
Feb-Mar	N1/90	n.s.	120	60	180	
	N1/91	n.s.	200	400	(600)	
	N1/93	45	325	0	370	
May-Jun	A1/91	26			(560)	
	N2/90		360	200	575	
	N1/92	45	510	20	361	197
	N2/93	98	253	10		
Aug	A2/91	130	n.s.	n.s.		
	A1/92	210	n.s.	n.s.		
Nov-Dec	N2/91	120	513	88	721	
	N2/92	n.s.	300	150	(450)	
Mean of surveys			323	116		

n.s.: no survey

The low estimate from the first survey is thought to have been caused by a lack of awareness, at that time, of the periodic inshore distribution of pilchard in the Cape Frio area. Otherwise the estimates show that the standing stock of pilchard remained at a level of 600,000–700,000 t from 1990 through 1992. Early 1993 there is a sudden decline to about half the previous level. It is assumed that the 197,000 t of juvenile pilchard (modal length 11 cm) found near the border to South Africa between Panther Head and Orange River in survey 2/93 would not represent recruits to the Namibian stock.

The size compositions from the trawl samples pooled by areas usually showed one or a few distinct modal groups. However, it is uncertain whether a representative size sampling was achieved. Table 7.10 shows modal lengths by areas over the survey period. On the Tombua-Cunene shelf only adult large sized pilchard was found. In the Cunene-Ambros Bay area which accounted for the largest part of the biomass, young pilchard of 15–17 cm was commonly found together with medium sized, 19–21 cm, and some times larger specimens. This seems to have been the main feeding area. Another conclusion which may be drawn from a review of the distribution of modal groups over the period is that the pilchard stock in this period was not dominated by one or a few strong year classes. Recruitment seems to have occurred over most of the survey period at roughly the same level.

The observed decline of the pilchard stock coincided with a northward shift of its distribution. A possible explanation may be found in the structure of the original Namibian pilchard stock. As a whole it may have represented a super-population consisting of several partly mixing sub-populations arranged along the coast. Stocks in the central area would be more vulnerable to fishing and to predation from the seal population. The natural predator prey relationship between the two populations has been distorted by the collapse of the pilchard stock and at its recent low level the stock was not sustainable.

Table 7.10 Modal lengths in pooled samples of pilchard by survey, sub-areas and season. Main modes underlined

Season	Survey	Angola Tombua-Cunene	Namibia Cunene-Ambros Bay	Namibia Ambros Bay-Easter Point	Namibia (S) Panther Head Orange River
Feb-Mar	N1/91		15, 24	14, 23	
	N1/93	26	16, 19	15, 20	
May-Jun	N2/90	n.s.	20	22	
	N1/92	20, 23	15, 21	10, 24	
	N2/93	23	15, 20	21	11
Nov-Dec	N2/91	25	17, 23	23	
	N2/92		16	21	

n.s.: no survey

Anchovy and round herring

In larval surveys in 1978/79 when the anchovy stock was still relatively abundant (Badenhorst and Boyd, 1980) the highest densities were found inshore and from Walvis Bay northwards. In acoustic surveys, Cruickshank (1983) found anchovy inside 100 m and more shallow than pilchard.

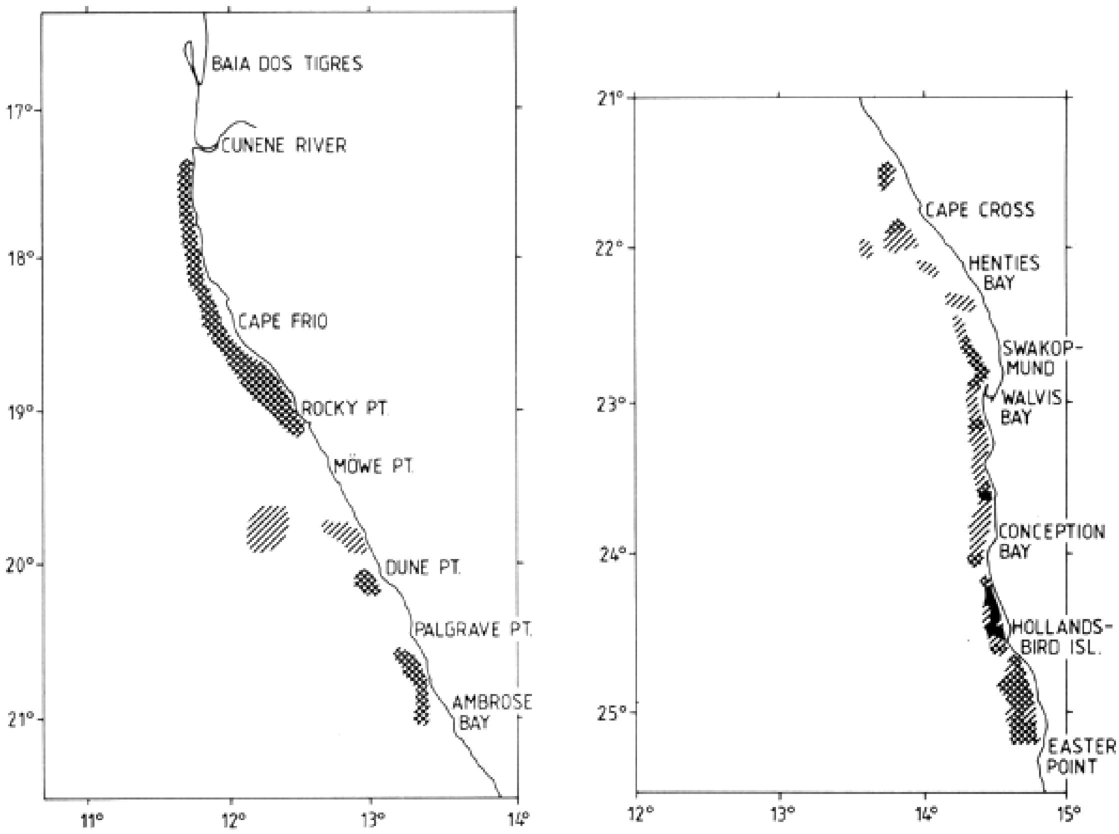

Figure 7.6 Distribution of anchovy and round herring in May-June 1992 (2/92)

After a decline in the early 1980s, there was a brief recovery of the anchovy stock and the fishery in 1987 and 1989 which has been related to the contemporary large increase in the abundance of South African anchovy. The stock again declined and the surveys show that it remained at a low level until 1993.

Anchovy and round herring were assessed together in six out of nine surveys. Figure 7.6 shows the distribution of the two species in the DR. FRIDTJOF NANSEN survey 2/92. The two species were found in the same inshore zone as the pilchard. In contrast with the pilchard, no northward shift of the anchovy and round herring stocks seems to have occurred.

The combined biomass estimates for anchovy and round herring are presented in Table 7.11. Based on the trawl samples, anchovy was twice as abundant as round herring. The mean total biomass for all surveys in Namibia is 184,000 t with 124,000 t anchovy and 60,000 t round herring. There was little variation in the standing stock biomass estimates over the survey period apart from the low estimate of survey 2/92, thought to have been caused by inadequate survey coverage.

Table 7.11 Anchovy and round herring: Combined biomass estimates by season, survey and area (1,000 t)

Season	Survey	Angola	Namibia		Total	Namibia (S)
		Tombua-Cunene	Cunene-Ambros Bay	Ambros Bay-Easter Point	Tombua-Easter Point	Panther Head Orange River
Feb-Mar	1/90	n.s.	90	125	215	
	1/91	n.s.	10	125	135	
	1/93	0	150	185	335	
May-Jun	2/90	n.s.	70	115	185	
	1/92	5	100	75	180	
	2/93	6	76	72	154	84
Nov-Dec	2/91	70	242	0	312	
	2/92	n.s.	27	5	32	
Mean			96	88		

n.s.: no survey

Cape horse mackerel

In a survey between Walvis Bay and Cunene, Olivar and Rubiés (1983) found eggs and larvae of horse mackerel only north of 22°S (Cape Cross), with the highest concentrations offshore over depths of 200–300 m. This also represents the main distributional area of adult horse mackerel in Namibia.

The inshore distribution area of young horse mackerel overlaps with that of pilchard and anchovy and this was covered in all of DR. FRIDTJOF NANSEN's pelagic surveys, while the middle and outer shelf off the central and northern regions were covered in four of the surveys: 1/90, 2/90, 2/91 and 1/92. Because horse mackerel was only a secondary objective of these investigations, sampling intensities on the outer shelf were not high and the precision of the estimates may be low. There may also be a bias because of lack of coverage of the shelf edge and the slope.

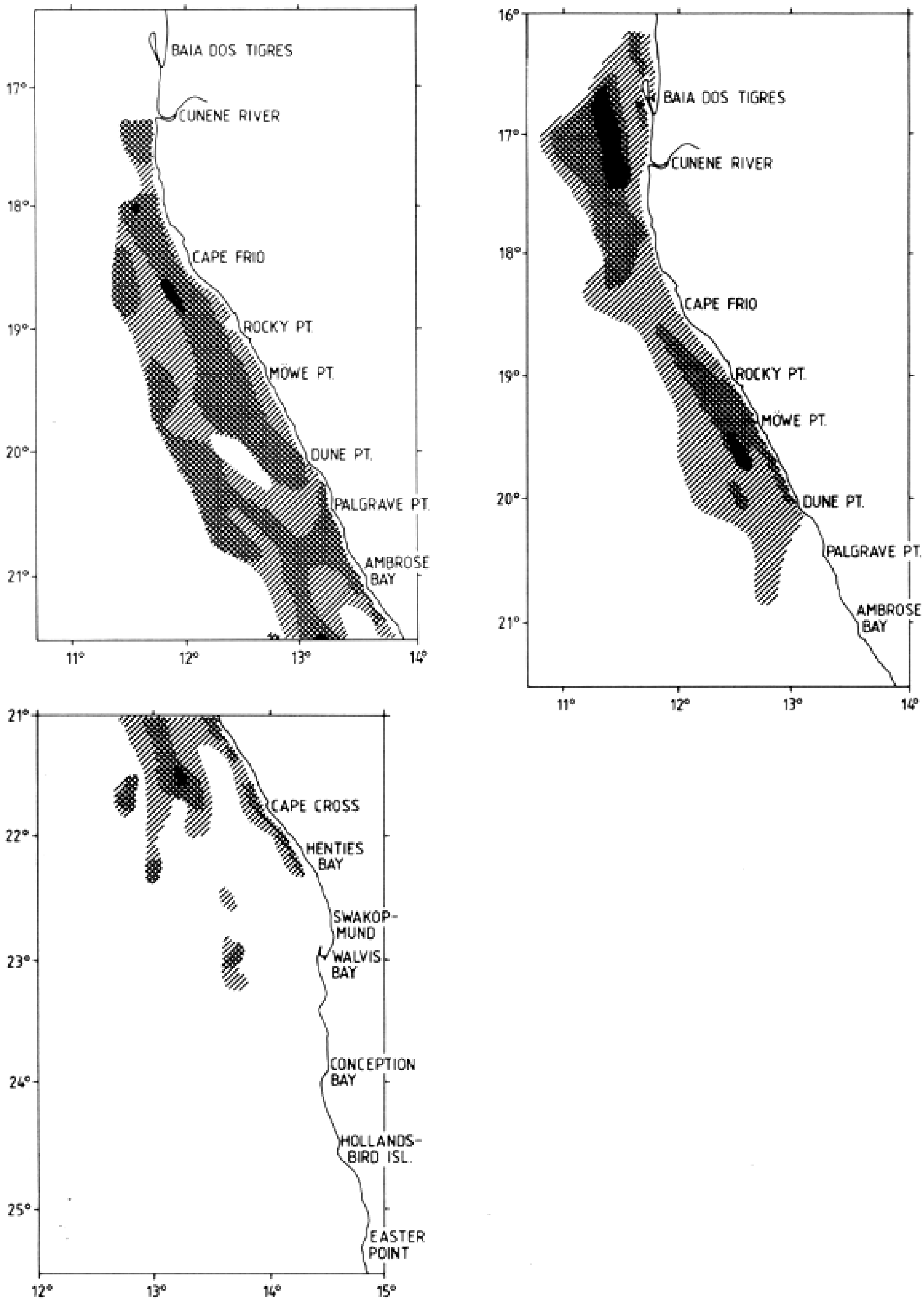

Figure 7.7 Distribution of horse mackerel in surveys 2/90 (left) and 1/92 (right)

Figure 7.7 shows the distribution in surveys 2/90 and 1/92. The central region was well covered in 1990, but had low survey intensities in 1991 and 1992. These last surveys included the Angolan shelf from Tombua to Cunene, which is the northern boundary of the Cape horse mackerel. In several of the surveys the seaward limits of the distribution were not well defined in various locations.

In most cases the inshore high densities represented juvenile horse mackerel which tended to form dense day-time schools. The adult fish usually formed looser aggregations during the day often near the bottom or at middle depths, and dispersed in upper water layers during the night. Surface schools might be formed in the morning.

These characteristics of behaviour determine the catchability of these fish by different gears. Juvenile horse mackerel is fished with purse-seines, and the adult fish by trawl. Offshore purse-seining has not been developed in Namibia although this is a common fishing method for horse mackerels in other parts of the world.

Measurements of swim bladder volumes from the early surveys indicated that horse mackerel might have a lower acoustic target strength than clupeids, but subsequent *in situ* observations did not confirm this. Therefore, also in this case the target strength used for North Sea herring was assumed in the biomass estimates, combined with a condition factor of 0.85.

Table 7.12 shows the biomass estimates with totals ranging from 1.2 to 2.1 million t. The data by sub-areas seem to demonstrate a northward displacement of the biomass, but the course tracks of the 1991 and 1992 surveys show an inadequate coverage of the central offshore shelf and the 1990 surveys did not include southern Angola. It may be concluded that the mean biomass in the survey period probably exceeded 2 million t.

Table 7.12 Biomass estimates of Cape horse mackerel by season, survey and area (1,000 t)

Season	Survey	Angola	Namibia		Total
		Tombua-Cunene	Cunene-Ambros Bay	Ambros Bay-Easter Point	
Feb-Mar	1/90	n.s.	560	660	(1,220)
May-Jun	2/90	n.s.	340	1,360	(1,700)
	1/92	700	1,400	0	2,100
Nov-Dec	2/91	340	1,100	0	1,440
Mean of surveys			850	505	

n.s.: no survey

Summary of biomass estimates and densities of small pelagic fish

It is of interest to consider the mean standing biomass of the various stocks over the period of the surveys and their densities by shelf area and coastline length. Table 7.13 provides a summary of these data.

Table 7.13 Small pelagic fish: rough estimates of standing biomass (mean of survey results) by species; means of annual landings (1,000 t) and derived densities in t per nmi² and t/nmi of coast line

	Cunene-Ambros Bay	Ambros Bay-Easter Point	Total area	Mean landings
Shelf area (nmi²)	7,400	10,900	18,300	
Coast length (nmi)	250	250	500	
Species groups:				
Pilchard	323	116	439	100
Anchovy and round herring	96	88	184	50
Horse mackerel	850	505	1,355	300
Total pelagics	1,269	709	1,978	450
Density (t/nmi²)	171	65	108	(25)
Density (t/nmi coastline)	5,076	2,836	3,956	(900)

The density of small pelagic fish measured per unit shelf area was almost three times higher in the northern than in the central region. Measured by length of coastline it was nearly twice as high.

The densities observed in the 1986, 1989 and 1992 DR. FRIDTJOF NANSEN surveys of the corresponding shelf of perennial upwelling in the Canary Current system, the coast from Cape Bojador to Cape Blanc (Chapter 6) were 295 t/nmi^2 of shelf and 12,500 t per n.mile of coastline. Comparable densities in Namibia were about 60% lower per unit shelf and unit coastline. It seems likely that sardine, that dominates in northwest Africa, is placed lower in the food chain than the horse mackerel and is a more efficient utilizer of biological production. Therefore the productivity of small pelagic fish in Namibia may have been considerably higher than the present level prior to the depletion of the pilchard stock.

7.1.4 Demersal fish

Survey effort

The effort in the eight trawl surveys during 1990 to 1993 (see Table 7.7) to study the demersal resources was high (Table 7.14) and provided sets of very comprehensive data on the composition, distribution and abundance of most of the commercial bottom fishes of the shelf and slope. All catches were sampled to species level by weight and numbers, and biological sampling was made of commercially important stocks. The NAN-SIS databank was used for storing and processing all data.

The two species of hake (*Merluccius capensis* and *M. paradoxus*) were the primary objective and since these species do not occur inside 100–120 m depth off Namibia except in the extreme south, the nearshore grounds were not surveyed.

Table 7.14 Effort in Namibian hake surveys 1990–93. Swept-area fishing stations, number of samples (mostly by sex) and number of specimens measured, in thousands

Survey			Orange River-St. Francis	St. Francis-Ambrose Bay	Ambrose Bay-Cunene	Total Namibia
I	1/90	No. of stations	59	73	37	169
	25/1–10/3	No. of samples	37	73	25	114
		No. measured	6.0	10.7	2.6	18.6
III	3/90	No. of stations	44	51	34	129
	11/9–6/10	No. of samples	68	106	77	251
		No. measured	9.3	10.3	5.6	25.2
IV	1/91	No. of stations	41	77	56	174
	25/1–28/2	No. of samples	104	170	114	388
		No. measured	6.8	13.3	6.9	27.0
V	2/91	No. of stations	52	69	49	170
	23/10–21/11	No. of samples	110	132	110	352
		No. measured	7.1	14.3	9.6	31.0
VI	1/92	No. of stations	57	60	47	164
	23/4–21/5	No. of samples	136	141	102	379
		No. measured	9.0	11.2	8.2	28.4
VII	2/92	No. of stations	64	78	50	192
	20/10–1/12	No. of samples	188	169	143	500
		No. measured	13.1	13.4	7.8	34.3
VIII	1/93	No. of stations	72	56	56	184
	20/1–25/2	No. of samples	197	162	118	477
		No. measured	12.7	11.9	7.6	32.2
IX	2/93	No. of stations	61	78	69	208
	22/4–25/5	No. of samples	173	202	163	538
		No. measured	10.8	13.9	10.2	34.9

Problems of methods in the hake surveys

Early estimates of the Namibian hake stocks were made by acoustic methods (Cushing, 1968), while ICSEAF survey assessments were by the swept-area method.

The survey design was a semi-random allocation of stations along course tracks which covered the distributions from their eastern shallow to the western deep limit at 500–600 m. Post-stratification by densities was used for biomass estimates of Cape hake. The validity of this method is discussed in Chapter 2. With the increased effort towards the end of the period, the precision of the biomass estimates was generally high, 11–14% (95% confidence limits).

Sources of bias probably represented more serious problems. Assumptions regarding the effective fishing width and height of the trawl and the distance of towing are critical for the accuracy of the estimates.

In survey 3/90 observations were made with SCANMAR™ instrumentation of headline height and distance between wings of the type of bottom trawl used by the vessel in the Namibian surveys (Table 7.15).

Table 7.15 Observations of headline height and distance between wing tips during trawling. Means of 4–6 observations (m)

Section No.	Bottom depth (m)	Distance of wing tips	Headline height
360	173	20.3	5.5
367	165	19.4	5.4
397	202	18.9	5.7
455	253	16.5	4.8
464	322	18.9	5.3
500	150	17.5	6.2

The positions of the wing sensors were slightly more forward on stations 360 and 367 than in the following experiments. The experiments at stations 455, 464 and 500 were performed with a different net of the same design. The low values obtained at station 455 may have been caused by a catch of jellyfish which is expected to have resulted in heavy drag of the net due to clogging. The overall mean of the observations of distance is very close to the value used in the swept-area estimates of 1/100 nmi or 18.6 m. The SCANMAR measurements indicated that in normal hauls the distance may be somewhat greater, and perhaps lower when by-catches of jellyfish occur.

Following these measurements and perhaps not entirely justified, no change was made in the assumption that 18.6 m was the effective fishing width of the trawl for all species and fish sizes. In addition to the reduced wing-spread of hauls with jellyfish, it was realized that clogging of the meshes by jellyfish would also reduce the fishing power resulting in a trend of underestimation because of low catch rates in seasons of high abundance of jellyfish.

The trawl gear was not instrumented for bottom contact and the start of the 30 min (exceptionally 60 min) tows was determined by the fishing master who estimated the interval after shooting needed to reach the bottom. Instrumented tows with the new vessel have indicated that the time allowed for the trawl to sink to the bottom may have been consistantly underestimated, which again would result in an underestimate of the biomass.

However, the most important source of bias in the biomass estimates of the hakes based on swept-area calculations relates to their mid-water occurrence. Hakes are often described as mid-water feeders with swarms of krill, mysids and various pelagic fish as their main food source. In Namibia, gobies, myctophids and horse mackerel are important potential food sources in mid-water in addition to the krill.

The general experience of hake behaviour over the survey period was that it varies with size and age of the fish and with depth. The 1–2 year Cape hake of 20–30 cm length, found in highest concentrations in the 180–250 m depth range, often stayed very close to the bottom during the day, but regularly lifted during the night and formed well defined single fish layers. In southern Namibia, near the Orange River, this group was found close inshore, at 70–110 m depth, a difference in behaviour which is probably related to different environmental conditions. With sampling restricted to daylight hauls the 1–2 group hake will be well covered.

With increasing size, above 30–35 cm and age 3–4 years, the Cape hake moves into deeper water, 250–300 m, where it mixes with larger fish. At higher ages, hake is found on the slope, from 300 m to more than 400 m. At these depths it was frequently observed in mid-water also during the day. There were, however, special difficulties in observing and measuring the density of hake at these depth ranges, primarily because it was found together with other organisms which appeared as spurious scattering layers in the echograms. To distinguish hake traces, in dense layers of crustaceans or myctophids in mid-water or in layers of other fish such as blackbelly rosefish or Jacobever (*Helicolenus dactylopterus*) or greeneyes (*Chlorophthalmus atlanticus*) nearer the bottom, was often difficult and a separation for density estimations was at times not possible.

Acoustic estimates of the pelagic hake by areas or depth ranges were not attempted, but a procedure was developed to compensate for the occurence of hake in mid-water, above the headline of the trawl. The density obtained from trawl hauls was adjusted by simple adding the mean acoustic density observed in this mid-water layer during the tow to the trawl estimate. A target strength similar to that used for cod was applied: TS = 20 logL - 68.

A considerable change in the behaviour was already observed in the first surveys. In survey 1/90, mid-water occurrence of the hake was expected and attempts were made to observe it, but significant amounts were only recorded in mid-water in some areas at night. Then the swept-area estimates were considered to be reliable. A few months later, in survey 3/90, hake was only found to be distributed in mid-water both day and night in the north from Ambrose Bay to Cunene. Attempts were made to estimate the densities by acoustic methods. These indicated that the swept-area method would result in a considerable underestimate, perhaps as much as 100%.

The SIMRAD™ EK 500 acoustic system installed in the vessel in January 1991, provided a better tool for observations and estimates of the density of hake in mid-water. Figure 7.8 shows an example of an echogram of hake above the bottom recorded with this equipment during trawling in daytime.

Table 7.16 shows the level of the adjustments which were made in the surveys from 1991 onwards, in an attempt to include the biomass of the pelagic hake. Survey 1/91 stands out with very high correction factors indicating that a very high proportion of the Cape hake biomass was found in mid-water. In general there was a tendency for the northern region to have the highest incidence (% occurrence in the trawl hauls) and correction factors. This is the area with the highest proportion of large-sized Cape hake. There seemed to be no clear seasonal trend except perhaps lower spring (Oct-Dec) than summer (Jan-Feb) values. Adult deep-water hake in the south was seldom found in mid-water.

Stock evaluation of semi-demersal fish by a combination of swept-area trawl surveys and acoustics has been approached in different ways by researchers. For walley pollock in the Eastern Bering Sea independent surveys were developed using the two techniques (Karp and Walters, 1994) with a qualitative comparison of the results considering their respective biases rather than a combined assessment. For cod and haddock in the Barents Sea a simultaneous twin-method survey system has been developed (Korsbrekke *et al.*, 1995) which provides two comparable indices.

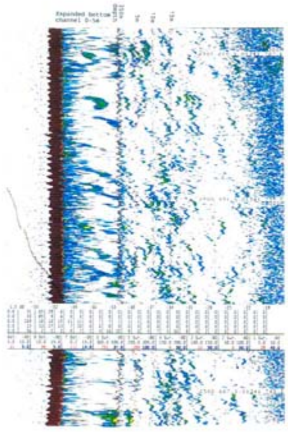

Figure 7.8 Echogram showing traces of hake off the bottom during trawling in daytime. Bottom depth 350 m. Lines indicate distance from bottom: 5 m, 10 m, 20 m

Table 7.16 Mean correction of swept-area densities by acoustic estimates of pelagic hake during towing and incidence of stations with corrections, 1991–93 by surveys and regions. Day-time observations only (%, incidence in brackets)

	Region	Orange River-St. Francis Bay 28°38' - 25°30'		St. Francis Bay-Ambrose Bay 25°30' - 21°00'		Ambrose Bay-Cunene River 21°00' - 17°15'	
	Survey						
IV	1/91 Jan-Feb	59	(48)	67	(43)	185	(84)
V	2/91 Nov-Dec	0		0		17	(41)
VI	1/92 Apr-May	4	(12)	2	(9)	9	(28)
VII	2/92 Oct-Nov	9	(22)	5	(36)	10	(42)
VIII	1/93 Jan-Feb	5	(29)	6	(40)	23	(65)
IX	2/93 Apr-May	10	(15)	6	(19)	30	(42)

Undoubtedly, it would be an advantage to have more comprehensive information on the mid-water occurrence of the hake in Namibia. There would seem to be no special difficulties in developing acoustic surveys for juvenile hake using night-time observations, but for adult Cape hake on the outer shelf and slope, effective acoustic density measurements covering the region would need adoption of a technique that could overcome the problem of the masking of hake echoes by the often dense scattering layers from other organisms.

The simple approach of adding mean acoustic density for each trawl haul to the trawl estimate undoubtedly improves the accuracy of the total estimate, but the few observations made may not be representative of the fish behaviour over larger areas and the masking problem may introduce a bias. If the fish remaining near the bottom would form a constant proportion of the total stock, the swept-area measure would be a valid index of stock changes, but the variation between surveys as shown in Table 7.16 indicates that this is not the case. It may, perhaps, be concluded that the present approach has made the best use of the available data pending further technical advances.

Distribution of the hakes

O-group Cape hake of about 10 cm could be detected in the surveys in the early part of the year. At this stage they did not have a wide continuous distribution, but were in daytime for the most part found in restricted locations along the coast in dense patches at depths of 120– 150 m mainly in mid-water. This group was not a target of the surveys.

Juvenile Cape hake of 1.5–2 years with a size of 20–25 cm was found over wide parts of the shelf in relatively shallow water, 130–200 m, sometimes at very high densities. The areas of high abundance of this group were especially extensive in the Central Region, from St. Francis Bay to Ambrose Bay, while near the Orange River it was found closer to the coast.

With increasing size the Cape hake was found at greater depth, with the 30–40 cm fish still mainly over the middle part of the shelf, and the larger fish near the shelf edge and the slope down to about 500 m.

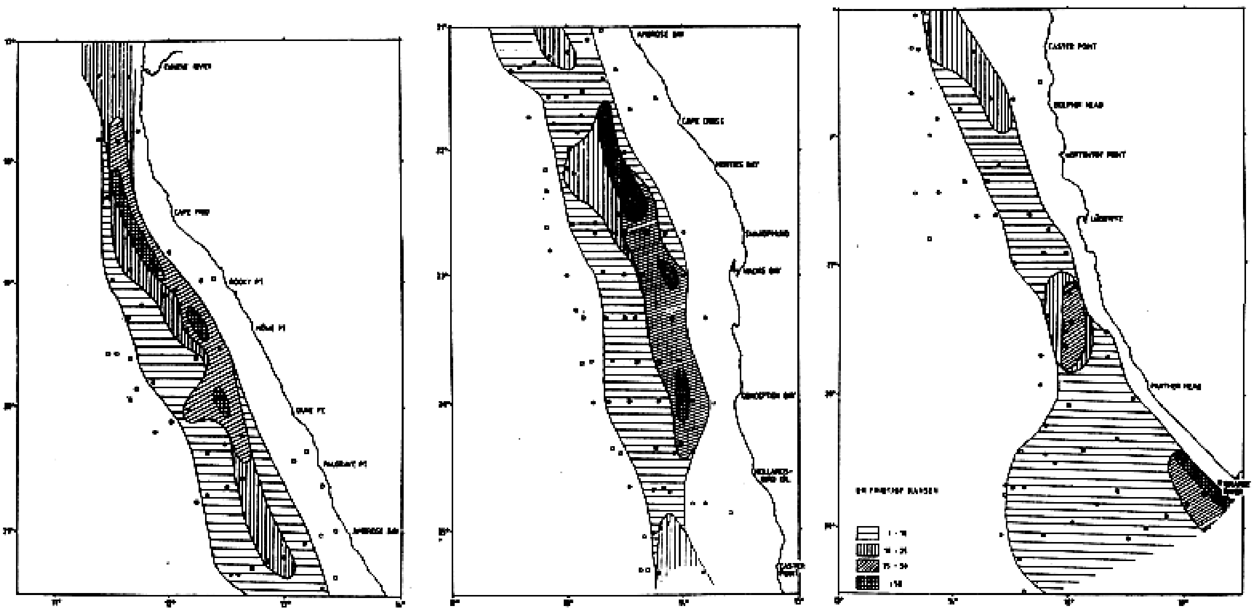

Figure 7.9 Distribution of Cape hake from swept-area densities, survey 1/90

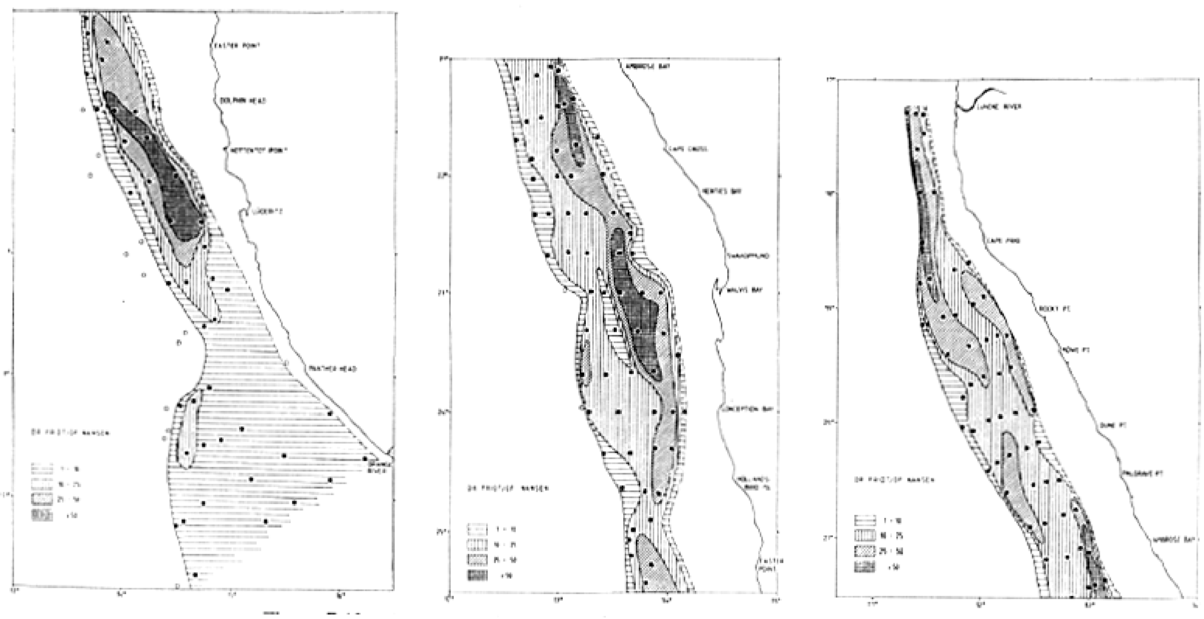

Figure 7.10 Distribution of Cape hake from swept-area densities, survey 1/92

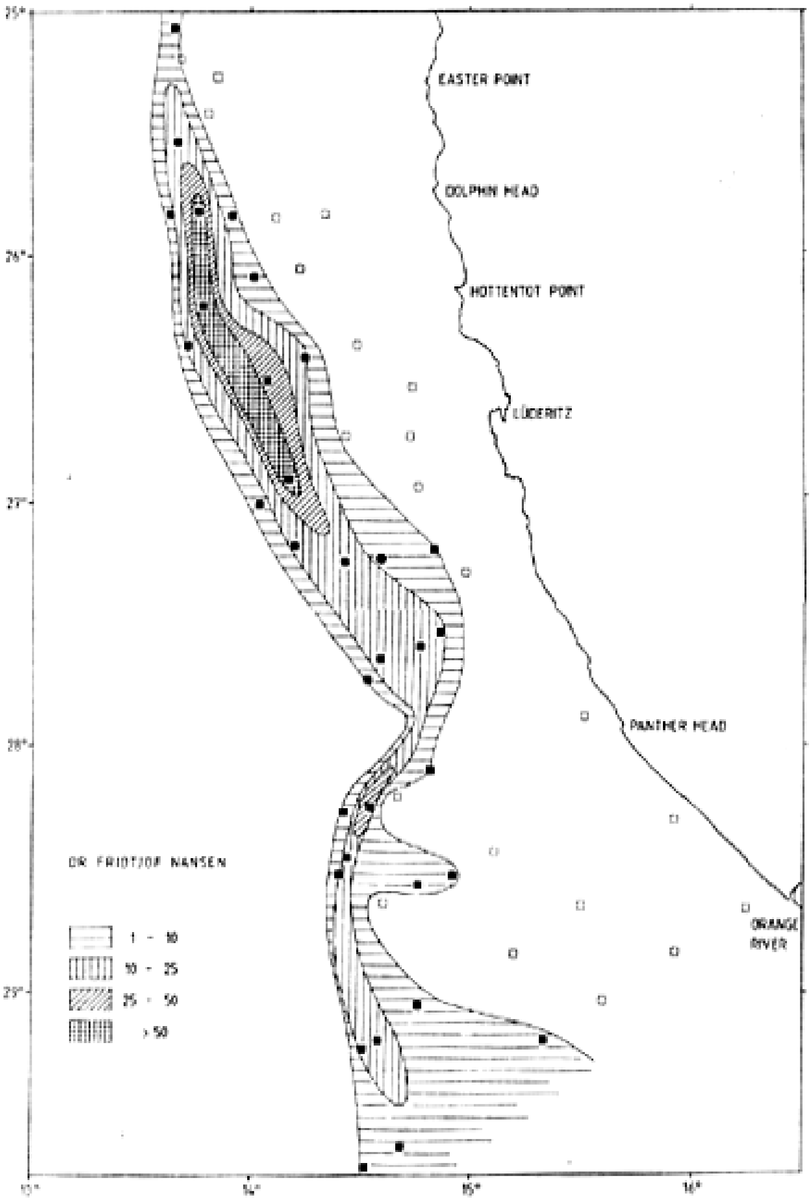

Figure 7.11 Distribution of deep-water hake in the southern region, survey 1/92

Figure 7.9 shows the Cape hake distribution by regions as found in the first survey (1/90). The basis for this chart is formed by the swept-area estimates with post-stratification by arbitrary density levels. The areas with high densities were juvenile fish, 20–25 cm in the Central Region and somewhat larger fish, 25–30 cm in the Northern region.

Figure 7.10 shows the distribution of Cape hake found in survey 1/92. The general picture was similar to that from 1990, but in addition to areas of high density of juvenile fish in the shallow part of the Central Region, patches and larger areas of high density of large-sized fish were now found in all three regions.

As expected, the distribution of the deep-water hake was found to be very different from that of the Cape hake. Juveniles, of 20–30 cm were found on the outer shelf and upper slope, 200–300 m and the adults mainly from 300–600 m. Figure 7.11 shows post-stratified densities from survey 1/92 from the Southern Region when this species had the highest densities measured in all Namibian surveys. At its central depth of distribution, 400–500 m, deep-water hake was found all along the slope northward to Cunene.

The general characteristics of the distribution of the two hake species as shown in Figures 7.9, 7.10 and 7.11 were confirmed in each of the surveys, but with deviations. For the Cape hake deviations were caused by variations in recruitment which appeared as changes in the extent of the high density aggregations of small-sized fish inshore, especially in the Central Region. Recruitment variations are analysed separately below.

There was also a trend of increased density at greater depth for the Cape hake with time in all regions as shown by Table 7.17, most pronounced from 1990 to 1991, but which also continued from 1991 to 1992. There was also a difference in the depth distribution of the Cape hake by regions with increasing densities at greater depths northwards.

Table 7.17 Cape hake: Mean densities by depth range, survey and region (t/nmi^2)

Depth range	100–250 m	250–350 m	350–450 m	450–550 m
Southern region				
1/90	21.9	4.4		
1/91	11.3	8.8	0.9	
2/91	6.3	12.5	0.7	0.7
1/92	12.6	28.4	4.6	
2/92	11.6	12.2	1.1	0.2
1/93	14.2	25.7	7.2	0.3
2/93	11.0	18.2	4.7	
Central region				
1/90	27.1	7.4	0.4	
1/91	14.5	9.1	2.2	
2/91	34.2	19.0	7.2	1.0
1/92	36.5	14.6	8.5	1.7
2/92	53.6	20.1	10.5	0.8
1/93	34.1	9.5	8.9	0.3
2/93	34.4	23.8	4.6	0.6
Northern region				
1/90	41.3	20.9	1.0	
1/91	15.0	27.0	11.5	
2/91	13.6	23.5	24.3	4.3
1/92	25.4	26.1	15.5	
2/92	29.6	18.6	17.6	
1/93	13.7	23.2	14.7	2.8
2/93	9.3	16.5	12.8	2.3

Changes in the distribution of adult Cape hake among regions were also observed and these were interpreted as migrations. This is evident from an examination of the distribution charts, but can more easily be demonstrated by an analysis of the fishable biomass estimated for each region through the surveys. As shown in Table 7.18 the proportion of fishable biomass was as an average of all surveys 24%, 34% and 42% for the Southern, Central and Northern Regions respectively. But there were variations between the surveys. A seasonal shift from the Northern to the Central Region in the spring was observed, probably the effect of spawning migrations. There also appears to have been a decrease in the proportion in the Northern Region over the period. The distribution of the fishery in the period, predominantly in the northern half of the coast, must have affected that of the biomass.

Table 7.18 Cape hake: Distribution of fishable biomass by region, season and survey and total biomass

Season	Survey	Southern region %	Central region %	Northern region %	Fishable biomass 1,000 t
Jan-Mar	1/90	19	19	62	106
	1/91	19	23	58	291
	1/93	28	40	32	331
Apr-Jun	1/92	36	27	37	398
	2/93	32	39	29	309
Oct-Nov	2/91	15	44	41	331
	2/92	18	47	35	382
Mean	All	24	34	42	

A very different picture is shown by the analysis of the distribution by regions of the nonfishable biomass, defined as fish below 36 cm length corresponding approximately to the 50% selection length of an 110 mm mesh (Table 7.19). This biomass will be dominated by the 1.5– 3 year old juvenile fish affected by recruitment variation, and the central region with a mean of about 58% clearly held the main nursery grounds, followed by the southern region with 27%. It can only be speculated whether or not the juvenile fish found inshore near the Orange River, such as in survey 1/90, would recruit to the Namibian stock of Cape hake or migrate south of the border. Generally the highest amount of juvenile fish was found in the central region, but in some surveys their distribution also extended into the northern region. In survey 1/91 and in 1993 the distribution was central and south. These changes may be related to environmental factors.

Table 7.19 Cape hake: Distribution of the non-fishable biomass by region, season and survey and total biomass

Season	Survey	Southern region %	Central region %	Northern region %	Non-fishable biomass 1,000 t
	1/90	25	40	35	391
Jan-Mar	1/91	41	45	14	179
	1/93	40	47	13	323
Apr-Jun	1/92	19	63	18	250
	2/93	31	61	8	259
Oct-Nov	2/91	17	80	3	202
	2/92	18	69	13	510
Mean	All	27	58	15	

Depth distribution of juvenile Cape hake

The size-dependent depth distribution of Cape hake facilitates the use of fishery protection zones to assist in obtaining a suitable minimum fishing size in the trawl fishery. An analysis based on data from the four first hake surveys during 1990–91, was presented to the Namibian authorities in late 1991 (IMR, 1991d).

The distribution by density strata were used to estimate the total biomass inside and outside two selected isobaths, 200 m and 250 m in each region. Figure 7.12 shows, as an example, the chart for the Central Region in survey 2/91. The proportion of juvenile (< 35 cm) and of adult fish (> 34cm) was estimated from the size compositions by length converted to weight.

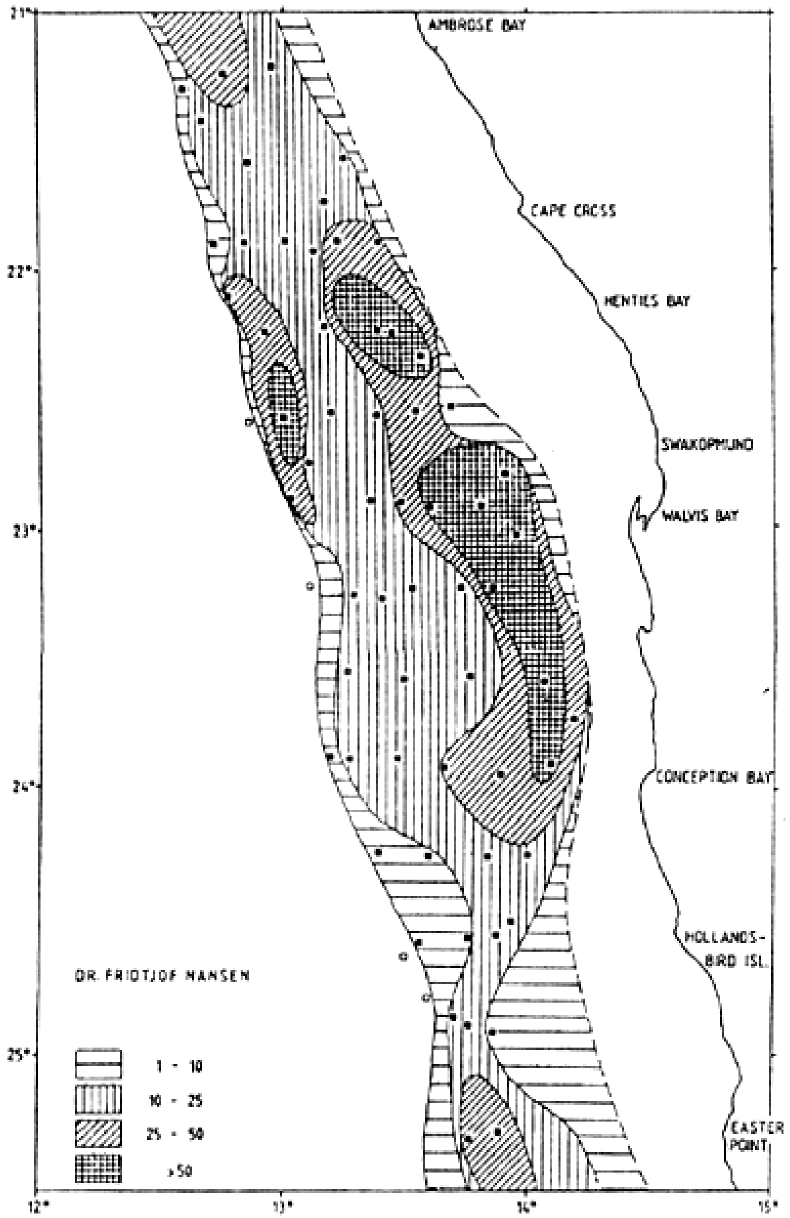

Figure 7.12 Cape hake: Distribution in the central region in survey 2/91

Table 7.20 shows the results of this analysis. The figures for adult fish (survey 3/90 in the Northern region) were put in brackets because an unknown quantity of hake observed, but not quantified in mid-water, could not be included.

In the first two surveys a relatively high proportion of the adult stock, 40 to 70% was found inside the 200 and 250 m isobaths in the northern and central regions. Because of depletion by the previous fishery there was little middle-sized hake and no large-sized hake in 1990. The proportion was much smaller in the last two surveys. In most surveys the larger part of the juvenile stock was found inside the 200 m line and about 70–90% inside 250 m.

Table 7.20 Cape hake: Estimates of proportions of adult and juvenile biomass inside the 200 m and 250 m depth lines* by regions and surveys (%)

Depth range	Inside 200 m		Inside 250 m	
Northern region	**Adult**	**Juvenile**	**Adult**	**Juvenile**
Survey 1/90	56	60	72	92
Survey 3/90	(16)	55	(51)	89
Survey 1/91	6	19	23	67
Survey 2/91	2	67	16	83

Central region				
Survey 1/90	43	80	43	95
Survey 3/90	53	58	71	89
Survey 1/91	14	52	22	74
Survey 2/91	16	88	30	98
Southern region				
Survey 1/90	9	71	22	87
Survey 3/90	9	26	33	56
Survey 1/91	8	36	23	85
Survey 2/91	7	47	33	74

* Inside 150 m south of Panther Head, 28°S

The mean proportions weighted by the corresponding biomass would give the most representative relationships. These were as follows:

	Inside 200 m		Inside 250 m	
	Adult	Juvenile	Adult	Juvenile
Mean, all regions, all surveys	15%	62%	33%	87%
Mean, all regions, survey 2/91	9%	80%	25%	93%

It seems reasonable to conclude that over the period covered by these surveys, more than 60% of the juvenile stock was distributed inside 200 m of depth and nearly 90% inside 250 m. With the perhaps more normal composition of the stock components which existed in survey 2/91 these proportions were even higher, 80% and 93% respectively. Only small proportions of the adult stock, about one-third was found shallower than 250 m during the period and only a quarter in the last survey.

Biomass estimates of Cape hake

From the discussion of the methods of the swept-area surveys under 7.1.4 above it is concluded that estimates of biomass represent indices of the standing stock which may have been biased in various ways. The estimates are in the following referred to as biomass, but this reservation should be kept in mind.

Table 7.21 shows the estimates of biomass by regions and surveys and split into non-fishable and fishable parts at the defined minimum fishable size of 36 cm of total length. The estimate for the northern region in survey 3/90 was incomplete due to an unknown amount of hake in mid-water.

Table 7.21 Cape hake: Summary of adjusted estimated of biomass by surveys and regions (1,000 t)

	1990 Feb-Mar	**1990 Sep-Oct**	**1991 Jan-Feb**	**1991 Oct-Nov**	**1992 Apr-May**	**1992 Oct-Nov**	**1993 Jan-Feb**	**1993 Apr-May**
Northern region								
Non-fishable	137	54*	25	6	45	66	41	21
Fishable	66	62*	170	134	145	133	106	89
Central region								
Non-Fishable	156	126	80	162	157	350	152	158
Fishable	20	76	67	147	108	180	133	121
Southern region								
Non-fishable	98	98	74	34	48	94	130	80
Fishable	20	44	54	50	145	69	92	99
Total								
Non-fishable	391	(278)	179	202	250	510	323	259
Fishable	106	(182)	291	331	398	382	331	309
Grand total	497	(460)	470	533	648	892	654	568

* unadjusted underestimate due to fish off the bottom

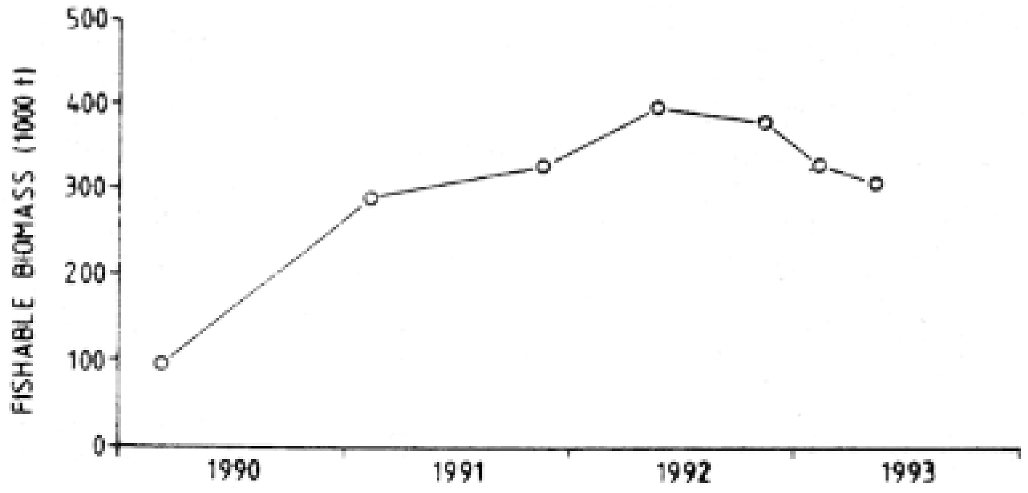

Figure 7.13 Cape hake: Estimates of fishable biomass in 1990–93

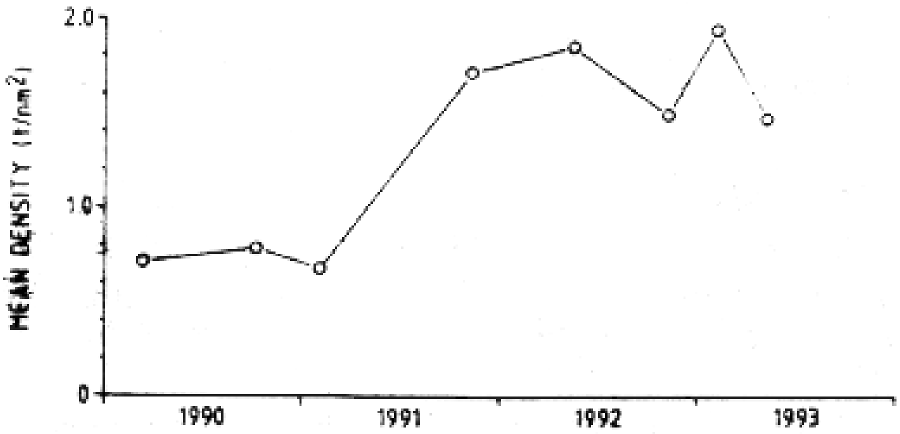

Figure 7.14 Jakobever: Estimates of mean density in the central and northern regions 1990–92

For the two first surveys the stock size compositions for each region were originally estimated from the size samples by simple adding, (IMR, 1990a and c). For the surveys from 1991 onwards, the size samples were weighted by the catch rates. In a recent revised processing of all the data the length frequency samples were weighted by the estimated density of the hake at the respective fishing stations including acoustic observations above the headline. The biomass estimates in Table 7.21 are based on these revised data. Compared with the original estimates they show considerably lower biomasses of fishable hake and higher biomasses of non-fishable hake in the 1990-surveys. There are only minor changes for the later surveys.

The fishable biomass of hake was only about 100,000 t at the start of the surveys in 1990 but it increased to about 400,000 t in 1992. The non-fishable biomass varied between 180,000 t in survey 1/91 and 510,000 in survey 2/92. The mean total biomass for all surveys over the period (except 3/90) was 608,000 t, of which about 50% was fishable.

In Figure 7.13 the estimates of fishable biomass of the Cape hake are shown on a time scale. The stock increased by about four times over the first two years, but the expansion then stopped and there was some decline in 1993.

It is important to see to what extent this history of the Cape hake stock over the period 1990– 93 can be explained in terms of changes in rate of exploitation and in recruitment.

Changes in the rate of exploitation

With the new management regime adopted by independent Namibia from 1990 on, the high rate of exploitation of the hake stocks which existed towards the end of the ICSEAF period was sharply reduced. Total annual reported landings of both species declined from about 300,000 t in 1987–89 to about 130,000 t in 1990, about 60,000 t in 1991 and then increased to about 100,000 t in 1992–93. Although there may be uncertainty about the amount of hake by-catch in the continued trawl fishery for horse mackerel, it seems reasonable to assume that the fishing mortality of hake was reduced by 2–3 times by the new regime. This represents a unique experiment in the history of management of fisheries on heavily exploited demersal stocks.

The fishery-dependent monitoring of the stocks organized through ICSEAF ceased in 1989, while resource survey programmes planned in the ICSEAF period were incomplete and of limited use for comparison and reference. The data from the DR. FRIDTJOF NANSEN surveys started in 1990 allowing a monitoring of the changes in the composition and abundance of the stock. However, because of the high variability in the recruitment of the Cape hake only a long time-series of survey data can be expected to show the effect of changes in the fishery on the stock.

Such effects may, however be traced in species appearing as a common by-catch in the hake fishery. The Jacobever (*Helicolenus dactylopterus*) is a common demersal species distributed between about 200 and 400 m depth along the whole Namibian shelf, but with increasing density northwards. In the central and northern regions its distribution is similar to that of adult hake. Mean catch rates in the surveys were 30–90 kg/h in the depth range 250–550 m in the northern region and about half that in the central region. It grows to a maximum size of 30 cm and it may be assumed that in the relatively stable environment of the deep shelf, variations in recruitment to the stock are not very great and the density of the population would then largely depend on fishing and natural mortality.

Table 7.22 Mean density of Jacobever (*Helicolenus dactylopterus*) from swept-area hauls by regions and surveys, 250–550 m depth (t/nmi^2)

Survey	1/90 Feb-Mar	3/90 Sep-Oct	1/91 Jan-Feb	2/91 Oct-Nov	1/92 Apr-May	2/92 Oct-Nov	1/93 Jan-Feb	2/93 Apr-Mar
Region								
Northern	1.10	1.50	0.95	2.73	2.54	1.79	2.21	1.85
Central	0.34	0.33	0.29	0.67	1.06	1.24	1.61	1.11
Southern	0.19	0.17	0.37	0.34	0.32	0.33	0.30	0.38

Table 7.22 shows the mean density of Jacobever by surveys and regions for the depth range of main distribution beyond 250 m depth. There is an increase of densities in all regions, in the central and northern regions from end 1991. In Figure 7.14 the mean densities weighted by the numbers of stations for the central and northern regions are plotted on a time-scale. The first three observations represented the stock density as determined by the intensive hake fishery towards the end of the ICSEAF period. The fishing effort was greatly reduced after Namibia's independence, thus also the fishing mortality of the Jacobever by-catch. After some time a new equilibrium stock density was established reflecting the rate of hake fishing as managed by Namibia. The observed level of density in this later period is 2.4 times higher than that of the first period. This confirms that the regulation of the fishery by Namibia resulted in a significant reduction of fishing effort and indicates that this lower level was maintained at least into 1992. If further studies confirm that the Jakobever is a stable stock with little recruitment variation its density may be used in the future as an indicator of changes in the fishing mortality of the adult Cape hake.

A changed fishing pattern with reduced fishing on small-sized hake under the Namibian regime may also have contributed to the rapid recovery of the Cape hake stock after

1990. An even more important circumstance was the composition of the stock at the time of the change in management: a very high absolute abundance of juveniles which formed a high proportion of the stock. Out of a total stock abundance of about 500,000 t, 80% were below 36 cm length. This group then benefited from the reduction in fishing and probably had in addition an especially high survival and growth rate due to the low abundance of the adult stock.

However, the rapid increase of the adult stock ceased in 1992 and there was some decline in 1993 although the exploitation was maintained at a low or moderate level. A possible explanation for the decline is the low abundance of juveniles observed in the 1991 surveys.

These relationships indicate the great importance of the recruitment and its variation in the dynamics of the Cape hake. This type of life history with great apparently stochastic variations in recruitment is also well known from many gadoid stocks at high latitudes.

Summary of Cape hake stock history 1990–93

Cape hake had been heavily fished under the last years of the ICSEAF regime at the end of the 1980s, and Namibia's management regime started with an adult stock of only 100,000 t in 1990. The fishing effort on hake was drastically reduced, probably by 2–3 times under the new Namibian regime. This is reflected in the hake commercial catches and in the effects of the hake fishery on the stock of the by-catch species of Jacobever. Thus a reduced fishing mortality allowed two year-classes of juvenile fish, the 1988 year-class of medium abundance and the 1987 yearclass of probably high abundance to recruit to the fishable stock which increased its biomass from 1990 on reaching about 400,000 t in 1992. This rapid growth ceased, however, in 1992 and there was some decline in 1993.

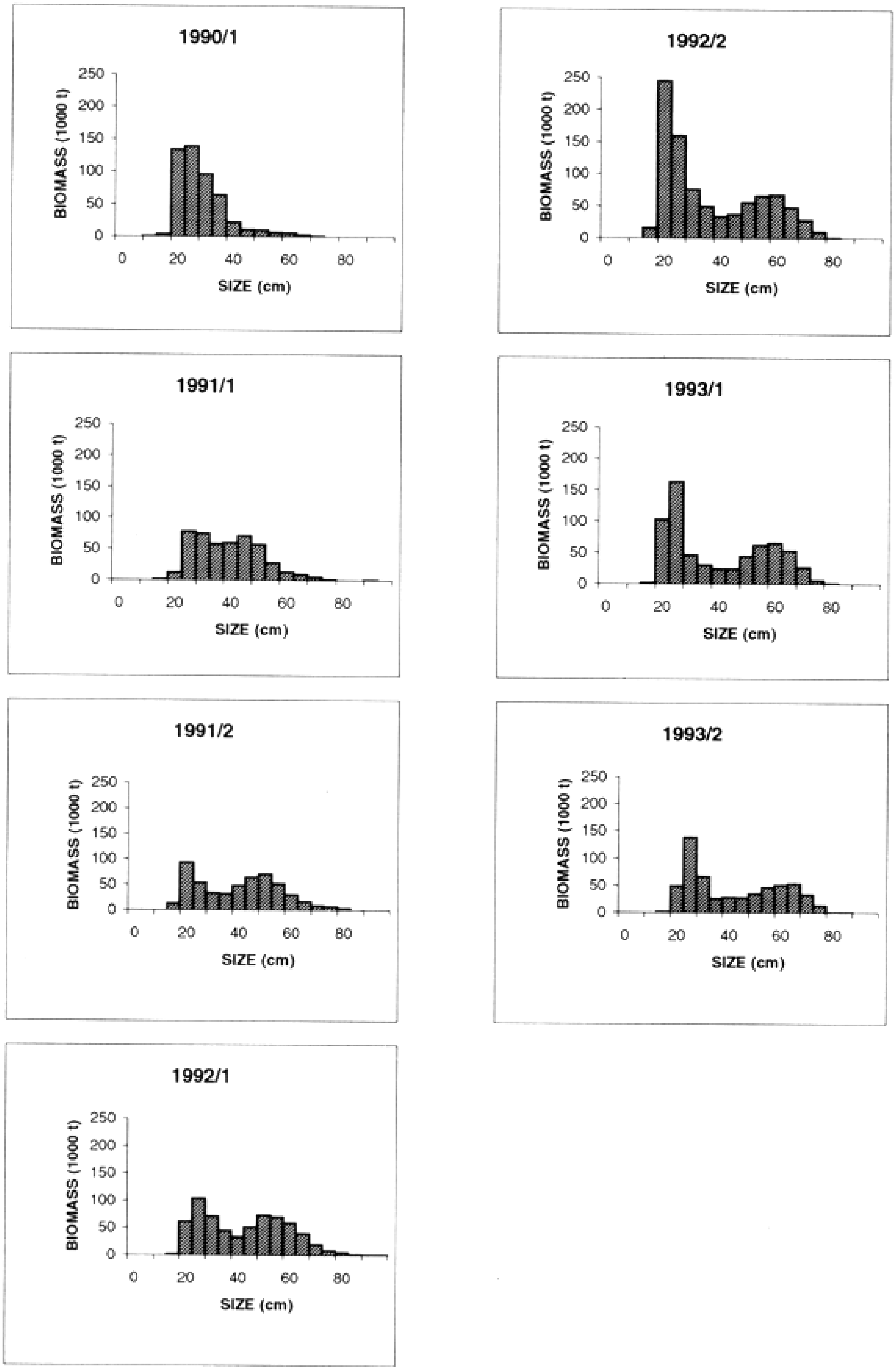

Figure 7.15 Cape hake: Estimated size composition by weight of the stock, 1990–93

Figure 7.15 shows the estimated size composition by weight of the total Cape hake stock in this period. The gradual build-up of the adult stock is clearly shown. In 1990 there was hardly any fish above 40 cm, while in the two 1991 surveys there appeared a group of 40–60 cm fish, which increased to 50–70 cm fish in 1992 and even somewhat larger size in 1993, while in this year the abundance of this group evidently declined.

There are few data available on the fishery and the part of the standing stock caught is hardly known. It seems, however, fairly safe to conclude that from 1992 to 1993 the growth of the adult stock did not balance the rate of fishing, even though it was kept moderate as compared with the late ICSEAF period.

This break in the planned recovery of the Cape hake stock must then first of all be ascribed to failing recruitment. A review of the history of recruitment since the start of the fishery showed that high recruitment variation is a typical feature in the life history of the stock. The strength of the yearclasses 1988–91 was at a low level with a mean of 1,600 million fish and a range of 500–2,500 million, while in previous periods, 1968–74 and 1981–85 the mean yea-class strength was 4,000 million or more and the most abundant cohorts had more than 6,000 million fish. The probability of high recruitment may increase with the size of the spawning stock. That the spawning potential of the Cape hake stock in 1991 was sufficient to produce an abundant year-class is demonstrated by the estimate of the 1991 year-class of 4,300 million in the autumn survey of 1992 prior to its exposure to an abnormal mass mortality.

Recruitment thus plays an essential role in the dynamics of the Cape hake stock and information on recruitment on a current basis must form part of the vital stock data needed for management considerations.

Biomass estimates of deep-water hake

Juvenile and young deep-water hake may have been misidentified in the first surveys. But the biomass estimates for the adult stock were, as shown in Table 7.23, at a very low level during the first years and the possibly missing juvenile component cannot have been large. The increase was slower than in the Cape hake and the stock reached a level of about 150,000 tonnes in 1992–93. In this period the proportion of juvenile biomass of the total deep-water hake stock was 22% compared with 48% in the Cape hake. This low proportion and the distribution being largely limited to the southern region and extending southward into the Republic of South Africa indicates that the deep-water hake of Namibia is probably a shared stock. For the Cape hake with its juveniles in relatively shallow water, the Lüderitz upwelling-cell may form a southern boundary as assumed for the pelagic stocks, whereas there are no similar environmental barriers for the depth ranges of the deep-water hake.

The depth range of young deep-water hake overlaps that of adult Cape hake and predation may be main obstacle to the northward penetration of deep-water hake into the dense Cape hake regions.

For deep-water hake the mean proportions of non-fishable biomass by regions over the survey period were 85%, 11% and 4% for the southern, central and northern regions respectively.

Table 7.23 Deep-water hake: Summary of estimates of biomass by surveys and regions (1,000 t)

	1990 Feb-Mar	**1990 Sep-Oct**	**1991 Jan-Feb**	**1991 Oct-Nov**	**1992 Apr-May**	**1992 Oct-Nov**	**1993 Jan-Feb**	**1993 Apr-May**
Northern region								
Non-fishable				0	0	0	0	0
Fishable				2	4	8	4	6
Central region								
Non-Fishable	0	0	0	9	2	5	3	0
Fishable	4	5	6	6	13	12	13	1
Southern region								
Non-fishable	5	10	20	41	32	45	27	20

Fishable	16	20	14	42	113	80	123	95
Total								
Non-fishable	5	10	20	50	34	50	30	20
Fishable	20	25	20	50	130	100	140	102

7.2 ANGOLA, 1985–92

Angola, located within the zone of enhanced biological production of the southwest African shelf represented an appropriate choice for a DR. FRIDTJOF NANSEN survey programme. Following discussions between the Angolan Government, FAO and NORAD in 1984 a series of surveys were planned for 1985. The objectives of the programme were established between the Instituto de Investigação Pesqueira, Luanda (IIP) and IMR. The 1985 surveys represented the start of a very comprehensive and long-lasting co-operation, which would entail a large effort, by IIP and IMR in the conduct of surveys and in training of scientists, but which also involved active participation of FAO in support of fishery research in Angola.

7.2.1 History of Angola's fisheries

Angola has an important history of fisheries. A considerable fishmeal industry supplied by purse-seine fleets was developed in the early 1950s with total catches exceeding 300,000 t by the middle of that decade (Campos Rosado, 1974a). After a decline around 1960 the production increased and reached nearly 600,000 t in 1972, but then the fishery collapsed during the war for independence. According to Campos Rosado (1974a) the capacities of fishmeal plants and the purse-seiners were about equal on the Lobito coast, (ICSEAF Division 1.2) and the southern, Namibe to Cunene, coast (within ICSEAF Division 1.3), where the latter had higher landings. Pilchard (*Sardinops ocellatus*) dominated the high landings in the south in the mid 1950s, but this species declined in the early 1960s and was replaced by horse mackerels (*Trachurus capensis* and *T. trecae*). Further north annual catches of sardinellas (*Sardinella aurita* and *S. maderensis*) reached about 150,000 t (1969) and of horse mackerels 180,000 t (1966). The existence of a high potential of small pelagic fish was further confirmed by the yield of sardinellas and horse mackerel in a licensed USSR industrial fishery in Angola from the late 1970s to the late 1980s.

It must be assumed that pilchard or sardine (*Sardinops ocellatus*) in Angola represents a transboundary extension of the Namibian pilchard stock, once a main pelagic resource in the Benguela Current system. The fishery which produced annually more than 1 million t in the late 1960s declined substantially in the first half of the 1970s when the stock collapsed. The total stock biomass which was estimated at about 6 million t in the 1960s had declined to about 100,000 t by 1978. The stock has been monitored from Namibia and it has remained at a level of some hundred thousand tonnes since the collapse.

The depletion of the main Namibian stock must have affected the availability of pilchard in Angolan waters. Pilchard formed part of the raw material for the Angolan fish meal industry which was established in the 1950s and worked until 1973. Campos Rosado (1974a) provides back data on the purse-seine landings for this industry and their species composition. These data show annual landings of pilchard in Baia dos Tigres and Tombua up to about 150,000 t in the late 1950s followed by a period of very low landings until a recovery in 1969 to about 60,000 t and with a mean for the years 1969 to the apparent end of the fishery in 1973 of 42,000 t. These data may include some sardinellas as they were not distinguished in the landing statistics.

Table 7.24 History of the sardinella fishery in Angola (t)

Angolan purse-seine ICSEAF Div. 1.2, 1964–68, mean 6,120 t
Angolan purse-seine ICSEAF Div. 1.1 & 1.2, 1969–73, mean 113,600 t
Angolan & USSR purse seine fishery
ICSEAF Div. 1.1, 1.2 & 1.3, FAO Statistical area 47

1976	20,900	1982	181,300	1988	135,800
1977	135,000	1983	126,000	1989	106,400
1978	240,600	1984	192,300	1990	56,600
1979	207,200	1985	211,400	1991	57,500
1980	205,400	1986	164,800	1992	14,700
1981	160,500	1987	108,000		

Sources: 1964–72, Campos Rosado, J.M. 1974a, Stat. Bu. ICSEAF, 1976–88, FAO, Yearbook of Fishery Statistics, Vols. 48–74

Table 7.24 summarizes historical data on sardinella landings from the area. The fishery is reported mainly from ICSEAF Divisions 1.1 and 1.2 which roughly correspond to the regions Luanda-Cabinda and Benguela-Luanda respectively. Prior to 1973, annual landings did not exceed 160,00 t and were apparently at a very low level from 1974 to 1976 when fishing was resumed by licensed USSR factory expeditions. Total landings exceeded 200,000 t in the late 1970s and in the mid 1980s, but then, at least partly as a result of management measures, declined to about 100,000 t by the end of the 1980s. Effort data from the fishery are not available, but a comparison of catch levels in the mid 1980s with the estimates of biomass from the surveys indicates very substantial rates of fishing mortalities even when allowing for some underestimation of biomass with the acoustic method. The observed trend of decline of biomass from 1985 to 1989 also supports the impression of a stock affected by the fishery. The reduced catches in recent years may have caused some stock recovery.

As reported by Campos Rosado (1974a) horse mackerels were principal species of the Angolan purse-seine fishery up to 1973. In ICSEAF Division 1.3 landings ranged between 100,000 and 200,000 t in the period 1964–73, but this represents a mixture of unknown proportions of the two species. Landings of Cunene horse mackerel (*T. trecae*) in Division 1.2 reached nearly 50,000 t as a mean of 1956–59, but then declined with only a few years exceeding 10,000 t up to 1973.

Reported landings for both species in ICSEAF Sub-Area 1 for 1973–1986 and the FAO Area 47 for 1987–1988 are shown in Table 7.25. The ICSEAF data showed that the main part of Cape horse mackerel (*T. capensis*) landings derived from Divisions 1.3 and 1.4, while the Cunene horse mackerel was reported from Divisions 1.1–1.3. There are uncertainties regarding the proper identification of these species in the landings particularly as regards the high catches of Cunene horse mackerel in the period 1973–79.

Table 7.25 History of horse mackerel landings (1,000 t)

	Horse mackerels	
Year	**Cape**	**Cunene**
1973	272	192
1974	194	133
1975	274	128
1976	525	46
1977	404	253
1978	551	380
1979	425	297
1980	549	110
1981	598	142
1982	662	105
1983	603	110
1984	612	55

1985	462	57
1986	502	108
1987	557	106
1988	583	131
1989	505	159
1990	336	116
1991	447	86
Source: No 16. Sub-Area 1; 1987–91, FAO Yrb.Fish.Stat. Vol 74		

Over the period 1976–89 the stock of Cape horse mackerel yielded an annual catch of between 500,000 and 700,000 t with no trend of decline.

For the southern sub-stock of the Cunene horse mackerel there was no decline of nominal stock size and it seems unlikely that the rate of exploitation has been substantial. For the stock north of Benguela where the reported landings exceeded 50,000 t in 1986 the impact of the fishery on the adult stock may have been significant and may have caused the observed decline of the stock size.

Campos Rosado (1974b) also has reported on the deep-sea shrimp fishery by Spanish trawlers prior to 1972. Landings increased from about 1,200 t in 1967 to about 8,100 t in 1972 and was reported as a mixture of the three species: deep-sea rose, striped red and scarlet shrimp caught between 200 and 800 m depth. A licensed fishery was resumed in 1985 with catches of about 9,000 t/year until 1988 when, partly following management restrictions, they declined to about 5,500 t with a further decline to about 4,000 t in 1992. Of this roughly one-third was reported as striped red shrimp, the rest being rose shrimp (FAO Yearbook of Fishery Stat. Vol. 74). Data on effort in this fishery is not available, but there is a close correspondence between the decline in the estimated indices of abundance and in that of the landings over this period. A similar decline was observed over the same period in the density of the Benguela hake which forms a by-catch in the shrimp fishery. The state of the stock of the hake in the shrimp fishing areas could thus perhaps be used as a guide to the conditions of the shrimp stocks as the condition of the hake is easier to monitor than that of the shrimp stocks.

7.2.2 Surveys with the DR. FRIDTJOF NANSEN, 1985–93

Survey objectives and effort

Against this background the principal objectives of the survey programme were:

1. Investigations of the marine fish resources of Angola with emphasis on the distribution, composition and abundance of the stocks of small pelagic schooling fish.
2. Investigations of the stocks of demersal fish on the northern shelf by bottom trawling using the swept-area method.
3. Investigations of the deep-sea shrimp and hake resources on the slope north of Luanda was (included in late 1985).

In later surveys the swept-area programme for the assessment of demersal fish was extended to cover also the regions Benguela-Luanda and Cunene-Tombua. More detailed objectives included the collection of data on size, sex and maturity of the main species for biological studies, collection of taxonomic material for the preparation of a national species guide and observations on the type of bottom from echograms.

The swept-area method was applied with standardized trawl hauls semi-randomly positioned assuming effective fishing over the 18.5 m distance between the wing tips.

The FAO Species Identification Sheets for Fishery Purposes, Fishing Area 34, and FAO World Species Catalogues were used as the main tools for taxonomic identification.

With the assistance from the Nansen programme, FAO undertook the preparation of a field guide for identification of Angolan marine species of economic interest (Bianchi, 1986).

A programme for the monitoring of the main hydrographical features off the Angolan coast was followed from the start with 5–6 fixed main profiles and a more detailed coverage around the estuary of the Congo River.

The 1985 survey programme included four complete coverages of the Angolan shelf and slope from the Cunene River in the south to Cabinda in the north distributed over the year in order to cover the different seasons. An extension was later made to allow two further coverages during the first half of 1986. The objectives for this extension were to study possible inter-annual variations of the distribution and abundance of the stocks of small pelagics and to intensify the trawling programme in order to obtain a better database for the assessments of the demersal resources. An additional objective, time permitting, was to explore offshore parts of the Benguela Current system for the occurrence of horse mackerel, a possibility suggested by the distributional characteristics of a closely related species off the Peruvian coast.

In January 1989 a new survey programme was agreed upon with largely the same objectives as that of the 1985/86 surveys. Special interest was expressed in obtaining new assessments of the important pelagic resources sardinellas and horse mackerels. In 1990 Angola requested an extension of the programme with two surveys in 1991, and a further survey was added in 1992. After the start, in 1990, of a programme of surveys in Namibia, the surveys in Angola, especially in the south, attained increased importance since they covered the northern part of the Benguela Current system. Conversely the surveys off northern Namibia provided information on stocks shared between the two countries.

Also the shelf north of Angola, off Congo and Gabon was covered by a number of surveys programmes starting in 1985 and repeated in 1989 (see Section 7.3).

Operational data for the surveys

Table 7.26 shows the details of the surveys. The degree of coverage is somewhat higher than usual, because a certain amount of steaming not related to acoustic surveys has been included, however, the level indicates a high degree of coverage.

Table 7.26 Operational details of the Angolan surveys 1985–92

Survey		Months	Days at sea	Distance steamed	Degree of coverage	No. of trawl stations
I	1/85	Jan-Feb	23	3,900	27	117
II	2/85	Apr-May	28	4,400	31	131
III	3/85	Aug-Sep	28	4,800	33	154
IV	4/85	Nov-Dec	28	4,500	31	131
V	1/86	Jan-Mar	44	6,900	48	244
VI	2/86	Mar-Apr	35	6,300	44	215
VII	1/89	Feb-Mar	31	5,000	35	187
VIII	2/89	Apr-May	34	5,300	37	231
IX	3/89	Nov-Dec	24	4,100	28	113
X	1/91	May-Jun	44	5,000	35	231
XI	2/91	Aug-Sep	39	5,800	40	226
XII	1/92	Aug-Sep	47	7,500	52	307

All surveys covered the shelf area from a depth of about 20 m along the shore out to the shelf edge at about 200 m depth. The slope down to 500 m depth was also covered extensively, while the five or six hydrographic sections, which included acoustic recording, extended a further 20–30 nmi into the ocean. As an example, Figure 7.16 shows the cruise tracks with fishing and hydrographic stations for one of the surveys (VII).

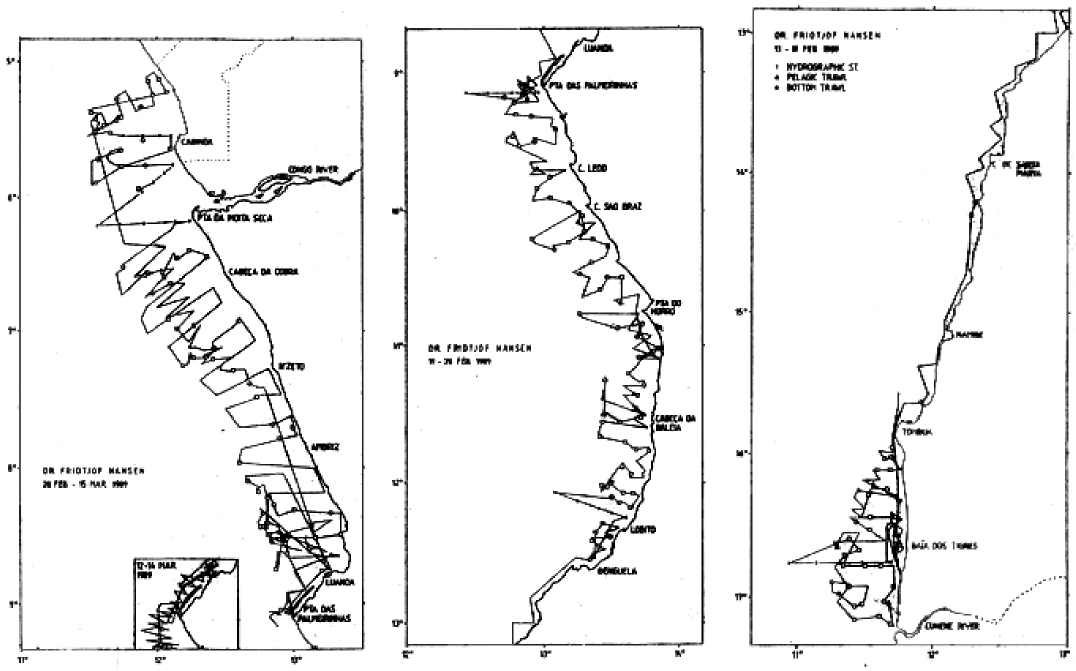

Figure 7.16 Angola: Example of coverage during a survey. Course tracks of survey 1/89 in the three regions Cunene-Benguela, Benguela-Luanda and Luanda-Cabinda

During survey V (1/86) a few exploratory tracks were made outside the shelf, extending up to 240 nmi offshore in search for possible resources of horse mackerel in these oceanic parts of the Benguela Current, but only squid was observed. Except for some concentrations during survey IV (4/85) of medium sized horse mackerel 2–15 nmi outside the shelf edge off Baia dos Tigres, very little pelagic fish was observed at depths of more than about 200 m, and the main concentrations were located over the shelf inside this depth. However, the possibility that offshore resources of small pelagic fish may have been missed by the programme cannot be excluded.

Acoustic equipment

The EK500 was used in 1991 and 1992, replacing the EK400 system used in 1985–89. As discussed in Chapter 6, signal saturation could occur in the EK400 system under special circumstances, dense schools close to the transducer. This technical problem was solved by the new system. Schools of adult small pelagic fish may have a specially high density and time-series of estimates of their biomass may thus be biased. A comparison of the frequency distribution of integrator readings (per nmi averaged over 5 nmi) from the two systems may indicate whether saturation has occurred. The effect would be to suppress high values. Table 7.27 shows such frequencies by levels of integrator values for sardinellas between Cabinda and Luanda, comparing survey 2/86 and 2/92 with biomass estimates of 130,000 t and 154,000 t respectively and for horse mackerel on the Baia dos Tigres shelf comparing surveys 4/85 and 1/91 with estimates of 370,000 and 410,000 t respectively. There was a somewhat higher proportion of high integrator readings in the 1991 surveys which may indicate that saturation took place in the EK400 system. A quantification is not possible, but the possible bias of time series can not be very substantial.

Table 7.27 Comparison of frequency distributions of integrator readings between surveys with EK400 and EK500 systems (Unit 0.1 * m^2/nmi^2)

Species	Sardinellas		Species	Horse mackerels	
Region	Luanda-Cabinda		Region	Baia dos Tigres	
Survey	2/86	2/91	Survey	4/85	1/91
Echosounder	EK400	EK500	Echosounder	EK400	EK500
Readings			Readings		
10–49	41	35	10–100	71	65
50–99	7	11	101–200	8	14
100–149	1	8	201–300	5	4
150–199	1	3	301–400	2	5
200–249	2	1	401–500	4	1
250–299	1	1	501–600		1
300–349			601–700	1	1
350–399			701–800		1
400–449		1	801–900		
			901–1,000		
			1,001–1,100		1
Totals	**53**	**60**		**91**	**93**

Continental shelf and slope

Angola has a coastline of 800 nmi of which that of Cabinda is 45 nmi. The total shelf area is about 17,000 nmi^2 and the mean width is thus about 20 nmi. Three main regions are distinguished:

> Cunene River to Benguela (sub-divided into Cunene-Tombua and Tombua-Benguela) Benguela to Luanda (also identified as Ponta das Palmeirinhas) Luanda to Cabinda.

Estimates of the extension of the shelf by depth ranges in the different regions are shown in Table 7.28. These are based on measurements taken from special bathymetric charts prepared from echosounding during the surveys. The southernmost sub-region from Cunene up to Tombua has a relatively wide and shallow shelf, but with a steep slope except in the extreme southern part. From Tombua to Benguela the shelf is very narrow and the slope too steep for any bottom water trawling. From Benguela northwards the shelf is generally wide all the way up to Cabinda, but with a narrow part off Luanda and a steep “canyon” outside the Congo River. The slope down to 600 m and beyond has a gradient which over wide distances is sufficiently low and smooth to permit bottom trawling.

From five of the surveys, records are available of the character of the bottom with reference to its suitability for trawling based on analysis of the echograms. These observations are set out in Figure 7.17 and show that most of the shelf and the slope can be fished with trawls. Some areas may be too rough especially along the narrow shelf from Tombua to Benguela and off N'Zeto. In the northern areas offshore oil exploration and production may prevent or endanger trawling operations, not only near the installations, but also in areas of previous exploration and along supply vessel routes where debris may have been dumped.

Table 7.28 The shelf areas off the Angola coast by depth ranges and regions (nmi²), and length of coastline by region (nmi)

Depth range (m)	Cunene River-Tombua	Tombua-Benguela	Benguela-Ponta das Palmeirinhas	Ponta das Palmeirinhas-Cabinda	Total
0–50	507	274	1,854	3,023	5,658
50–100	591	402	1,728	2,693	5,414
100–200	594	410	1,252	2,693	4,341
200–300	100	221	497	755	1,573
300–400	77	181	346	660	1,264
400–500	48	128	445	540	1,161
500–600	39	111	448	600	1,198
0–200	1,692	1,086	4,834	7,801	15,413
Length of coast (nmi)	85	190	275	250	800

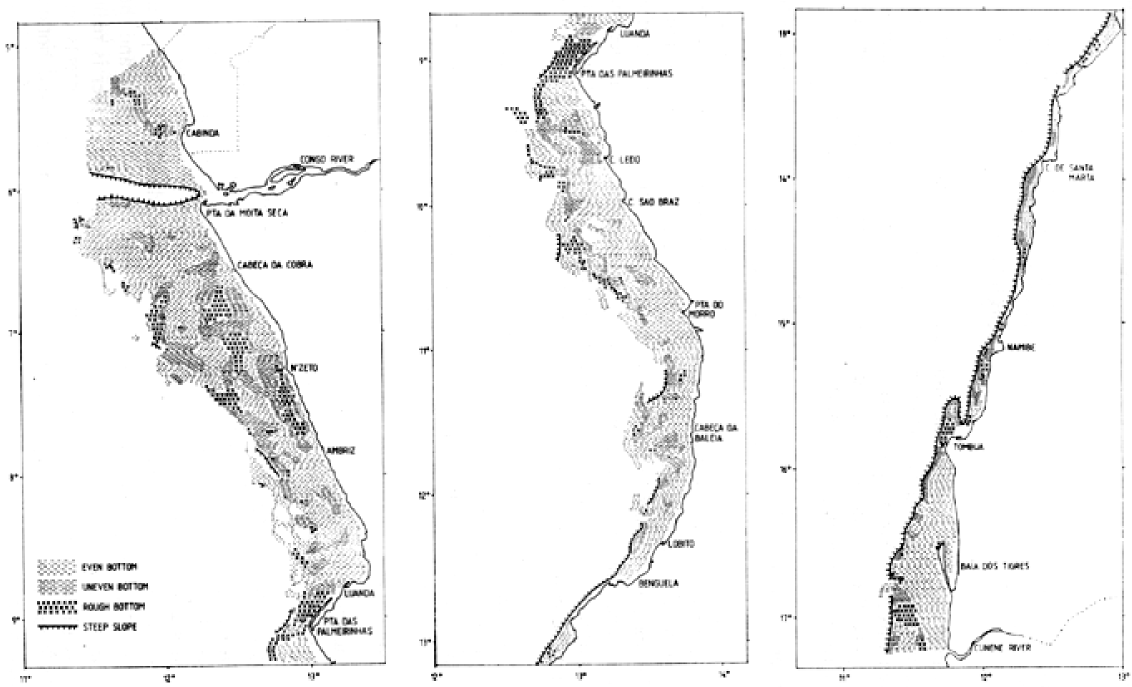

Figure 7.17 Angola: Sea bottom types by area Cunene River-Benguela, Benguela-Luanda and Luanda-Cabinda

Hydrography[1]

The literature describes the main circulation off the Angolan coast as being dominated by the Angola Current flowing mainly southward and apparently formed by the southeast branch of the South Equatorial Countercurrent and southward-turning waters from the north branch of the Benguela Current.

The Angola Current is a generally southward moving stream from 9° (Ponta das Palmeirinhas) to 16°S (Tombua) that penetrates to depths of 250–300 m and covers not only the shelf regions, but also the continental slope, with surface velocities exceeding 50 cm/sec (about 1 knot).

The Benguela Current, part of the anticyclonic sub-tropical gyre of the South Atlantic and forming its eastern boundary, flows parallel to the southwest African coast in a north to northwest direction. Streams of the Benguela Current proceed northward along the shore and reach 13°–14°S (Cabo de Santa Marta), and they form a divergence zone along 11°E from 17°S to 13°S, as a result of an interaction with the Angola Current.

The series of simple oceanographic data acquired during the DR. FRIDTJOF NANSEN surveys made it possible to add details to this general large-scale picture, particularly as regards the regime along the coast and over the shelf. Confirming previous observations the data collected thus indicate that the direction of the surface current over the shelf area is southward only in the (southern) summer season. During most of the autumn, winter and spring seasons a surface current flows northward along the coast causing inshore upwelling in various locations. That the flow is towards the south in summer is demonstrated by low salinity surface water originating from the Congo discharges being found off N'Zeto and Punta das Palmeirinhas and remnants even off Lobito.

The offshore waters were not covered by the surveys, but judging from the observations in the frontal area between the Benguela and the Angola Current at about 16°S it seems likely that the more offshore waters off central Angola are also in winter affected by the southward turning gyre formed by a right-hand branch of the Benguela Current and the southeast branch of the South Equatorial Countercurrent.

The characteristics of the hydrographical regimes along the coast and their ecological significance can be summarized as follows:

In the region from Benguela to Cabinda the hydrographical regime of the shelf waters is characterized by a marked seasonal shift. According to the observations during the surveys the surface current flows southwards during less than half the year, in the period January to May. The sea surface temperature at this time is high: 27°–28°C and the surface layer is stable with a well developed thermocline at 30–50 m depth. The temperature below the thermocline decreases from about 20°C at 50 m to 15°C at 200 m and the oxygen level declines to 1.5–2 ml/l at 200 m. The salinity of the top surface layer is reduced by mixing with the outflow of the Congo River, but this is unlikely to have effects on the fish fauna except for the area around the river mouth, although turbidity and bottom deposits are noticeable over large areas.

[1] This section is a brief summary of a thesis prepared on the basis of data from the 1985/86 surveys by Antonio Fontes Pereira, IIP, Luanda. His contribution is gratefully acknowledged.

In late May-June the change of season initiates with a reduction in the surface temperature apparently starting in the north and with a reversal of the direction of the coastal current. Extreme conditions of the winter season occur in August-September with surface temperatures of 20°–22°C, some times as low as 19°C inshore. Upwelling results in pockets of cold water at locations along the coast especially outside and north of cape configurations along the coastline. The discharges of the Congo River now turn northwest along the coast past Cabinda.

With the approaching spring season in November-December the surface layer heats up with temperatures reaching 25°–26°C, the current still flows predominantly northward, but at reduced velocity and upwelling only occurs in isolated spots.

The most significant feature of this regime in an ecological context is the upwelling process which starts in May-June, has its maximum in August-September and probably ceases towards the end of the year. The upwelling results in intensified primary production of high significance for fish production and distribution. Especially the small pelagic fish, sardinellas and horse mackerel and juveniles of other species low in the food chain, are likely to be affected by these phenomena. The high rate of production in upwelling locations sometimes results in areas of surface water being discoloured by high plankton content and drifting northwards along the coast. Such areas were found in late August 1985 and one area off N'Zeto coincided with a dense distribution of surface schooling sardinella. It seems likely that the upwelling along the coast has a higher persistence and intensity in certain locations such as the area between Punta das Palmeirinhas and Luanda. This may affect the distribution of the plankton-consuming types of fish.

The pronounced seasonal changes in oceanographic parameters were found to occur only in the upper water masses over the shelf. Below the discontinuity layer, which in summer reached down to 60–70 m depth the seasonal change consisted only in 1°–2°C higher temperature in summer down to about 100 m and in that water with oxygen levels below 1 ml/l occured shallower than 100 m. In the 200–500 m depth range, the environment of deep-sea shrimp and Benguela hake stocks, conditions are quite stable throughout the year with temperatures ranging from about 14°C at 200 m to 7°–8°C at 500 m and oxygen levels of around 1 ml/l. From Punta das Palmeirinhas southwards, there is a minimum below this level at 300–400 m depth.

Since fish often adjust their reproduction strategies to current systems and to cycles in basic productivity it seems likely that the spawning seasons and areas of the main Angolan species have seasonalities which coincide with the observed oceanographic patterns.

It should be noted that although marked seasonal changes only affect the upper 100 m or so of the water column, the high productivity here is spread out and available over wider depth ranges. Predating fish undertake vertical migrations and some of the plankton consumers, e.g., mesopelagic fish have regular diurnal migrations between the surface layers and depths of several hundred metres.

Strong seasonal variations are also a characteristic of the regime in the region from Cunene to Namibe on the south coast. Here the variations consisted mostly in a displacement in a north-south direction of the frontal zone between water masses from the Benguela and the Angola Currents. In summer (February) the front had moved towards the southern part of the area. The intrusion of Angolan water from the north was demonstrated by a well developed surface tongue of warm water stretching south in the open water some 20 nmi outside the shelf edge. Cooler water then extended northwards inshore with indications of upwelling even in the summer. With the displacement northwards of the front in autumn and winter the cold Benguela water covered the shelf up to Punta Albina and the distribution of isolines indicated strong upwelling.

The ecological significance of this regime lies first of all in the varying influence of the Benguela Current system. The characteristic fauna of this system follows its displacements, but perhaps with some lag in the southward return migration. Seasonal and interannual variations in the position of the frontal area are then likely to result in changes in the availability to Angola of the stocks shared with Namibia.

The upwelling process in this area is of great significance for its productivity also in respect of the true Angolan fauna such as sardinellas and Cunene horse mackerel which predominate in the northern part of the area. The hydrographical findings indicated that the upwelling which causes enhanced primary productivity may occur not only along the Baia dos Tigres shelf, but also during a considerable part of the year, further north along the narrower shelf from Tombua to Namibe. In an ecological context it may therefore prove appropriate to consider this part of the coast as being included in the southern regime affected by the Benguela Current conditions of low temperature and high productivity.

Reporting

Cruise Reports, containing brief descriptions of the work done and the main findings, were issued upon the completion of each cruise (IMR 1985a, 1985c, 1985e, 1986a, 1986d, 1986e, 1989b, 1989c, 1989g, 1991b, 1991c, 1991e (in 1991d), 1992f.)

Furthermore, two Summary Reports were produced (Strømme and Sætersdal, 1986 and 1991).

In all these reports the results were presented by the three main regions identified above.

Three main regions are distinguished:

> Cunene River to Benguela (sub-divided into Cunene-Tombua and Tombua-Benguela) Benguela to Luanda (also identified as Ponta das Palmeirinhas) Luanda to Cabinda.

These regions do not correspond directly to areas which can be distinguished on an ecological or faunistical basis, but contain some differences in these respects.

Cunene-Benguela region

The southernmost part of this region, the relatively broad shelf from Cunene to Tombua represents the frontal zone between the Benguela Current and the Angola Current and hence also of the stocks which belong to the Benguela ecosystem: pilchard, Cape horse mackerel and Cape hake. All these species seem to undertake migrations in the border area between Angola and Namibia.

In many surveys the distribution of some of the pelagic resources was found to extend from Cunene to a little northwards of the Baia dos Tigres shelf up along the narrower shelf towards Namibe. It is likely that the species found in this continuous distribution, Cunene horse mackerel and sardinellas, constitute sub-stocks which are more or less independent from the stocks of these fish found north of Benguela, since only a few and usually scattered formations were located on any of the surveys over the long and narrow stretch of shelf from Namibe to Benguela.

Benguela-Luanda region

This region lies within the Angola Current regime with high surface temperature and a well developed thermocline in the summer, but with a northward flowing surface current in winter and spring at which time the thermocline largely breaks down and inshore upwelling occurs locally. The locations of upwelling seem to affect the distribution of small pelagic fish. There is no ecological barrier towards the region further north and it seems probable that pelagic fish migrates between the two regions and that other forms of mixing may occur.

Luanda-Cabinda region

This area can ecologically be considered as an extension of the Benguela-Luanda shelf, but the northern part and in particular the shelf off Cabinda is more directly affected by the discharges from the Congo River.

7.2.3 Pelagic resources

The acoustic integration system provided the observations of fish density from which distribution charts were developed. On the basis of identification by trawl sampling and fish behaviour two groups of pelagic fish were distinguished:

Type 1, consisting of:	
Pilchard or sardine	(*Sardinops ocellatus*)
Sardinellas	(*Sardinella aurita* and *S. maderensis*)
Anchovy	(*Engraulis encrasicolus*)
Ilisha	(*Ilisha africana*)
Type 2, consisting of:	
Horse mackerels	(*Trachurus capensis and T. trecae*)
Various other Carangidae	(*Chloroscombrus chrysurus, Selene dorsalis*)

Scombridae	(*Sarda sarda, Scomberomorus trito, Scomber japonicus*, *Euthynnus alletteratus*)
Barracudas	(*Sphyraena guachancho and S. sphyraena*)
Hairtail	(*Trichiurus lepturus*)

The survey results will be presented by species or species groups, following the list given above. For several species the results will also be presented by regions.

Table 7.29 shows the biomass estimates for type 1 pelagic fish, which consist mainly of sardinellas, but with small amounts of anchovy and ilisha from Benguela northwards.

Table 7.29 Angola: Estimates of biomass of pelagic fish type 1, mainly sardinellas, by regions and surveys (1,000 t)

Survey	Cunene-Benguela	Benguela-Luanda	Luanda-Cabinda	Total Angola
1/85 Jan-Feb	25	220	80	330
2/85 Apr-May	110	190	180	480
3/85 Aug-Sep	0	70	190	260
4/85 Nov-Dec	0	200	110	310
1/86 Jan-Feb	10	140	110	260
2/86 Mar-Apr	10	130	130	270
1/89 Feb-Mar	40	200	60	300
2/89 Apr-May	20	40	130	190
3/89 Nov-Dec	40	100	60	200
1/91 May-Jun	+	180	120	300
2/91 Aug-Sep	+	70	150	220
1/92 Aug-Sep	+	120	160	280
Mean	22	138	123	283

There appeared to be some change with time in the mean estimates. For the main regions of distribution of type 1 pelagic fish, from Benguela to Cabinda, there was a decline from a mean of 310,000 t for the four 1985 surveys, to 255,000 t for the two 1986 surveys and down to 195,000 t for the three 1989 surveys, but then the estimates increased to 260,000 t in 1991 and 280,000 t in 1992.

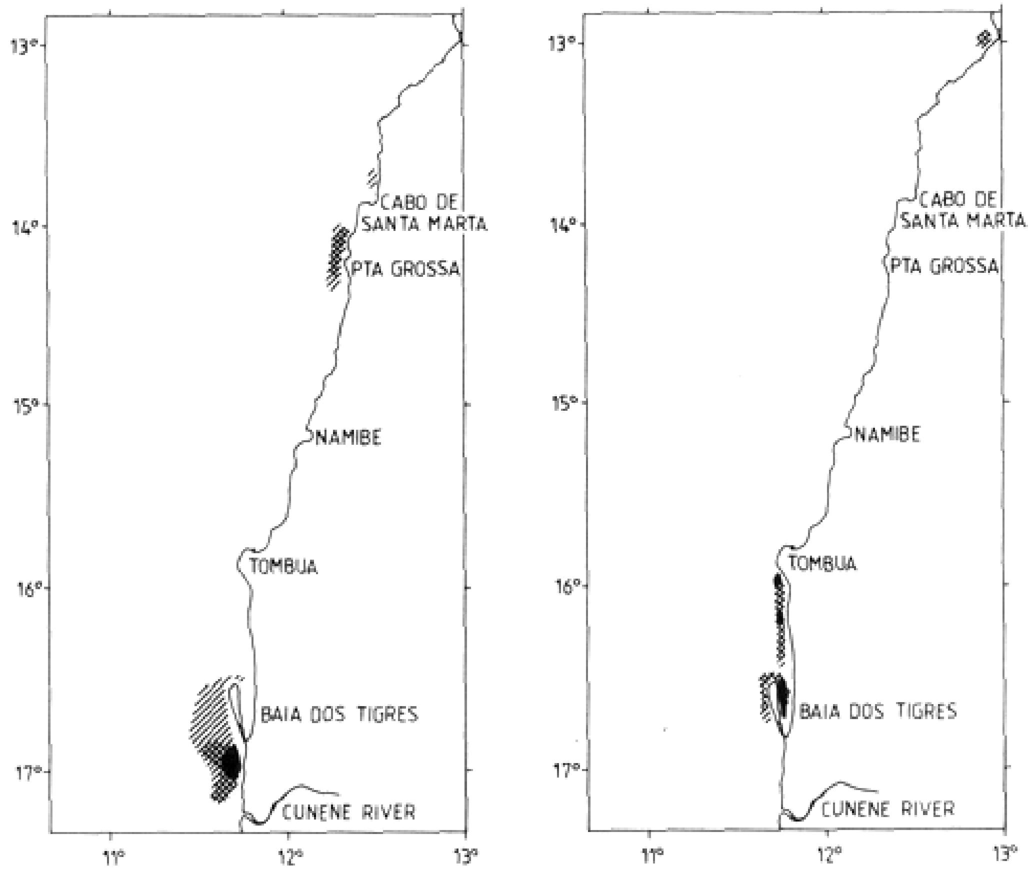

Figure 7.18 Cunene-Namibe: Distribution of type 1 pelagics mainly pilchard in surveys 1/85 (left) and 1/91 (right)

Figure 7.18 shows distribution of the type 1 species in surveys 1/85 and surveys 1/91, mainly pilchard which may serve as examples of the characteristics of the distribution of this type of fish. The whole series of data shows that aggregations in school areas were usually of limited extension, not exceeding 10–20 nmi along the cost, always on the inner part of the shelf, and often quite close to the shore. When pilchard was located it was found on the Baia dos Tigres shelf, often inside the bay itself.

Pilchard or Sardine

Pilchard was found in nine out of the twelve surveys.

Table 7.30 Cunene-Tombua: Biomass estimate of pilchard by surveys (1,000 t)

Season	**Jan-Mar**	**Apr-Jun**	**Jul-Sep**	**Oct-Dec**
Survey				
1985 I–IV	25	0	120	10
1986 V–VI	0	0	n.s.	n.s.
1989 VII–IX	50	10	n.s.	5
1991 X–XI	26	n.s.	130	n.s.
1992 XII	n.s.	n.s.	210	n.s.

n.s.: no survey

Table 7.30 shows biomass estimates of the pilchard by surveys. The surveys with the highest biomass were all in late winter, August-September, which coincides with the northern position of the oceanographic front indicating seasonal migrations of parts of a joint Namibian-Angolan stock.

Pilchard was in all cases located inshore on the extreme southern part of the Angolan shelf from Baia dos Tigres southwards. The 12 estimates of the biomass of the species ranged from 0 to 210,000 t with an average of about 50,000 t. This average is not very meaningful since there is a seasonal migration pattern with the highest abundance in Angola in late winter-spring when the Benguela/Angola front is in its northernmost position.

Sardinellas

The two species round sardinella (*Sardinella aurita*) and flat sardinella (*S. maderensis*) occur along the whole coast from Cunene to Cabinda and with an apparently extended continuous distribution along the coasts of Congo and Gabon.

The relative proportion of the two species was assessed from their incidence and catch rates in trawl samples from the 1985–89 surveys. These data indicated that in the southern area, Cunene-Benguela, the round sardinella was more common than the flat sardinella. In the samples from Benguela northwards the overall mean catch rates were similar, but with a slightly higher incidence for the flat sardinella. In the following analysis the two species were dealt with together.

Table 7.31 Sardinellas: All surveys 1985–1992. Mean biomass by regions and densities over the shelf area, 0–200 m and by 100 nmi of coastline

	Biomass (t)	Densities (t/nmi^2)	(t/100 nmi)
Cunene-Benguela	22,000	8	8,000
Benguela-Luanda	138,000	29	50,000
Luanda-Cabinda	123,000	16	49,000

Table 7.31 shows the estimated biomass of sardinellas (with small amounts of anchovy and ilisha) as means for all 12 surveys by regions and the densities by unit shelf area and by 100 nmi of coastline. By shelf area the density was highest in the Benguela-Luanda region, by coastline the densities were nearly the same.

Cunene-Benguela

Sardinellas were found in small school areas inshore, mostly south of Namibe, but in a few surveys also in the north close to Benguela. Table 7.32 shows that the estimated biomass of these species in most surveys ranged between 0 and 40,000 t, but reached 110,000 t in April 1985. Both species, round sardinella (*Sardinella aurita*) and flat sardinella (*Sardinella maderensis*) occurred in the area.

No sardinellas were found in the 1991–1992 surveys in this area.

Table 7.32 Cunene-Benguela: estimates of biomass of sardinellas, including small amounts of anchovies (1,000 t)

Season Survey	Jan-Mar	Apr-Jun	Jul-Sep	Oct-Dec
1985 I–IV	25	110	0	0
1986 V–VI	10	10	n.s.	n.s.
1989 VII–IX	40	20	n.s.	20
1991 X–XI	0	n.s.	0	n.s.
1992 XII	n.s.	n.s.	0	n.s.

n.s.: no survey

Benguela-Luanda

Of the pelagic type 1 fish, the two sardinella species, round sardinella (*Sardinella aurita*) and flat sardinella (*S. maderensis*) were by far the most common. Anchovy (*Engraulis* *encrasicolus*) and West African ilisha (*Ilisha africana*) were found in minor aggregations inshore, but the distribution charts will mainly represent the flat and round sardinellas. Figure 7.19 shows characteristic distributions of this group of fish from surveys 2/85 and 3/89. The sardinellas were found in more or less well defined school areas located inshore in most surveys near Benguela-Lobito and otherwise often near the capes along the coast, Cabeça da Baleia, Punta do Morro, Cabo São Braz and Punta das Palmeirinhas. There seem to be less high density areas during the autumn surveys than at other times of the year, possibly an effect of the fluctuations in oceanography and production in the surface layers.

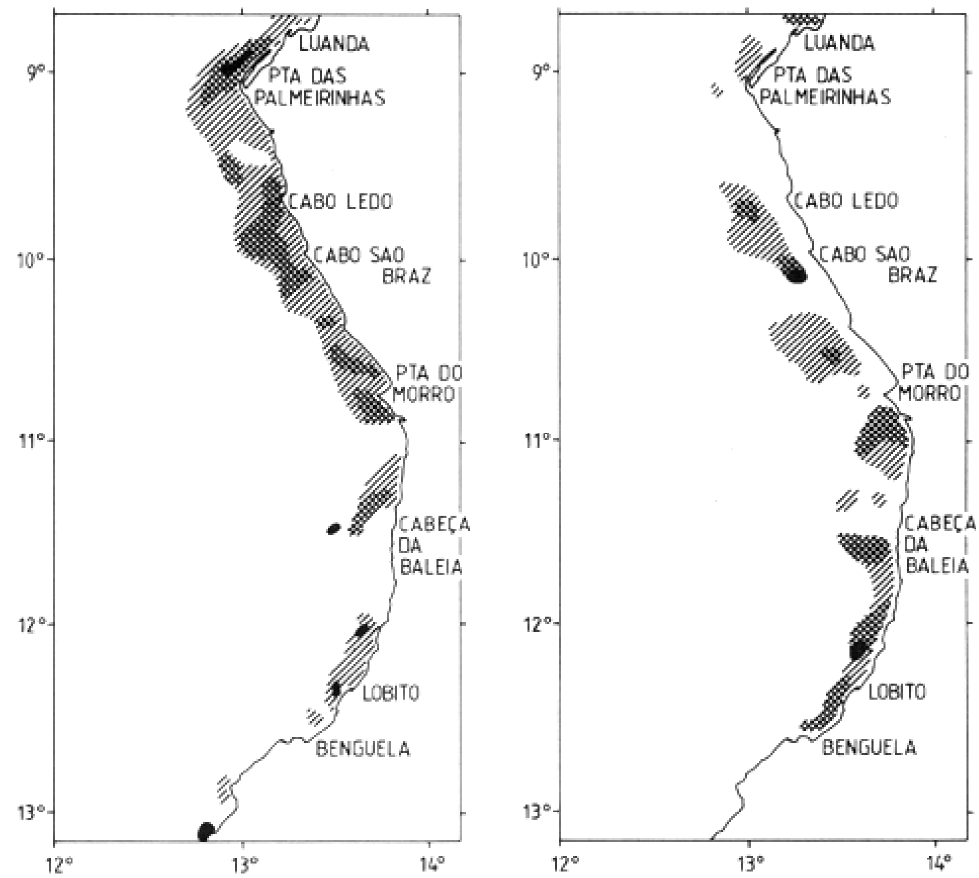

Figure 7.19 Benguela-Luanda: Distribution of sardinellas in surveys 2/85 (left) and 3/89 (right)

Table 7.33 Benguela-Luanda: Incidence and mean catch rates of the two sardinella species, 1985–89

Survey	Round sardinella Incidence (%)	Round sardinella Catch rate (kg/h)	Flat sardinella Incidence (%)	Flat sardinella Catch rate (kg/h)
1/85	28	80	40	50
2/85	38	38	52	62
3/85	11	32	26	36
4/85	23	25	26	20
1/86	30	89	26	53
2/86	15	17	31	20
1/89	14	17	14	21
2/89	11	13	14	17
3/89	45	24	48	24

Because of the low catchability of the sardinellas, the data on the catches are of little interest for studies of changes in abundance, but may serve for a comparison of the two species. Table 7.33 gives the percentage incidence and the mean catch rates in hauls with catch of the species within the shelf, 0–200 m for the period 1985–89. There is some similarity in the trends of the figures for the two species. The two first surveys show relatively high levels followed by a decline and then an increase in survey 1/86 and survey 3/89. The overall mean incidence is 24% for round and 31% for flat sardinella with mean catch rates of 37 kg and 34 kg respectively. This indicates a slightly higher availability of flat sardinella, but since this species is reported to have a more inshore distribution than the round sardinella, the difference in incidence may have been caused by higher accessibility to the fishing gear.

Table 7.34 shows the biomass estimates of the sardinellas in this region. The levels vary considerably between surveys. There may be a tendency of low biomass in this area in winter-spring.

Table 7.34 Benguela-Luanda: Biomass estimate of sardinellas by surveys and season (1,000 t)

Season / Survey	Jan-Mar	Apr-Jun	Jul-Sep	Oct-Dec
1985 I–IV	220	190	70	20
1986 V–VI	140	130	n.s.	n.s.
1989 VII–IX	200	40	n.s.	100
1991 X–XI	n.s.	178	68	n.s.
1992 XII	n.s.	n.s.	125	n.s.

n.s.: no survey

Samples of size compositions of both species showed the presence of modal groups of highly varying sizes from 10 to about 35 cm modal length without any apparent seasonal trend. These incomplete data can probably not be used for studies of growth and recruitment, but they demonstrate that in some years reproduction takes place over wide areas.

Luanda-Cabinda

The distribution of the pelagic fish type 1, consisting mostly of sardinellas is shown in Figure 7.20 exemplified by the situations found in survey 3/85 and 2/86. High density school areas were nearly only found along the inshore shelf between Luanda and N'Zeto and in a few surveys also off Cabinda. In the vicinity of the Congo River mouth the sardinellas were in several surveys found on the outer shelf, some times off the shelf edge as in August 1985.

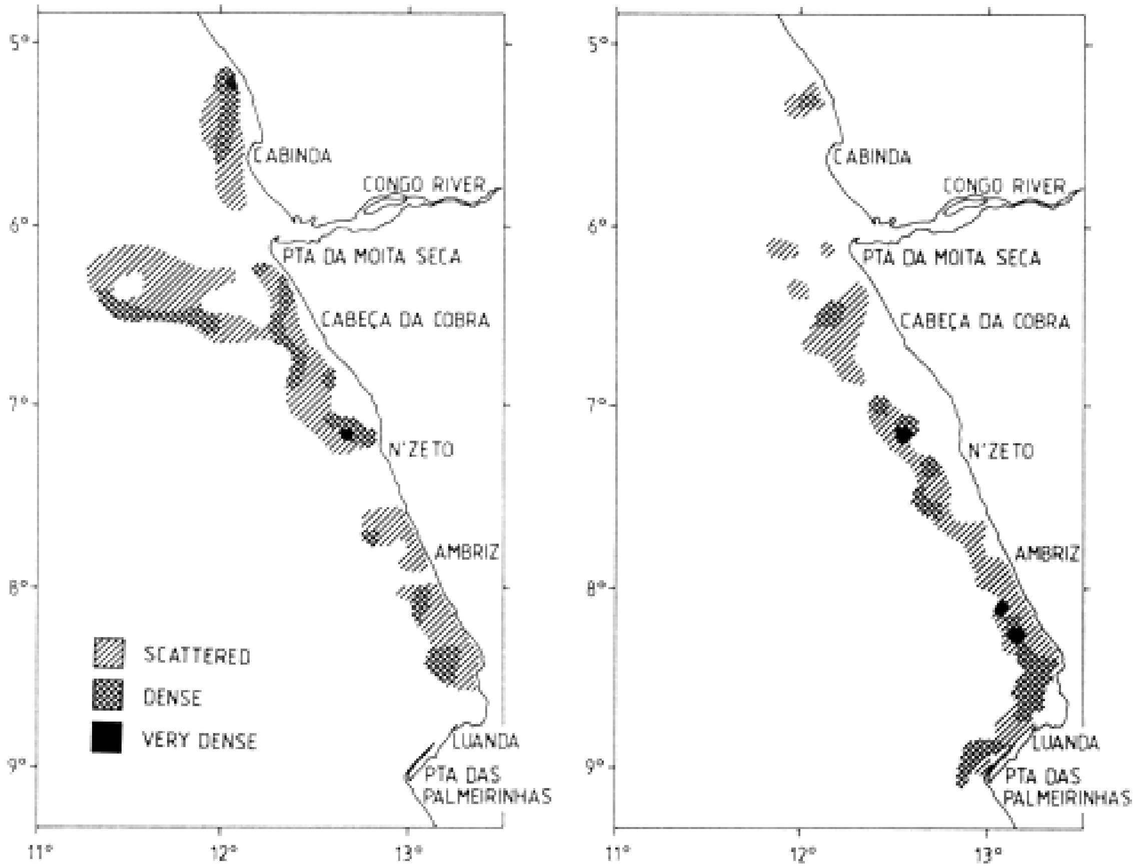

Figure 7.20 Luanda-Cabinda: Distribution of sardinellas in surveys 3/85 (left) and 2/86 (right)

The mean incidence and catch rates of round and flat sardinella in all hauls on the shelf in the 1985–89 surveys are shown in Table 7.35. The overall means were 20% and 24% respectively with mean catch rates of 37 kg and 39 kg. This indicated a slightly higher availability of flat sardinella, as was the case in the southern area, but this could also be explained by a more inshore distribution of flat sardinella.

Table 7.35 Luanda-Cabinda: Incidence and mean catch rates of the two sardinella species

	Round sardinella		Flat sardinella	
Survey	**Incidence (%)**	**Catch rate (kg/h)**	**Incidence (%)**	**Catch rate (kg/h)**
1/85	16	5	30	59
2/85	24	21	32	76
3/85	25	38	32	50
4/85	23	25	20	15
1/86	24	149	26	44
2/86	16	29	20	30
1/89	9	6	15	3
2/89	19	44	16	44
3/89	23	16	25	32

Table 7.36 shows the biomass estimates of this group of pelagic fish consisting mainly of sardinellas over the Luanda-Cabinda shelf. The mean of all the survey estimates is about 10% lower than that of the Benguela-Luanda region and the mean fish density over the shelf is only about half, perhaps reflecting a lower basic productivity in this northern area.

Table 7.36 Luanda-Cabinda: Acoustic biomass estimates of sardinellas by season and year (1,000 t)

Season Survey	Jan-Mar	Apr-Jun	Jul-Sep	Oct-Dec
1985	80	180	190	110
1986	110	130	n.s.	n.s.
1989	80	90	n.s.	70
1991	n.s.	130	150	n.s.
1992	n.s.	n.s.	180	n.s.

n.s.: no survey

Samples of the size compositions of the two sardinella species showed groups with widely different modal length from below 10 to about 35 cm as in the southern region, but it seems doubtful whether representative sampling was achieved.

Anchovy

An other species of the pelagic fish type 1 group in this area is the anchovy (*Engraulis encrasicolus*). Anchovy was only found in small and scattered formations on the coast from the Cunene River to the Baia dos Tigres.

Horse mackerels

Southern Angola forms the northern border for the Cape horse mackerel (*Trachurus capensis*) and also the approximate southern border of the Cunene horse mackerel (*Trachurus trecae*). The two species are mixed on the fishing grounds in the Cunene-Benguela area and may occur together in the catches. This has caused problems for the identification to species level of the commercial horse mackerel catches in this border region.

Figure 7.21 shows the distribution of horse mackerels in the surveys of April-May and November-December 1985 with the high densities on the outer shelf characteristic of these fish. In some surveys such as in November 1985 and in February 1989 horse mackerels were also found in mid-water up to 5–15 nmi outside the shelf edge. On these occasions the outer limits of distribution appeared to coincide with the tongue of warm Angolan water reaching southwards off the shelf. In many of the surveys there was a more or less continuous distribution of horse mackerel from the Baia dos Tigres shelf northwards past Tombua up to Namibe.

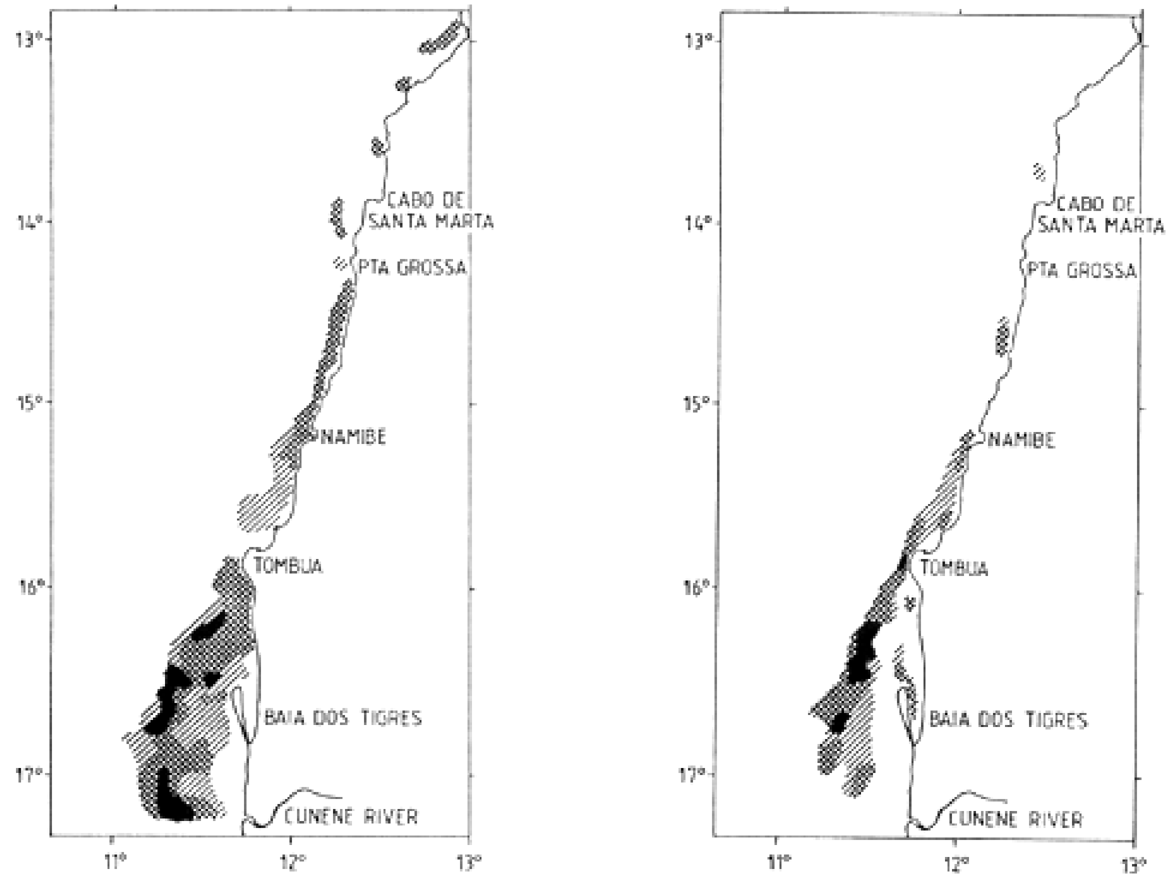

Figure 7.21 Cunene-Namibe: Distribution of horse mackerels in surveys 4/85 (left) and 1/89 (right)

Juvenile horse mackerel was often found in abundance inshore usually *T. trecae*. Adult horse mackerel had a more offshore distribution and occurred in mid-water in schools and other aggregations of varying density often close to or near the bottom during daytime, but usually lifting and dispersing at night. A bottom trawl can be an efficient gear for these species, as they are close to the bottom during the day.

Table 7.37 Cunene-Benguela: Estimates of the biomass of Cape and Cunene horse mackerels by surveys (1,000 t)

Survey	Cape horse mackerel	Cunene horse mackerel	Total
1/85	170	30	200
2/85	75	55	130
3/85	220	50	270
4/85	270	70	340
1/86	40	130	170
2/86	10	30	40
1/89	125	35	160
2/89	135	25	160
3/89	240	170	410
1/91	310	100	410
2/91	95	100	195
1/92	250	100	350
Mean	162	75	236

Table 7.37 shows the estimates of biomass of the horse mackerels from the acoustic integration system for each of the surveys. There is a considerable variation in available biomass with a range from 40,000 to 400,000 t. The estimates also show a tendency of a seasonal shift with high levels in the spring and low in the autumn. These are mainly

caused by changes in the distribution of the Cape horse mackerel related to the seasonal shift of the front between the Benguela and the Angola Current systems.

The Cape horse mackerel represents the major part of this biomass, but the Cunene horse mackerel is also at times relatively abundant. Their distribution is largely segregated with Cunene horse mackerel dominating in the northern and innermost parts of the Baia dos Tigres shelf and up to Benguela and the Cape horse mackerel the offshore and southern parts.

Cape horse mackerel

Like the pilchard the distribution of this species in Angola is restricted to the Cunene-Tombua region. Its availability depends on migrations out from and into Namibia where this stock which has a total biomass of several million tonnes, has its main area of distribution. Table 7.38 presents an overview of the biomass estimates from the twelve surveys arranged by season. The highest estimates were usually from the last half of the year demonstrating a relationship between the migrations and the northward shift of the border between the Benguela and the Angola Currents. These data indicate that the availability of Cape horse mackerel in Angola exceeded 200,000 t probably over a substantial part of the year in each of the seasons covered by the survey.

Table 7.38 Cunene-Tombua: Acoustic biomass estimates of Cape horse mackerel by seasons (1,000 t)

Season Survey	Jan-Mar	Apr-Jun	Jul-Sep	Oct-Dec
1985	170	75	220	270
1986	40	10	n.s.	n.s.
1989	125	135	n.s.	240
1991	310	n.s.	95	n.s.
1992	n.s.	n.s.	250	n.s.

n.s.: no survey

Cunene horse mackerel

The Cunene horse mackerel is found over the entire Angolan shelf. In the following analysis the biomass data from the autumn surveys have been excluded because they are thought to have been biased. Table 7.39 shows the mean acoustic biomass estimates by regions for the whole survey period and the densities by shelf area and by coastline. The southern region showed by far the highest density both by area and by coastline.

While normally most of the Cunene horse mackerel was found over the northern part of the Baia dos Tigres shelf, its distribution in surveys 1/86 and 3/89 included also the southern part of the shelf where it was found mixed with Cape horse mackerel.

Table 7.39 Cunene horse mackerel: Mean estimates of biomass by regions and densities over shelf area, 0–200 m and by 100 nmi of coastline

	Biomass	Densities	
	(t)	(t/nmi^2)	(t/100 nmi)
Cunene-Namibe	84,000	42	67,000
Benguela-Luanda	95,000	20	35,000
Luanda-Cabinda	41,000	5	16,000

These findings might indicate that there is a separate sub-stock of Cunene horse mackerel in southern Angola and northern Namibia which benefits from the high basic productivity in an area that most of the year is influenced by the Benguela Current system.

The relative geographical isolation of this southern distribution area and the fact that both adults and juveniles were found here, the juveniles sometimes in high densities inshore, suggest the existence of a separate southern stock unit benefiting from the high productivity of the Benguela Current system and extending its distribution into northern Namibia.

The more or less continuous distribution observed from Benguela past Ponta das Palmeirinhas and the biological data with similarity of size distributions strongly indicate that there is one main stock over the whole shelf from Benguela to Cabinda, but with a markedly lower density north of Luanda.

Table 7.40 shows time-series of the acoustic biomass estimates over the survey period. There is a high variability especially in the southern region where there is no clear trend. For the Benguela-Cabinda stock there may be a trend of decline from 1985 to 1989 and some recovery to 1992 similar to that found for the sardinellas.

Table 7.40 Cunene horse mackerel: Time series of biomass estimates of by regions, autumn surveys excluded. Estimates from bottom trawl hauls in brackets (1,000 t)

Survey	Cunene-Namibe		Benguela-Luanda		Luanda-Cabinda		Total
1/85	30		196		41	(19)	267
3/85	50		91		41	(3)	182
4/85-1/86	100		126	(21)	19	(21)	245
1/89	35		55	(7)	41	(16)	131
3/89	170		38		36	(51)	244
2/91	100	(13)	70	(49)	30	(12)	200
1/92	100	(8)	85	(75)	80	(20)	270

The estimates of the horse mackerel from their part of the bottom trawl catches were as shown in Table 7.40 usually, lower than the acoustic estimates. There was a wide variation in the ratios between the estimates and this may in part have been caused by changes in the size composition of the horse mackerels between surveys.

Other Carangidae, hairtail and barracudas

The other types of pelagic fish associated with horse mackerel have their main distribution north of Benguela. Table 7.41 shows the mean acoustic- and swept-area estimates by regions and for the survey periods from which these data are available. The group “other Carangidae” include bumper, lookdown and false scad. Large-sized false scad were sometimes found in dense schools off Ponta das Palmeirinhas and these concentrations may have been exposed to the industrial purse-seine fishery. This group as well as the barracudas may have declined in abundance, while hairtails were observed in fairly unchanged abundance over the period. Judging from the ratios of the two methods of abundance estimation, these species seem to have a more pronounced mid-water behaviour than the horse mackerels.

Table 7.41 Mean biomass estimates (1,000 t) of groups of type 2 pelagic fish associated with horse mackerels by regions and survey periods. Estimates from random trawl hauls in brackets

	Other Carangidae		Hairtail		Barracudas		Total
Benguela-Luanda							
1985/86	16		32		8		56
1989	26	(8)	26	(8)	12	(2)	64
1991		(1)		(7)		(2)	
1992		(2)		(13)			
Luanda-							

Cabinda							
1985/86	60	(16)	29	(19)	7	(1)	96
1989	9	(6)	24	(12)	5	(2)	38
1991		(10)		(8)			
1992		(4)		(7)			

On the shelf from Benguela northwards the pelagic fish classified as type 2 consisted of a number of species in addition to the Cunene horse mackerel. Hairtail (*Trichiurus lepturus*) occurred in abundance over a wide depth range. Among the other Carangidae bumper (*Chloroscombrus chrysurus*) and lookdown (*Selene dorsalis*) often appeared in the catches in shallow water together with other species of this family. Barracudas (*Sphyraena guachancho*) and (*S. sphyraena*) appeared with low catches, but high incidence. The contribution of the former species was 3–4 times higher than the latter. The Scombridae gave only scarce and small catches with bonito (*Sarda sarda*) and Spanish mackerel (*Scomberomorus trito*) occurring more often than chub mackerel (*Scomber japonicus*) and little tunny (*Euthynnus alletteratus*). This last species was often observed in schools near the surface in the slope region.

The catchability of these species in mid-water and bottom trawl probably varied considerably. It should be expected to be low for bonito, tuna and chub mackerel and for large-sized schooling horse- and jack mackerels, but high for hairtail, bumper, lookdown, small-sized horse mackerel and probably also barracudas. The catch data will thus only give a rough indication of the true proportions of the various species and when used their probable bias should be kept in mind.

Benguela-Luanda

Time-series of biomass estimates by groups of the pelagic type 2 fish were calculated for part of the surveys using their mean proportions in the catches and the total biomass figures (Table 7.42). In view of the difference in catchability these estimates should be considered as indications only. There may be a trend of declining abundance of horse mackerel.

Table 7.42 Benguela-Luanda: Time series of biomass estimates of horse mackerels and associated species (1,000 t)

Survey	Horse mackerel	Other Carangidae	Hairtail	Barracudas	Total
1/85	196	22	48	11	277
3/85	91	10	22	5	128
4/85-1/86	126	15	26	7	174
1/89	55	30	30	14	129
3/89	38	21	21	10	90
1/91	80		50		130
2/91			70		70
1/92		86			86

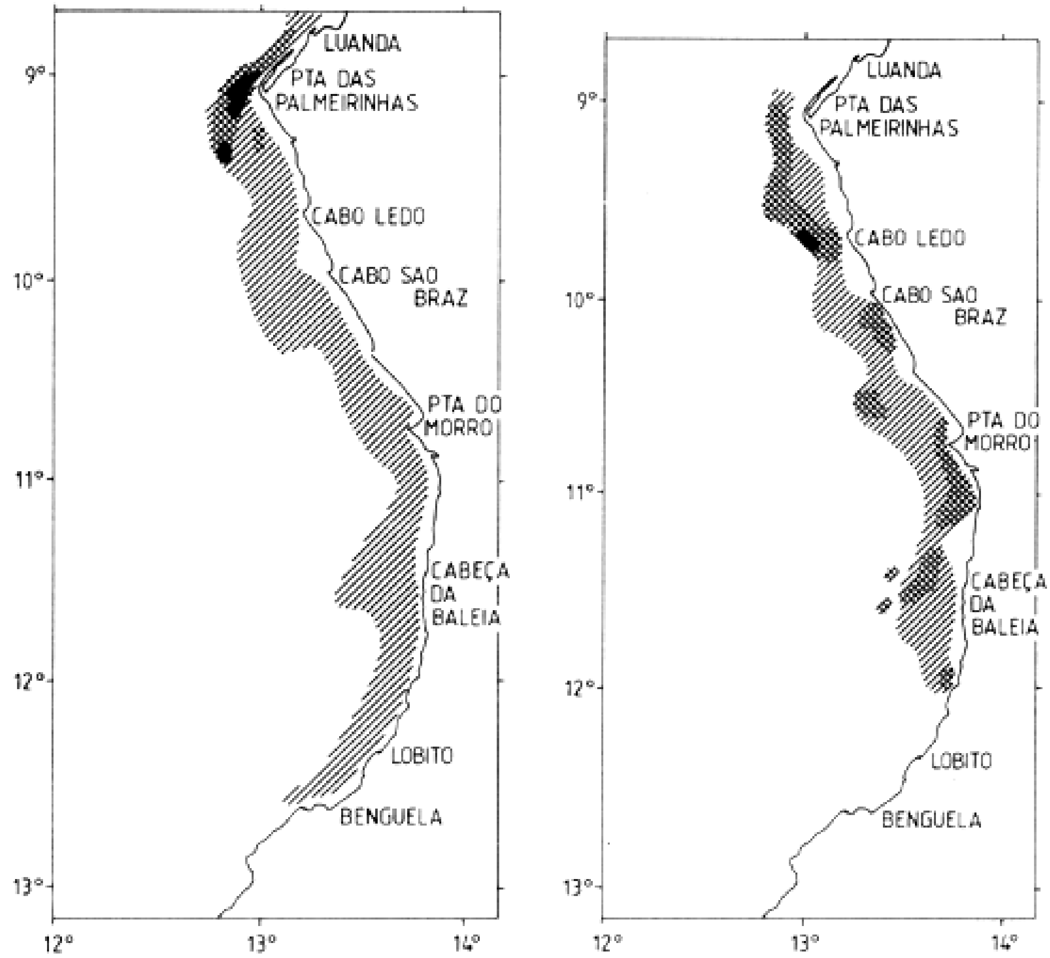

Figure 7.22 Benguela-Luanda: Distribution of horse mackerels, other Carangidae and associated species in surveys 1/86 (left) and 1/89 (right)

Figure 7.22 shows the distribution charts of the pelagic fish classified as type 2 between Benguela and Luanda from the surveys 1/86 and 1/89 which provide examples of the typical distribution of these fish. In general they were found in lower densities over wider areas than the sardinellas. The high-density school areas which were usually quite restricted, consisted mostly of large-sized Cunene horse mackerel, false scad (*Decapterus rhoncus*) or chub mackerel. In a number of the surveys such school areas were located off Punta das Palmeirinhas.

Luanda-Cabinda

Table 7.43 shows the biomass estimates from the acoustic integration system. There was a considerable survey-to-survey variation which may include changes in availability. Thus several of the autumn surveys (April-June) seem particularly low as was also the case with estimates of demersal fish. The mean biomass for all surveys was only about two-thirds of that on the Benguela-Luanda shelf and the mean density of the fish over the shelf area was as for the sardinellas considerably lower, in this case 40% of that in the southern region.

Table 7.43 Luanda-Cabinda: Acoustic biomass estimate of horse mackerel, other Carangidae and associated species by surveys (1,000 t)

Season	Jan-Mar	Apr-Jun	Jul-Sep	Oct-Dec
Survey				
1985 I–IV	140	50	140	60
1986 V–VI	70	40	n.s.	n.s.
1989 VII–IX	80	90	n.s.	70
1991 X–XI	n.s.	40	40	n.s.
1992 XII	n.s.	n.s.	110	n.s.

n.s.: no survey

Time-series of biomass estimates of the main groups have been calculated applying the mean proportions in the catches for the 1985/86 and the 1989 surveys to the total biomass figures (Table 7.44). The three autumn surveys have been omitted because of suspected bias. There is a declining trend in “Other Carangidae” which demonstrates reduced abundance principally of bumper.

Table 7.44 Luanda-Cabinda: Time series of biomass estimates of horse mackerels and associated species (1,000 t)

Survey	Horse mackerel	Other Carangidae	Hairtail	Barracudas
1/85	41	78	35	8
3/85	41	78	35	8
4/85-1/86	19	25	17	4
1/89	41	9	25	5
3/89	36	8	22	4

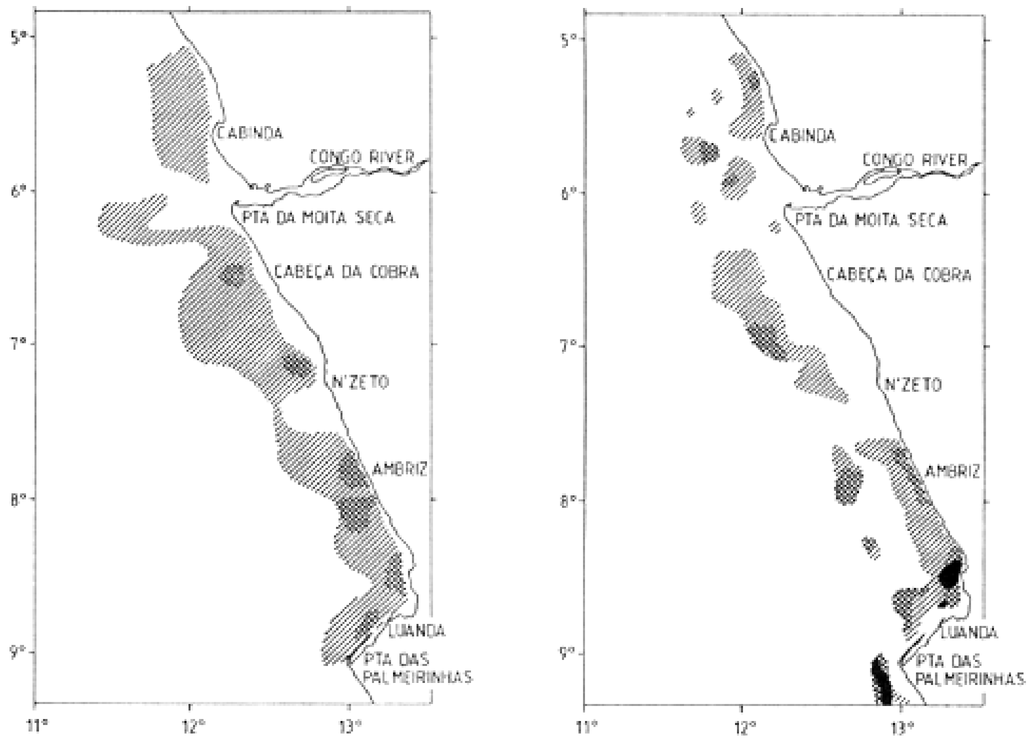

Figure 7.23 Luanda-Cabinda: Distribution of Carangidae and associated species in surveys 3/85 (left) and 1/89 (right)

The size samples of horse mackerel were dominated by groups of juvenile or young fish. In most of the surveys the juvenile groups had approximately the same modal size as the dominating group found in the Benguela-Luanda region. This is a strong indication of a unit stock in the two regions. A closer comparison shows that the modal size of these groups tended to be slightly higher in the northern region. This indicates either a higher growth rate in the north, an earlier spawning period or, perhaps more likely, that spawning mainly occurs in the Benguela-Luanda region and that the juveniles in the north derive from the first part of the spawning period and have drifted northwards with the prevailing surface current in winter-spring.

Figure 7.23 shows the distribution of these types of fish exemplified by those found in surveys 3/85 and 1/89. The few high density school areas were mostly located in the south. In most surveys the fish was found distributed thinly over wide areas. There was usually a paucity of fish off the Congo River, perhaps an effect of the discharges.

The proportions between the types of fish in this group were roughly similar to those found on the shelf between Benguela and Luanda with "other Carangidae" and hairtails showing largely similar catch levels as horse mackerel.

Hairtail

Table 7.45 shows the biomass and density data for largehead hairtail (*Trichiurus lepturus*) this species from the trawl surveys and also the acoustic estimates since this fish is commonly found in mid-water. The bottom trawl probably gave a serious underestimate and it is not unlikely that the true biomass is in excess of 50,000 t.

Table 7.45 Hairtail: Mean biomass estimates based on trawl hauls by regions and survey periods and mean acoustic estimates from the 1985 through 1989 surveys (1,000 t)

	1985	1986	1989	1991–92	Acoustic estimate 1985–1989
Benguela-Luanda	n.s.	10.0	12.6	8.6	29
Luanda-Cabinda	13.4	7.3	15.5	7.7	27
Total		**17.3**	**28.1**	**16.3**	**56**

Benguela-Luanda

Hairtail was found all over the shelf, but in highest abundance at shallow and intermediate depths as shown by Table 7.46.

Table 7.46 Benguela-Luanda: Incidence and mean catch by bottom trawl of hairtail by depth and surveys

	Incidence %			Mean catch (kg/h)		
Depth (m) Survey	**10–50 m**	**50–100 m**	**100–200 m**	**10–50 m**	**50–100 m**	**100–200 m**
1/86	54	82	50	37	337	10
2/86	57	47	50	11	12	1
1/89	53	73	46	94	71	30
2/89	54	45	27	21	22	2

Luanda-Cabinda

Hairtail was found all over the shelf with common incidence rates around 50% in all three depth zones.

7.2.4 Demersal resources

The analysis of the demersal resources is based on the semi-random swept-area stations. The most abundant demersal fish of commercial interest on the Angolan shelf are reviewed below. They include seabreams, grunts, croakers, groupers and Benguela hake.

Table 7.47 shows the biomass estimates for the conventional commercial demersal species: seabreams, croakers, groupers and grunts (big-eye grunt and Benguela hake are not included).

The total 1991–92 estimates ranged from 115,000 to 120,000 t. The stocks seem to have had an increase of abundance in the regions Cunene-Tombua and Benguela-Luanda.

In addition to these demersal fish which have a conventional commercial use in Angola, the surveys identified other groups which have commercial value in other countries and may thus be added to the potential resources for a commercial Angolan fishery. The most important of these are the big-eye grunt with an estimated biomass of 100,000 t, hairtail with 50,000 t and other Carangidae and barracudas with perhaps 30,000–40,000 t. The total biomass of the resources for a mainly demersal fishery seems thus to be of the order of 300,000 t. In addition comes the Benguela hake in the slope with a biomass of about 30,000 t.

Table 7.47 Commercial demersal fish*: Estimates of biomass by surveys and regions (1,000 t)

Survey	Cunene-Tombua	Benguela-Luanda	Luanda-Cabinda	Total
1/85	n.s.	n.s.	31.6	
3/85	n.s.	n.s.	48.3	
4/85	n.s.	n.s.	83.9	
1/86	10.1	16.8	32.1	91.4
2/86	21.1	25.7	44.6	65.4
1/89	17.3	18.6	29.5	77.9
3/89	n.s.	n.s.	31.7	
1/91	26.4			
2/91	36.4	50.1	35.9	122.4
1/92	47.7	33.0	34.0	114.7
Mean	26.5	28.8	41.3	

n.s. = no survey
* Seabreams, croakers, groupers and grunts except big-eye grunt

Cunene-Benguela

The southern part of this area, from the Cunene River to Tombua, has a relative wide shelf (about 1,690 nmi^2), with smooth bottom conditions. The northern part, from Tombua to Benguela, has a narrow and rough shelf (about 1,090 nmi^2) and only a few hauls were made in this area. No semi-random hauls were made in 1985.

The number of successful semi-random trawl hauls by survey were as follows:

1/86	2/86	1/89	2/89	3/89	1/91	2/91	1/92
22	13	25	19	12	37	47	42

The effort was thus especially low in surveys 2/86 and 3/89 and highest in 1991 and 1992.

As regards species distribution, this region seems to represent a transition zone between the tropical regime in the north and the sub-tropical/temperate regime found further south. The shelf south of Tombua is inhabited by a lower number of species, including the large-eye dentex (*Dentex macrophthalmus*), the African weakfish (*Atractoscion* aequidens*), the Cape hake (*Merluccius capensis*) and the Benguela hake (*M. polli*). Less abundant, but common are the wedge sole (*Dicologoglossa cuneata*), the John dory (*Zeus faber*) and the red pandora (*Pagellus bellottii*).

More sporadic trawl hauls made on the shelf between Tombua and Benguela showed that this part is also inhabited by the large-eye dentex, but other species with affinity for tropical waters are also found, such as the big-eye grunt (*Brachydeuterus auritus*) and the Angola dentex (*Dentex angolensis*). Other species are the red pandora, the Canary drum (*Umbrina canariensis*) and common, but less abundant, the bogue (*Boops boops*) and the African weakfish.

Table 7.48 shows biomass estimates of the commercially important groups of demersal fish calculated from mean densities by the depth ranges 10–50 m, 50–100 m and 100–200 m.

Among the causes of the variation in the estimates are survey variability and migrations into and out of Namibia. The timing of the surveys has not been favourable for an analysis of possible seasonal variations in the abundance of these demersal stocks. The apparent trend of increase of the last surveys is discussed below.

Table 7.48 Cunene-Tombua: Biomass estimates (1,000 t) of main groups from random trawl survey over the shelf to 200 m depth

	1/86 Jan-Feb	**2/86 Mar-Apr**	**1/89 Feb-Mar**	**2/89 Apr-Mar**	**3/89 Nov-Dec**	**1/91 Mar-Jun**	**2/91 Aug-Sep**	**1/92 Aug-Sep**	**Mean**
Demersals									
Seabreams	6.5	12.9	11.5	24.8	13.2	20.7	26.6	40.0	19.5
Croakers	0.9	2.6	1.1	2.8	1.4	1.7	1.6	2.0	1.8
Hakes	0.8	2.6	0.3	0.9	3.8	4.0	8.2	5.0	3.2
Total	**8.2**	**18.1**	**12.8**	**28.4**	**18.3**	**26.4**	**36.4**	**47.0**	**24.5**
Semi-demersals									
Cape horse mackerel*	12.8	5.9	8.5	9.4	14.7	21.3	26.7	82.0	22.7
Cunene horse mackerel*	9.6	47.9	1.5	0.7	5.8	20.8	12.7	8.0	13.4

* These estimates are for horse mackerel occurring near the bottom, see also acoustic estimates

Benguela-Luanda

The demersal fauna between Benguela and Luanda was not investigated during the 1985 programme, except for nine test hauls during the November survey. The number of successful swept-area hauls in the subsequent surveys were as follows:

1/86	2/86	1/89	2/89	3/89	1/91	2/91	1/92
29	32	52	66	15	62	41	48

The total shelf area (0–200 m) is about 4,800 nmi^2 with a mean width of about 18 nmi, the effort of only 15 hauls in survey 3/89 is considered too low and therefore these data will not be used here.

The main species groups in this region were grunts (Pomadasyidae), seabreams (Sparidae) and largehead hairtail (*Trichiurus lepturus*). Of the grunts, the big-eye grunt (*Brachydeuterus auritus*) was the dominating species, while three *Pomadasys* species were far less common. The seabreams were mainly represented by the red pandora, but various *Dentex* species were also common.

Table 7.49 shows the biomass estimates from the swept-area calculations.

Table 7.49 Benguela-Luanda: Biomass estimates (1,000 t) of main groups from swept-area surveys over the shelf to 200 m depth. Conventional commercial species are summed

	1/86 Jan-Feb	2/86 Mar-Apr	1/89 Feb-Mar	2/89 Apr-Mar	1/91 Mar-Jun	2/91 Aug-Sep	1/92 Aug-Sep	Mean
Demersals								
Seabreams	11.8	14.2	12.0	12.9	10.6	24.6	28.0	16.3
Grunts*	2.7	6.0	5.6	1.6	0.7	5.5	2.0	3.6
Croakers	6.2	7.1	1.7	3.6	3.5	19.0	2.0	6.2
Groupers	0.6	0.7	0.7	2.6	0.2	1.0	1.0	1.0
Snappers	0.2		0.1	0.1				0.2
Total	**21.4**	**27.9**	**19.9**	**20.6**	**15.1**	**50.1**	**33.0**	**27.3**
Semi-demersals								
Big-eye grunt	44.6	27.9	18.9	59.9	31.3	18.5	52.0	36.2
Cunene horse mackerel	21.0	25.4	7.4	9.2	75.0	4.9	75.0	31.1
Other Carangidae	3.2	2.7	8.6	6.0	1.7	0.3	1.7	3.4
Barracudas	1.9	1.7	3.0	1.2	0.8			1.2
Hairtail	17.8	2.3	12.6	2.8	10.0	4.1	13.0	7.2

* Excluding big-eye grunt

The big-eye grunt (*Brachydeuterus auritus*) and the Cunene horse mackerel (*Trachurus trecae*) were the most abundant species. Both species as well as the other Carangidae, and the barracudas and hairtails were found to have a more pronounced semi-demersal behaviour than most of the other species caught by the bottom trawl and this may explain a part of the large survey to survey variation in their biomass estimates. Acoustic estimates of the biomass were also made for these groups.

Luanda-Cabinda

The region from Luanda to Cabinda was covered with swept-area hauls during all surveys since January 1985. The number of semi-random hauls were as follows:

1/86	2/86	3/85	4/85	1/86	2/86	1/89	2/89	3/89	1/91	2/91	1/92
21	29	32	30	66	72	48	62	30	62	71	65

The area of this shelf is about 4,800 nmi^2 and the precision of the biomass estimates from the surveys in 1985 and survey 3/89 is expected to be low.

The main species in the bottom trawl catches were the big-eye grunt, the hairtail, the red pandora, other seabreams (*Dentex* spp. and *Sparus* sp.), other grunts (*Pomadasys* spp.), croakers (*Pseudotolithus* spp., *Miracorvina angolensis, Umbrina* spp.) and groupers (*Epinephelus* spp.), mentioned in their order of dominance.

Biomass estimates of main groups based on mean densities by depth ranges are shown in Table 7.50. The high variation for the semi-demersals, big-eye grunt, horse mackerels, other Carangidae, barracudas and hairtails may in part be caused by changes in their pelagic behaviour from survey to survey. For the demersals this long series of estimates may indicate that they in part depended on the season of observations. If within-year estimates are compared those from April-May and May-June were markedly lower than estimates from August-September and November-December (2/85 compared with 3/85 and 4/85; 2/89 compared with 3/89 and 1/91 compared with 2/91). In the late autumn season April-June the Angola current flows southward over the shelf with Congo water in the surface layers and the thermocline is deep. These conditions may have caused a reduced availability of demersal fish to the bottom trawl. Estimates from this warm season should thus not be used in time series for stock evaluation purposes.

Table 7.50 Luanda-Cabinda: Biomass estimates (1,000 t) of main groups from random trawl survey over the shelf to 200 m depth

	1/85 Jan-Feb	2/85 Apr-May	3/85 Aug-Sep	4/85 Nov-Dec	1/86 Jan-Feb	2/86 Mar-Apr	1/89 Apr-May	2/89 Nov-Dec	3/89 Nov-Dec	1/91 May-Jun	2/91 Aug-Sep	1/92 Aug-Sep	Mean
Demersals													
Seabreams	15.9	15.7	23.3	41.8	23.8	30.8	18.4	8.9	17.0	6.7	16.5	16.0	19.6
Grunts*	1.6	1.2	5.0	19.7	2.6	3.6	1.5	2.0	3.8	0.6	2.9	1.0	3.8
Croakers	4.1	13.6	9.3	18.1	14.9	9.0	5.8	7.9	9.5	0.8	1.0	3.0	8.1
Total*	**22.4**	**32.4**	**41.3**	**83.8**	**42.7**	**45.2**	**27.2**	**20.1**	**31.1**	**15.9**	**36.0**	**34.0**	**31.5**
Semi-demersals													
Big-eye grunt	53.9	11.9	20.2	90.5	84.8	18.7	11.6	14.5	50.4	17.2	19.7	21.0	34.5
Cunene horse mackerel	4.6	5.1	16.0	33.1	8.7	10.0	16.0	14.0	50.8	12.5	12.0	20.0	16.9
Other Carangidae	19.4	3.2	3.2	16.8	18.0	4.1	2.8	4.2	11.7	8.6	0.9	4.0	8.0
Barracudas	1.0	0.9	0.3	1.8	3.2	1.3	1.6	4.7	1.1	0.8		1.0	1.5
Hairtail	26.4	2.7	6.9	6.8	5.8	8.8	2.5	4.9	28.4	8.0	8.3	7.0	9.7

* Excluding big-eye grunt

The big-eye grunt and the Cunene horse mackerel were also in this region the most abundant species in the bottom trawl catches. The large variations in the estimates for these species and well as for the other semi-demersal: (the other Carangidae, the barracudas and hairtails) may, as discussed above, be caused by changes in their behaviour from survey to survey.

The depth distribution of the big-eye grunt was similar to that found in the region Benguela-Luanda. This species was common in hauls down to 100 m depth, but the highest catch rates were obtained in the 50–100 m depth range. Other grunts, far less abundant than the big-eye, the bastard grunt (*Pomadasys incisus*), the sompat grunt (*P. jubelini*) and the rubberlip grunt (*Plectorhynchus mediterraneus*) were common in catches in the 10–50 m range, but catch rates were low.

Grunts

The small-sized big-eye grunt is by far the most abundant of the demersal fish on the Angolan shelf. It inhabits the inner shelf from Benguela northwards with roughly equal densities in each of the two regions (Table 7.51). The total biomass representing the mean of all the survey estimates for each region is about 70,000 t. The individual survey estimates show, however, a very high variability. The very low estimates in some of the surveys could well be the result of reduced availability to bottom trawl of this species which at times is found in abundance in mid-water. The true biomass of the big-eye grunt could thus well exceed 100,000 t.

Table 7.51 Big-eye grunt: Estimates of biomass by surveys and regions (1,000 t)

Survey	Benguela-Luanda	Luanda-Cabinda	Total
1/85	n.s.	53.8	
3/85	n.s.	20.1	
4/85	n.s.	90.5	
1/86	44.6	84.8	129.4
2/86	27.9	18.7	46.6
1/89	18.9	11.6	30.5
3/89	n.s.	50.4	
2/91	18.5	19.7	38.2
1/92	52.0	21.0	73.0
Mean	29.0	41.2	70.2
Density (t/nmi^2)	6.0	5.3	

n.s. = no survey

Table 7.52 shows the estimated biomass of other grunts, mainly various *Pomadasys* species. They are also restricted to shallow waters to the north of Benguela, but are far less abundant than the big-eye grunt with an estimated biomass of about 9,000 t.

Table 7.52 Other grunts: Estimates of biomass by surveys and regions (1,000 t)

Survey	Benguela-Luanda	Luanda-Cabinda	Total
1/85	n.s.	1.6	
3/85	n.s.	5.0	
4/85	n.s.	19.7	
1/86	2.7	2.6	5.3
2/86	6.0	3.6	9.6
1/89	5.6	1.5	7.1
3/89	n.s.	3.8	
2/91	5.5	2.9	8.4
1/92	2.0	1.0	3.0
Mean	4.4	4.6	9.0

n.s. = no survey

The sompat grunt (*Pomadasys jubelini*) and the bastard grunt (*P. incisus*) were the most common of the other species of this family.

An analysis of the 1986–89 data (Table 7.53) shows that the big-eye grunt was common in shallow waters (10–50 m) and at intermediate depths (50–100 m), but was seldom caught beyond 100 m depth.

Table 7.53 Benguela-Luanda: Incidence and mean catch of big-eye grunt by depth and surveys 1986–89

	Incidence %			Mean catch (kg/h)		
Depth (m) Survey	10–50 m	50–100 m	100–200 m	10–50 m	50–100 m	100–200 m
1/86	62	82	0	90	813	0
2/86	79	73	0	84	345	0
1/89	63	73	23	115	150	7
2/89	58	45	27	189	690	62

The other grunts, except the big-eye grunt were common in the shallow water range (10–50 m), were found occasionally in the 50–100 m zone, but never beyond 100 m bottom depth, as can be seen in the incidence rates in Table 7.54.

Table 7.54 Benguela-Luanda: Incidence and mean catch of *Pomadasys* species by depth and survey

	Incidence %			Mean catch (kg/h)		
Depth (m) Survey	10–50 m	50–100 m	100–200 m	10–50 m	50–100 m	100–200 m
1/86	54	24	0	8	15	0
2/86	79	27	0	17	59	0
1/89	53	27	0	70	13	0
2/89	38	6	0	16	9	0

Seabreams

Table 7.55 shows the time series of biomass estimates, but with the assumed biased autumn estimates for the northern regions omitted. The mean biomass density for the small area Cunene-Tombua was higher than in the northern regions, which demonstrates the high productivity also for demersal fish of this region of intensive upwelling. In this area the seabreams consisted mainly of the large-eye dentex, but with some red pandora in shallow waters. From Benguela northwards, the species composition is much more diversified.

A part of the variability of the estimates in the Cunene-Tombua region could be the effect of shifts in the distribution of a common stock of large-eye dentex covering northern Namibia and southern Angola. This stock has been exploited in a trawl fishery with catches reported from ICSEAF Division 1.3 and 1.4 ranging from 3,000 to 12,000 t in the period 1973–86. The reported landings of large-eye dentex in area 47 declined from about 9,000 in 1986 to about 6,000 t in 1984 through 1986, 4,000 t in 1987 through 1989 and nearly 0 t in 1990–91 (FAO, 1993). The increased biomass estimate of seabreams in the southern region in 1992 since early 1989 could be a response to a decline in exploitation.

Table 7.55 Seabreams: Estimates of biomass by surveys and regions (1,000 t)

Survey	Cunene-Tombua	Benguela-Luanda	Luanda-Cabinda	Total
1/85	n.s.	n.s.	15.8	
3/85	n.s.	n.s.	23.2	
4/85	n.s.	n.s.	41.8	
1/86	9.4	9.0	16.5	34.9
2/86	17.3	13.8	30.2	61.3
1/89	16.2	10.9	17.2	44.3
2/89	35.3			
3/89	n.s.	n.s.	17.0	
1/91	20.7			
2/91	26.6	24.6	16.5	67.7
1/92	40.0	28.0	16.0	84.0
Mean	23.6	17.0	22.0	62.6
Density (t/nmi^2)	14.1	3.5	2.8	

n.s. = no survey

Cunene-Benguela

The seabreams were dominated by large-eye dentex (93%).

An analysis of the 1986 and 1989 data showed that large-eye dentex was found mainly between 50 and 200 m, but could be traced to 30 m bottom depth (Table 7.56).

Table 7.56 Cunene-Benguela: Incidence and mean catch of large-eye dentex by depth and year

Year	Incidence %			Mean catch (kg/h)		
	30–50 m	50–100 m	100–200 m	30–50 m	50–100 m	100–200 m
1986	25	80	100	0.6	275	295
1989	56	95	100	62	530	402

Benguela-Luanda

The seabreams were represented by a number of species. The 1986–89 species composition was 50% red pandora (*Pagellus bellottii*), 15% large-eye dentex (*Dentex macrophthalmus*), 15% Angola dentex (*D.angolensis*) and 7% Barnard dentex (*D. barnardi*).

Red pandora was very common at intermediate depths during all surveys, as shown from the high incidence rates in Table 7.57. In the shallow waters, it occurred in more than 50% of the hauls, but with low catch rates.

Table 7.57 Benguela-Luanda: Incidence and mean catch of red pandora by depth and surveys

Depth (m) Survey	Incidence %			Mean catch (kg/h)		
	10–50 m	50–100 m	100–200 m	10–50 m	50–100 m	100–200 m
1/86	46	82	0	10	92	0
2/86	64	87	50	8	80	18
1/89	26	77	46	5	29	3
2/89	67	87	45	17	89	8

The other *Dentex* species were common in both the 50–100 and the 100–200 m depth ranges (Table 7.58).

Table 7.58 Benguela-Luanda: Incidence and mean catch of *Dentex* species by depth and surveys

Depth (m) Survey	Incidence %			Mean catch (kg/h)		
	10–50 m	50–100 m	100–200 m	10–50 m	50–100 m	100–200 m
1/86	38	76	50	7	27	18
2/86	43	73	100	4	62	88
1/89	32	64	92	2	66	95
2/89	25	87	91	2	39	76

Luanda-Cabinda

The number of seabream species was higher than in the region south of Luanda. The 1985–89 species composition was on average: *Pagellus bellottii* 30%, *Dentex angolensis* 18%, *Dentex congoensis* 12%, *Dentex canariensis*, 10%, *Dentex gibbosus* 7%, *Dentex barnardi* 3%, *Dentex macrophthalmus* 2%, *Sparus caeruleosticus* 7%, *Boops boops* 4%.

Table 7.59 Luanda-Cabinda: Incidence and mean catch of red pandora by depth and survey

Depth (m) Survey	Incidence %			Mean catch (kg/h)		
	10–50 m	50–100 m	100–200 m	10–50 m	50–100 m	100–200 m
1/85	29	82	33	10	31	1
2/85	25	70	14	29	13	0
3/85	29	58	20	25	13	0
4/85	75	60	38	17	30	4
1/86	61	88	57	17	44	37
1/89	40	87	56	15	29	2
2/89	24	89	44	1	31	1

The incidence rates for the 1985–89 surveys show that the red pandora was most common in the depth range 50–100 m where it was found in most of the hauls (Table 7.59).

For the *Dentex* species the highest mean catch rates were obtained deeper than 50 m where this group was represented in most hauls, as shown by the high incidence rates in Table 7.60.

Table 7.60 Luanda-Cabinda: Incidence and mean catch of *Dentex* species by depth and surveys

Depth (m) Survey	Incidence %			Mean catch (kg/h)		
	10–50 m	50–100 m	100–200 m	10–50 m	50–100 m	100–200 m
1/85	21	73	100	1	49	99
2/85	33	80	100	6	36	72
3/85	57	83	80	20	138	38
4/85	67	80	100	44	37	139
1/86	35	93	100	8	46	26
2/86	28	66	100	3	53	139
1/89	27	87	100	5	50	27
2/89	18	78	89	3	23	35

Croakers

Table 7.61 shows a summary of the biomass data for croakers. In the south this group is represented by the African weakfish found down to 200 m depth, while there are a number of species in the northern regions especially north of Luanda where the genus *Pseudotolithus* is especially important. The time series of the biomass estimates indicate a possible decline of the abundance of this group from 1985/86 to 1989 followed by a recovery in 1991/92. This may have been an effect of changes in the fishery for the species of high commercial value of croakers. The estimated mean biomass over the period of survey is about 20,000 t.

Table 7.61 Croakers: Estimates of biomass by surveys and regions (1,000 t)

Survey	Cunene-Tombua	Benguela-Luanda	Luanda-Cabinda	Total
1/85	n.s.	n.s.	4.1	
3/85	n.s.	n.s.	9.3	
4/85	n.s.	n.s.	18.1	
1/86	0.9	6.2	14.9	22.0
2/86	2.6	7.1	9.0	18.7
1/89	1.1	1.7	5.8	8.6
2/89	2.8			
3/89	1.4	n.s.	9.9	
1/91	1.7			
2/91	1.6	19.0	15.6	36.2
1/92	2.1	2.0	14.0	18.1
Mean	1.8	7.2	11.2	20.2
Density (t/nmi^2)	14.1	3.5	2.8	

n.s. = no survey

Cunene-Benguela

In 1986 the African weakfish was found mainly between 50 and 100 m, but in 1989 it was found at greater depths (Table 7.62).

Table 7.62 Cunene-Benguela: Incidence and mean catch of African weakfish by depth and year

Year	Incidence %			Mean catch (kg/h)		
	30–50 m	50–100 m	100–200 m	30–50 m	50–100 m	100–200 m
1986	20	79	18	13	71	11
1989	9	47	70	0.5	19	60

Luanda-Cabinda

Croakers, mainly longneck croaker (*Pseudotolithus typus*), cassava croaker (*P. senegalensis*), bobo croaker (*P. elongatus*), Angola croaker (*Miracorvina angolensis*) and Canary drum (*Umbrina canariensis*), were common north of Luanda, especially in the shallow waters where the group was represented in most of the hauls (Table 7.63). Also beyond 50 m the group was relatively common with typical incidence rates around 50% from 50 to 100 m depth. The blackmouth croaker (*Pentheroscion mbizi*) was common in deeper waters. Mean catch rates, between 35 and 90 kg/h, were relatively consistent in the shallow waters.

Table 7.63 Luanda-Cabinda: Incidence and mean catch of croakers by depth and surveys

Depth (m) Survey	Incidence %			Mean catch (kg/h)		
	10–50 m	**50–100 m**	**100–200 m**	**10–50 m**	**50–100 m**	**100–200 m**
1/85	71	45	33	92	20	13
2/85	92	50	43	78	18	35
3/85	79	50	80	80	42	65
4/85	67	70	25	35	16	140
1/86	45	41	43	89	9	37
2/86	94	56	43	56	18	14
1/89	47	43	33	39	43	8
2/89	88	50	44	49	14	36

Groupers

Groupers are commercially valuable fish, but restricted to the northern part of the shelf and less abundant. As shown in Table 7.64 the total biomass was estimated at only 2,000 to 3,000 t. This is, however, likely to be an underestimate as the groupers often have a preference for a hard, untrawlable bottom.

Table 7.64 Groupers: Mean biomass estimates by regions and survey periods (1,000 t)

	1985	**1986**	**1989**	**1991–92**
Benguela-Luanda		0.7	0.7	1.0
Luanda-Cabinda	3.0	1.7	1.1	2.1
Total		**2.4**	**1.8**	**3.1**

Luanda-Cabinda

Groupers were mainly represented by the white grouper (*Epinephelus aeneus*) and the dusky grouper (*E. guaza*). Typical incidence rates were in the order of 35–40% in waters shallower than 100 m. Beyond this depth the group was less common.

The Benguela hake

The Benguela hake was found from the Cunene River to Tombua together with Cape hake and as the only hake species on the slope further north from Benguela to Cabinda.

Table 7.65 shows the mean catch rates for the two regions northern and by depth intervals for survey periods. In nearly all cases the highest rates were from the 300–500 m depth range. There is a sharp decline in catch rate below 500 m. In the 400–500 m range there was a tendency for the catch rate to be somewhat higher on the grounds between Cabinda and Luanda than on the southern grounds. This indicates that the hake had its main distribution somewhat deeper in the northern than in the southern Angolan grounds.

Table 7.65 Benguela hake: Mean catch rates by depth ranges and survey period (kg/h)

Survey period	**1985/86**	**1989**	**1/1991**	**1992**
Benguela-Luanda				
No. of trawl stations: Depth range (m)	39	63	37	51
101–200	3	51	0	0
201–300	177	138	37	96
301–400	734	109	374	225
401–500	493	112	377	161
>501	66	80		29
Luanda-Cabinda				
No. of trawl stations: Depth range (m)	126	80	33	62
101–200	49	47	1	13
201–300	103	39	11	104
301–400	248	141	372	264
401–500	524	233	525	224
>501	56	56		33

Table 7.66 shows the biomass estimates by regions and survey periods. There was a decline of about 50% from 1985/86 to 1989 with some increase to 1991, but again a low estimate in 1992. There is no reported directed fishery for Benguela hake, however, it is caught as a by-catch in the deep-water shrimp fishery and it is likely that at least part of the observed decline in the biomass of Benguela hake has been caused by the increasing effort in the shrimp fishery.

Table 7.66 Benguela hake: Biomass estimates by survey-periods (1,000 t)

	1985/86	**1989**	**1991**	**1992**
Benguela-Luanda	20	10	11	8
Luanda-Cabinda	22	13	18	14
Total	**42**	**23**	**29**	**22**

7.2.5 Cephalopods

This analysis is limited to findings from the surveys 1/86, 2/86, 1/89 and 2/89. Cephalopods appeared in varying but generally small amounts in swept-area bottom trawl hauls. The sampling of the area Tombua to Benguela was particularly poor because of limited trawling grounds. The coverage of the areas Benguela-Luanda and Luanda-Cabinda includes a varying number of hauls on the slope, 200 to 600/800 m for testing of deep-sea shrimp and hake.

The cephalopods along the Angolan coast can be grouped in accordance with two ecological regimes; that related to the waters of the shelf and upper slope (0 to about 200 m) and that of the slope and oceanic waters from about 200 m of depth outwards. The most important representatives inhabiting the shelf are cuttlefishes (*Sepiidae*); shelf squids (*Loliginidae*) and with much less abundance the octopus (*Octopodidae*). The commercially interesting representatives of the deeper slope and offshore waters are the flying squids (*Ommastrephidae*) with the genera *Illex, Todaropsis* and *Todarodes*.

The behaviour of the cephalopods affects the results of the analysis that can be made of their appearance in the bottom trawl. The Loliginidae are known to undertake diurnal migrations, being bottom dwellers during the day and lifting into mid-waters at night. Whether or not the Sepiidae have a similar behaviour is uncertain, but the data to be analysed have been restricted to demersal hauls during daylight hours.

The Ommastrephidae are also known to undertake diurnal migrations, being found in surface layers during the night where they often can be aggregated by light from vessels and at considerable depths during daytime, in mid-water or near the bottom. Their distribution may be related to that of the mesopelagic fish which has a similar diurnal vertical migration and has been recorded in abundance along parts of the Angolan shelf. It is doubtful whether the records of the catches of Ommastrephidae in the bottom trawl, even if limited to daytime hauls, provide much more than evidence on the presence of the species. Since, however, there is a commercial fishery for deep-sea shrimp on the trawlable grounds along the slope these records may be of some interest in showing the by-catches of cephalopods in this fishery.

Another important feature of cephalopod biology is that a seasonal variation in abundance often occurs, an effect of a short life cycle, usually of about one year. The distribution in time of these surveys, is not favourable with reference to this phenomenon as it is limited to the first half of the year.

The analysis of the cephalopods on the shelf is in the following restricted to day light hauls made at depths down to 200 m. At times these species were also recorded in small amounts in catches beyond this depth limit. Hauls beyond 200 m depth are analysed for Ommastrephidae.

The degree of reliability and precision of the taxonomic classification of the cephalopods varied between surveys. Cuttlefish was often only identified to family or genus level, but in later surveys generally to species level including *Sepia officinalis, S. orbignyana* and *S. bertheloti.* There is some doubt about some of the distinctions between *S. officinalis* and *S. bertheloti.* Squid on the shelf was usually identified as *Loligo vulgaris*, but there are indications that Ommastrephidae on the slope were at times also identified as Loligo.

Ommastrephidae species included shortfin squid (*Illex coindetii*), flying squid (*Todarodes sagittatus*) and lesser flying squid (*Todaropsis eblanae*). There were some uncertainties about the reliability of these identifications.

A number of other cephalopod forms of little or no commercial interest appeared occasionally in the catches. They included the small sized African squid (*Alloteuthis africana*), the ornate cuttlefish (*Sepiella ornata*) and in the deep hauls representatives of the families Amphitretidae, Bolitaenidae and Lepidoteuthidae.

Cunene-Tombua

The main forms from this shelf were: cuttlefish identified as *Sepia officinalis* in survey 1/89 and as *Sepia bertheloti* and *S. orbignyana* in survey 2/89 squid identified as *Loligo vulgaris* and common octopus identified as *Octopus vulgaris*. Octopus was found in a few catches only. The lesser flying squid *Todaropsis eblanae* was identified in survey 1/89 in small amounts in offshore catches.

In survey 1/86 *Todarodes sagittatus* was identified as the species found up to 250 nmi offshore. This squid was observed in good numbers at the surface at night over a wide area, but catch rates in a few jigging trials were not high.

Table 7.67 summarizes of the catch rates of squid (*Loligo vulgaris*) for each of the four surveys, with the mean rate in all day hauls on the shelf, the three highest rates and the rate of occurrence. It was found in about 50% of hauls in the two 1985 surveys and in 70% of the hauls in the 1989 surveys. The abundance seems to have been highest in April 1989. Interannual changes of abundance of squids are well known from other areas.

The highest catch rates were obtained in the depth range 20–130 m with a mean of 65 m.

Table 7.67 Cunene-Tombua: Summary of catch rates and occurrence of the squid (*Loligo vulgaris*), random day hauls only (kg/h)

Survey	Mean rate	Three highest rates			Incidence %
1/86	43	248	68	17	50
2/86	12	86	17	15	46
1/89	10	59	41	23	71
2/89	24	12	10	47	74

Table 7.68 shows the summarized catch data for the cuttlefish. Both the rate of occurrence and the catch rates were highest in April 1989. The highest rates were obtained in the depth range 20–110 m with a mean of 57 m.

Table 7.68 Cunene-Tombua: Summary of catch rates and occurrence of cuttlefish (*Sepia* sp.), random day hauls only (kg/h)

Survey	Mean rate	Three highest rates			Incidence %
1/86	5	24	15	3	38
2/86	12	34	28	26	54
1/89	14	237	44	2	29
2/89	37	300	65	61	79

An inspection of the distribution of the catch rates over the shelf for both the squid and the cuttlefish indicate that they may have a spotty character with areas of high density over the mid and inner shelf. Commercial rates are thus likely to be higher than the mean rates obtained in the hauls from the preselected positions in our survey, perhaps within the range of the highest rates.

Benguela - Luanda

Over this part of the shelf cuttlefish appeared in the catches with rates as shown in Table 7.69, by far the greater part identified as *S. officinalis* with small amounts of *S. orbignyana.* In Survey 2/86 identification was only by genus.

Table 7.69 Benguela-Luanda: Summary of catch rates and occurrence of cuttlefish (*Sepia* sp.), random day hauls to 200 m depth only (kg/h)

Survey	Mean rate	Three highest rates			Incidence %
1/86	4	22	26	17	21
2/86	7	64	63	38	38
1/89	1	11	6	2	6
2/89	8	60	53	48	61

The highest catch rates were obtained in the depth range 60–120 m with a mean of 82 m. The depth distribution of the cuttlefish is thus fairly restricted.

The highest abundance was found in April 1986 and April 1989 with hardly any occurrence in February 1989 and also low abundance in January 1986. In general it was, however, lower than on the Cunene-Tombua shelf.

The shelf squids had low abundance in this part of the coast. *Loligo vulgaris* was recorded in very small amounts in only 6 of the 167 hauls of all the four surveys, while the small sized African squid (*Alloteuthis africana*) appeared in 25 catches.

Table 7.70 shows the catch data for the Ommastrephidae in the slope hauls. An identification in 1986 to *Loligo* sp. is assumed to be incorrect.

Table 7.70 Benguela-Luanda: Summary of catch rates (kg/h) and occurrence of Ommastrephidae, random day hauls deeper than 200 m

Survey	Mean rate	Three highest rates			Incidence %
1/86	21	140	31	24	71
2/86	1	3	2	-	67
1/89	2	3	3	-	67
2/89	21	38	37	13	100

The highest rates were obtained within 200–460 m of depth with a mean of about 300 m. The deep part of the slope was, however, inadequately covered.

Luanda - Cabinda

Table 7.71 shows the catch data for cuttlefish. The highest catch rates were obtained in the depth range 50–110 m with a mean of 79 m. The rate of occurrence is low, 25–30%, but spots of higher abundance may exist.

Table 7.71 Luanda-Cabinda: Summary of catch rates (kg/h) and occurrence of cuttlefish (*Sepia* sp.), daylight hauls to 200 m depth only

Survey	Mean rate	Three highest rates			Incidence %
1/86	5	125	36	32	32
2/86	4	60	32	26	31
1/89	2	45	10	7	27
2/89	2	15	15	11	25

The 1986 data showed highest abundance.

Table 7.72 shows a summary of the catch data for the ommastrephids from the slope hauls. The highest rates were from 200–500 m with a mean of 330 m. The rate of occurrence is high in some of the surveys.

Table 7.72 Luanda-Cabinda: Summary of catch rates (kg/h) and occurrence of Ommastrephidae, daylight hauls deeper than 200 m

Survey	Mean rate	Three highest rates			Incidence %
1/86	19	127	50	46	96
2/86	5	66	14	12	35
1/89	17	66	46	33	79
2/89	7	23	15	2	67

7.2.6 Deep-sea shrimp

Deep-sea shrimps were included among the survey objectives from survey 4/85 onwards. There were special problems of uncertainty as regards the true catchability of the trawl for the various shrimp species and biomass estimates were accepted only as indices of abundance.

The following species were commonly found:

Deep-sea rose shrimp, (Spanish: gamba, camarón de altura), *Parapenaeus longirostris*. This species is found in the upper slope, 150–350 m and represents a main target for the commercial fishery.

Striped red shrimp, (gamba listada), *Aristeus varidens*, is found mostly in the depth range 400–600 m and also commercially important.

Scarlet shrimp, (gamba carabinero), *Plesiopenaeus edwardsianus*, occurs in the range 400–900 m and is highly appreciated, but less abundant.

Golden shrimp, (camarón de oro), *Plesionika martia*, occurs at 300–700 m, and is less common.

African mud shrimp, (gamba de fango), *Solenocera africana*, at 50–300 m, less common.

African spider shrimp, (camaron araña africano), *Nematocarcinus africanus*, at 200–700 m, is small sized, of little commercial interest, and abundant.

Attempts at identification to genus or species were only made from survey 4/1985 onwards, but the records from this and several later surveys indicate various instances of apparent misidentification and these data were omitted from the analysis.

The fishery for the rose shrimp is restricted to daytime, whereas the species in deeper waters apparently may be fished both day and night. The fleet may work the 200–300 m grounds during the day and the grounds 400–500 m and more during the night. The catches in the deeper waters often contain small sized shrimp, some times in large quantities in addition to the larger sized main commercial species which form the target of the fishery. These small sized shrimp are of doubtful commercial interest and have in the surveys often only been classified as "shrimp, small, non commercial".

Deep-sea rose shrimp

Table 7.73 shows the mean catch rates in all hauls in the depth range, the three highest rates and the rate of occurrence measured as the number of hauls with catch rates exceeding 1 kg/h related to the total number of hauls made in that depth stratum.

The number of hauls in each survey is not very high and the usually few high catch rates result in a high variance. The rate of occurrence is high in both regions. There was a decline of catch rates over the survey period.

As regards the geographical distribution of the catches the highest rates on the grounds between Benguela and Luanda were in most cases obtained in the south between Lobito and Cabeca de Baleia, but some good rates were from scattered positions up past Cape Ledo. Between Luanda and Cabinda nearly all the highest catches came from the slope out of Luanda up past Ambriz, and also two from positions just south and north of the Congo River outflow.

Table 7.73 Deep-sea rose shrimp: Catch rates, mean of periods, highest rates and rate of incidence, day hauls 150–350 m (kg/h)

Benguela-Luanda	Mean rate	Three highest rates			Incidence %
4/85	24	82	14	12	100
1/86	19	58	55	25	88
1/89	20	37	26	10	100
2/89	27	56	47	21	100
3/89	9	21	12	6	100
1/92	9	61	36	34	88
Luanda-Cabinda					
4/85	25	112	39	19	100
1/86	33	186	59	23	91
1/89	14	94	20	10	90
2/89	17	41	29	17	100
3/89	4	12	12	4	63
1/92	5	167	39	18	79

Striped red shrimp

Table 7.74 shows the catch data from the surveys in which this species was covered. The data from 1986 and 1989 were based on relatively few hauls and only to 600 m depth while the more extensive survey in 1992 showed that the species is found down to 800 m (Anon., 1992). The catch rates showed a trend of decline also for the striped red shrimp.

Table 7.74 Striped red shrimp: Mean catch rates, highest rates, mean of periods, and rates of incidence, 350 m and deeper (kg/h)

Benguela-Luanda	Mean rate	Three highest rates			Incidence %
1/86	15	64	25	20	56
1/89	7	18	5	4	100
2/89	8	22	12	11	89
3/89	7	17	15	10	88
1/92	5	35	26	16	82
Luanda-Cabinda					
1/86	7	97	17	11	39
1/89	3	10	8	8	69
2/89	5	18	12	9	75
3/89	1	4	2	1	57
1/92	5	23	16	15	82

Among a number of other species found the following were the most common:

Scarlet shrimp

Scarlet shrimp has a distribution in the range 400–800 m and only the upper part of this was covered by the 1985–89 surveys. In the surveys of February 1986 and February and May 1989 the species appeared in hauls from 450 m and deeper in both regions with mean rates of 1 or 2 kg/h and a few catches ranging up to 15 kg/h. About the same rates were obtained in the 400–800 m range in 1992.

Golden shrimp

Golden shrimp was recorded in the catches down to 550 m. As it is generally small sized it is uncertain to what extent it has been identified separately or grouped as “small-sized shrimp, non commercial”.

African mud shrimp

African mud shrimp was recorded in many catches, but at very low rates up to a few kg/h between 80 and 400 m of depth.

African spider shrimp

Very large catches of African spider shrimp were made in the depth range 350–550 m especially on the grounds between Luanda and Cabinda. In the January 1986 survey the mean catch rate for this region below 350 m of depth was 280 kg/h with maximum catches of 420 kg/h. In February 1989 catches ranged up to 1 t/h. The size was small, mean weight typically 3–5 g. Its soft body and the extremely long legs forming large entangled masses reduce the commercial interest for this species.

Biomass estimates of shrimp

The following biomass estimates (t) were obtained based on the mean catch rates of deep-sea rose shrimp in the 150–350 m depth range and of striped red shrimp in the 350–600 m range for 1985/86 (t):

	Benguela-Luanda	Luanda-Cabinda	Total
Deep-sea rose shrimp	1,300	2,500	3,800
Striped red	620	230	940

shrimp	
Scarlet shrimp	260
Total	5,000

These are likely to be underestimates especially for the striped red shrimp and the scarlet shrimp which have their main distribution deeper than 350 m where the coverage was incomplete. Furthermore, there is the problem of uncertainty regarding the true catchability of the trawl for shrimps, therefore the biomass estimates should only be used as indices. Using the mean catch rates obtained in the 1989 surveys the corresponding estimate of the total shrimp biomass is 3,300 t and for the 1992 survey about 2,600 t. There is thus an indication of a decline of one-third of the shrimp biomass between 1985/86 and 1989 and perhaps some further decline in 1992.

7.2.7 Summary of resource evaluations

A synthesis of the assessments of fish biomass by main groups, for the southern region Cunene-Namibe and the combined central and northern regions Benguela-Cabinda is given in Table 7.75.

Among the small pelagic fish, the pilchard and the Cape horse mackerel represent resources which are shared with Namibia and the biomass estimates are indications of seasonal availability in Angola. The mean standing biomass of sardinellas and Cunene horse mackerel of 500,000 t compares with a mean annual catch of 230,000 t in the period which perhaps roughly indicates that these resources were fully utilized over that period. Data on fishing for Cape horse mackerel in Angola are not readily available, but a full utilization of that stock and of a recovered stock of sardine would raise Angola's potential annual yield of small pelagics to 300,000–400,000 t.

Table 7.75 Angola: Mean estimated standing biomass (1,000 t) of the main fish resources and densities per species group, by regions

Region	Cunene-Namibe	Benguela-Luanda	Luanda-Cabinda	Total Angola
Pelagic fish				
Pilchard*	50	0	0	50
Sardinellas, etc.	22	138	123	283
Cape horse mackerel*	162	0	0	162
Cunene horse mackerel	84	95	41	220
Sub-total pelagics	318	233	164	715
Density t/nmi^2	114	48	21	46
Density t/nmi coastline	1,156	847	656	894
Semi-pelagic fish				
Big-eye grunt	+	36	35	71
Hairtail	+	38	27	65
Other Carangidae	+	30	40	70
Barracudas	+	9	6	15
Sub-total	+	113	108	221
Demersal fish				
Seabreams	20	16	20	56
Grunts	0	4	4	8
Croakers, groupers etc.	2	8	8	18
Benguela hake	0	12	17	29
Hake*	3	0	0	3
Sub-total	25	40	49	114
Total	**343**	**386**	**321**	**1,050**
Total density t/nmi^2	123	80	41	68
Total density t/nmi coastline	1,247	1,404	1,284	1,313

* Resources shared with Namibia

Angola's reported catches of demersal fish in 1991/92 were less than 20,000 (FAO, 1994). It is uncertain whether these data include all fisheries, but in general there seems to be room for expansion of the national fisheries in many directions.

The surveys in general confirmed the high productivity of the Angolan shelf demonstrated by the history of its industrial fishery. Angola's position in the northern part of Benguela Current upwelling system determines the characteristics of both its fauna and its productivity and is parallelled in the southern position of Mauritania-Senegal-Guinea Bissau in the Canary Current system.

Data for a comparison of the mean standing biomass and densities of Angola's pelagic stocks with the corresponding findings from the DR. FRIDTJOF NANSEN surveys in Namibia and of the shelf from Mauritania to Guinea Bissau in 1981, 1982, 1986 and 1992 (see Chapter 6) are presented in Table 7.76. The data seem to indicate that the densities per unit area of Angola and “NW Africa” are comparable, and considerably lower than in Namibia. However, the density per unit of coastline in Angola is considerably lower than in Namibia and NW Africa.

Table 7.76 Mean standing biomass estimates of pelagics, based on DR. FRIDTJOF NANSEN surveys in Namibia (Cunene-Easter Point), Angola and Mauritania to Guinea Bissau, and densities by area and coastline

Resource (1,000 t)	Namibia (Cunene-Easter Point)	Angola	Mauritania-Guinea Bissau
Pilchard	439	50	100?
Anchovies, round herring	184	0	0?
Sardinellas	0	283	1,120
Horse mackerels	1,355	382	930
Semi-pelagics	0	221	0?
Total	1,978	936	2,150
Shelf area (nmi^2)	18,300	15,400	32,000
Coastline (nmi)	500	800	720
Density t/nmi^2	108	61	67
Density t/nmi coastline	3,956	1,170	2,986

7.3 CONGO AND GABON, 1981–89

Survey objectives and effort

Several coverages of the EEZs of Congo and Gabon were performed by the DR. FRIDTJOF NANSEN (Strømme *et al.*, 1983; IMR 1985b, d, f; 1986b and 1986c). The first coverage took place in August 1981, as part of a survey of the offshore sub-surface community from Equatorial Guinea to the Congo River (Strømme *et al*, 1983). Because of technical problems and hence reduced survey time, the sampling intensity was very low (Table 7.77), which limits the usefulness of the results from this survey.

Table 7.77 Operational details of the surveys off Gabon and Congo

Survey/ country	Month	Days at sea	Distance steamed (nmi)	Degree of coverage	No. of trawl stations
1/81 Gabon	Aug	6	910	7.1	23
1/81 Congo	Aug	3	200	4.0	1
1/85 Gabon	Mar	8	1,393	12.8	36
1/85 Congo	Mar	2	*	*	8
2/85 Gabon	Jun	11	1,593	14.6	57
2/85 Congo	Jun	3	407	8.1	14
3/85 Gabon	Sep	8	1,363	12.5	45
3/85 Congo	Sep	3	*	*	13

4/85 Gabon	Dec	8	1,414	12.9	32
4/85 Congo	Dec	3	636	12.7	6
1/89 Gabon**	Jan-Feb	6	1,100	11.9	55
1/89 Congo	Feb	5	640	12.8	41
2/89 Gabon**	Jun	6	1,200	12.9	58
2/89 Congo	May-Jun	4	420	8.4	23

* Not available
** South of Cape Lopez only

In 1985 four seasonal coverages were performed, in combination with the surveys off Angola. The main objectives were to ensure a complete coverage of the small pelagic stocks shared by Gabon, Congo and Angola, and to provide information on the distribution and the abundance of the main demersal stocks. In 1989 two surveys took place in the first half of the year (January-February and May-June, respectively) with similar objectives as in 1985. However, the shelf north of Cape Lopez (Gabon) was excluded from the survey programme. In fact, as a result of the 1985 surveys, fish densities south of Cape Lopez were found to be several times higher than on the narrower shelf north of the Cape and, in agreement with Gabonese authorities, it was decided to limit the survey coverage to the southern region. Furthermore, the shelf between Cape Lopez and just north of Iguela was never covered because of ongoing oil drilling activities. Figure 7.24 shows an example of a survey track from the 1985 programme.

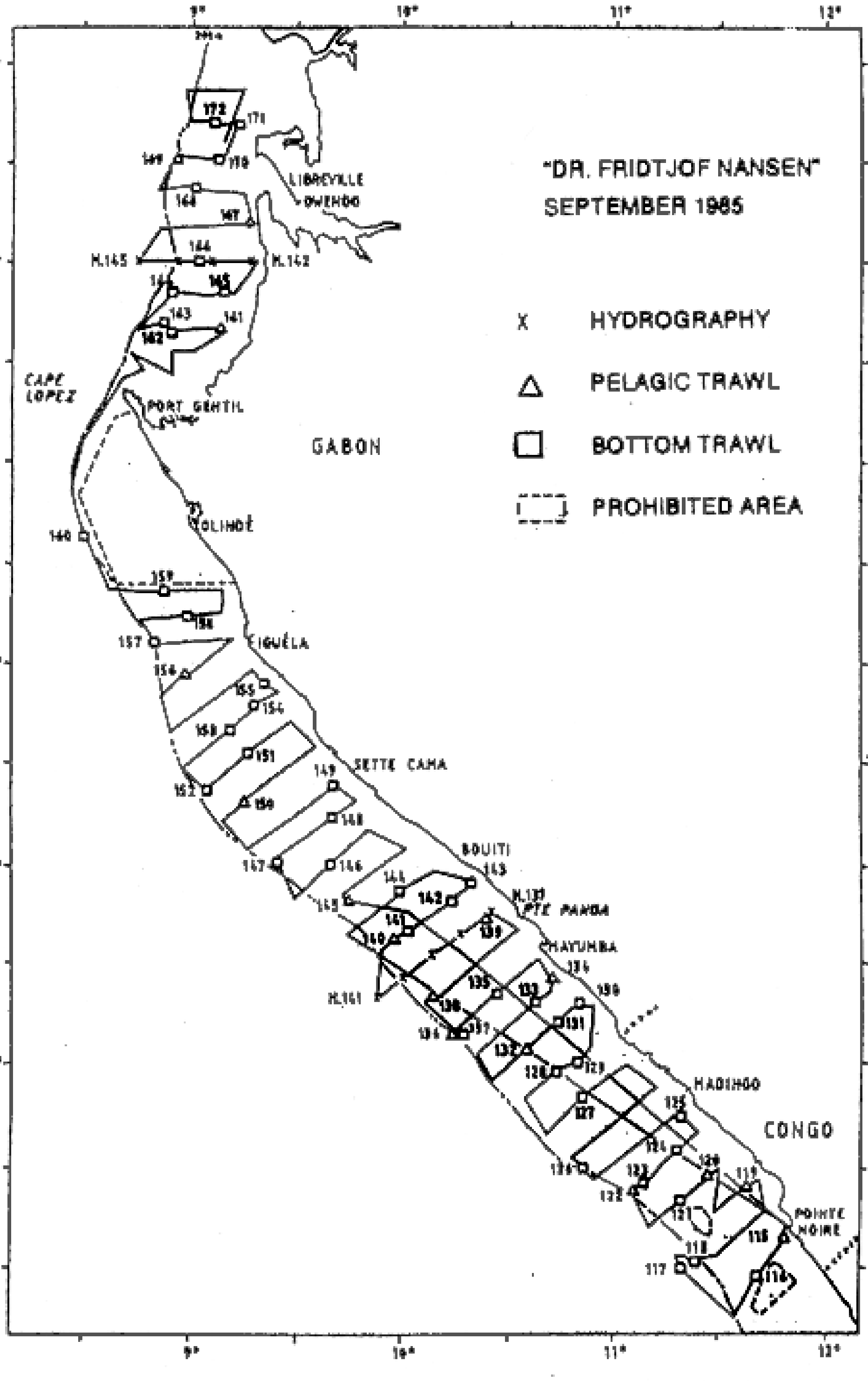

Figure 7.24 Congo and Gabon: Example of coverage, September 1985 survey

Hydrographic conditions

A description of the hydrographic conditions found in the four 1985 surveys is presented in a summary report covering that survey period (IMR, 1986c). This account is largely based on that document.

Fig. 7.25 shows the general circulation pattern of surface waters in the region. According to the results from the DR. FRIDTJOF NANSEN, two main hydrographic seasons can be distinguished, related to the austral summer (December to March) and austral winter (June to September) respectively. The region is dominated by the South Equatorial Current (SEC) flowing westwards from the African coast in the equatorial region. The northern, inshore branch of the SEC transports low-saline warm water from the Gulf of Biafra, southwest along the northern Gabon coast, to about Cape Lopez. The Congo Current flows northwards, transporting low saline water originating from the Congo River estuary. During the austral summer, it reaches as far north as Cape Lopez before turning westwards, while during the austral winter it is less coastal and has an offshore direction.

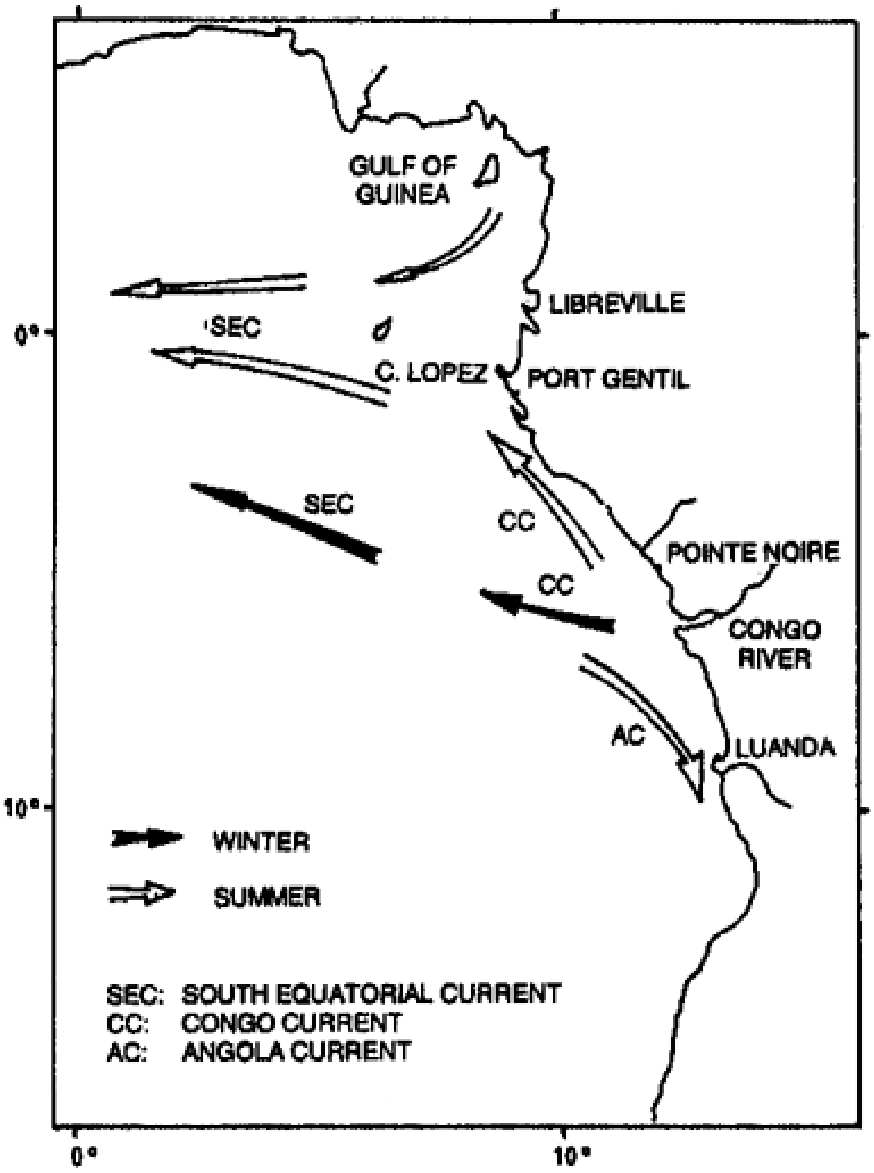

Figure 7.25 General circulation pattern off the southern Gulf of Guinea and the northern Benguela system

A strong thermocline at around 20 to 40 m depth and a warm upper layer with temperatures between 26 and 30°C characterize the austral summer. This is the period of maximum rainfall resulting in low salinity surface waters, mainly due to the discharges of the Congo River and low-salinity water originating from the Gulf of Biafra. In winter, there is a marked decrease in surface temperatures (22 to 26°C), with lowest values in the inshore southern parts (off Congo) where upwelling seems to take place. This upwelling may be related to the changed direction of the Congo Current that flows westwards from the Congolese shelf. The shelf north of Cape Lopez seems to be under the influence of the shoreward branch of the SEC throughout the year.

Voituriez and Herbland (1982) argue that the seasonal upwelling of this region does not seem to be wind-induced and that there is no real vertical transport. This upwelling might be due to increasing strength of the winds in the Western Atlantic originating a Kelvin wave along the Equator in a west-east direction.

Continental shelf

The shelf is a regular strip with an average width of about 40 nmi, strongly narrowing only off Cape Lopez. Figure 7.26 shows the bottom type as observed with the echo integration system during the four surveys in 1985 (IMR, 1986c). The shelf bottom is mainly smooth, and thus trawlable, with a few patches of rough/rocky formations mainly toward the shelf edge (150 to 180 m). These formations are fossil Holocene coral banks, characteristic of the tropical Eastern Atlantic. The shelf becomes very steep from about 120 m depth.

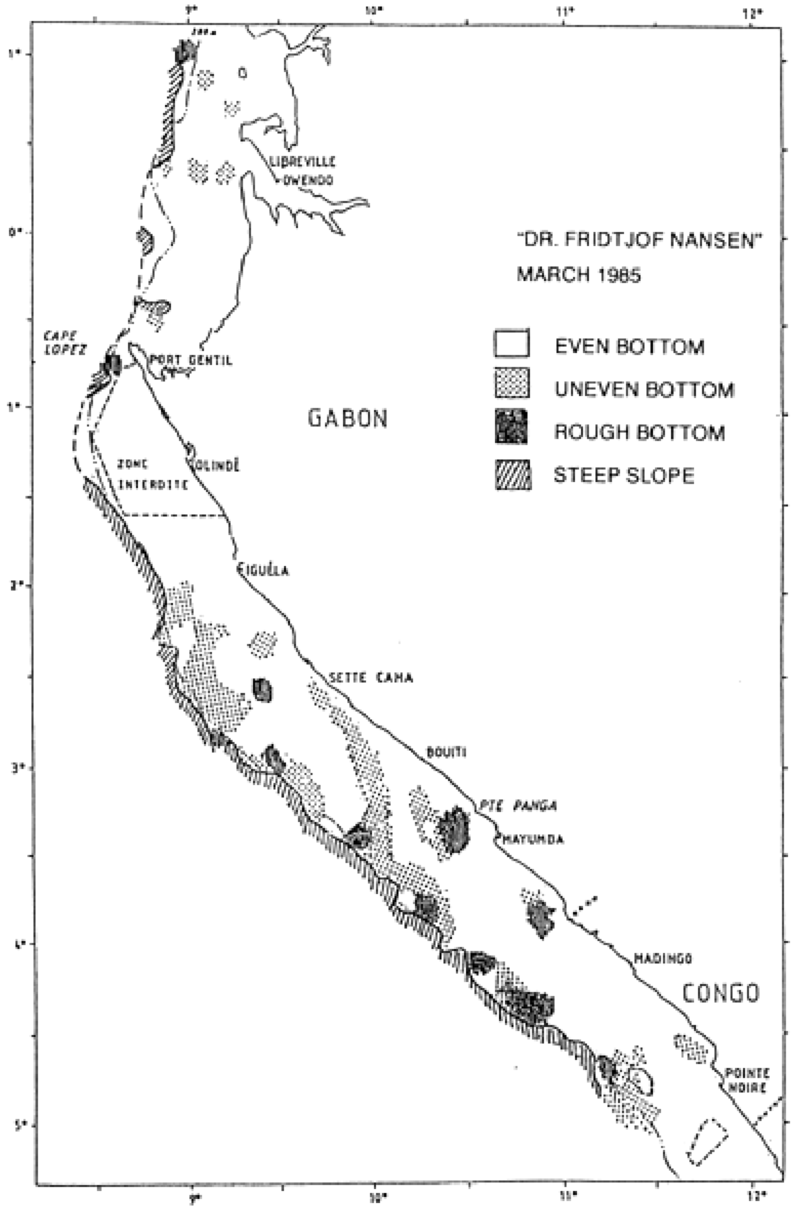

Figure 7.26 Congo and Gabon: Bottom type, as recorded by the echo integration system of the DR. FRIDTJOF NANSEN

Table 7.78 provides some information on shelf area by depth regions and length of coastline, for both countries.

Table 7.78 Congo and Gabon: Shelf area (nmi^2) by depth ranges, and length of coastline (nmi) by region

Depth range (m)	Gabon (north of Cape Lopez)	Gabon (south of Cape Lopez)	Congo
0–50	2,340	4,182	750
50–100	442	2,893	1,520
100–200	576	1,478	250
Total 0–200	3,358	8,553	2,520
Length of coastline (nmi)	140	240	90

Reporting

The results from the 1981 survey are presented in a report covering the regions from Togo to Cameroon and from Equatorial Guinea to Congo, respectively (Strømme *et al*, 1983). Four cruise reports cover the 1985 surveys in Congo and Gabon (IMR 1985b, 1985d, 1985f and 1986b). A report was produced summarizing the results from the 1985 surveys off Gabon (IMR, 1986c). Two cruise reports are available for the 1989 surveys (IMR 1989a and 1989b), each covering both countries.

7.3.1 Pelagic resources

The biomass estimates for pelagic fish are based on the allocation of the integrator readings to two main categories: Pelagic fish type 1, including Clupeidae and Engraulidae (*Sardinella aurita* and *S. maderensis, Ilisha africana* and *Engraulis encrasicolus*) and Pelagic fish type 2, including various species of Carangidae (*Trachurus trecae, Chloroscombrus chrysurus, Selene dorsalis*), smaller Scombridae (mainly *Scomber japonicus*), barracudas (various species of *Sphyraena*) and the hairtail *Trichiurus lepturus*. The triggerfish, *Balistes capriscus*, was considered as a separate category.

Species belonging to Pelagic fish type 1 prefer shallow coastal habitats (except maybe for *S. aurita* that is also found over the deeper part of the shelf), while Pelagic fish type 2 includes both species of shallow waters and of the deeper parts of the shelf.

Allocation of integrator recordings to species groups is based on the composition in the catches and identification of the echo traces. Because of extremely low echo levels, at times it has been difficult to separate integrator values according to the above categories and only rough estimates including all species of pelagic fish have been calculated. In some cases, no estimate has been attempted at all.

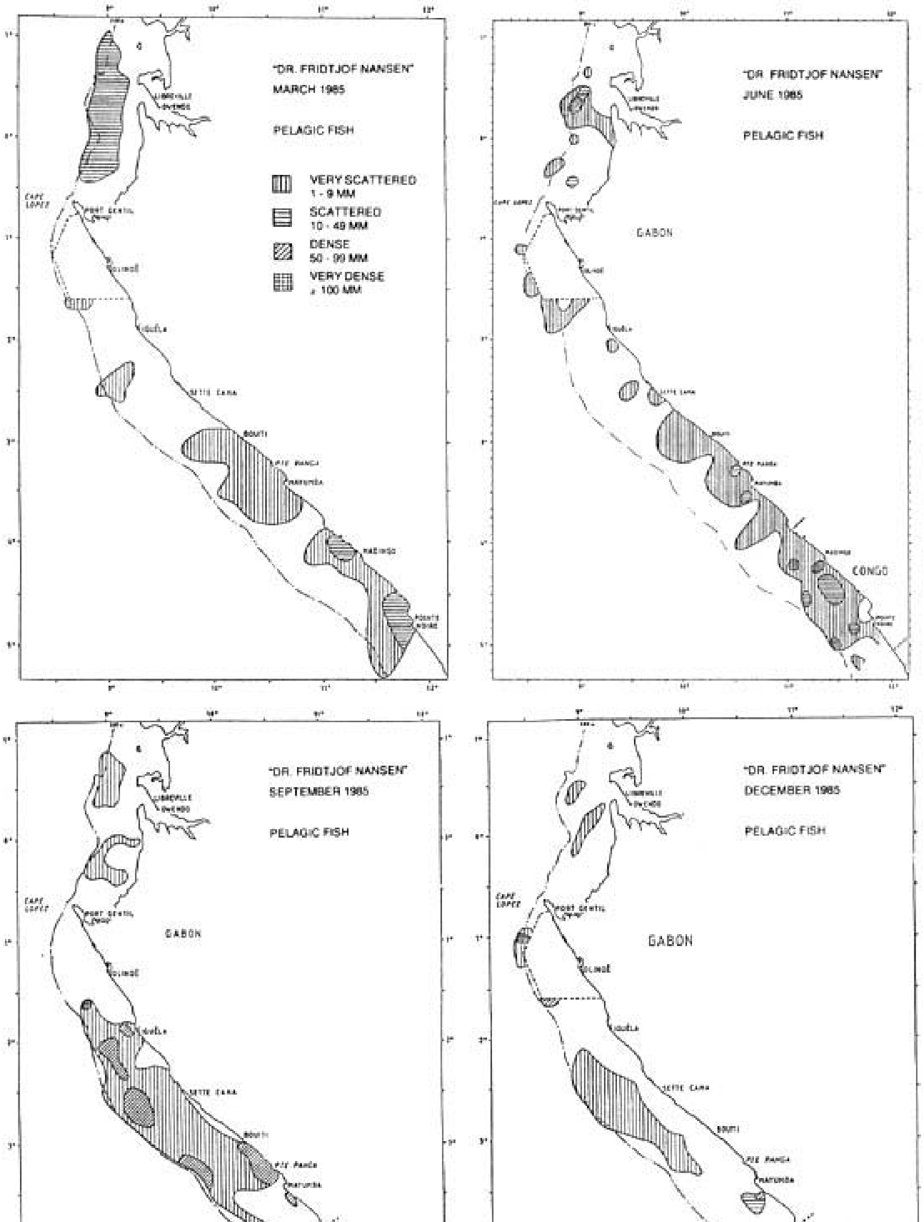

Fig. 7.27 Congo and Gabon: Distribution of pelagic fish during the four 1985 surveys

Figure 7.27 shows the distribution of pelagic fish for the four surveys in 1985. This may be representative of the seasonality in fish availability and distribution. During the March 1985 survey, pelagic fish appeared to be very scattered and consisted mainly of Pelagic type 2 species. Sardinella was caught only on a few occasions. The pelagic recordings north of Cape Lopez were identified as triggerfish (*Balistes capriscus*) and in March 1985 the biomass was estimated at 52,000 t. However, this species decreased sharply in the May-June 1985 surveys (15,000 t) and disappeared thereafter. During the September 1985 survey (corresponding to the winter season) dense aggregations of pelagic fish were found over the whole shelf. The increase was mainly due to juvenile stages of horse mackerel and round sardinella. No triggerfish was recorded during this survey. This pattern is probably due to a seasonal effect, with triggerfish migrating southward from the Gulf of Biafra following the northern branch of the SEC during the summer season and migrating northwards, at the onset of the winter season.

Table 7.79 Estimates of biomass of combined Pelagic fish type 1 and type 2, by areas and surveys (1,000 t)

Survey	Gabon (north of Cape Lopez)	Gabon (south of Cape Lopez)	Gabon (total)	Congo
1/85 Mar	*	24	(24)	28
2/85 May-Jun	*	30	(30)	51
3/85 Sep	10	160	170	57
4/85 Dec	3	54	57	7
1/89 Jan-Feb	**	109	(109)	*
2/89 May-Jun	**	109	(109)	26

* Estimate not available due to too low recordings
** Not surveyed

The most remarkable feature of the Table 7.79 is the marked increase in biomass September 1985 as compared to the two previous surveys. Most of the biomass consisted of juvenile stages (<20 cm total length) of horse mackerel and sardinellas. The inshore waters south of Cape Lopez serve in fact as a nursery ground for these species. With increasing size their distribution range expands both seawards and along the coast (Ghéno and Fontana, 1981). The sharp increase in biomass may be due to the movement of recruiting fish to the open shelf from the shallow coastal waters that are inaccessible to the DR. FRIDTJOF NANSEN. The main spawning grounds are probably located further south, off northern Angola and Congo. Eggs and larvae are transported northwards and to the shallow coastal areas by a cyclonic movement of surface currents. The main resources of small pelagic fish in this region appear therefore to be shared by Angola, Congo and Gabon. The presence of immature individuals of both sardinellas and horse mackerel along the Angolan coast, as far south as Lobito, indicates, however, that spawning probably takes place all along the coast.

7.3.2 Demersal resources

A study of the bottom fish communities of the shelf and slope off southern Gabon (from Cape Lopez) and Congo, based on the 1989 surveys (Bianchi, 1992d), showed that the main environmental gradient along which faunal changes take place is depth. A sharp faunal discontinuity is located between the shelf and the upper slope, due to the steepness of the shelf edge. Another “environmental boundary” is represented by the area where the thermocline impinges on the shelf, effectively separating the shallow-water communities from the mid-shelf communities.

Clear differences were found, within similar depth ranges, between the communities off the two countries. Two main shallow-water communities were identified off Gabon: species typical for sandy bottoms, like blue-spotted seabream (*Sparus caeruleostictus*), stingray (*Dasyatis margarita*), spiny lobster (*Panulirus regius*) and spiny turbot (*Psettodes belcheri*) while off Congo, where a soft mud-clay bottom prevails, the shallow waters were dominated by the eurybathic bumper (*Brachydeuterus auritus*), the croakers (*Pseudotolithus senegalensis*) and (*P. typus*), the threadfins (*Galeoides decadactylus*) and (*Pentanemus quinquarius*) and hairtail, (*Trichiurus lepturus*). Also the sub-thermocline communities differed, with a typical “sparid community” off Gabon (with representatives of the family Sparidae accounting for more than 40% of the catches), while *Brachydeuterus auritus* made up 55% of the catches in the corresponding community off Congo.

It should be noted however that Durand (1967) reported *Dentex angolensis* as the dominant species of the deeper shelf (sub-thermocline) community off Congo. Therefore, the observed differences in species composition may not only be caused by differences in substrate, but also be the result of the respective exploitation regimes in the two countries.

Table 7.80 presents the biomass estimates of demersal fish derived from the DR. FRIDTJOF NANSEN survey in 1981, based on an acoustic estimate, in 1985, as average of the four surveys and of the May-June survey in 1989 (no biomass estimate is available for the January-February 1989 survey). These latter estimates are based on the swept-area method.

Table 7.80 Congo and Gabon: Biomass estimates of demersal shelf fish (1,000 t)

Survey	Gabon (north of Cape Lopez)	Gabon (south of Cape Lopez)	Gabon (total)	Congo
Aug 1981	-	-	120*	-
Average 1985	16	120	136	26
May-Jun 1989	**	34	38***	13

* Based on an acoustic estimate
** Not surveyed
*** Inferred by assuming the same proportions between the areas as in 1985

No great seasonal changes were observed in the bottom fish densities during the 1985 survey programme. The sharp drop between the 1985 and the 1989 estimate is therefore quite remarkable and apparently this applies to both countries.

8 SURVEYS OFF THE PACIFIC COAST OF CENTRAL AMERICA

8.1 INTRODUCTION

Survey objectives and effort

A programme of surveys with the DR. FRIDTJOF NANSEN of the Pacific shelf from the southern border of Colombia to the Gulf of Tehuantepec in Mexico was organized in 1987 within the framework of the UNDP/FAO Project GLO/82/001. The work was planned through the “Working Group on Fisheries Research in the Region of Central America and Panama” organized jointly by FAO and the Latin American Organization for Fisheries Development, OLDEPESCA. During 1987 four complete surveys of the study area, each of some six weeks duration, were made to cover (eventual) seasonal changes.

Cruise Reports, to outline the work done and present the main findings were issued after each survey (IMR, 1987c to 1987n). A final report was submitted in draft version to a Technical Consultation held in Costa Rica in May 1988 and subsequently issued in English and Spanish (Strømme and Sætersdal, 1988a and b). This chapter gives a brief review of the surveys and the findings.

The agreed general objectives of the programme were set out as follows:

- describe the composition, distribution and abundance of small pelagic- and demersal fish, squid and crustaceans on the shelf and upper slope to evaluate the potentials of these stocks;
- conduct taxonomic studies for the purpose of preparing a regional guide to the marine resources;

- conduct hydrographic investigations and prepare charts of bottom type based on echosounder observations;
- provide data on catch rates for specific selected gears and areas including deep-water shrimp and langostino on the slope and jigging for giant squid off the shelf.

Surveys took place in February-March, May-June, August-September and November-December 1987. The total survey effort comprised about 170 days of research work at sea with about 27,000 nmi survey distance and some 1,100 fishing stations. The mean degree of coverage with reference to the acoustic investigations was 11, which is not very high. Figure 8.1 shows as an example the course tracks and stations worked in one of the surveys off Panama.

Small pelagic schooling fish were investigated using acoustic echo integration combined with fishing with bottom and mid-water trawls for identification and sampling.

The demersal resources were investigated with a bottom trawl survey programme where most fishing trials were made in pre-located positions so that the results formed the basis for a swept-area analysis of the composition and abundance of the species.

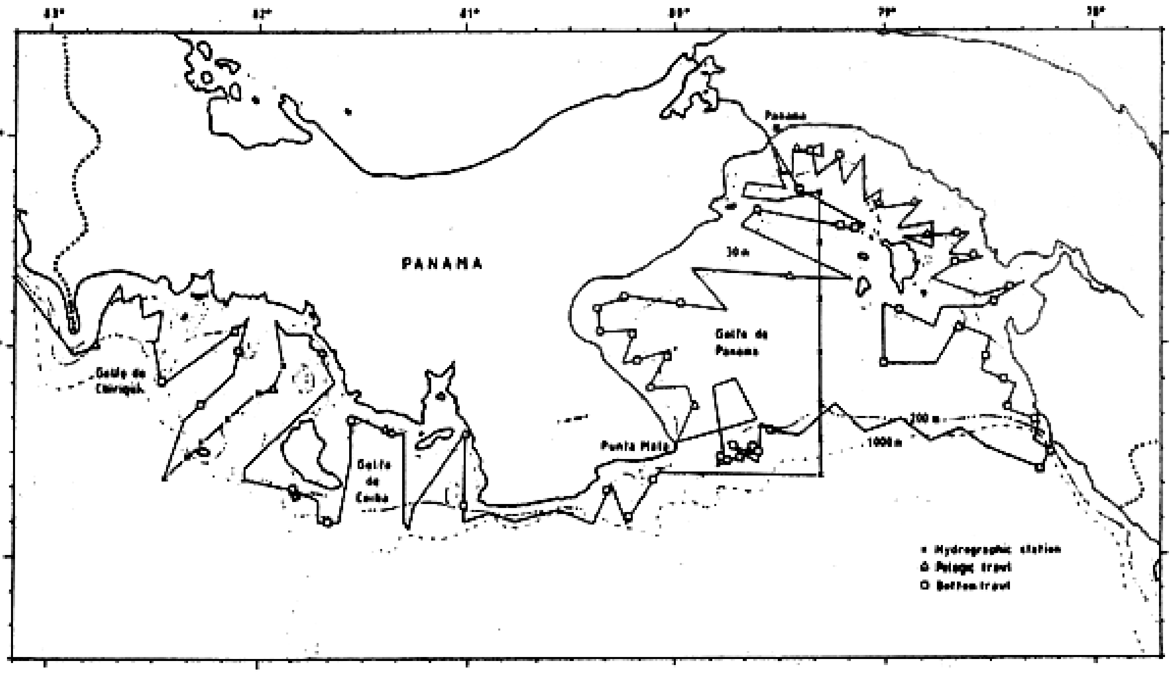

Figure 8.1 Example of course tracks and stations in survey off Panama, February 1987

The various types of shrimp resources could not be covered in an appropriate way within the trawl survey programme. This would have necessitated a concentration of effort both seasonally and in the various special shrimping grounds which would have precluded most of the other survey objectives. For the inshore shallow-water penaeid shrimps the survey data only provide records of incidental catches. For shrimp at intermediate depth, such as the crystal shrimp (*Penaeus brevirostris*), the survey results may for some areas give indications of catch rates and seasons. A similar consideration applies to the shrimps in deep-water beyond 150 m, mainly kolibri shrimp (fidel) (*Solenocera agassizii*) and nylon shrimp (cabezon) (*Heterocarpus vicarius*).

Among the other crustaceans, a special effort was made to cover the resources of langostino (*Pleuroncodes planiceps*) by area, season and depth.

Ecological and faunistic studies

An analysis of the hydrographical data is available in Strømme and Sætersdal (1988a). The main finding regarding fishery oceanography was the confirmation of the disruption of the stable tropical conditions of the surface layers by the well-known seasonal upwellings in the Gulfs of Panama, Papagayo and Tehuantepec caused by strong winds blowing through passages in the mountain ranges between the Atlantic and the Pacific. Conditions of oxygen deficient bottom water (< 1 ml/l) were generally found on the outer shelf from about 100 m depth.

The type of bottom on the shelf and in the slope was observed along the survey tracks based on examination of the echograms and recorded by four categories: smooth even bottom, relatively smooth but uneven bottom, rough bottom and very steep bottom. Most parts of the shelf proper were smooth, but the slope was often rough and steep (Strømme and Sætersdal, 1988a).

Participation in the surveys of taxonomists appointed by FAO Department of Fisheries represented the start of the preparation a species identification guide for fishery purposes (Fischer *et al.*, 1995).

Based on the survey data the demersal fish assemblages in the region were analysed and described (Strømme and Sætersdal, 1988a and Bianchi, 1992a). These studies showed that depth and the associated physical oceanographic conditions, were the main factors in determining the composition of the different species groups.

1. The catches from the deeper continental shelf and upper slope, where oxygen levels were very low (< 0.5 ml/l), were characterized by a low faunal diversity and species adapted to live in almost anoxic conditions.

2. Another group could be identified as intermediate shelf-dwellers, below the thermocline but in waters with higher oxygen content than that found in the deeper shelf and upper slope areas. Many of the species dominant in this part of the shelf were also found, although in smaller quantities, in shallower and/or deeper waters.

3. Finally, another major group could be defined as shallow water or littoral, with species usually encountered above the thermocline and in oxygen rich waters.

Within each of the three main groups, changes in species composition occurred with changes in type of substrate. In shallow coastal waters, the presence of estuaries and brackish waters strongly influenced species composition.

The combined results of the four surveys will be presented below on a country-by-country basis.

8.2 COLOMBIA, 1987

The Pacific shelf of Colombia is narrow, on average about 20 nmi. There is little variation through the year in the vertical structure of the water masses with a well defined thermocline between about 50 and 100 m of depth. There is some variation in surface salinity resulting from river runoffs in the rainy season. The northernmost part of the Colombian shelf and slope may be influenced by the seasonal upwelling system of the Gulf of Panama.

Pelagic fish

Small pelagic fish was found well inshore above the thermocline and distributed in patches along the coast and with the densest aggregations in the south. The main components were thread herring, anchovy, Carangidae (mostly bumper) with some lookdown and big-eye scad, and smaller amounts of sierra and barracuda.

The distribution of the pelagic fish was similar in all surveys and Figure 8.2 shows as an example that of the October-November survey. Highest densities were found in the south and the inshore surface assemblage here was dominated by the Pacific anchoveta (*Cetengraulis mysticetus*) and thread herring (*Opisthonema libertate*) found in school areas and with Pacific bumper (*Chloroscombrus orqueta*) closest inshore. Other accompanying Carangidae were lookdowns (mostly *Selene peruvianus*) and bigeye scad (*Selar crumenophthalmus*) with some green jack (*Caranx caballus*) and bright leatherjack (*Oligoplites refulgens*). Among the larger predators in this system were the sierra (*Scomberomorus sierra*), barracuda (*Sphyraena ensis*) and sharks, mostly hammerheads (*Sphyrna* spp.).

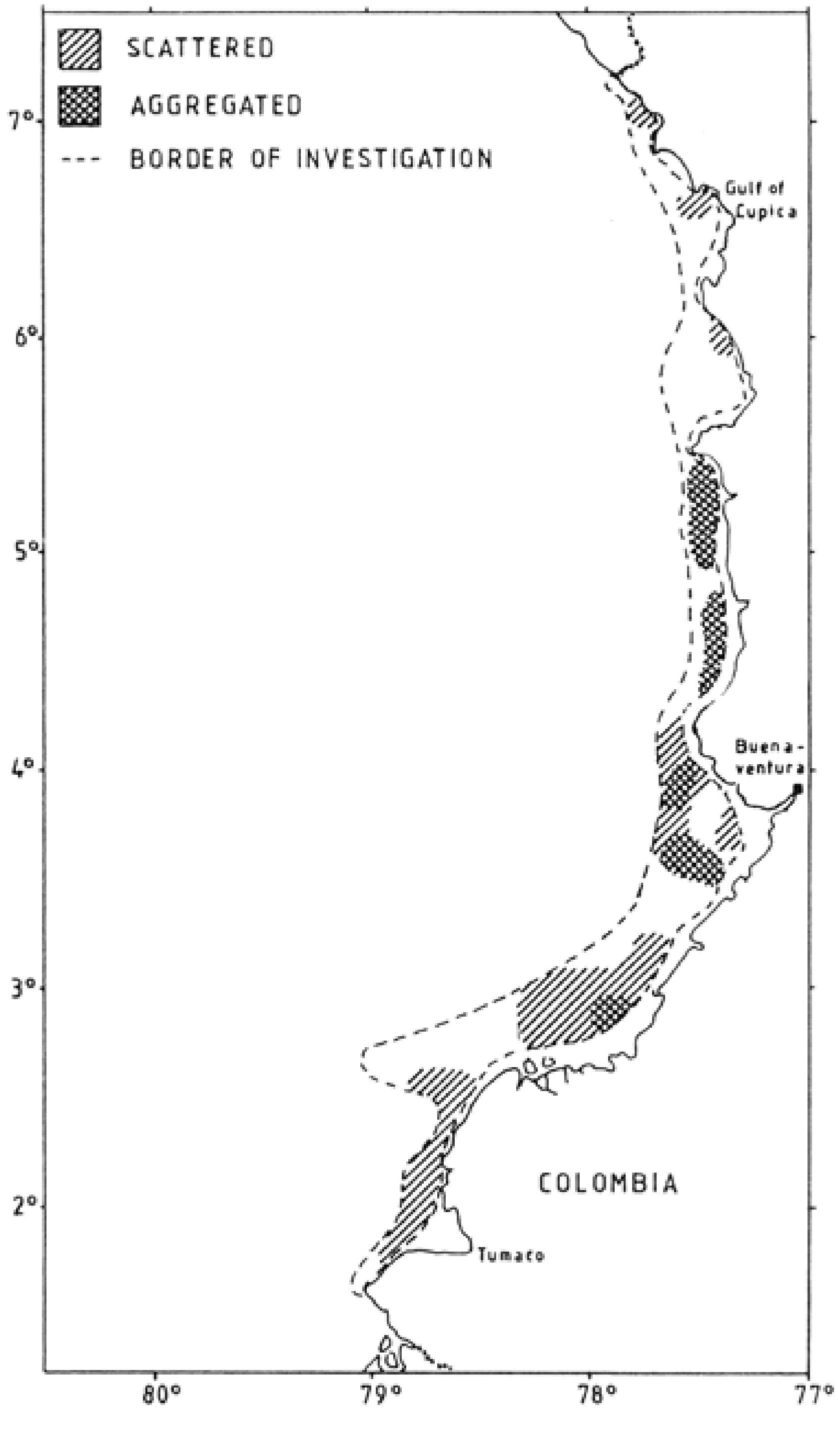

Figure 8.2 Colombia: Distribution of pelagic fish as recorded by the acoustic system in the October-November survey

A different fauna of pelagic fish was found below the thermocline from about the Gulf of Cupica northwards with hairtail (*Trichiurus nitens*), scad (*Decapterus macrosoma*) and argentine (*Argentina aliceae*). These species may also be present in deeper waters further south, but the very steep slope there prevented observations and sampling. The most interesting of these species is the scad which was found in some abundance in the deeper offshore parts of the shelf off Panama.

Demersal resources

Demersal fish was found mostly in the 20–100 m depth range along the coast and with highest catch rates in the south. About half of the catches consisted of small-sized species of no commercial interest. Among the potentially commercial fish, butterfish was most common, followed by mostly small-sized seabasses, sharks, snappers and grunts. The bottom trawl hauls in deeper waters in the north gave some high catch rates of hairtails and argentine.

The main demersal fish species found were butterfishes (*Peprilus medius* and *P. snyderi*), rose threadfin bass (*Hemanthias signifer*), catfish (*Bagre panamensis*), lizardfish (*Synodus evermanni*), spotted rose snapper (*Lutjanus guttatus*), Panama grunt (*Pomadasys panamensis*), argentine (*Argentina aliceae*) and widespur seabass (*Diplectrum euryplectrum*).

The catch rates in the bottom trawl were low with an overall mean of about 130 kg/h for all commercial families.

The nylon shrimp (*Heterocarpus vicarius*), colibri shrimp (*Solenocera agassizii*) and crystal shrimp (*Penaeus brevirostris*) were the most abundant shrimp species, all at depths beyond 50 m. The mean catch rates were low, 2–12 kg/h, but reached 150 kg/h for nylon shrimp in the north. Various penaeid shrimps inhabit the 0–50 m bottom depth range, but only incidental catches were obtained of these.

Dart squid (*Loliolopsis diomedeae*) appeared in the catches in somewhat deeper hauls, 50–100 m and beyond in various locations, but especially on the southern shelf where catches up to 190 kg/h were obtained in April. The catch rates reached a mean of about 50 kg/h with a maximum of nearly 200 kg/h. The data from Panama indicated a clear annual cycle in the availability of this squid with a maximum in the first part of the year and near-absence from August to November. A seasonal change is likely also for Colombia. The dart squid could only be fished in bottom trawl during daytime as it lifts off the bottom at night.

Biomass estimates

Table 8.1 shows the estimated standing biomass for the groups of resources and with a rough allocation on the most important species or sub-groups.

Table 8.1 Colombia: Estimated standing biomass by resource groups

Resource groups	Biomass t	%
Small pelagic fish		
Thread herring	29,000	38
Anchovy	9,000	12
Carangidae, sierra, barracuda and hairtails	39,000	50
Sub-total pelagics	**77,000**	100
Commercial demersal fish		
Butterfish	12,000	50
Sea basses	6,000	25
Sharks	3,000	13
Snappers	2,000	8
Grunts	1,000	4
Sub-total demersals	**24,000**	100
Total	**101,000**	

The total biomass was thus estimated at about 100,000 tonnes and this gives a mean density for the shelf (0–200 m) of 18 t/nmi^2. If the estimated amount of non-commercial demersal fish of about 24,000 t is included, the density is 22 t/nmi^2. This is a level of density found in many tropical countries with similar ecological conditions (see Chapter 10).

8.3 PANAMA, 1987

The shelf of Panama can conveniently be separated into two main parts: the wide and extensive Gulf of Panama in the east and the western coast, with the Gulfs of Coiba and Chiriqui (Fig. 8.1). The Gulf of Panama is known as an important fishing area where seasonal upwelling and perhaps also river runoffs create conditions for higher productivity. Seasonality is evident in the hydrographic environment especially in the deeper parts of the Gulf, with important fluctuations in temperature and oxygen content near the bottom. In addition, there are also seasonal changes in the surface layers with a lifting and weakening thermocline in the upwelling season.

8.3.1 The Gulf of Panama

Pelagic fish

As an example, Figure 8.3 shows the distribution from the August survey. A general feature for this area is that aggregations of high densities were found throughout the year around the shores of the Gulf, while in the central and deeper parts, fish was only recorded in May and August, with a nearly complete absence in February and November, probably caused by the low oxygen levels near the bottom in this season.

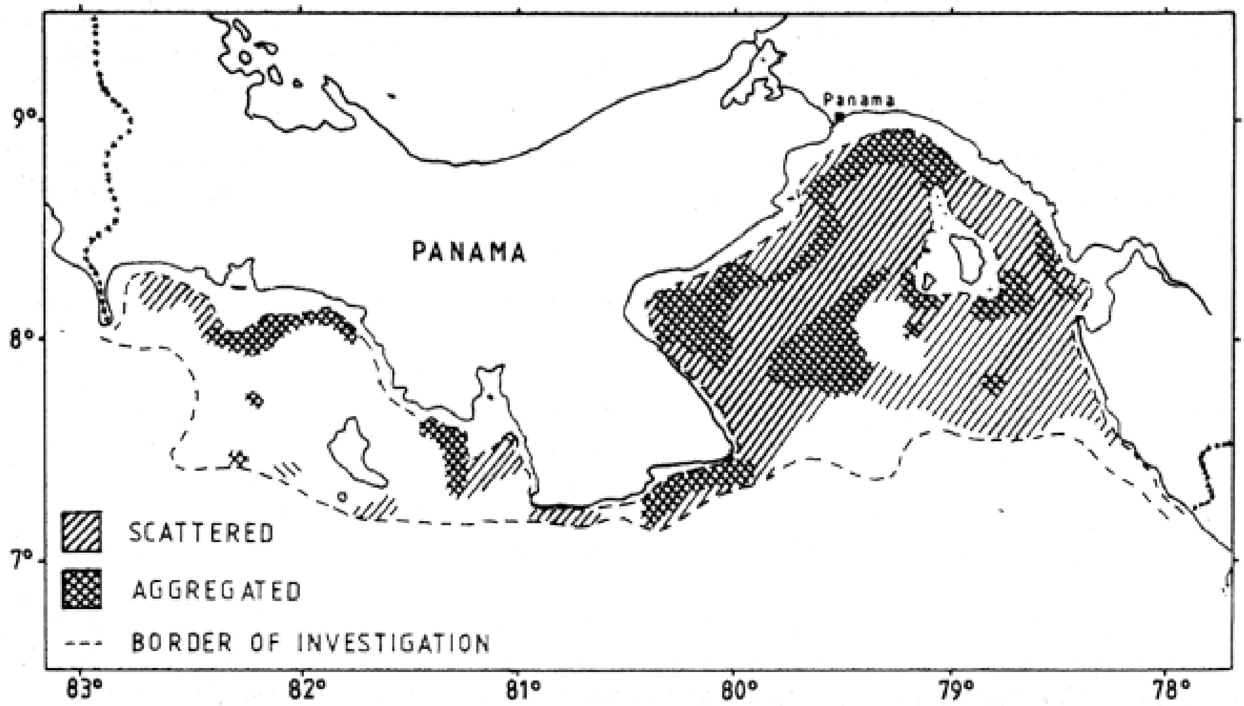

Figure 8.3 Panama: Distribution of pelagic fish in the August 1987 survey

The assemblage of fish found above the thermocline, which seems to prefer depths of less than 50 m was dominated by thread herring (*Opisthonema libertate*) and anchovies (*Anchoa* sp. and *Cetengraulis* sp.) found in school areas in which schools of bumper (*Chloroscombrus orqueta*) were usually also frequent. Frequent predators mixed with these schools were sierra (*Scomberomorus sierra*), barracuda (*Sphyraena ensis*), sharks and various demersal fish.

The fauna below the thermocline in the middle offshore part of the Gulf, which is only present in significant quantities in May and August, was dominated by scads (*Decapterus macrosoma*) mixed with some round herring (*Etrumeus teres*) and various demersal fish.

Demersal resources

The demersal fish fauna of the Gulf of Panama can be grouped by three main habitats:

- nearshore to about 50 m bottom depth;
- offshore from about 50 m to the shelf edge;
- the slope, from the shelf edge and into the deep-sea.

The seasonally fluctuating hydrographic regime gives varying environmental conditions in the offshore shelf region, mainly through changes in oxygen content.

The main demersal fish species found in the Gulf of Panama were butterfishes (*Peprilus medius* and *P. snyderi*), rose threadfin bass (*Hemanthias signifer*), Pacific red snapper (*Lutjanus peru*), lizardfish (*Synodus evermanni*) and widespur seabass (*Diplectrum euryplectrum*). Frequent in the catches, but with less abundance, were Panama grunt (*Pomadasys panamensis*), yellow bobo (*Polydactylus opercularis*) and bigscale goatfish (*Pseudupeneus grandisquamis*).

The 0–50 m depth zone was relatively poor in demersal fish, compared to the deeper strata. The main species in the shallow waters were butterfishes, spotted rose snapper (*Lutjanus guttatus*) and the Panama grunt.

The main species in the 50–100 m bottom depth stratum were butterfish, lizardfish, searobin (*Prionotus quiescens*) and the widespur seabass.

In the 100–200 m bottom depth range the dominating species were the argentine (*Argentina aliceae*), deep-water seabasses (*Hemanthias signifer* and *Pronotogrammus multifasciatus*) and Pacific red snapper (*Lutjanus peru*). Notable in the catches were also lizardfish, widespur seabass and fortune jack (*Seriola peruana*). The mean density of fish recorded in this bottom depth stratum was considerably higher than in the shallower waters.

The shrimps found in deeper waters beyond about 150 m of depth were the nylon shrimp (*Heterocarpus vicarius*) and the colibri shrimp (*Solenocera agassizii*). Various penaeid shrimps inhabit the shallow depth range of which the crystal shrimps (*Penaeus brevirostris*), the western white shrimp (*P. occidentalis*) and the yellowleg shrimp (*P. californiensis*) were most frequent in the catches.

Trawl hauls were made on the well known ground for deep-water shrimp at 200–300 m on the slope off Punta Mala (Fig. 8.1) in order to test the availability of the shrimp there. The mean catch of nylon shrimp was about 500 kg/h, but with highest rates of several tonnes per hour. The rates were at a similar level as those obtained in previous exploratory surveys.

Of the two species of squids found, the dart squid (*Loliolopsis diomedeae*) was by far the most abundant while the Panama brief squid (*Lolliguncula panamensis*) was less frequently caught and only in minor amounts. These squids are semi-pelagic species aggregating near the bottom during the day, but dispersing into the water column at night.

The dart squid appeared to be distributed in special areas of high abundance at 50–100 m depth southeast and south of the Pearl Islands and in the southeastern part of the Gulf, where in February the mean catch rate was about 300 kg/h with a highest rate of about 1.5 t/h and in May the mean rate was about 500 kg/h and the highest 5 t/h. In the August and November surveys no catches were obtained demonstrating the strong seasonal fluctuations of this short-lived species.

The giant squid (*Dosidicus gigas*) was caught as incidental by-catch in 24 bottom trawl hauls on the slope with catch rates up to about 90 kg/h mostly from depths of 200–400 m and by both day and night. In the May survey a haul with the mid-water trawl gave a catch of approximately 0.5 t near the shelf edge.

8.3.2 Panama west coast, the Gulfs of Coiba and Chiriqui

The hydrographic environment on the western shelf is far more stable than that in the Gulf of Panama with only minor variations in the surface temperature and small changes in the depth and strength of the thermocline through the year.

Pelagic fish

Large parts of the western shelf were almost without any acoustic recordings of pelagic fish in all of the surveys. Aggregations of schooling pelagic fish were only located close inshore and the school areas were in most cases quite small. This inshore assemblage consisted mainly of the same species as in the Gulf of Panama: various species of anchovies, thread herring, different Carangidae and with barracudas as predators.

Demersal resources

The demersal fish fauna of this region can be grouped by three main habitats:

- the narrow shelf between Punta Mala and the Gulf of Coiba with a relative rich and varied fauna;
- the Gulfs of Coiba and Chiriqui with an extensive shelf but with poor demersal catches;
- the slope, from 100 to 400 m bottom depth. The slope was generally steep and narrow and was given only a limited coverage during the surveys.

The main demersal species on the narrow shelf between Punta Mala and Gulf of Coiba were various snappers (*Lutjanus guttatus, L. peru, L. argentiventris, L. colorado*), Peruvian mojarra (*Diapterus peruvianus*), barracuda (*Sphyraena ensis*), shark (*Rhizoprionodon longurio*) and bonefish (*Albula vulpes*). This fauna showed a marked difference both in size and composition, compared to the rest of the Panama shelf. This is probably related to the bottom type, sandy with patches of rocks and corals. The apparent absence of any trawl fishery may account for the relatively large size of the specimens.

The narrow shelf between Gulf of Panama and the Gulf of Coiba gave fairly good catches of commercially valuable fish. The snappers alone gave an average catch rate of 335 kg/h. The trawlable area is quite limited with patches and more extensive areas of rocks and corals. The area may, however, be suitable for a fishery with lines and traps. There were indications from the surveys that similar aggregations of demersal fish may be found further west along the Panama shelf. In the August survey good recordings were obtained over the Hannibal Bank, but in fishing trials with pots all gear was lost.

The main demersal species in the Gulfs of Coiba and Chiriqui were butterfishes (*Peprilus medius* and *P. snyderi*), lizardfishes (*Synodus evermanni* and *S. scituliceps*) and noncommercial species such as mojarra (*Diapterus aureolus*) and toadfish (*Porichthys nautopaedium*). Panama grunt (*Pomadasys panamensis*) and goatfish (*Pseudupeneus grandisquamis*) occurred in about one third of the catches but at low catch rates. The species composition in the two western Gulfs is quite similar to that of the Gulf of Panama.

The shrimps caught include the colibri shrimp (*Solenocera agassizii*) beyond 50 m bottom depth and the crystal shrimp (*Penaeus brevirostris*) in the 50–100 m bottom depth range. Various shrimps inhabit the 0–50 m bottom depth range of which the yellowleg shrimp (*Penaeus californiensis*) occurred in the catches most frequently.

Dart squid was found over wide parts of the western Gulfs and mostly in the 50–100 m depth range. Catch rates were considerably lower than in the Gulf of Panama.

Summary for Panama and biomass estimates

Small pelagic fish were found well inshore and above the thermocline. The highest densities were located along the northern, northeastern and western coasts of the Gulf of Panama. Only minor aggregations were recorded in the western Gulfs. The pelagic fish consisted of thread herring, anchovies, Carangidae mostly bumper with some lookdowns and jacks, while sierra and barracudas were present as predators. In addition to this inshore assemblage, pelagic fish occurred over the deeper offshore parts of the Gulf of Panama in May and August. These aggregations, which were almost completely absent in the February and November surveys, consisted of scad and round herring.

Demersal fish were found in highest densities in deeper waters, 50 m and more, and in the whole area the highest catch rates were obtained in the May-August surveys. Among the groups of potential commercial interest butterfishes dominated followed by grunts, snappers, sea basses and sharks. The fauna was similar in all gulfs, but an offshore component was located in the Gulf of Panama consisting of argentine, small sized sea basses and Pacific red snapper. High catch rates were obtained in one of the surveys in a limited area here. Relatively high densities of demersal fish, mainly snappers, some grunts, sea basses and sharks were found on the narrow shelf between Punta Mala and the Gulf of Coiba. There were indications that similar aggregations can be found further west, e.g., the Hannibal Bank.

The dart squid was found in special areas of high abundance in the 50–100 m depth range in the Gulf of Panama. It appeared to have an annual cycle of production. In the western Gulfs it occurred with far less abundance. Tests for giant squid confirmed its presence, but were inconclusive as fishing trials.

Some tests on the *deep-water shrimp* ground off Punta Mala confirmed that high catch rates of nylon shrimp can be obtained here.

Table 8.2 summarizes the biomass estimates for the Panama shelf by areas and types of resources. These are likely to lie below the true values for several groups and thus represent minimum levels. The total biomass exceeds 400,000 t and by far the main part, 88%, derives from the Gulf of Panama. The bulk of this again is from small pelagic fish, the inshore assemblage and the scads and round herring in the offshore part of the Gulf. Demersal fish and squid represent about 30% of the biomass in the Gulf. With a mean density of biomass of 44 t/nmi^2, (56 t/nmi^2 if an estimated biomass of 117,000 t of non-commercial bottom fish is included), the Gulf of Panama must be classified as an area of relatively high productivity. This is undoubtedly related to the local phenomenon of seasonal upwelling. With a mean density of 13 t/nmi^2 the western coast lies at a more typical level of tropical productivity.

Table 8.2 Panama: Estimated standing biomass by resource groups and sub-areas

Resource groups	Biomass t	%
Sub-area: Gulf of Panama		
Small pelagics		
Thread herring	76,000	29
Anchovy	28,000	11
Carangidae, inshore	86,000	33
Barracuda and sierra,	4,000	0
Scad and round herring	65,000	25
Sub-total	259,000	100
Demersal fish		
Butterfish	36,000	44
Grunts	23,000	28
Groupers	12,000	15
Snappers	7,000	8
Sharks	4,000	5
Sub-total	82,000	100
Dart squid	30,000	
Sub-area: Shelf Punta Mala - Gulf of Coiba		
Snappers etc.	5,000	
Sub-area: Western Gulfs		
Small pelagics	38,000	
Demersal fish	9,000	
Panama total		
Small pelagics	297,000	70
Demersal fish	96,000	23
Dart squid	30,000	7
Total	**423,000**	**100**

8.4 COSTA RICA, 1987

The hydrographic environment over the Costa Rican shelf was fairly stable over the year with the thermocline reaching down to 70–80 m at which depth the oxygen content drops below 2 ml/l. Inside the Golfo Dulce this low oxygen level was reached already at 50 m of depth. The surface salinity was low in August and November probably as a result of increased river run-offs. In the westernmost part of the Costa Rican shelf, the Gulfs of Culebra and Papagayo, the environmental system is influenced by seasonal offshore winds causing upwelling.

Pelagic fish

Figure 8.4 shows as an example fish distribution in the February survey. Dense aggregations of pelagic schooling fish were located inshore especially in the Gulf of Nicoya, but often also eastward in the Bahia de Coronado. The species in this inshore assemblage were largely the same as in Panama, anchovies, clupeids, various Carangidae, barracuda and sierra, but the relative proportions seem to be different with more large-sized Carangidae and more of the predators including demersal fish. A deep-water assemblage was located in the border area between Costa Rica and Nicaragua with partly dense concentrations of hairtail (*Trichiurus nitens*), argentine (*Argentina aliceae*) and various seabasses.

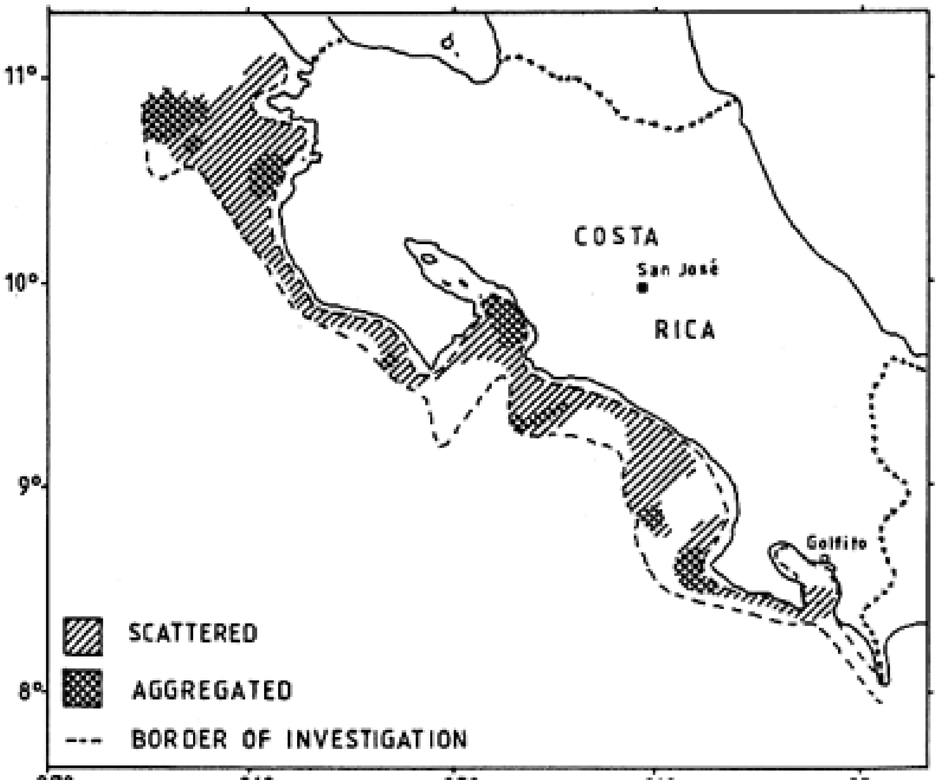

Figure 8.4 Costa Rica: Pelagic fish distribution in the February survey

The dominating species of anchovy were *Anchoa argentivittata, A. ischana* and *A. curta*, and by far the most common clupeid was the yellowfin herring (*Pliosteostoma lutipinnis*).

The Carangidae contained a large number of species, but lookdowns, (*Selene peruvianus* and *S. brevoorti*) were most common, representing 50–60% of the catches. Various jacks, (species of *Caranx, Hemicaranx, Carangoides* and *Oligoplites*) represented together some 25% of the catches, while trevally (*Gnathonodon speciosus*) and pompanos (*Trachinotus* spp.) were less abundant.

Scombridae and the barracuda (*Sphyraena ensis*) had a relatively high availability, especially in the August survey. The sierra dominated, but with a few occasional catches of striped bonito (*Sarda orientalis*).

Demersal resources

The main demersal species in Costa Rica were snappers (*Lutjanus guttatus* and *L. peru*) and Peruvian mojarra (*Diapterus peruvianus*). Frequent in the catches, but at lower catch rates were butterfish (*Peprilus* spp.), toadfish (*Porichthys nautopaedium*), flounder (*Cyclopsetta querna*) and lizardfish (*Synodus evermanni*).

The mean catch rates of the species of commercial or potential commercial interest were low overall, about 110 kg/h, but the commercial fish in the catches were often large in size. The snappers were mostly caught inside the 50 m depth range. Good catches were obtained in the outer parts of Bahia de Coronado, in the entrance to Gulf of Nicoya and in locations close inshore from Cabo Blanco to Gulf of Culebra. Snappers usually prefer hard bottoms often unsuitable for trawling. This may cause underestimation when using trawl data for biomass estimates for this group. Some very large catches of small sized seabasses (*Hemanthias signifer* and *Diplectrum macropoma*), argentine (*Argentina aliceae*) and hairtails (*Trichiurus nitens*) were made at 100–200 m depth on the shelf edge in the border area with Nicaragua.

Deep-water nylon shrimp was found with langostino in the border area with Nicaragua.

Only few hauls were made for the deep-water nylon shrimp (*Heterocarpus vicarius*) as the slope was untrawlable over large parts except near the border with Nicaragua. Here a catch rate of about 500 kg/h was obtained for this species. Catch rates of colibri shrimp (*Solenocera agassizii*) at intermediate depths did not exceed 20 kg/h. Crystal shrimp (*Penaeus brevirostris*) appeared only sparingly, but no special night surveys were made for this species. Various shallow water shrimps appeared in the catches especially during the fourth survey in November.

Dart squid occurred in catches over most of the Costa Rican shelf. The catch rates were generally low.

Biomass estimates

Table 8.3 presents a summary of the biomass estimates which for several groups are thought to lie below the true levels. The total of 95,000 t which excludes the offshore assemblage in the north gives a density of 23 t/nmi^2.

Table 8.3 Costa Rica: Estimated standing biomass by resource groups

Resource group	Biomass t	%
Pelagic fish		
Clupeidae	13,000	16
Anchovy	13,000	16
Lookdowns	25,000	31
Jacks	13,000	16
Barracuda & sierra	13,000	16
Others	4,000	5
Sub-total	81,000	100
Demersal fish		
Snappers	10,000	70
Sea basses	2,000	14
Grunts	1,000	7
Butterfish	1,000	7
Sub-total	14,000	100
Total	**95,000**	

8.5 NICARAGUA (INCLUDING PARTS OF HONDURAS AND EL SALVADOR IN THE GULF OF FONSECA), 1987

North of Costa Rica, the coast and the shelf change character with a straighter coastline and a wider, even shelf. The slope, from about 200 to 500 m is smooth and fishable with bottom trawl over large parts. Prevailing offshore winds off the coast of southern Nicaragua during part of the year cause seasonal upwelling which undoubtedly contributes significantly to the productivity of the area.

The distribution of fish and crustaceans on the shelf from northwest Costa Rica to the Gulf of Tehuantepec in southern Mexico can be described in a simplified way by reference to inshore and offshore faunas. The inshore fauna was found along the coast out to a depth of 60–70 m and consisted of anchovies, Clupeidae (mainly thread herring), Carangidae such as bumper, lookdowns and jacks, sierra, barracuda, demersal fish, predominantly snappers and shallow-water shrimps and lobster. The offshore assemblage was found near the edge of the shelf and over the slope. Mesopelagic fish were recorded in many parts of the slope and further offshore and probably form an important component of the food chain of this community. This mainly consisted of argentine, hairtails, seabasses and cephalopods. Crustaceans dominated the upper slope areas, with langostino (*Pleuroncodes planiceps*), deep-water shrimp, especially nylon shrimp (*Heterocarpus vicarius*) and mantis shrimp (*Squilla* sp.) at greater depth. The pelagic giant squid (*Dosidicus gigas*) was mainly found off the shelf edge.

The intermediate shelf depths, from about 50–150 m seldom held any important quantities of fish, but in the upper part of this range, grounds of crystal shrimp (*Penaeus brevirostris*) could be found and shelf squids (*Loliolopsis* and *Lolliguncula* sp.) extended their depth range well below 100 m.

Pelagic fish

Pelagic fish was found in an inshore assemblage at depths down to about 50 m with smaller dense school areas usually between Corinto and San Juan del Sur. The stocks of small pelagics may be shared between Nicaragua and El Salvador. Their composition include anchovies, thread herring, Carangidae (mainly lookdown, bumper and jacks) and barracuda.

Offshore, an assemblage consisting of hairtails, argentine and seabasses was found near the shelf edge with the highest abundance off San Juan del Sur towards the border with Costa Rica. Very high catch rates were sometimes obtained.

Figure 8.5 shows as an example the distribution of fish over the shelf off Nicaragua, Honduras and El Salvador in the August-September survey. All surveys show similar features with a belt of recorded fish along the coast showing the inshore assemblage. Dense recordings of hairtails, argentines and seabasses were made offshore in the south in the February survey.

The Engraulidae consisted mainly of *Anchoa* spp., of which some seven were identified with *A. argentivittata* (silverstripe anchovy) and *A. nasus* as the most abundant. The most important clupeid species was the threadfin herring (*Opisthonema libertate*).

Catches of Carangidae included a number of species with lookdowns, almost exclusively *Selene peruvianus* and bumper (*Chloroscombrus orqueta*) followed by jacks of the genera *Caranx, Carangoides, Hemicaranx* and *Oligoplites*.

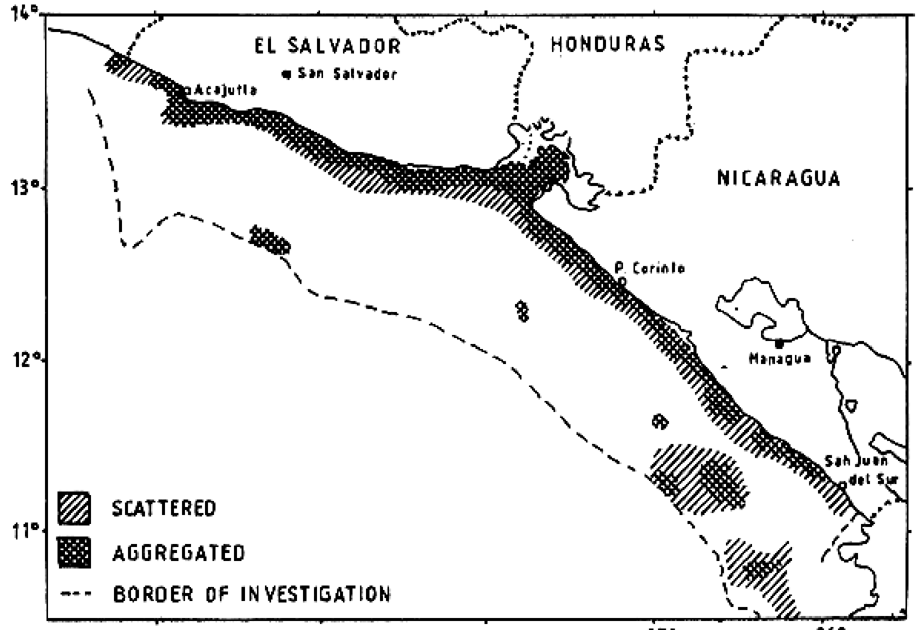

Figure 8.5 Distribution of fish over the shelf off Nicaragua, Honduras and El Salvador in the August-September survey

Sierras were relatively scarce throughout, but barracuda was common especially in August.

The mean catch rates in the bottom trawl of the pelagic fish inshore were generally low, up to a few hundred kg/h.

Very high catch rates, up to 80 t/h could be obtained of hairtails (*Trichiurus nitens*), argentine (*Argentina aliceae*) and seabasses, (*Diplectrum* and *Hemanthias* spp.) on the southern offshore grounds.

Demersal fish

Most of the demersal fish of assumed commercial interest were found within the 100 m depth range although the butterfish and the small seabasses were mostly caught at greater depths. The shallow demersal fish included snappers, grunts, and some sharks and croakers. Catch rates were generally low, but with a few high rates for snappers and croakers.

The main demersal species in the nearshore waters 0–50 m were Peruvian mojarra (*Diapterus peruvianus*), spotted rose snapper (*Lutjanus guttatus*), Panama grunt (*Pomadasys panamensis*) and threadfin (*Polydactylus approximans*). The intermediate zone (50–100 m) was dominated by searobin (*Prionotus ruscarius*), butterfish (*Peprilus* spp.), croaker (*Cynoscion stolzmanni*) and lizardfish (*Synodus evermanni*). The offshore region 100–200 m was characterized by argentine, rose threadfin bass (*Hemanthias signifer*), searobin, butterfish, cagua seabass (*Diplectrum macropoma*) and scorpionfish (*Scorpaena* spp.).

The average catch rate of commercial fish in all hauls with the bottom trawl in the 0–100 m range was low, about 90 kg/h with snappers dominating.

Crustaceans

Of the crustaceans, langostino was found in abundance in all surveys over large parts of the outer shelf and slope. Nylon shrimp gave occasionally high catch rates in the 200–300 m depth range. Crystal shrimp occurred at intermediate depth, but not in high densities.

The langostino (*Pleuroncodes planiceps*) was by far the most abundant crustacean appearing in high densities over a depth range from about 100 to 300 m. Areas of high abundance varied between the surveys but generally covered the outer shelf and the slope from Corinto southwards. In some parts of the slope, nylon shrimp (*Heterocarpus vicarius*) shared the deeper parts of the langostinos depth range and occasionally small amounts of colibri shrimp (*Solenocera agassizii*) the medium depths. Crystal shrimp (*Penaeus brevirostris*) was found at intermediate depths, especially in night hauls, but not with high catch rates. Various penaeid shrimps were taken as incidental by-catch in small quantities in the 15–50 m depth zone.

The catch rates of langostino were high with a mean of about 2 t/h in the 100–300 m depth range with a highest catch of 18 t/h. For nylon shrimp the corresponding rates in the 200–300 m depth zone were 400 kg/h and about 6 t/h. There was no difference between day and night catch rates for langostino, but night catches of nylon shrimp were only about 20% of the day rates.

Squid

Dart squid was found commonly in the 50–150 m depth range with some good catch rates. A modest effort in testing for giant squid with light and jigging confirmed the presence of this species and showed, in conformity with previous exploratory work, the highest catch rates off the western part of the slope.

The dart squid (*Loliolopsis diomedeae*) was caught over the mid-shelf (50–150 m) in all surveys with highest catch rates around 100 m depth. The species only occurred in bottom trawl during the day, lifting off the bottom at night. The mean catch rates in the 50–150 m range in the May and August surveys were about 100 kg/h with highest catches of 400 kg/h.

Incidental catches of giant squid (*Dosidicus gigas*) were taken in a number of bottom trawl hauls in the slope, but with low catch rates. More information of the distribution of this species was obtained from a modest programme of experiments with light attraction and jigging conducted with varying and never very high effort over the four surveys. The test programme demonstrated the presence of this resource and indicated that the highest availability seemed to be off western Nicaragua.

Biomass estimates for Nicaragua

Table 8.4 shows a summary of the assessments of the biomass of the standing stocks of the various groups. Some are likely to be underestimates, e.g., dart squid. The estimates for the offshore fish resources, especially the seabasses, are likely to have a low precision and further exploratory data should be obtained if there is an interest in this resource.

Table 8.4 Nicaragua: Summary of estimates of standing stock biomass

Resource group	Biomass t	%
INSHORE		
Pelagic fish		
Thread herring	20,000	28
Anchovy	22,000	30
Carangidae	19,000	26
Barracuda & sierra	11,000	15
Sub-total	72,000	100
Demersal fish		
Butterfish	19,000	63
Snappers	6,000	20
Grunts	3,000	10
Sharks	2,000	7
Sub-total	30,000	100
OFFSHORE		
Silver smelt	75,000	42
Hairtails	35,000	19
Seabasses	70,000	39
Sub-total fish	180,000	100
Langostino	160,000	
Nylon shrimp	9,000	
Dart squid	10,000	
Giant squid	+	
Total	**461,000**	

Since the weight of the shells form an unusually high proportion in langostino only part of it (perhaps some 25 %) should be included in evaluations of total productivity. This gives a total estimated biomass of 340,000 t for the Nicaraguan shelf, the mean density to 200 m depth is 50 t/nmi^2 and 62 t/nmi^2 if non-commercial bottom fish is included. This reflects a fairly high productivity which seems reasonable to relate to the process of seasonal upwelling identified in this region.

Gulf of Fonseca

All of the three countries Nicaragua, Honduras and El Salvador border on the shallow Gulf of Fonseca. It forms part of the environment of the inshore assemblage of fish and crustaceans and is an important shrimp fishing ground.

Particularly dense aggregations of fish were not recorded in the Gulf except in the November survey when a concentration of small pelagic fish, mainly anchovy, was located there.

The pelagic fish consisted of much the same species as in the neighbouring zones. The demersal fish classified as commercial consisted of croakers, catfishes and a few sharks and rays. The total mean catch rates in the bottom trawl were a few hundred kg/h.

8.6 EL SALVADOR, 1987

The shelf off El Salvador is wider near the Gulf of Fonseca and narrows towards the border with Guatemala. No important seasonal changes were detected, but there was a trend of a sharper and lifted thermocline in September-November as compared with March-May and this may have resulted in a more shoreward distribution of the assemblage above the thermocline in the autumn.

Pelagic fish

Pelagic fish was found inshore in all surveys with denser areas of schooling fish in patches westwards to Acajutla. The composition included anchovy, thread herring, Carangidae (mostly bumper, lookdowns and jacks) with barracuda as a fairly common predator. Fish was only sparsely recorded offshore, but occasionally high catch rates of argentine were obtained.

There was a continuous distribution inshore from Nicaragua through the Gulf of Fonseca westward along the coast of El Salvador (Fig. 8.5). The composition of the pelagic fish was similar to that further east, but here barracudas seem a more important predator than off Nicaragua.

On the offshore grounds the species were the same as those found in the offshore Nicaragua assemblage, hairtails, argentine and sea basses but the catch rates were considerably lower although argentine was still fairly abundant.

Demersal fish

The composition of demersal fish was similar to that observed in Nicaragua, but the densities were considerably lower, about one half to one quarter. The main demersal species in the nearshore waters 0–50 m were butterfish (*Peprilus* spp.), mojarra (*Diapterus peruvianus*), catfish (*Bagre panamensis*), Panama grunt (*Pomadasys panamensis*) and threadfin (*Polydactylus approximans*). Snappers were rare in the catches.

The intermediate zone (50–100 m) was dominated by searobin (*Prionotus ruscarius*), butterfish (*Peprilus* spp.), croaker (*Micropogonias altipinnis*) and mojarra.

The offshore region (100–200 m) was characterized by argentine, cagua seabass (*Diplectrum macropoma*), widespur seabass (*D. euryplectrum*) and scorpionfish (*Pontinus sierra*).

The deeper waters (200–300 m) were the main distribution area for langostino and mantis shrimp, and were inhabited by small quantities of hake (*Merluccius angustimanus*) and scorpionfish.

The mean catch rates of commercial species in the 0–200 m depth zone were very low, less than 100 kg/h.

Crustaceans

As in Nicaragua the most abundant crustacean resource was the langostino which had its main depth distribution between 150 and 300 m. The highest catch rates were taken somewhat deeper than in Nicaragua, the mean depth of hauls with more than 1 t/h was 220 m.

Nylon shrimp (*Heterocarpus vicarius*) and colibri shrimp (*Solenocera agassizii*) occurred in some hauls beyond 100 m. In the intermediate depths between 50 and 100 m, crystal shrimp (*Penaeus brevirostris*) was found, but generally at low catch rates. Various penaeid shrimps occurred in the 0–50 m bottom depth zone of which the whiteleg shrimp

(*Penaeus vannamei*), the blue shrimp (*P. stylirostris*) and the Pacific seabob (*Xiphopenaeus riveti*) were the most common.

Both langostino and nylon shrimp were caught at high rates. More than 40% of the langostino catches exceed 1 t/h while about 25% of those for nylon shrimp exceeded 100 kg/h.

Squid

The distribution of dart squid at intermediate depth seemed to be continuous from the Nicaraguan up along the El Salvador shelf. Mean catch rates by surveys were highest in the May-June survey.

Jigging trials demonstrated the presence of giant squid. A few incidental catches of giant squid were taken in bottom trawl hauls in the southeastern part of the El Salvador slope area.

Biomass estimates for El Salvador

Table 8.5 summarizes the assessed stock biomasses of the important groups. Some of these, such as for dart squid and nylon shrimp are probably underestimates. If a quarter of the langostino biomass is included the mean density for the El Salvador shelf is 25 t/nmi^2.

Table 8.5 El Salvador: Summary of estimates of standing stock biomass

Resource group	Biomass t	%
INSHORE		
Pelagic fish		
Thread herring	26,000	35
Anchovy	24,000	32
Carangidae	15,000	20
Barracuda	10,000	13
Sub-total	75,000	100
Demersal fish		
Butterfish	4,000	40
Sea basses	4,000	40
Grunts	1,000	10
Sharks & Snappers	1,000	10
Sub-total	10,000	100
OFFSHORE		
Fish	25,000	
Langostino	50,000	
Nylon shrimp	min. 1,100	
Dart squid	min. 3,800	
Total	**165,000**	

8.7 GUATEMALA, 1987

From the narrow part near the border to El Salvador the Guatemalan shelf widens off San José and forms a wide platform which continues into the Gulf of Tehuantepec off Mexico. As in El Salvador, the thermocline was sharper and shallower in late summer and autumn, September-December, than in winter-spring, March-June, but no important seasonal changes were observed.

Pelagic fish

Pelagic fish was found in an inshore zone to about 20 nmi from the coast, in quite extensive and dense school areas from San José to the Mexican border. Carangidae and Clupeidae dominated these aggregations. Surface schools of thread herring were observed inshore.

There was little variation in the distribution of pelagic fish in the four surveys along both the Guatemalan shelf and that of the Gulf of Tehuantepec in Mexico, and Figure 8.7 shows as an example that from the March survey. For management purposes the pelagic fish on the Guatemala-Gulf of Tehuantepec shelf may have to be considered as one shared unit stock.

Carangidae and Clupeidae dominated this inshore assemblage with some Engraulidae, Scombridae and barracudas.

Pacific thread herring (*Opisthonema libertate*) represented by far the main part of the clupeid catches with small bycatches of tropical longfin herring (*Neoopisthopterus tropicus*) and more occasionally yellowfin herring (*Pliosteostoma lutipinnis*).

Measured by the simple proportion in the total catches about 70% of the Carangidae were bumper (*Chloroscombrus orqueta*), about 20% lookdown (*Selene* spp.) and 10% consisted of other species mostly jacks of the genera *Caranx, Carangoides, Hemicaranx* and *Oligoplites*.

The fish catches in the trawl hauls over the deeper parts of the Guatemalan shelf were in general insignificant.

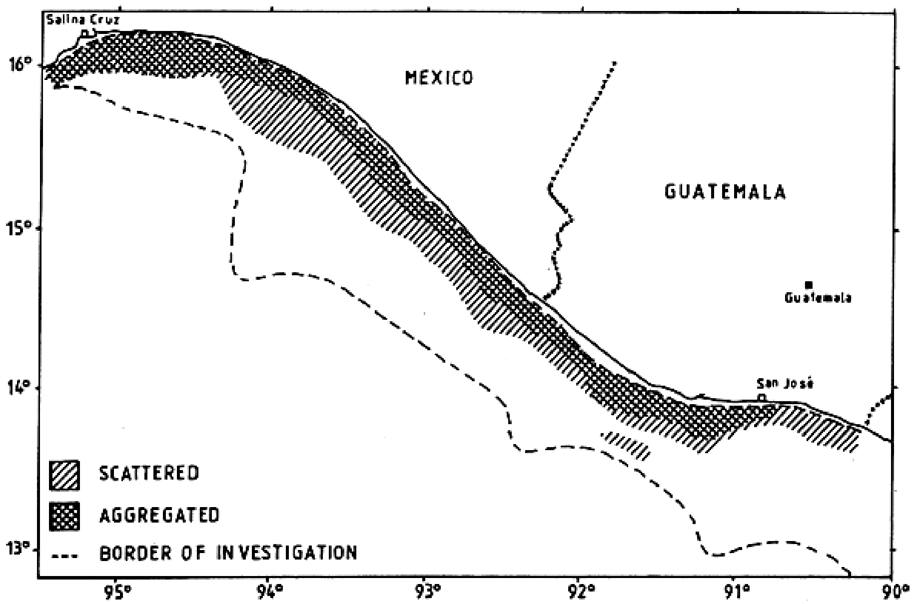

Figure 8.6 Guatemala and Gulf of Tehuantepec (Mexico): Distribution of pelagic fish in the March survey

Demersal fish

Demersal fish were dominated by grunts with some butterfish, snappers and sharks and small sized seabasses offshore.

Demersal fish was mostly restricted to depths less than 100 m. Inside 50 m the most common species were mojarra and grunt (*Pomadasys axillaris*) with some snapper (*Lutjanus guttatus*); within 100 m catfish (*Bagre panamensis*) and butterfish (*Peprilus* spp.) with some snapper (*L. peru*) and threadfin (*Polydactylus approximans*) were most common. The mean catch rate of commercial species was low, about 150 kg/h.

Crustaceans

Langostino was still a common species in the offshore parts of this shelf, with a mean catch rate of about 500 kg/h in the 100–300 m depth range. Deep-water shrimps were only caught occasionally. Crystal shrimp was found commonly at intermediate depths, but with low catch rates.

Squid

There were only minor indications of the presence of dart squid at intermediate depths on the shelf and of giant squid off the slope.

Biomass estimates for Guatemala

Table 8.6 summarizes the estimates of standing stock biomass for the various types of resources. With a mean density close to 50 t/nmi^2, the productivity on the Guatemalan shelf seems to be fairly high with small pelagics representing the main part.

Table 8.6 Guatemala: Summary of standing biomass by resource groups

Resource groups	Biomass t	%
Pelagic fish		
Thread herring	110,000	59
Anchovy	30,000	16
Carangidae		
Bumper	29,000	16
Lookdowns	8,000	4
Jacks	3,000	2
Barracuda	5,000	3
Sub-total	185,000	100
Demersal fish		
Sea basses	9,000	41
Grunts	8,000	36
Butterfish	2,000	9
Snappers	2,000	9
Sharks	1,000	5
Sub-total	22,000	100
Langostino	+	
Total	**207,000**	

8.8 THE GULF OF TEHUANTEPEC, MEXICO, 1987

The wide shelf in this area extends from the border with Guatemala along the coast up past Salina Cruz but becomes very narrow as the coast turns towards the southwest from this point. The outer part of the shelf forms a deeper platform at 200–300 m depths. The hydrographic environment has some special features, with the presence of pronounced oxycline at relatively shallow depths (50 to 100 m) and seasonal upwelling in late winter-spring.

Pelagic fish

Pelagic fish was found as a continuation of the distribution along the Guatemalan coast with some denser aggregations of schooling fish mostly east of about 94°. The thread herring was the most common species in this inshore assemblage with Carangidae dominated by bumper with some jacks and lookdowns and notable amounts of barracuda. Scads were found at medium depths in March and June when the thermocline deepened.

The possible environmental and/or biological role of the extensive lagoon systems should be considered. An addition to the inshore assemblage was recorded in March and June with scad (*Decapterus macrosoma*) at 50–100 m. This species was seasonally abundant in the offshore parts of the Gulf of Panama and occurred also in Costa Rica but was hardly noted in the intermediate region.

The only recordings made in the more distant offshore parts of the Gulf of Tehuantepec were of mesopelagic fish (Myctophidae). At times such recordings covered extensive parts of the deeper shelf.

The Carangidae were the most abundant group dominated by the bumper with some lookdowns and various jacks. The Clupeidae were mostly thread herring (*Opisthonema libertate*) with smaller catches of longfin herring (*Neoopisthopterus tropicus*) and yellowfin herring (*Pliosteostoma lutipinnis*). Barracudas were common in the catches especially in June and September.

The mean catch rates were some 400 kg/h.

Demersal resources

Demersal fish was dominated by grunts with some butterfish and snappers.

Demersal fish were mostly found inside the 100 m depth zone. In the 0–50 m range the most common species was mojarra and followed by snapper (*Lutjanus peru*), grunt (*Orthopristis* spp.), butterfish, catfish and bonefish. Common, but less abundant were lizardfish and threadfins (*Polydactylus* spp.). The mean catch rates of the commercial groups were low, about 100 kg/h.

Crustaceans

Crystal shrimp was found commonly at intermediate depths 50–100 m, with a mean catch rate (at night) of 19 kg/h.

Squid

Dart squid (*Loliolopsis diomedeae*) was caught at rates up to 120 kg/h in a limited area off Salina Cruz at intermediate depth (50–80 m) in March and December.

A few tests for giant squid with light attraction and jigging were made off the eastern slope in the March and June surveys. No catches were obtained.

Biomass estimates for the Gulf of Tehuantepec

Table 8.7 summarizes the estimates of standing stock biomass for the various types of resources. With a mean density close to 30 t/nmi^2, the productivity on the shelf in the Gulf of Tehuantepec was lower than in Guatemala. The high densities of mesopelagics observed in the Gulf of Tehuantepec are not included in this density estimate. Their abundance may relate to surface waters enriched by upwelling and advected offshore by the strong winds in the Gulf.

Table 8.7 Gulf of Tehuantepec, Mexico: Summary of estimates of standing standing stock biomass

Resource group	Biomass t	%
Pelagic fish		
Thread herring	55,000	41
Anchovy	13,000	10
Carangidae		
Bumper	34,000	25
Lookdowns & Jacks	10,000	7
Scad	16,000	12
Barracuda	7,000	5
Sub-total	135,000	100
Demersal fish		
Butterfish	5,000	9
Sea basses	1,000	2
Sharks	100	0
Snappers	2,000	4
Grunts	18,000	32
Other	30,000	53
Sub-total	56,100	100
Total	**191,100**	

9 SURVEYS IN THE CARIBBEAN SEA OFF NORTHERN SOUTH AMERICA

9.1 INTRODUCTION

Survey objectives and effort

Within the framework of the UNDP/FAO Project GLO/82/001 arrangements were made for a survey programme with the R/V DR. FRIDTJOF NANSEN during 1988 of the shelf region of the northern coast of South America from Suriname to the western border of Colombia.

The programme was planned at a meeting between representatives of the coastal countries of the region, IMR, Bergen, FAO and ORSTOM (Office de la Recherche Scientifique et Technique d'Outre Mer) called by FAO in Port of Spain, Trinidad in January 1988. The main part of the planned work was successfully completed through four surveys during 1988. Cruise reports with outlines of the work done and some main findings were issued after each survey in four parts (IMR, 1988a to 1988p) and a final report (Strømme and Sætersdal, 1989a and b) was presented at a seminar in Cartagena, Colombia in October 1989. This chapter provides a brief review of the surveys and the findings.

The general objectives were, to:

- describe the composition, distribution and abundance of small pelagic and demersal fish and crustaceans on the shelf and slope, to evaluate the potentials of the stocks;
- collect biological samples of the most important species for studies of growth, maturity, etc.;
- conduct taxonomic studies for the purpose of preparing a regional species guide;
- conduct oceanographic investigations.

The main survey methods were echo integration with trawl sampling for pelagic fish and bottom trawling for demersal resources. In areas where snappers occurred in mid-water over hard bottom, sampling with hand lines was to be tried. Fishing in shallow-water shrimp areas was not expected to cover the stocks for biomass estimates, but trawl results would provide biological samples and distributional characteristics.

Test hauls would be made to provide information on catch rates and species composition of deep-water shrimp on the slope at 200–900 m from Suriname westwards.

The one year programme January-December 1988 allowed for four surveys spaced about equally through the year. Generally the shelf from about 20 m to the edge was investigated with work also on the slope when testing for deep-water shrimp and squid. Table 9.1 shows some details of the investigational effort, which did not vary much between surveys and the averages are shown. The acoustic degree of coverage was adequate throughout, but highest on the Venezuelan shelf because of the higher abundance of small pelagics in this area.

Table 9.1 Details of investigational effort for the four surveys: months and the average (of four surveys) of duration, survey distance, degree of coverage and number of trawl stations per sub-area

Sub-area	Months	Duration (days)	Distance (nmi)	Degree of coverage	Trawl stations
Suriname	Jan May Aug Nov	5.4	1,060	8.3	38
Guyana	Feb May Aug Nov	5.1	813	6.5	42
Venezuela Orinoco	Feb May Aug Nov	2.6	458	6.1	20
Joint fishing area	Feb May Aug Nov	1.5	200	5.7	25
Trinidad	Feb May Aug Nov	4.0	800	10.7	22
Venezuela oriente	Feb Jun Sep Nov	8.0	1,390	12.6	58
Venezuela west	Feb Jun Sep Dec	10.8	1,290	17.4	61
Colombia	Mar Jun Sep Dec	6.5	900	10.0	41

The total field effort of the survey comprised about 170 days of active research work with some 27,000 nmi steaming and 1,200 trawl stations.

The distribution of the survey effort did not vary much between the surveys. Figure 9.1 shows as an example the course tracks and fishing stations in the October-November survey for the shelf from Suriname to Orinoco. A similar survey coverage was made of the shelf regions of Trinidad, the east and west coast of Venezuela and Colombia.

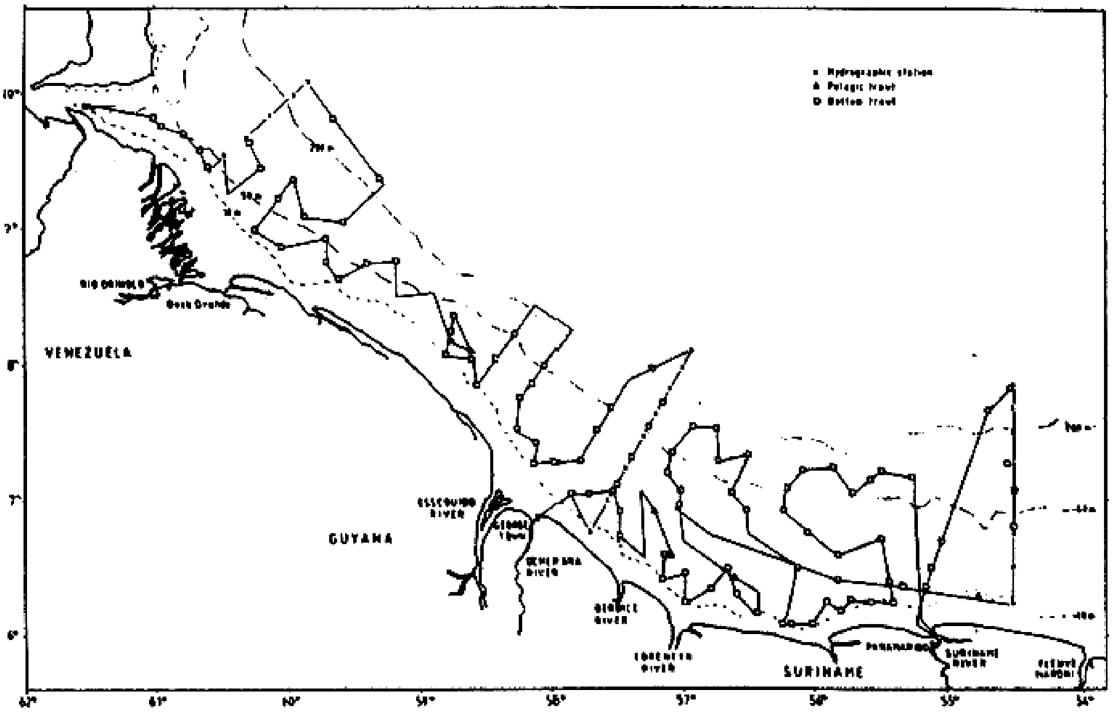

Figure 9.1 Course tracks and stations Suriname to Orinoco, October-November 1988

Environmental and faunistic studies

The results of the hydrographic investigations of the surveys described on the background of the existing knowledge of the meteorology and oceanography of the region was presented in the final report (Strømme and Sætersdal, 1989a and b).

Briefly the hydrography can be described by three coastal regions:

Region 1: Suriname, Guyana and eastern Trinidad and Tobago;
Region 2: Trinidad and Tobago to Golfo de Venezuela;
Region 3: Peninsula de Guajira to Golfo de Uraba.

Both from meteorological and oceanographic points of view the surveyed area maintains a rather stable climate on a short time scale basis, however subjected to a fairly strong seasonal signal. This is due to the stability of the trade winds which blow steadily throughout three-quarters of the year.

The dominant feature of the oceanography of the coastal regions is the proximity of a major ocean current system: in the eastern areas the Guiana Current, which is an extention of the South Equatorial Current and in the northern areas (Venezuela and Colombia) the Carribbean Current, which in the coastal zone predominantly is an extention of the Guiana Current.

The ocean current system, flowing northward with a coast on its left side, indicates its presence by sloping density surfaces upwards towards the coast in both the Atlantic and Caribbean regions. This feature is present at all times of the year, but is subject to regional and seasonal disturbances.

The sloping isopycnals on the Guiana coast do not demonstrate true upwelling; it is more a stationary feature, although responsible for the elevation of colder water, usually rich in nutrients, to higher levels in the sea. Combined with wind-induced vertical eddy exchange, the structure will complete the transport of nutrients to the euphotic zone. The discharge of large amounts of freshwater on the Guiana shelf is also a phenomenon of significance for fishery oceanography.

The deflection of the coastal water of the Caribbean to the north results in a prolonged and intensive upwelling along the eastern Venezuelan coast. Because of the Caribbean Current being further offshore and the configuration of the coast, there is no upwelling off western Venezuela.

Off the Guajira Peninsula only a modest seasonal upwelling was detected, but the surface layers were stable along the Colombian coast to the southwest.

The type of bottom on the shelf and on the slope was observed acoustically along the survey tracks. Based on examination of the echograms, four categories were distinguished:

- smooth even bottom
- relatively smooth but uneven bottom
- rough bottom
- very steep bottom

Charts of these observations were presented in the final report (Strømme and Sætersdal, 1989a)

Work started by FAO taxonomists in these surveys contributed to the later preparation of a species guide for fishery purposes (Cervigón *et al.*, 1993), while also the assemblages of demersal fish in the region were analysed and described (Strømme and Sætersdal, 1989a and Bianchi, 1992a).

9.2 SURINAME, 1988

Pelagic fish

General trends in the distribution of pelagic fish off Suriname were similar in the four surveys, Figure 9.2 shows the echo integration charts from the January-February survey. This shows that pelagic fish were found aggregated in areas over the inner shelf where they occurred in schools and layers. Fish densities were high and the areas extensive in all except the third survey in August. This assemblage consisted of a large number of species from three main families, Engraulidae, Clupeidae and Carangidae accompanied by larger-sized predators, barracudas, Scombridae and sharks. Lower densities of pelagic fish were found over the outer shelf consisting of fewer species, mainly round sardinella and rough scad and other Carangidae. Pelagic fish also formed an important component of the catches of the bottom trawl.

Various *Anchoa* species dominated the Engraulidae, while the most common genera of the Clupeidae were *Opisthonema, Pellona* and *Chirocentrodon*. Bumper (*Chloroscombrus chrysurus*), lookdowns (*Selene* spp.), and horse mackerel (*Trachurus lathami*) were the most abundant Carangidae. The Scombridae were mainly the king mackerel (*Scomberomorus cavalla*) with some sierra (*S. brasiliensis*) and the barracudas, mainly *Sphyraena guachancho*, with less *S. picudilla*.

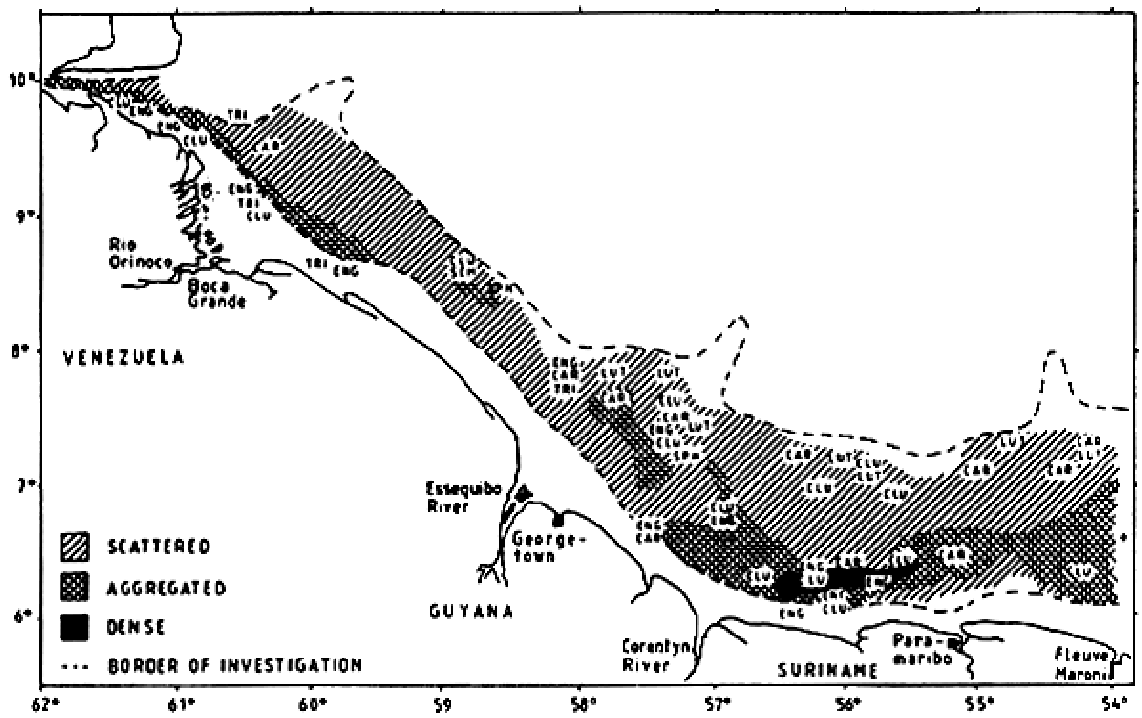

Figure 9.2 Suriname-Orinoco: Distribution of pelagic fish January-February 1988. (Car: Carangidae; Clu: Clupeidae; Eng: Engraulidae; Lut: Lutjanidae; Scm: Scombridae; Sph: Sphyraenidae; Tri: Trichiuridae)

Demersal fish

The main demersal species groups found in Suriname waters were snappers, croakers and grunts. The outer shelf was clearly dominated by snappers, while the the inner shelf in addition held important amounts of croakers and grunts.

On the outer shelf the main species were vermillion snapper (*Rhomboplites aurorubens*), southern red snapper (*L. purpureus*) and cardinal snapper (*Pristipomoides macrophthalmus*).

The main species on the inner shelf were: lane snapper (*Lutjanus synagris*), Corocoro grunt (*Orthopristis ruber*), king weakfish (*Macrodon ancylodon*), Acoupa weakfish (*Cynoscion acoupa*), dwarf goatfish (*Upeneus parvus*), American harvestfish (*Peprilus paru*) and Jamaica weakfish (*Cynoscion jamaicensis*) in decreasing order of abundance.

The demersal fish distribution extended continuously from Suriname into the shelf of Guyana. The stocks seem thus to be shared, but to what extent is uncertain.

The mean catch rates for all surveys were:

Inner shelf 0–50 m	
Snappers	60 kg/h
Grunts	50 kg/h
Croakers	62 kg/h
Outer shelf 50–120 m	
Snappers	108 kg/h

Occurrence of sharks in the catches seemed to be associated with that of their main prey, small pelagic fish, but catch rates were modest and the incidence low.

Only incidental observations were made on the important resources of shallow-water shrimps. Fishing tests were made for deep-sea shrimps.

Squids were found in modest amounts in the mid-shelf consisting mainly of small *Loligo* species. The highest catch rates were obtained in the May survey.

Summary of biomass estimates

Table 9.2 summarizes the assessments of the standing stock of the various groups. Some are likely to have been underestimates, e.g., sharks and perhaps red snapper. With a total biomass of 693,500 t (excluding shrimps) and a shelf area of 15,000 nmi^2 the mean density of biomass of the Suriname shelf was 45 nmi^2 which indicates a fairly high productivity.

The swept-area biomass estimate of demersal fish including larger pelagics Scombridae, barracudas and the semi-demersal hairtails was 150,000 t of which 128,000 t on the inner shelf (0–50 m)

Summarized data are available on the findings from a number of previous trawl surveys of the shelf of Suriname. In order to compare the various estimates of standing biomass the same catchability coefficient (q) must be applied in the calculations. In Table 9.3 where the results for each survey have been converted to the use of q = 1, a considerable variation can be noted. Some of the variability could be attributable to differences in survey methodology, e.g. surveys targeting on shrimp may have a high proportion of night hauls which will have a negative bias on fish catches. Also the groups of fish included may have varied between surveys. The comparison may, however, demonstrate a real decline of demersal fish biomass on the outer shelf over the long period from the 1960s, when these offshore grounds must have held accumulated virgin stocks till to date. On the inner shelf, however, the DR. FRIDTJOF NANSEN results fell reasonably well into the ranges of the previous findings, but here a careful examination of the species composition is required.

Table 9.2 Suriname: Summary of estimates of standing stock biomass

Resource group	Biomass t	%
Pelagic fish		
Engraulidae	130,000	23
Clupeidae	230,000	41
Carangidae	147,000	26
Scombridae	14,000	2
Barracudas	16,000	3
Hairtails	23,000	4
Sub-total pelagics	560,000	100
Demersal fish		
Snappers	38,000	30
Grunts	18,500	15

Croakers	22,500	18
Other demersal mostly non-commercial	46,500	37
Sub-total demersals	125,500	100
Sharks	5,000	
Squid	3,000	
Shallow-water shrimp		
Deep-water shrimp		
Total	**693,500**	

Table 9.3 Suriname: Comparison of estimates of standing biomass (t) from various trawl surveys with calculations adjusted to a catchability coefficient q = 1

Vessel	Year	Inner shelf	Outer shelf	Total
COQUETTE	1962–65	169,000	83,000	252,000
CALAMAR	1967–68	91,000		
LA SALLE	1969	74,000		
OREGON II	1972–77		72,000	
BONITO	1980–81	105,000		
DR. FRIDTJOF NANSEN	1988	128,000	22,000	150,000
Sources: Klima, 1976 and Losse, 1982.				

9.3 GUYANA, 1988

Pelagic fish

Pelagic fish were found mainly in dense inshore aggregations which extended from the border with Suriname onto the southeast Guyana shelf. West of the Essequibo River densities were low. The catch composition by groups was roughly the same as in Suriname: Clupeidae, Engraulidae and Carangidae with some large pelagic predators, but with lower mean catch rates.

Demersal fish

The principal groups were the same as in Suriname: snappers, croakers and grunts.

The main species on the inner shelf were in order of importance and using the pooled data from all surveys: king weakfish (*Macrodon ancylodon*), southern red snapper (*Lutjanus purpureus*), green weakfish (*Cynoscion virescens*) and shortfin corvina (*Isopisthus parvipinnis*). On the outer shelf the dominating species were vermillion snapper (*Rhomboplites aurorubens*), cardinal snapper (*Pristipomoides macrophthalmus*) and Acoupa weakfish (*Cynoscion acoupa*). As mentioned above according to their distributional pattern these stocks must to some extent be considered as shared with Suriname.

Only incidental observations were made of the important resources of shallow-water shrimps.

Squids were found in modest amounts in the mid-shelf consisting mainly of small *Loligo* spp. some times with a patchy distribution.

Summary of biomass estimates

Table 9.4 shows a summary of the assessments of the standing stock of the various groups. Some of these are likely to be especially negatively biased such as those for sharks and perhaps the red snapper. With a total biomass of 374,200 t and a shelf area of 13,900 nmi^2 the mean density of biomass of the shelf of Guyana was 27 t/nmi^2 which indicates a moderate productivity. The total biomass may be somewhat underestimated, but the density is markedly lower than that found off Suriname. A part of the difference could be explained by a higher rate of exploitation in Guyana.

The swept-area trawl survey showed a total biomass of 87,000 t, which included, demersals, Scombridae, barracudas, and hairtails.

Data are available on the findings from previous trawl surveys of the Guyana shelf. In Table 9.5 the results for each survey have been converted to the use of the same catchability coefficient as that applied to the results of the DR. FRIDTJOF NANSEN surveys, viz., q = 1. There is a considerable similarity between the standing stock estimates for the inner shelf. The low standing stock found in the DR. FRIDTJOF NANSEN survey on the outer part of the Guyana shelf as compared to the results of the OREGON II 1972–77 may demonstrate a stock decline brought about by fishing.

Table 9.4 Guyana: Summary of estimates of standing stock biomass

Resource group	Biomass t	%
Pelagic fish		
Engraulidae	55,000	18
Clupeidae	105,000	35
Carangidae	104,000	35
Scombridae	15,000	5
Barracudas	9,000	3
Hairtails	12,000	4
Sub-total	300,000	100
Demersal fish		
Snappers	15,000	22
Grunts	4,400	6
Croakers	27,500	39
Groupers	800	12
Other demersal mostly non-commercial	21,500	31
Sub-total	69,200	100
Sharks	3,000	
Squid	2,000	
Shallow water shrimp		
Total	374,200	

Table 9.5 Guyana: Comparison of estimates of standing biomass (t) from various surveys with calculations adjusted to a catchability coefficient q = 1

Vessel	Years	Inner shelf	Outer shelf	Total
CALAMAR	1967–68	84,000		
LA SALLE	1969	60,300		
OREGON II	1972–77		37,000	
DR. FRIDTJOF NANSEN	1988	76,500	10,700	87,000
Source: Klima, 1976 and Fabres, 1980				

9.4 TRINIDAD AND TOBAGO, 1988

Various parts of the shelf off the coasts of Trinidad are affected by different ecological regimes:

- the Colombus Channel in the south can be considered an extention of the Orinoco estuary and is dominated by the seasonal discharges of this large river. Under an agreement with Venezuela this part is defined as the “Joint Fishing Zone south of Trinidad and north of Venezuela”;

- the east coast, where the Orinoco regime extends along the inner parts of the shelf, while its more offshore parts are covered by the Guiana Current;

- the shelf off the north coast is located at the start of the Caribbean Current with its inshore upwelling system and relatively high productivity;
- the Gulf of Paria, which was not surveyed.

The pelagic and demersal resources of the north coast and the Joint Fishing Zone were surveyed with the standard methods, and the east coast with echo integration only and some test hauls for deep-water shrimp. Rough bottom prevented a coverage of the outer shelf of the north and east coasts by the trawl survey for demersal fish.

It should also be recalled that this type of survey does not adequately cover large pelagic species such as Spanish mackerel. The description of the resources will therefore be somewhat inadequate. However, the main features of the distribution of the resources are probably reflected in the data and the estimates of standing stocks can be used for comparison with other sources of information.

The small pelagic fish were in general found to be limited to the inshore parts of the shelf and the low densities offshore probably give a true picture of the distribution of these resources.

Table 9.6 summarizes the biomass estimates for the different parts of the coast by main groups. A minimum estimate of the biomass density within 100 m of depth is 26 t/nmi^2 which indicates a moderate level of productivity. A further breakdown of the 38,000 t biomass of Carangidae, etc., by using the proportions of the total catch indicates a biomass of hairtails, barracudas and Scombridae of 15,000 t. A swept-area estimate of these species referring to the north coast and the Columbus Channel only, gives 4,000 t which for these mainly pelagic species must be a clear underestimate. The best assessment of the standing stock of this group based on the data is probably 10,000 t.

Table 9.6 Trinidad and Joint Fishing Zone: Overview of estimates of biomasses by main groups (t)

	North coast	**East coast**	**Joint Fishing Zone**	**Total**
Pelagic fish				
Anchovies & Sardinellas	6,000	16,000	24,000	46,000
Carangidae etc.	12,000	14,000	12,000	38,000
Sub-total				84,000
Demersal fish				
Croakers	3,600	*	5,500	9,100
Snappers	400	*	450	850
Others	750	*	2,300	3,050
Sub-total	4,750	*	8,250	(13,000)
Sharks		600	500	1,100
Total				**(98,100)**

* No estimate available

9.5 VENEZUELA, 1988

The Venezuelan coast falls naturally into four regions with environmental regimes which differ significantly and affect the composition and abundance of the fish resources:

- the Orinoco shelf between Guyana and Trinidad and the eastern part of the north coast;
- the so-called Oriente which covers the shelf from the Dragon's Mouth to Cabo Codera;
- the western part of the main coastline to the Paraguana peninsula;

- the Gulf of Venezuela, in part shared with Colombia.

The Oriente with its broad shelf and favourable conditions for high production through upwelling represents the richest and most interesting part, whereas the west coast has a narrow shelf and a generally low productivity and the Gulf of Venezuela the characteristics of a shallow enclosed sea area.

9.5.1 Orinoco shelf

This small shelf between Guyana and Trinidad is characterized by a soft muddy bottom prevalent over the inner and mid-shelf and an inshore hydrography dominated by the discharges of the Orinoco River.

Pelagic fish

Small pelagic fish were found in aggregations in a narrow inshore belt with largely moderate densities where catch compositions included anchovies, sardines, and Carangidae, with some hairtails and Spanish mackerel.

Demersal fish

Demersal fish was found mainly on the inner shelf with croakers as the main group and giving high catch rates. The distribution of croakers extended also out to the mid-shelf region where the main species was cardinal snapper (*Pristipomoides macrophthalmus*).

Sharks were caught in modest amounts mostly at depths less than 40 m.

Biomass estimates

Estimates of the standing stocks were 70,000 t of pelagic fish and 30,000 t of demersals. There was a special uncertainty concerning the estimates on this shelf because of the large inshore shallow areas which could not be covered.

9.5.2 Oriente

In the analysis of the fishing experiments a distinction was made between the data from the inner part of the shelf, inside the Testigos Archipelago and Margarita Island and the coastal side of the Cariaco Trench and those from the outer part, outside the Islands and westwards past Tortuga island. The main difference in the fish assemblages of these two parts was that the inner shelf was dominated by small pelagic fish, sardines and anchovies with catfish and croakers as the most common demersal fish, while the pelagic fish of outer part was characterized by horse mackerel and mackerel and as demersal groups snappers and grunts with some breams, groupers and glasseyes. Hauls were made at various depths along the outer slope to test the availability of deep-sea shrimps and cephalopods.

Pelagic fish

In all surveys pelagic fish were found in abundance on the inner shelf along the coast from the Gulf of Cariaco eastwards. The main component was the Venezuelan sardine (*Sardinella aurita*).

Figure 9.3 shows the distribution of pelagic fish in the four surveys from the echo integration data.

The geographical distribution of the school areas of sardinella conformed with previous finding from sardine surveys of the Oriente and with the general information from the fishery. High densities were observed in a narrow inshore zone from the Dragons Mouth westwards past Cabo Tres Puntas towards Isla Margarita, in the bay outside Peninsula de Araya and in the Golfo de Cariaco, especially its western part and the entrance. A pattern of seasonal migration along the coast may be indicated with an easternmost location in November, some shift westwards in February, a westernmost distribution in May-June and the start of a shift towards the east in August-September. This could be related to a spawning and reproduction cycle which includes a westwards drift of larvae and a larval-and early juvenile stage adjusted to the season of high rates of upwelling and production.

There was a clear relationship between high-density school areas and inshore cool upwelled water.

Estimates of the biomass (Table 9.7) were made for two pelagic groups: Pelagic 1 consisting of Clupeidae and Engraulidae and Pelagic 2 consisting mainly of Carangidae, especially rough scad (*Trachurus lathami*), Scombridae, barracudas and hairtails.

Table 9.7 Oriente: Estimates of standing biomass (t) of pelagic fish by surveys

Survey	Pelagic 1	Pelagic 2	Total
1 February	1,220,000	230,000	1,450,000
2 May-June	830,000	40,000	870,000
3 August	1,100,000	140,000	1,240,000
4 Oct-Nov	840,000	20,000	860,000

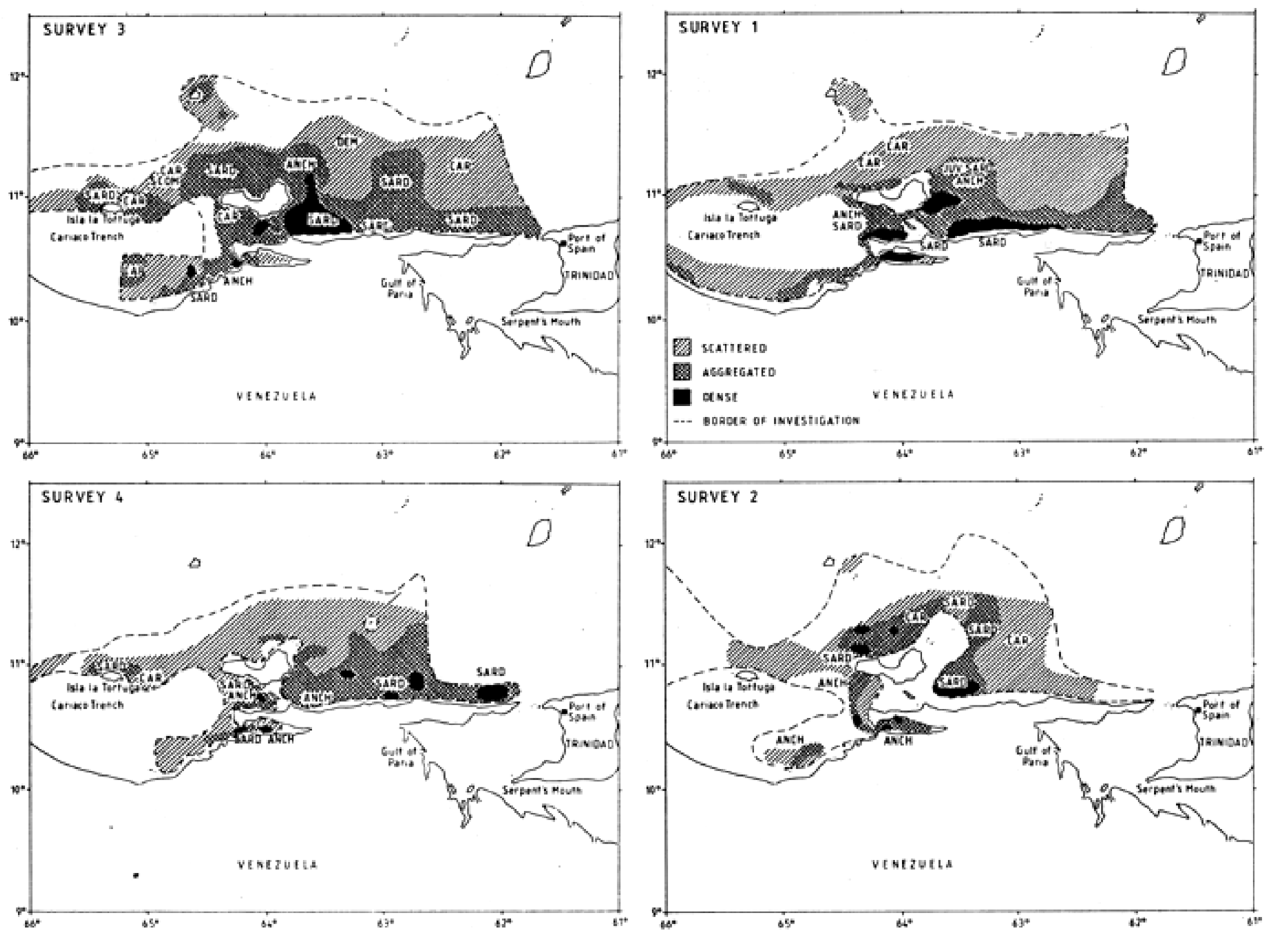

Figure 9.3 Venezuela, Oriente: Distribution of pelagic fish, mainly Venezuelan sardine in the four surveys. (Anch: anchovies; Car: Carangidae; Dem: demersal fish; Sard: Sardinella; Scom: Scombridae)

The variation of the estimates between surveys is unlikely to reflect stock variations for the Pelagic 2 group, more probably changes in availability. The mean standing stocks were estimated as follows:

Venezuelan sardine	800,000 t
Other Clupeidae and anchovies	200,000 t
Rough scad	180,000 t
Other Carangidae	20,000 t
Scombridae and barracudas	20,000 t
Total	1,220,000 t

Demersal resources

The main demersal fish on the inner shelf were catfish, croakers and grunts, with lesser amounts of groupers. The outer shelf was clearly dominated by snappers and grunts but contained also minor amounts of groupers, croakers and seabreams.

The principal species for the inner shelf were: catfishes (*Cathorops spixii* and *Bagre marinus*), barbel drum (*Ctenosciaena gracilcirrhus*), bronze-striped grunt (*Haemulon boschmae*), cardinal snapper (*Pristipomoides macrophthalmus*) and whitemouth croaker (*Micropogonias furnieri*). For the outer shelf the main species were: cardinal snapper, bronze striped grunt, vermillion snapper (*Rhomboplites aurorubens*), dwarf goatfish (*Upeneus parvus*) and Atlantic bigeye (*Priacanthus arenatus*).

Biomass estimates for the main commercial bottom fishes varied between 27,000 and 55,000, with a mean of 47,000 t.

Small-sized squids (*Loligo* spp.) were common over large parts of the shelf with the highest abundance in the intermediate depths near Margarita Island. There was a clear seasonal trend in the catches with highest rates in the February and May-June surveys, undoubtedly reflecting the production cycle for these short-lived species. Swept-area biomass estimates for two first surveys were: 7,000 t and 8,200 t respectively. The catches consisted nearly exclusively of the two species, *Loligo plei*, (70% on average) and *L. pealei* (30%).

Test hauls were made for deep-sea shrimp at 200–800 m depth in the fishable parts of the slope between the Testigos Archipelago and Tortuga Island. The catch rates were low with means of 5–10 kg/h for the main species, with the highest rates up to 50 kg/h. The megalops shrimp (*Penaeopsis serrata*) was the most common species at 300–400 m and the royal red shrimp (*Pleoticus robustus*) at 300–500 m. The giant red shrimp (*Aristaemorpha folicea*) and the striped red shrimp (*Aristeus varidens*) occurred at intermediate depths, 400–500 m, while the scarlet shrimp (*Plesiopenaeus edwardsianus*) was taken in a few hauls at 700–800 m. The Caribbean lobster (*Metanephrops binghami*) was caught in a few hauls at 300 m depth.

9.5.3 West coast

The shelf along the West coast of Venezuela from Cabo Codera to the Paraguana Peninsula is narrow. the biological productivity of these inshore coastal waters is known to be low and this was confirmed by the findings of the surveys.

Pelagic fish

The pelagic fish were dominated by Carangidae, the most abundant species of which was the rough scad (*Trachurus lathami*). The mean biomass estimates were:

Clupeidae and anchovies	10,000 t
Carangidae	22,000 t
Scombridae and barracudas	8,000 t
Total	40,000 t

Demersal fish

The demersal fish fauna was mainly composed of snappers. The main species were mutton snapper (*Lutjanus analis*), lane snapper (*L. synagris*), vermillion snapper (*Rhomboplites aurorubens*) and cardinal snapper (*Pristipomoides macrophthalmus*). The mean biomass estimate of the commercial bottom fishes which included croakers, seabreams and grunts was 8,500 t.

In some test hauls for deep-sea shrimp at depths between 200 and 400 m only low catch rates were obtained.

9.5.4 Gulf of Venezuela

This enclosed sea proved to support fish stocks of only moderate abundance.

Pelagic fish

The schooling behaviour of pelagic fish was different from that found in the Oriente with numerous smaller schools distributed in patches over the various parts of the Gulf. Patches of high densities were not extensive and mainly restricted to the outer part of the Gulf.

The pelagic fish biomass were assessed at:

Clupeidae and anchovies	100,000 t
Carangidae	18,000 t
Scombridae	3,000 t
Barracudas	5,000 t
Hairtails	9,000 t
Total	135,000 t

Demersal fish

The demersal fish fauna was mainly composed of croakers inside the Gulf and snappers in the deeper waters of the mouth. The dominating species were whitemouth croaker (*Micropogonias furnieri*), American harvestfish (*Peprilus parus*) and lane snapper (*Lutjanus synagris*) in the inner part of the Gulf and Atlantic bigeye (*Priacanthus arenatus*), mutton snapper (*L. analis*) and dwarf goatfish (*Upeneus parvus*) in the deeper waters in the mouth. The inner shallow waters of the Gulf were insufficiently covered and the total biomass estimate for the Gulf of about 10,000 t may have been too low especially for the croakers.

Squids, mainly *Loligo pealei* and *L. plei*, showed a seasonal cycle with the highest abundance in February and June with a swept-area estimate of 2,500 t.

9.5.5 Review of survey results in Venezuela

The most notable finding was the high abundance of fish found on the Oriente shelf from the Dragons Mouth to Cabo Codera in all four surveys. The narrow shelf further west to the Paraguana Peninsula was found to contain only very sparce resources. In the Gulf of Venezuela small pelagics appeared seasonally in variable abundance and demersal fish had moderate abundance.

It should be noted that some areas of importance for small-scale fisheries could not be covered by the surveys, viz. the inner shallow parts of the Gulf of Venezuela and Lake of Maracaibo.

The biomass estimates are reviewed in Table 9.8.

Table 9.8 Venezuela: Review of biomass estimates (t)

	Orinoco	Oriente	West Coast	Gulf	Total
Pelagic fish					
Sardine		800,000			800,000
Other		420,000	40,000	135,000	595,000
Sub-total	(70,000)	1,220,000	40,000	135,000	1,465,000
Demersal fish					
Snappers		20,000	7,000	3,000	30,000
Croakers		7,000		3,000	10,000
Grunts		14,000	1,000	1,000	16,000
Others		6,000	1,000	4,000	11,000
Sub-total commercial		47,000	9,000	11,000	67,000
Sub-total demersal	(30,000)	84,000	17,000	17,000	145,000
Squid		8,000		3,000	11,000
Total	**(100,000)**	**1,312,000**	**54,000**	**155,000**	**1,621,000**

Using the shelf area to a depth of 200 m, the total standing stock per unit shelf area was as follows: for the Oriente 109 t/nmi^2 which indicates a high productivity, for the West Coast 10 t/nmi^2 a very low figure and for the Gulf of Venezuela 20 t/nmi^2, which indicates a modest level of production.

Among the previous investigations of Venezuela's marine fishery resources, the programmes conducted by Fundación La Salle de Ciencias Naturales in co-operation with ORSTOM are most directly comparable with the DR. FRIDTJOF NANSEN programme. Reporting on results of acoustic surveys during 1980–85 under this programme Gerlotto and Gines (1988) presented assessments of total pelagic fish biomass for the Oriente region of 1,400,000 t of which sardinella was estimated to represent between 730,000 and 1,000,000 t. This compares well with the assessments presented in Table 9.8 of respectively 1,220,000 and 800,000 t.

9.6 COLOMBIA

Expectations as to resource availability on the Atlantic coast of Colombia had been centred on the shelf off the Guajira Peninsula and the upwelling processes nearby as a source of primary production. During the surveys it appeared, however, that the upwelling was rather local and not very pronounced, strongest in the winter, and weak in the summer and autumn observations.

Pelagic fish

The acoustic survey showed that aggregations of small pelagic fish consisting of sardinella, thread herring and Carangidae could be found with medium densities and over restricted areas mainly along the shelf from Santa Marta northeastward and especially to the northwest and north of the Guajira Peninsula. Sardinella dominated in the March and June surveys and thread herring in the September and December surveys. This may be related to the season of most intensive upwelling. There appears to be a continuous distribution of pelagic fish from the shelf north of the Guajira Peninsula into the outer part of the Gulf of Venezuela and the resources in this area may thus be shared between Colombia and Venezuela. Very little pelagic fish was found along the shelf between Santa Marta and the Uraba Gulf.

The most important pelagic species were sardinella (*Sardinella aurita*), thread herring (*Opisthonema oglinum*), rough scad (*Trachurus lathami*) and various other Carangidae.

Demersal fish

The trawl survey showed that snappers represented the most important demersal group while grunts, groupers, croakers and seabreams were found at much lower densities. An analysis by depth strata revealed no consistent difference in species composition by depth. Catch rates on the southwestern shelf were much lower than in the northeast, but snappers dominated the catches also here. A significant increase in the densities of snappers off the Guajira Peninsula in the December survey coincided with observed decreased rates in the Gulf of Venezuela in the same survey and a possible connection between the two areas with shared stocks is thus suggested.

The main demersal species were lane snapper (*Lutjanus synagris*), vermillion snapper (*Rhomboplites aurorubens*), mutton snapper (*Lutjanus analis*), southern red snapper (*L. purpureus*) and tomtate grunt (*Haemulon aurolineatum*), while triggerfish (*Balistes capriscus*) was also frequent in the catches.

Squids (*Loligo pealei* and *L. plei*) occurred with relatively high catch rates in a zone around the Guajira Peninsula in the March survey, but with lower rates in the other surveys probably reflecting an annual production cycle.

A few hauls were made at 300–500 m depth west of Santa Marta to test the presence of deep-sea shrimps. Giant red shrimp (*Aristaemorpha folicea*) and royal red shrimp (*Pleoticus robustus*) were among the species which occurred in modest amounts, with catches up to about 2 kg/h. These data added no information additional to that provided by the very extensive surveys made jointly with the Japanese Agency for International Co-operation (JICA) in 1980.

Biomass estimates

The biomass estimates by main groups are shown for the two parts of the coast in Table 9.9.

Table 9.9 Colombia: Biomass estimates by main groups (t)

	Guajira Peninsula-Santa Marta	Shelf west of Santa Marta	Total
Pelagic fish			
Sardine	60,000		
Thread herring	40,000		
Others	18,000		
Sub-total	118,000	13,000	131,000
Demersal fish			
Snappers	7,000	3,000	10,000
Others	3,000	1,000	4,000
Sub-total commercial	10,000	4,000	14,000
Sub-total all demersal	14,000	6,000	20,000
Squid	5,000		5,000
Total	**137,000**	**19,000**	**156,000**

A calculation of mean biomass density per unit shelf area to a depth of 100 m gives 23 t/nmi^2 for the Colombian Atlantic coast, which indicates low production. However, the shelf northwest of Santa Marta has a of standing stock biomass level of 48 t/nmi^2 indicating a fairly good level of productivity. The corresponding estimate for the southwest shelf is 5 t/nmi^2 which demonstrate the paucity of resources here.

It must be noted that the DR. FRIDTJOF NANSEN surveys did not cover the shallow inshore waters. The important resources of shrimp on the shelf and the tuna resources which are supposed to be associated with the upwelling system off the Guajira Peninsula were not covered. The total assemblage of resources was thus somewhat underestimated by the surveys.

Other surveys

Various resource surveys have been made of this area. Under a UNDP/FAO Fisheries Project, 1968–72, a bottom trawl survey was made of the inner shelf which in coverage that corresponded roughly to that of the DR. FRIDTJOF NANSEN survey. The estimated biomass of species of commercial interest was 65,000 t which included pelagic fish caught in the bottom trawl. This represents a similar general level of resource availability as found in the DR. FRIDTJOF NANSEN surveys.

10 SUMMARY REVIEW OF FINDINGS

10.1 REVIEW OF FAUNISTIC STUDIES

The data collected through the bottom trawl sampling programme on tropical continental shelves and slopes constitutes one of the most comprehensive databases on tropical demersal resources. This database is unique in that it includes data collected with the same type of gear throughout the programme and in being readily available for further analyses.

Data sets from the Western Indian Ocean, the Eastern and Western Central Atlantic and Eastern Central Pacific were selected to carry out a community study, i.e., detection of recurring patterns of species associations in the demersal trawl catches, correlation of these with the main environmental parameters and finally inference of different “communities” or “assemblages”. This study was a welcome contribution to the knowledge on species interactions and responses of different assemblages to environmental gradients, that is still limited despite the substantial literature on biology and stock assessment of tropical species. The results from this work may have applications in inferring unknown assemblages and catch composition in unexplored areas, and may be an aid to the stratification of fisheries by ecological regimes or in the identification of ecological regimes as a basis for holistic and multispecies modelling. For a detailed description of the results of the above work, the reader should refer to Bianchi (1991; 1992a, b, c, d; 1996).

The classification of communities, based on their predictability in time and space, describes the existence of a spectrum of community types ranging from deterministic to stochastic, of which the former are found in relatively undisturbed habitats, and the latter in environments so variable as not to allow predictable communities to develop. The type of species found will reflect this situation, with specialized feeders in the deterministic communities and nonspecialized feeders in the stochastic communities.

“Tropical” communities have generally been ascribed to the deterministic type because of the stable conditions found in tropical areas. Bianchi (*op. cit.*) has pointed to the inadequacy of this generalization as large areas of tropical shelves are subject to important seasonal fluctuations of different types. For example, many estuarine areas are flooded during the rainy season; the shallow and sharp thermoclines in shallow waters of the tropical west coasts of Africa and America are subject to vertical displacements due to tidal and internal waves, while shelf areas in the northwestern Indian Ocean are seasonally exposed to low-oxygen conditions due to upwelling. In such areas, according to ecological theory, more stochastic types of communities can be expected. On the other hand, the shelf waters off Tanzania, with rather stable conditions throughout the year, should show the existence of the more deterministic type of communities. This pattern clearly emerged from the community analyses, that also showed how highly adaptive species dominated the assemblages in the variable habitats.

The sharpest changes in species composition seem to occur along the depth gradient. This is particularly evident in shelf regions where different water layers impinge on the shelf bottom. Tropical shelves of the Eastern Atlantic and Eastern Pacific, characterized by the presence of a sharp and shallow thermocline separating the upper mixed layer from the much cooler deeper waters, belong to this category. Within the various depth strata, other factors - such as bottom type or influence by processes along the coast - become more relevant. However, zonation at around 30 m depth seemed to be present in all the areas studied, independent of the structure of the water column. The reason for the presence of this faunal boundary may indicate the separation between the shallow-water environment and the intermediate shelf environment and related differences in energy sources and flows. In shallow waters the relationship to the bottom must be stronger and primary production is enhanced by the nutrients brought by the rivers and those made available through vertical mixing.

One interesting finding from the above study was the dominance in shallow coastal waters of most regions of species of pelagic/semi-pelagic types. For example, shallow water communities of the Americas hold a rich mainly zooplanktivorous clupeoid fauna, mostly small (< 10 cm) and characterized by a rapid turnover. Now the question is whether this is the result of intensive fishing for shrimp, by bottom trawl with fine meshes or an ecological adaptation to an environment that can be rather unstable because of tidal movements, changes in turbidity, etc. The continuous variation would prevent this system from reaching a climax and favour phylogenetically primitive taxa (clupeoids). On the other hand, intensive fishing with bottom trawl and fine trawl meshes must lead to a selection of small clupeoids as compared to larger, longer-lived demersal fishes. The present situation probably reflects both mechanisms.

Communities of the deeper part of shelf also showed interesting adaptations. The relatively stable environments of the Western and Eastern Atlantic host communities of long-lived demersal species, i.e., lutjanids and sparids, rich in numbers of species and in abundance. In the Eastern Central Pacific, characterized by the presence of oxygen-depleted waters in the deeper part of shelf, the galatheid crustacean *Pleuroncodes planiceps* dominated, apparently undisturbed by any predation or competition. Off Pakistan, where the presence of water with low-oxygen concentrations is seasonal due to upwelling, some species adapted to this by being able to live throughout the entire water column (e.g., *Trichiurus lepturus*).

The above study showed that the marine assemblages found in the tropical region cannot be classified under a common denomination as found in the more general literature (e.g., Ursin, 1984). This is important because generalizations that may be valid for a particular tropical region do not necessarily apply to other regions at similar latitudes. Tropical seas (at least the areas covered) display a wide variety of combinations of oceanographic conditions, type of bottom and zoogeographic patterns, and the type of fauna reflects these conditions with a wide variety of forms and life strategies.

10.2 FISH ABUNDANCE AND ECOLOGICAL REGIMES

The data on fish abundance from the many different regions surveyed represent an important output from the programme as a whole. Since the same methods and fishing gear were used throughout, the biomass estimates are in principle comparable. The database provides a unique opportunity to compare predictions made in 1970 in “The fish resources of the ocean” (Gulland, 1970) with direct observations. The ecological regime of a region affects the productivity at lower trophic levels and hence to a large extent the fish abundance. One of the main mechanisms of productivity is the rate of renewal of nutrient depleted water in the surface, and the hydrographical descriptions of the survey regions focussed on this process. The classification of the regimes used below and in Table 10.1 roughly reflects rates of replacement of surface water.

An analysis of fish abundance by class of ecological system from all the DR. FRIDTJOF NANSEN surveys is attempted in Table 10.1. The density of small pelagic fish is the most important indicator since they are low in the food chain and their abundance may be expected to be most directly related to the primary production. Observations on demersal fish were included where available to complete the picture and also because in some surveys it was difficult to provide meaningful separate estimates of pelagic and demersal fish.

Table 10.1 Densities of biomass by types of ecological regimes for small pelagic and demersal fish in all areas and mesopelagic fish in the northwest Arabian Sea. Mean annual catches in survey periods included

Ecological regimes	Location	Densities of standing stocks (t/nmi²)		
		Pelagic	Demersal	Total
Eastern boundary currents	Canary Current: Cape Blanc-Cape Bojador	295		
Perennial upwelling	Benguela Current: Namibia	170	30	200
Seasonal upwelling	Canary Current: Mauritania-Guinea Bissau	77		
	Benguela Current: Angola	64	22	86
Open ocean upwelling	Gulf of Oman, mesopelagic fish	190		190
	Western Arabian Sea, mesopelagic fish	75–120		120
Other seasonal upwelling	Oman, Arabian Sea	120	29	149
	Venezuela, Oriente, Caribbean Sea	116	18	134
	Somalia, NE Arabian Sea	68	42	110
	Sri Lanka, Indian Ocean			89
	India SW coast, Arabian Sea	52	24	76
	Panama Gulf, Pacific	52	22	74
	Nicaragua, Pacific	13	49	62
	Mexico, Gulf of Tehuantepec and Guatemala, Pacific	43	7	50
	Colombia, Guajira	41	7	48
Seasonal shelf enrichment	Myanmar, Indian Ocean	20	15	35
	Pakistan, Arabian Sea	59	26	85
	Suriname, Caribbean Sea	36	9	45
	Guyana, Caribbean Sea	22	5	27
Tropical, high stability	Tanzania, Indian Ocean			28
	El Salvador, Pacific			25
	Costa Rica, Pacific			23
	Kenya, Indian Ocean			20
	Colombia, Pacific			18
	Mozambique, Indian Ocean			17
	Malaysia, Peninsular			12
	Venezuela, west coast, Caribbean Sea			10
	Thailand, west coast, Indian Ocean			9
	Sumatra, north and west coast, Indian Ocean			9

The rate of exploitation which affects the standing biomass varied considerably between regions, and, in order to reduce the resulting bias, the mean annual catches were included in the density estimates.

By far the highest densities were found in the regions of perennial upwelling in the Canary and Benguela Current Systems off northwest and southwest Africa respectively. Information on the state of the stocks may explain some of the differences found between the two regions with considerably lower levels in the southern system. While the European sardine in the northern system has remained at a level of high production, the corresponding stock in the south, the Namibian pilchard, collapsed in the mid 1970s and has existed as a depleted stock since then. It may have been partly replaced by the horse mackerels, but those are higher in the food chain and less efficient utilizers of biological production. The existence of components of the fauna of small pelagics which were not included in the biomass estimates may also complicate the comparison. Observations indicate that one such component, myctophids, were less abundant off Morocco-West Sahara than in Namibia where these fish often complicated the estimates of horse mackerels. Pelagic gobies also had a high abundance near the southern upwelling centre in Namibia.

In the regions of seasonal upwelling in the eastern boundary currents, for example, Mauritania to Guinea Bissau and Angola the fish density was only about one-third of those in the regions with perennial upwelling.

For the open ocean upwelling in the western Arabian sea, the levels given correspond to total stocks estimates of 33–52 million t of mesopelagic fish.

Among the other seasonal upwellings those associated with the southwest monsoon cause the high production off Oman and Somalia. The relatively lower density off Somalia may be an effect of the very narrow shelf here. There is a clear seasonal effect of the southwest monsoon on the hydrographical regime also in southwest India along the Malabar coast. Sri Lanka is affected by both monsoons and consequently has a rather high density, but Myanmar only by the northeast monsoon and has rather low fish densities.

The surveys apparently did not detect any effect on fish abundance of the upwelling along the north coast of Mozambique during the northeast monsoon, which perhaps may be explained by the very narrow shelf along this coast.

The Caribbean coast of Venezuela offers an impressive example of the effect of upwelling on fish production. The density of small pelagics along the coast of the Oriente province where upwelling is intensive was estimated at 116 t/nmi^2, while it was only 10 t/nmi^2 for the neighbouring coast further west where the Caribbean Current has shifted offshore. Still further west, a local wind-induced upwelling was again observed to cause increased fish density off the Guajira Peninsula.

With the exception of Oman, Somalia and Venezuela-Oriente, the fish densities in these various regimes of seasonal upwelling were generally at an intermediate level, similar to those of the seasonal upwellings in the eastern boundary current systems.

The surveys of Pakistan and the Suriname-Guyana coast covered systems where current dynamics seasonally lifts deeper water onto the shelf and the surface layers are enriched by vertical mixing. The resulting increase of fish density was especially evident in Pakistan.

In the tropical regions of year-round stability of the surface layers the observed fish densities were low, on average about one-fifth of those of the seasonal upwellings. Obviously the surveys did not include coral reefs and mangrove areas, which are known to be highly productive.

It would have been desirable to use a more quantitative classification of the hydrographical regimes with, for instance, measures of duration and intensity of the process of renewal of surface water. Data on fish composition, the state of exploitation of the stocks, fish age, etc., would also be required for a more comprehensive study of fish production by type of ecosystem. However, the relatively simple analysis made here clearly demonstrates the limits to fish production set by the types of hydrographical regimes.

The use of biomass estimates per unit coastline instead of unit shelf gives different relationships of indices of fish production by ecosystems. In northwest Africa (Table 6.??) fish density in the area of perennial upwelling from Cape Bojador to Cape Blanc is 1.8 times higher than in the northern area from Cape Safi to Cape Bojador when measured by unit shelf area, but 3.3 times higher if measured by unit coastline length. In the region from Mauritania to Guinea Bissau fish density by unit shelf is only half that of Cape Safi to Cape Bojador, but nearly the same if measured by unit coastline. This difference may partly be caused by the effect of shelf width on fish production which is also indicated by some of the observations in the Indian Ocean, comparison of the northeast Somalia system with that of Oman, and the upwelling off northern Mozambique. The fish density by unit shelf area is of greatest general interest, but the difference between these indices may help to explain important features of the ecosystems.

10.3 REVIEW OF BIOMASS ESTIMATES BY REGIONS AND COUNTRIES

The biomass estimates obtained from the DR. FRIDTJOF NANSEN surveys will be reviewed below, following the sequence of the previous chapters, and where possible the survey results will be compared with one of the first estimates of the world's marine fish resource potentials. For this purpose rounded summary data have been extracted from Gulland (1970). Where possible these data have been converted into units of t/nmi^2. It should be noted, however, that Gulland's figures represent potential catches, while the results of the surveys represent the standing stock. The so-called Gulland formula, MSY = XMB_o, where X is usually 0.5, M is the natural mortality coefficient and B_o is the unfished biomass or Cadima's formula, MSY = 0.5 (Y + M * B), where Y is the total catch in a year and B is the average biomass in the same year (Sparre and Venema, 1991). These and similar formulas can be used to convert the results of surveys into estimates of potentials and vice versa.

10.3.1 The Arabian Sea and adjacent Gulfs

The North Arabian Sea with its seasonal systems of high primary productivity represented a region for which the Indian Ocean Programme had held the highest expectations to potentials for development. The information provided by the main resource surveys mounted by the programme was presented and reviewed at a special workshop in Karachi early in 1978 (FAO/IOP, 1978). There is historical interest in recording the gains in knowledge which may be attributed to these first survey efforts and in relating the new information to the main features of the ecosystem of this ocean.

The areas of high productivity were related to the upwellings associated with the southwest monsoon. Cushing (1971a and b) describes three coastal upwellings, in the Somali Current, southwest off the Arabian peninsula and off the Malabar coast. His maps of estimated tertiary production show high levels extending more than 500 nmi seaward and covering nearly half the Arabian Sea. This is referred to as high productivity in associated oceanic divergences or possibly the biological effects of the coastal upwelling drift seawards in the swift current. The boundary between the true coastal upwelling and the offshore divergences was described as being less precisely defined in the northwest Arabian Sea than in the four major eastern boundary current upwellings.

In Gulland (1970), the Arabian Sea was recognized as a highly productive area with average potentials of 13.4 t/nmi^2 of shelf area (0–200 m) for demersal fish and 16.8 t/nmi^2 of pelagic fish (Table 10.2). However, compared to the estimates for areas like the southeast Atlantic and the Eastern Central Pacific, the estimated densities were very modest, although the total potential was high. The large resources of mesopelagic fish, which absorb a large part of the estimated potential had not yet been identified. It is obvious that the DR. FRIDTJOF NANSEN surveys have very much contributed to a better understanding of fish distribution and population dynamics in this area.

Table 10.2 Arabian Sea: Summary of estimates of potential catches of demersal fish and small pelagic fish extracted from Gulland (1970)

Region or Country	Shelf area '000 km²	Potential Demersal fish			Potential Small pelagics		
		t/km²	t/nmi²	'000 t	t/km²	t/nmi²	'000 t
Arabian Sea + adjacent Gulfs	710	3.9	13.4	2,763	4.9	16.8	**3,500**
West Sri Lanka + India (South of 15°N)	**75**	**2.5**	8.6	**188**			
India (North of 15°N) + Pakistan	**245**	**5.0**	17.2	**1,225**			
Persian Gulf	**240**	**2.5**	8.6	**600**			
Arabian peninsula + Gulf of Aden	**80**	**5.0**	17.2	**400**			
Somalia (North of 5°N)	**70**	**5.0**	17.2	**350**			
Source: Gulland, 1970							
Bold figures as taken from Gulland; not-bold figures have been calculated							

A review of the DR. FRIDTJOF NANSEN estimates of standing biomass and densities of the pelagic and semi-demersal fish in the various systems is given in Table 10.3 which also includes the mesopelagics on the slope and adjacent oceanic parts of the northwest Arabian Sea. The densities of pelagics and semi-demersals are highest in the western coastal upwellings, intermediate on the Malabar coast of India and lowest on the Pakistan shelf. The best estimate from the 1975–77 surveys of total biomass of small pelagic and benthopelagic fish in the main shelf regions of the Arabian Sea is thus 6.3 million t. (The levels reported at the 1978 Karachi Workshop (FAO/IOP, 1978) for the area from Somalia to Pakistan were, however, only about half of those shown in Table 10.3, because the target strength used in the first surveys is now judged as having been too high.)

Table 10.3 Arabian Sea: Summary of results of acoustic surveys in the 1970s. Estimated mean standing biomass and densities of small pelagic, semi-demersal and mesopelagic fish by areas

Shelf resources	Pelagic		Semi-demersal		Total	
	Biomass 1,000 t	Density t/nmi²	Biomass 1,000 t	Density t/nmi²	Biomass 1,000 t	Density t/nmi²
Somalia	1,300	94			1,300	94
Arabian peninsula	1,600	84	300	16	1,900	100
Pakistan	400	31	400	31	800	62
India, Malabar coast	1,500	45	800	24	2,300	70
Total	**4,800**		**1,500**		**6,300**	
Mesopelagic fish	**Biomass (million t)**		**Densities (t/nmi²)**	**(g/m²)**		
Gulf of Oman	5		190	55		
NW Arabian Sea (oceanic)	30–50		75–120	22–35		

The reported catch of small pelagic and semi-demersal fish from the Western Indian Ocean for 1976 was about 1.2 million t (FAO Yearb. Fish. Stat., 45). Most of this would be from the surveyed area, and consequently the survey results, which for the Karachi workshop were interpreted to indicate a standing biomass of these fish of only about 3 million t, did not show any notable potential for expansion of the fisheries based on conventional shelf resources. The high abundance of mesopelagic fish in offshore and oceanic parts of the ocean, reported as about 100 million t at the Karachi Workshop caused considerable attention and interest, but it was recognized that various technological and economic problems might prevent an immediate utilization of this resource and that further research and development work would be required.

The main effect of these first surveys was thus in general to correct and perhaps over-correct the vision of the Arabian Sea as a region with a new great fishing potential. This vision was as discussed in Section 3.1, based on a widely accepted concept of the Arabian Sea as “one of the more productive parts of the world oceans” in terms of primary productivity and on a comparison of catch per area of the Indian Ocean with such data for the Atlantic and the Pacific.

It should be noted that in one of the background studies for the IOP, Cushing (1971b) presented estimates of tertiary production in the western coastal upwellings, Somalia and South Arabia of only 3.3 million t, a level which fits the biomass estimates for the Arabian Sea shown in Table 10.3.

All descriptions based on the findings of the IIOE relating to production in the Arabian Sea emphasised, however, its great seaward extent. In the early more general considerations of the high productivity at low trophic levels of the Arabian Sea and when assessing its significance for the fishery potentials of this ocean insufficient distinction seems to have been made between the coastal and the oceanic ecosystems. In a later description of upwelling in the Arabian Sea (Luther, 1991) such distinction is clearly made. The process is said to be driven primarily through the mechanism of open-ocean upwelling forced by the wind stress curl associated with the atmospheric Findlater Jet over the Arabian Sea during the southwest monsoon. This open ocean upwelling is combined with a narrower band of coastal upwelling due to the alongshore components of the winds.

Variability in the open ocean upwelling on an interannual and decadal scale can be related to that of monsoon rainfall in India. The data indicate a strong monsoon year in 1975 and an average one in 1976, the two years of the DR. FRIDTJOF NANSEN surveys. In view of the short lifespan of both the mesopelagic and the neritic small pelagic fish, variability in the extent and intensity of upwelling is likely to cause variability in standing stock biomass.

In a recent review of available information on zooplankton and nekton in the Arabian Sea, Peterson (1991) summarizes data on zooplankton abundance which shows biomass densities in productive parts of the open Arabian Sea of about 4 g dry weight m^{-2}, the same order as in the Somalia coastal area and similar to levels observed in eastern boundary current upwellings. In terms of fishery potentials this picture of the Arabian Sea as a highly productive region must be qualified by a faunistic distinction between the shelf and the oceanic provinces. The early acoustic surveys, the UNDP/FAO Pelagic Fishery Project on the Malabar Coast of India and the 1975–77 DR. FRIDTJOF NANSEN surveys provided important information for such a distinction. As shown in Table 10.3 the small pelagic and semi-demersal fish of the continental shelves around the Arabian Sea was estimated to have a standing biomass, corresponding roughly to the annual production, of 6.3 million t. This is probably an underestimate of the total production since the species and area coverage is not complete.

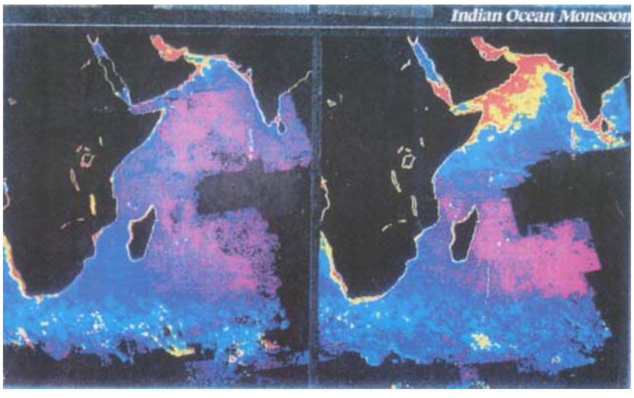

Figure 10.1 Satellite images showing phytoplankton concentrations in pre-and post-southwest monsoon conditions, May-June left and September-October right. Image

prepared by the Goddard Space Flight Centre and the University of Miami. Source: Olson, 1991

The mesopelagic fish of the oceanic province of the western part of the ocean was estimated to have a standing biomass of 33–52 million t. In view of the short lifespan of these fish the annual production may exceed the mean standing biomass. The surveys provided no information on the oceanic fish of higher trophic levels, tunas, etc. The highest densities of mesopelagics were still found near the shelf edge and slope, e.g., 190 t/nmi^2 in the Gulf of Oman compared with 75–120 t/nmi^2 in the offshore areas. But even if the production of mesopelagics near the slope is considered as "shelf production", the aggregate represents only about 20% of the total.

These surveys thus confirmed that the Arabian Sea is a region of high fish production, but a high proportion (about 80%) is mesopelagic fish produced off the shelf, in the slope and adjacent oceanic waters. That this distribution of production at higher trophic levels to a large extent reflects the geographical distribution of primary production is demonstrated by Figure 10.1 which shows a satellite image of the phytoplankton concentrations in two seasons, May-June and September-October.

The shelf hydrography in the northwest Arabian Sea is strongly affected by the southwest monsoon when oxygen-deficient bottom-water intrudes onto the shelf to shallow depths and affects fish distribution. Some enhancement of the productivity also occurs on the Pakistan shelf through shorewards advection and lifting of nutrient-rich deeper water by the east-and south flowing coastal current set up during the southwest monsoon. Furthermore, there is the well known strong coastal upwelling in the west, off Somalia, Yemen and Oman.

Pakistan, Iran, Oman, Yemen and Somalia had been covered in the initial exploratory programme in 1975–76. From 1977 to 1984 these surveys were repeated to confirm previous findings and obtain more detailed and comprehensive descriptions of the resources.

Pakistan

The estimates of pelagic fish were 550,000, 450,000 and 800,000 t in the three surveys compared with a mean of 750,000 t in the five 1975–76 surveys. Table 10.4 shows the estimates of the mean standing biomass from the 1983–84 surveys.

Table 10.4 Arabian Sea: Summary of survey results in 1983–84. Estimated mean standing biomass and densities of small pelagic and demersal fish by country

	Pelagic		**Demersal**		**Total**	
	Biomass 1,000 t	**Density t/nmi^2**	**Biomass 1,000 t**	**Density t/nmi^2**	**Biomass 1,000 t**	**Density t/nmi^2**
Pakistan	600	45	350	26	950	71
Oman (Gulf)	10	5	42	19	52	24
Oman (Arabian sea)	1,400	120	350	29	1,750	149
Yemen	265	37	182	25	447	62
Somalia	245	56	233	54	478	110
Total	**2,520**		**1,157**		**3,677**	

It seems unlikely that the semi-demersal fish for which there is an acoustic biomass estimate of 140,000 t was fully represented in the bottom trawl catches, and the "best estimate" of the mean standing biomass of demersal fish is perhaps 300–350,000 t.

The observed biomass represented partly exploited stocks. The reported landings of marine fish increased from 261,000 t in 1981 to 622,000 t in 1993.

Oman

The biomass estimates of the small pelagic fish were 1.0, 1.3 and 1.4 million t in the 1983–84 surveys compared with 250,000 t in early 1975 and 1.5–2.6 million t in the four subsequent surveys from late 1975 to late 1976. There has probably been a negative bias in the first two of the three 1983/84 surveys caused by instrument saturation.

The best estimate of demersal fish was 390,000 t when a November 1983 figure of 260,000 t was rejected as being caused by a seasonal low availability in deeper waters. This may still represent an underestimate as acoustic assessment of semi-demersal fish ranged from 38,000 to 148,000 t in the three surveys.

Table 10.4 shows the mean estimates of standing biomass and densities from the 1983–84 surveys. The resource of mesopelagic fish in the Gulf of Oman with a biomass estimated at 5 million t is described in Section 3.2.2.

A set of comparable data on Oman's fish resources are available from the 1989–90 surveys with the RASTRELLIGER which showed 470,000 t of pelagic fish and 500,000 t of demersals.

The main difference between the findings of the two sets of surveys is the low abundance of pelagic fish in 1989–90 compared with 1983–84. As noted above, a similar observation of low abundance of pelagic was made in the first 1975 survey, while pelagic fish were found in high abundance in the four subsequent surveys from late 1975 to late 1976. Such fluctuations indicate a dependence of populations size on a variable environment and interannual variations in the intensity and duration of the southwest monsoon are well known and reflected in the Indian summer monsoon indices (ISMR) available since 1871. The ISMR index for 1987 showed this to be the fourth driest year since 1871. The weak monsoon of 1987 could thus have caused the low biomass of pelagic fish in 1989–90 found in the RASTRELLIGER surveys.

The total landings of Oman fisheries have varied between 100,000 and 160,000 t since 1980. The high abundance shown in the surveys of such species as Japanese threadfin bream and Arabian and Indian scads is not reflected in the landings, probably due to the small size of these fish. There exists a large potential for growth of the fisheries in Oman.

Yemen and Northeast Somalia

The two surveys, from the northwest and southwest monsoon seasons respectively, showed the well known effect in this part of the Indian Ocean of redistribution of demersal fish caused by upwelling of oxygen depleted water during the southwest monsoon.

Using in each case the surveys assumed to have given the best coverage of the target group, the estimates of standing biomass shown in Table 10.4 were obtained.

A purse-seine fishery for oil sardine on the Yemen coast ceased about 1980. There is a considerable history of attempts and efforts to develop marine fisheries in Somalia few of which met with any success despite the relatively promising baseline resource studies. The problems of utilizing the marine fish production in Somalia are no doubt related to such factors as the remoteness of the northeastern coast, the limited tradition in fisheries, the narrow shelf, the rough sea and wind conditions during the monsoon and the low fish consumption in the country.

10.3.2 Eastern Indian Ocean

Relatively high potentials were assigned to several areas by Gulland (1970), see Table 10.5. In particular the high potential of demersal fish assigned to the shelf of Indonesia draws attention.

Table 10.5 Eastern Indian Ocean: Summary of estimates of potential catches of demersal fish and small pelagic fish extracted from Gulland (1970)

Region or Country	Shelf area '000 km^2	Potential Demersal fish			Potential Small pelagics		
		t/km^2	t/nmi^2	'000 t	t/km^2	t/nmi^2	'000 t
Eastern Indian Ocean	1,380	2.2	7.5	3,045	1.4	4.8	**2,000**
E. Sri Lanka + India (S of 20°N)	**85**	**1.0**	3.4	**80**			
India (N. of 20°N) + Bangladesh	**105**	**2.5**	8.6	**263**			
Myanmar	**250**	**2.5**	8.6	**625**			
W. Thailand + W. Malaysia (100°E)	**170**	**2.5**	8.6	**425**			
Indonesia (to 130°E)	**130**	**5.0**	17.2	**650**			
Western Australia	**380**	**2.5**	8.6	**950**			
South Australia (to 130°E)	**260**	**0.2**	0.7	**52**			

Source: Gulland, 1970
Bold figures as taken from Gulland; not-bold figures have been calculated

Large parts of the shelf in the northern part of the Eastern Indian Ocean were surveyed in 1978–80 after the completion of the first programme in the Arabian Sea. The first-generation echosounder was still in use and the acoustic estimates of dense-schooling fish may be too low. The swept-area trawl method had still not become a routine part of the programme, and except for the Bangladesh assignment the demersal and semi-demersal fish were mostly assessed by acoustics which again indicates underestimation. Semi-demersal fish was, however, the main component of the biomass in Sri Lanka and was also abundant in Myanmar.

In order to cover different monsoon seasons and verify findings Sri Lanka's shelf was surveyed three times and those of Bangladesh and Myanmar twice. Relatively large parts of the inshore shelf in these areas were too shallow for surveying: in Bangladesh more than 40%, in Sri Lanka with Palk Bay and Strait also about 40%, but in Myanmar only about 7% in the Delta area.

The hydrography of the shelf waters is also affected in these eastern parts by the monsoons, but in different ways in the various areas. Lifting of the transition layer and intrusion of oxygen-deficient water onto the shelf was found to occur on the west and southwest coast of Sri Lanka during the southwest monsoon, but on Sri Lanka's northeast coast and on the Bangladesh and Myanmar shelf during the northeast monsoon. These processes had distinct affects on the depth distribution of demersal fish - especially in Bangladesh and Myanmar - and enhance productivity in the surface layers, but widespread upwelling was not observed. River run-offs affected the surface salinity over wide inshore parts in Myanmar and Bangladesh in the post-southwest monsoon season.

Sri Lanka

The total biomass on the west, south and east shelves was found to be 400,000–500,000 t with some seasonal variation. This represents a mean density over the surveyed shelf of 67 t/nmi^2. The most important component of this was demersal and semi-demersal fish assessed at 250,000– 350,000 t and with a potential total yield of 50,000–70,000 t. Some 75% of these resources was located on the west and south coasts (see Table 10.6).

Sri Lanka's reported marine landings increased from about 150,000 t in 1979 to about 220,000 t in 1993. There is some uncertainty regarding the total potential since the wide northern shelf could not be surveyed.

Bangladesh

The total marine fishery resources of Bangladesh was estimated at 280,000 t, of which 130,000 t each of pelagic and demersal fish, 16,000 t of sharks, rays, cephalopods, etc., and 5,000 t of deep water fish. This represents a density of 17 t/nmi^2 over the shelf to 100 m depth. The reported marine fish landings of Bangladesh were 100,000 t in 1980 and 133,000 t in 1993.

Myanmar

The estimated biomasses of small pelagic and demersal fish are shown in Table 10.6. There is a strong seasonal variation that could partly be an effect of seasonal production of engraulids and aggregation from the deeper shelf caused by the intruding low-oxygen water.

Densities of fish measured as biomass per unit shelf area showed means of 12 t/nmi^2 in September-November and 24 t/nmi^2 in March-April. These represented low to moderate levels, indicating only a moderate effect on the total production from the upwelling caused by the northeast monsoon and by the considerable river discharges. For comparison, a similar estimate of mean density of biomass measured by acoustics on the Malabar shelf (see Section 3.2.1) with its upwelling from May to September during the southwest monsoon, was 67 t/nmi^2.

Table 10.6 Eastern Indian Ocean: Summary of estimates of biomass and densities by country

	Pelagic fish		Demersal fish		Total	
	Biomass 1,000 t	Density t/nmi^2	Biomass 1,000 t	Density t/nmi^2	Biomass 1,000 t	Density t/nmi^2
Sri Lanka	150	22.3	300	44.7	450	67
Bangladesh	130	8.0	146	9.0	276	17*
Myanmar	683	10.2	520	7.8	1,203	18
Thailand, west coast	73	6.3	27	2.6	100	9.1
Malaysia, west coast	183	11.0	35	2.1	218	13.2
Sumatra, north and west coast	160	6.4	65	2.7	225	9.2
Malaysia, east coast	200	5.8	80	2.4	280	8.2

*) Only a relatively small part has been covered

Taking the simple mean of the two biomass estimates as mean standing stock and yield fractions of 0.5 and 0.25 for small pelagic and semi-demersal fish respectively, a theoretical potential annual yield of about 470,000 t is obtained. Since the stocks were already exploited (the 1979 landings were reported to be 400,000 tonnes), the total potential would be higher probably some 600,000 t.

Thailand, Malaysia and Sumatra

Parts of the shelfs off western Thailand, peninsular Malaysia and northern Sumatra were covered only once implying a character of exploration, but each survey was conducted with a fair effort of trawling and acoustics.

In this tropical region a stable surface layer was found to cover a large part or even the whole shelf. Thus the thermocline was found at 40–50 m depth on the 80 m deep shelf of the east coast of peninsular Malaysia, at 40 m on the 100 m west coast shelf, and the surface layer covered the whole of the 100 m shelves of the west coast of Thailand and the north and west coast of Sumatra. As indicated by the catch rates by depth ranges, the main part of the fish was found within the stable surface layer: a mean of 87% of the pelagics and 83% of the demersals were found above the thermocline.

The very high species diversity known from the region was confirmed. Up to 160 species from 80 families were identified in one survey with 20 species of carangids only.

The biomass estimates are shown with shelf densities in Table 10.6. The densities are low and remarkably similar, especially for the demersal fish. These were single surveys made from June through August and a seasonal variation would not be observable. Still, it is thought that the densities found are roughly representative for these stable tropical systems.

10.3.3 Southwest Indian Ocean

The northern part of this area has generally been considered to have a low potential, as shown in Table 10.7, from Gulland (1970). This is largely confirmed by the DR. FRIDTJOF NANSEN surveys.

Table 10.7 Southwest Indian Ocean: Summary of estimates of potential catches of demersal fish and small pelagic fish extracted from Gulland (1970)

Region or Country	Shelf area '000 km^2	Potential Demersal fish			Potential Small pelagics		
		t/km^2	t/nmi^2	'000 t	t/km^2	t/nmi^2	'000 t
Southwest Indian Ocean	530	2.4	8.2	1,265	1.9	6.5	**1,000**
Somalia (5°-2°N)	**50**	**1.5**	5.1	**75**			
Kenya + Tanzania	**10**	**1.5**	5.1	**15**			
Mozambique	**120**	**2.5**	8.6	**300**			
South Africa	**140**	**2.5**	8.6	**350**			
Madagascar	**210**	**2.5**	8.6	**525**			
Source: Gulland, 1970							
Bold figures as taken from Gulland; not-bold figures have been calculated							

In the early 1980s, there was a great interest in establishing the resource potentials of Kenya, Tanzania and Mozambique. The quite considerable survey programme included four surveys in Kenya between 1980 and 1983, three surveys in Tanzania in 1982–83 and five survey programmes in Mozambique over the period 1977–90. The latter were part of an extensive bilateral programme of fisheries development between Norway and Mozambique. Through these many assignments the area was very well covered with acoustic and swept-area trawl surveys at different seasons.

During the southwest monsoon the current along the East African coast is directed northward from latitude 10°S and with the resulting onshore movement of the surface water off Kenya and Tanzania there is no upwelling. During the northeast monsoon wind-induced coastal upwelling occurs off the narrow shelf of northern Mozambique down to Angoche at latitude 16°S. The shelves have in general tropical conditions with stable surface layers. River runoffs affect the surface salinity of inshore parts seasonally and may also cause some local enrichment of productivity.

On the narrow Kenyan shelf the main part of the biomass was small pelagic fish and ponyfish, while in Tanzania and Mozambique demersal fish represented a larger part of the biomass with about one-third of the total.

Table 10.8 shows the summaries of mean standing biomass in the survey periods and the densities over the shelf to 200 m. There are uncertainties concerning shallow inshore parts which could not be covered. The densities are largely similar and their low levels are more or less as expected from the low-productive ecosystems. The reported landings may be underestimated due to inadequate statistical systems for the small-scale fisheries.

Table 10.8 East Africa: Review of biomass estimates, densities and reported landings

	Total biomass 1,000 t	**Total density t/nmi^2**	**Total landings in 1982 1,000 t**	**Total landings in 1993 1,000 t**
Kenya	35	20	7	5
Tanzania	150	28	36	45
Mozambique	250	17	32	26

10.3.4 Eastern Central Atlantic

This large area that includes one of the world's most important upwelling areas was assigned a relatively low potential in Gulland (1970) (Table 10.9). The DR. FRIDTJOF NANSEN surveys proved that this is one of the most productive areas as far as small pelagic fish are concerned.

Table 10.9 Eastern Central Atlantic: Summary of estimates of potential catches of demersal fish and small pelagic fish extracted from Gulland (1970)

Region or Country		**Shelf area '000 km^2**	**Potential Demersal fish**			**Potential Small pelagics**		
			t/km^2	**t/nmi^2**	**'000 t**	**t/km^2**	**t/nmi^2**	**'000 t**
Eastern Central Atlantic		480	1.9	6.5	**889**	4.6	15.8	2,200
N. Morocco - C. Bojador	36°-26°N	**65**	**2.5**	8.6	**163**	**5.0**	17.2	
C. Bojador - C. Blanc	26°-20°N	**65**	**2.5**	8.6	**163**	**5.0**	17.2	1,200
C. Blanc - Bissagos Islands	20°-8°N	**110**	**2.5**	8.6	**275**	**5.0**	17.2	
Sherbro Island coastal	10°-8°N	**70**	**1.2**	4.1	**84**	4.0	13.7	
W. Gulf of Guinea	8°W-3°E	**50**	**1.2**	4.1	**60**	4.0	13.7	1,000
C. Gulf of Guinea	3°E-0°	**65**	**1.2**	4.1	**78**	4.0	13.7	
S. Gulf of Guinea	0°-6°S	**55**	**1.2**	4.1	**66**	4.0	13.7	

Source: Gulland, 1970
Bold figures as taken from Gulland; not-bold figures have been calculated

The survey programme on the shelf of Northwest Africa as a whole consisted of a discontinuous series of investigations. There were four assignments, but with considerably different coverage and duration: 11 months in 1981–82, 4 months in 1986, 1 month in 1989 and 3 months in 1992. The area from Morocco to Sierra Leone was surveyed three to four times, while the southern area from Côte d'Ivoire to Ghana was surveyed only twice. The main objective in all surveys was to describe the distribution, composition and abundance of the small pelagic fish. Demersal fish were investigated by trawl surveys in a few selected areas only.

Strong seasonal variability and large contrasts between the waters in the north and in the south are the main characteristics of the Canary Current upwelling system. The latitudinal shift in upwelling results in a coastal surface temperature front in the southern part of the system between cold upwelled water to the north and warm southern tropical water. This front is found to the north near Cape Blanc in August-September and south of the Sherbro Islands in March. Between approximately Cap Timeris and Cap Bojador upwelling is most intensive and prevails throughout the year. Southward to Guinea, at about 10°N, upwelling is seasonal and takes place during late winter and spring.

Cape Blanc devides the region into a northern temperate and a southern sub-tropical regime, creating two main sub-regions for the assemblages of small pelagics: to the north mainly temperate species, European sardine, Atlantic horse mackerel and chub mackerel, and southward mainly tropical, round and flat sardinella, Cunene horse mackerel, yellow scad and other carangids and triggerfish (*Balistes capriscus*).

The surveys were organized by sub-regions and the main pelagic stocks covered by these subregional surveys were roughly as follows:

Cape Safi-Cape Blanc: Sardine stocks and main part of stocks of Atlantic horse mackerel and chub mackerel

Mauritania-Guinea Bissau: Main part of round and flat sardinella stocks, Cunene horse mackerel, scads and other carangids and triggerfish in the south.

Guinea-Sierra Leone: Triggerfish, sardinellas, scads and other carangids.

Côte d'Ivoire-Ghana: Sardinellas, Cunene horse mackerel and triggerfish.

Cape Safi to Cape Blanc

The mean estimates of standing biomass of the main groups in this area are shown in Table 10.10 for the 1986, 1989 and 1992 surveys which are thought to have given more reliable and complete data than the 1981–82 surveys. The data which include the mean annual reported landings in the period, are shown by the shelf regions Cape Safi to Cape Bojador and Cape Bojador to Cape Blanc which are thought to hold different sub-stocks of sardine. The density estimates used are based on combined biomass and catches which are thought to give better indices of the fish productivity of the systems than using standing biomass only.

Table 10.10 Cape Safi (Morocco) to Guinea Bissau: Mean estimates of standing biomass and densities of small pelagic fish from surveys in 1986, 1989 and 1992 and mean annual reported landings in the same period

Area	Pelagic fish Biomass 1,000 t	Landings 1,000 t	Density t/nmi^2	Shelf area nmi^2
C. Safi - C. Bojador	1,360	600	159.3	12,300
C. Bojador - C. Blanc	4,100	600	293.8	16,000
C. Blanc - Guinea Bissau	2,150	300	76.6	32,000
Total	**7,610**	**1,500**	**151.1**	**60,300**

A comparison of biomass with the level of the landings indicates that the central sardine stock in the sub-region Cape Safi to Cape Bojador was intensively fished in the period. The standing stock in this sub-region varied between 320,000 t and 1,650,000 t. The southern stock must only have been lightly fished and the stock estimates varied only between 3 and 4 million t.

It is thought that the surveys did not provide good estimates of biomass of horse mackerel and chub mackerel. For the Atlantic horse mackerel incomplete coverage of aggregations in the shelf slope and a possible oceanic distribution may have caused an underestimate.

The region Cape Bojador to Cape Blanc where upwelling is perennial had by far the highest density with nearly 300 t/nmi^2, nearly double that of the northern region Cape Safi to Cape Bojador.

Mauritania to Guinea Bissau

There were three highly variable estimates of the sardinellas from the 1981–82 surveys, which were probably caused by inadequate coverage of the distribution in shallow inshore parts. The likely time series is 500,000 t in 1981–82, 700,000 t in 1986 and the surprisingly high level of 4 million t in 1992. The estimates of standing stocks of carangids which consisted mainly of Cunene horse mackerel and yellow scad were approximately 900,000 t in all surveys.

Table 10.10 shows the mean estimates of the biomass over the period of the surveys and the mean annual reported landings. The reported landings of both sardinella species were low in the early 1980s, about 150,000 t, but increased to well over 200,000 t by 1986 and exceeded 300,000 t in the early 1990s. The landings of horse mackerels, etc., were low compared with the standing stocks.

The densities were here as expected much lower than in the region of high upwelling further north, about one quarter of those found between Cape Bojador and Cape Blanc.

Triggerfish

The occurrence of the grey triggerfish (*Balistes capriscus*) in high abundance in the 1970s and 1980s in two regions, Ghana-Côte d'Ivoire and Sierra Leone-Guinea Bissau was probably an unusual phenomenon. Most triggerfishes are slow-moving solitary reef-dwellers and this seems to be the more normal behaviour and habitat also of the grey triggerfish. However, the stocks in the Eastern Central Atlantic were able to expand their populations to a remarkable and (as would appear) unusual size, probably by utilizing the relatively high productivity of the yet tropical regimes of the shelf waters of the Western Gulf of Guinea and the coastal seasonal upwelling system south of Senegal. The DR. FRIDTJOF NANSEN surveys 1981–82 coincided with the culmination of the triggerfish stocks and those of 1986 and 1989 with their decline and collapse.

Biomass estimates of triggerfish from the relevant DR. FRIDTJOF NANSEN surveys were shown in Table 6.19 together with available data from other similar surveys. For the western stock there seems to have been a rapid growth from about 0.4 million t in 1978–79 to about 1.4 million t in 1982 and with a decline to only 0.2 million t in 1986. The eastern stock was about 0.5 million t in 1981, half that of the western stock, and had declined to 140,000 t by 1986 and to virtually zero in 1989.

The stocks were fished by Ghana and the USSR between 1972 and 1990 with an accumulated total yield for the period of well over 0.5 million t. It seems unlikely that the collapse was caused by fishing pressure and the growth and decline of the stocks is probably a phenomenon of natural ecosystem variability.

10.3.5 Southeast Atlantic

The potential of the resources in this area was already fairly well known in the late 1960s. Gulland's (1970) estimates of the potential catches for the whole region were 1,305,000 t demersal and 3,900,000 t pelagic fish. This estimate incorporates South Africa and a part of the Indian Ocean. For Angola plus Namibia the figures are for demersal fish 945,000 t and for pelagic fish 2.6 million t (see Table 10.11).

Table 10.11 Southeast Atlantic: Summary of estimates of potential catches of demersal fish and small pelagic fish extracted from Gulland (1970)

Region or Country	Shelf area '000 km^2	Potential Demersal fish			Potential Small pelagics		
		t/km^2	t/nmi^2	'000 t	t/km^2	t/nmi^2	'000 t
Southeast Atlantic	**285**	4.6	15.8	1,305	13.6	46.6	**3,900**
Angola	**50**	4.5	15.4	**225**	26.0	89.2	**1,300**
Namibia	**85**	8.5	29.2	**720**	15.2	15.4	**1,300**
South Africa	**150**	2.4	8.2	**360**	8.7	8.6	**1,300**

Source: Gulland, 1970
Bold figures as taken from Gulland; not-bold figures have been calculated

In Table 10.12 the average results of the surveys with the DR. FRIDTJOF NANSEN are presented. The total biomass or average standing stock in Angola plus Namibia is 647,000 t of offshore demersals and 3,6 million t of pelagics. The survey results alone would indicate a lower potential than that given by Gulland, but in this area the extremely heavy fishing pressure in the 1980s should also be taken into account. It may be concluded that Gulland's prediction was reasonably accurate in this case.

Table 10.12 Namibia-Angola: Mean estimates of standing biomass and densities of small pelagic an demersal fish from surveys, and mean annual reported landings in the survey period

	Pelagic fish			Demersal fish			Shelf
Area	Biomass	Landings	Density	Biomass	Landings	Density	area
	1,000 t	1,000 t	t/km^2	1,000 t	1,000 t	t/km^2	nmi^2
Namibia	2,675	450	170.8	(307)	(100)	(22.2)	18,300
Angola	936	(230)	15.9	340	?	(22.1)	15,400

The programme in Angola was very extensive: 12 surveys between January 1985 and September 1992 with both small pelagics and demersal fish as main objectives. Deep-water shrimps and other resources in the slope were also investigated. The stocks and their environment were well described in the 1985/86 surveys, and the subsequent assignments had partly a monitoring character.

The Angola shelf forms a northern extension of the Benguela Current System: seasonal upwelling in winter spring and sub-tropical conditions in summer with poleward surface current.

The division of the Benguela Current System into a southern temperate and a northern subtropical regime is found off southern Angola. Here sardine, Cape horse mackerel, large-eye dentex and other species represent shared stocks with Namibia, while northwards sardinellas and Cunene horse mackerel are the important pelagic fish partly shared with Congo and Gabon.

The many surveys produced a wealth of information on the resources by season and subregion. A summary of estimates of mean standing biomass of the main groups is shown in Table 10.12. Time-series of the sardinella stocks showed a trend of decrease from 1985 to 1989 possibly caused by high fishing rates, but with a stock recovery in the early 1990s when fishing declined.

There was a trend of decline of indices of deep-water shrimp abundance over the period of the surveys. A similar trend was observed in the Benguela hake which forms a by-catch in the shrimp fishery.

A sharp decline in the fishery on the large-eye dentex in the Cunene-Tombua region in the late 1980s may have caused the high biomass estimates for that species found in the last surveys.

The mean standing biomass of sardinellas and Cunene horse mackerel of 500,000 t compares with a mean annual catch of 230,000 t in the period which perhaps roughly indicates that these resources were fully utilized during that time. Data on fishing for Cape horse mackerel in Angola are not readily available, but a full utilization of that stock and of a recovered stock of sardine would raise Angola's potential annual yield of small pelagics to 300,000–400,000 t. This fits with the catch levels in the purse-seine fishery of the former fish meal industry in the 1950s and 1960s. Angola's reported catches of demersal fish in 1991–92 were, according to the official statistics, less than 20,000 t. It is uncertain whether these data include all fisheries, but in general there seem to be resources available for expansion of the national fisheries in many directions. The deep-water shrimps seem to have been too heavily fished.

The DR. FRIDTJOF NANSEN survey programme in Namibia 1990 through 1993 started immediately prior to the country's achieving Independence and consisted of bi-annual separate surveys of the demersal and pelagic stocks. The fisheries in Namibian waters prior to the declaration of an EEZ at Independence was international and had a considerable history with well-known stocks and yields. Substantial knowledge of the sea and the stocks was acquired through research organized in the period 1970–90 by ICSEAF, but Namibia took over a legacy of largely depleted stocks.

Upwelling and the intrusion of oxygen-deficient water onto the shelf are the two most important features of fishery oceanography. Upwelling is perennial off Namibia with two major centres, one in the north near Cape Frio and the other in the Lüderitz region in the south. Anoxic conditions were often observed in an inshore belt off the central part. Mass fish mortalities occur in this region.

The main pelagic stocks are pilchard with some round herring and anchovy inshore and Cape horse mackerel offshore. Cape and deep-water hakes are the main demersal stocks.

Estimates of mean standing biomass of the pelagic stocks in the survey period are shown in Table 10.12. The pilchard stock which in the 1960s sustained annual yields of more than 0.5 million t collapsed in the early and mid 1970s and catches in the 1980s were maintained at 50,000–70,000 t despite the clear evidence of the collapse of the stock caused by overfishing.

The stock level of pilchard was estimated at 600,000 to 700,000 t from 1990 to 1992, but declined to about half that level in 1993. The observed decline in 1993 coincided with a northward shift of its distribution, and the estimates include pilchard found in southern Namibia. A possible explanation may be found in the structure of the original Namibian pilchard stock. As a whole it may have represented a super-population consisting of several partly mixing sub-populations arranged along the coast. Stocks in the central area would be more vulnerable to fishing and to predation from the seal population. The natural preypredator relationship between the two populations has been distorted by the collapse of the pilchard stock and at its present low level the pilchard stock is not sustainable.

The anchovy stock was also overfished by the early 1980s and no lasting recovery has occurred.

The Cape horse mackerel stock probably had a mean standing biomass of about 2 million t in the survey period and the reported landings indicate that there may have been an unused potential catch.

The history of the hake fisheries showed total annual landings of 0.5–0.8 million t over a nearly 10-year period up to 1976 and then a decline with landings generally at 250,000–350,000 t. The stocks were very low in 1990, and the first survey showed a standing biomass of the Cape hake stock of only 0.5 million t, of which only 100,000 t was fishable. Namibia introduced a strict management regime, and estimates of the standing biomass increased by about four times over the first two years as shown in Figure 7.?. The expansion then stopped and there was some decline in 1993.

This break in the recovery of the stock was probably due to insufficient recruitment. Recruitment variations in the Cape hake prove to be high, similar to many gadoid stocks in the North Atlantic. Whereas in 1993 recruitment has been assessed at a level of 2 billion fish, in previous periods, 1968–74 and 1982–85, estimates indicate that the mean recruitment was about 4 billion and the abundant cohorts comprised more than 6 billion fish. The 1991 yearclass was assessed at about 4 billion in November 1992, but at only 2.5 billion in February 1993, demonstrating a phenomenon of mass mortality in the region off Walvis Bay.

10.3.6 Eastern Central Pacific

The DR. FRIDTJOF NANSEN surveys covered a large part of the tropical section of this region, for which Gulland (1970) had estimated potentials of 1 million t of demersals and 1.5 million t of pelagics (Table 10.13). The total standing biomass was estimated at nearly 1.6 million t at a time that landings were at a fairly modest level, probably below 200,000 t (Table 10.14). Both estimates indicate that there should be a potential for an expansion of fisheries.

Table 10.13 Eastern Central Pacific: Summary of estimates of potential catches of demersal fish and small pelagic fish extracted from Gulland (1970)

Region or Country	**Shelf area '000 km²**	**Potential Demersal fish**			**Potential Small pelagics**		
		t/km²	**t/nmi²**	**'000 t**	**t/km²**	**t/nmi²**	**'000 t**
Eastern Central Pacific (42°N - South Ecuador)	**450**	3.3	11.3	1,500	11.1	38.1	5,000
California Current + Gulf		**3.0**	10.3	**500**	21.0	72.1	**3,500**
Tropical areas incl. Gulf of Panama		**3.0**	10.3	**1,000**	4.5	15.5	**1,500**
Source: Gulland, 1970							
Bold figures as taken from Gulland; not-bold figures have been calculated							

The survey programme of the DR. FRIDTJOF NANSEN consisted of four surveys of the shelf from Colombia to the Gulf of Tehuantepec in different seasons during 1987.

The main feature regarding fishery oceanography was the confirmation of the disruption of the stable tropical conditions of the surface layers by the well-known seasonal upwellings in the Gulfs of Panama, Papagayo and Tehuantepec caused by strong winds blowing through passages in the mountain ranges between the Atlantic and the Pacific.

In addition to inshore assemblages of small pelagic fish dominated by thread herring and carangids and demersals (butterfishes, grunts and snappers being the most common), there were offshore assemblages in deeper waters in the highly productive areas consisting of sea basses, silver smelts and hairtails. Deep-water shrimps and langostino (*Pleuroncodes planiceps*) were found in high abundance off Nicaragua and El Salvador and squids in the Gulf of Panama. Giant squid occurred off the shelf.

Table 10.14 Eastern Central Pacific: Summary of total biomass, densities and recent reported annual landings. (Landings for Panama represent total for country)

	Biomass 1,000 t	**Density t/nmi²**	**Landings in 1987 1,000 t**	**Landings in 1993 1,000 t**
Colombia	100	18		
Panama Gulf	490	56	156	158
Costa Rica	95	23	17	18
Nicaragua	340	6	5	9
El Salvador	140	25	22	13
Guatemala	220	50	3	18
Gulf of Tehuantepec	190	30		
Total	**1,575**			

An overview of the estimates of total biomass of standing stocks, densities and recent landings is shown in Table 10.17. The effects of processes of enrichment of the surface layers by the seasonal upwellings are clearly evident in the Gulf of Panama and in Nicaragua from the Gulf of Papagayo upwelling. Guatemala has joint stocks with southern Mexico and may be affected by the upwelling there. The biomass density on the northernmost shelf in the Gulf of Tehuantepec was not particularly high, but the high densities of mesopelagic fish found off the shelf are not included in the biomass estimate. Their abundance may relate to surface waters enriched by upwelling and advected offshore by the strong winds in the Gulf.

The landings are low compared with the biomass levels. It may not be commercially feasible to utilize fully all small pelagic fish, but there is no doubt significant potential for expanding fisheries on many stocks, particularly in Nicaragua, Panama and Guatemala.

10.3.7 Western Central Atlantic

The DR. FRIDTJOF NANSEN surveys covered only a small part of this statistical area, viz. the north coast of South America from Suriname to Colombia. This includes an upwelling area off the eastern part of Venezuela, that was already known in the 1960s. Despite the incorporation of this area in the estimate of potential for the Caribbean a a whole, Gulland's (1970) potentials of demersals (125,000 t) and small pelagics (600,000 t) are low (Table 10.15). The estimate for the area between Trinidad and Brazil was 200,000 t for demersals and 200,000 t pelagics.

The DR. FRIDTJOF NANSEN estimates of the total standing biomass for Suriname + Guyana amounted to 950,000 t, indicating a somewhat higher potential (Table 10.16). The biomass of pelagics off Venezuela Oriente is very high and compared with Gulland's estimate of pelagics for the whole Caribbean. The landings from this resource appear to be reasonably high.

Table 10.15 Western Central Atlantic: Summary of estimates of potential catches of demersal fish and small pelagic fish extracted from Gulland (1970)

Region or Country	Shelf area '000 km^2	Potential Demersal fish			Potential Small pelagics		
		t/km^2	t/nmi^2	'000 t	t/km^2	t/nmi^2	'000 t
Western Central Atlantic	1370	1.4	4.8	1,943	2.1	7.2	2,830
Eastcoast of USA	**200**	**1.9**	6.5	**380**	4.3	14.7	850
Bahamas, N.E. Cuba	**120**	**0.3**	1.0	38	1.5	5.1	180
Gulf of Mexico	**600**	**2.0**	6.9	1,200	1.7	5.8	1,000
Caribbean (incl. Venezuela Oriente)	**250**	0.5	1.7	125	2.4	8.2	600
Atlantic S. America (Trinidad to F. Guyana)	**200**	1.0	3.4	200	1.0	3.4	200

Source: Gulland, 1970
Bold figures as taken from Gulland; not-bold figures have been calculated

Four surveys of the shelf from Suriname to Colombia were undertaken in different seasons during 1988.

The main known features of fishery oceanography were confirmed by survey observations. Sloping isopycnals set up by the current off the Suriname-Guyana coast do not demonstrate true upwelling, but deeper water is brought onto the shelf and some enrichment of surface layers occurs through vertical mixing. Discharges of large amounts of freshwater affect wide parts of the surface water in this region. In Venezuela there is intensive seasonal upwelling along the eastern coast, but stable surface layers off the west coast. In Colombia there is modest seasonal upwelling off the Guajira Peninsula, but elsewhere surface layers are rather stable.

Table 10.16 shows a review of the mean total biomass of the standing stocks, densities and recent landings by regions. The effects of the processes of enrichment of the surface layers on standing stock biomass are evident in Suriname and the eastern Venezuelan coast of the Caribbean.

Table 10.16 North coast of South America: Summary of total biomass, density and recent reported annual landings (Landings for Venezuela represent total for country).

	Total biomass 1,000 t	Total density t/nmi²	Total landings in 1988 1,000 t	Total landings in 1993 1,000 t
Suriname	580	45	4	10
Guyana	370	27	36	40
Venezuela Oriente	1,340	111	286	390
Venezuela West	55	10		
Colombia NW	137	48		
Colombia SW	19	5		
Total	**2,501**			

Statistics of reported landings in 1988 and 1993 show generally low levels compared with the biomass. It is not evident, however, that there may be a commercial basis for utilizing fully the small pelagic fish in for instance Suriname, but there is no doubt a considerable potential for growth of fisheries in this country. There has been a recent substantial increase in the landings in Venezuela, but there may still be potential for further growth.

10.4 CONCLUDING REMARKS

It is hoped that the review presented in this book has provided the reader with an appreciation of how the survey programme with the DR. FRIDTJOF NANSEN has contributed to increasing knowledge on the availability of fishery resources of the ocean in the last few decades.

In a rapidly changing environment, as a consequence of anthropogenic activities, the data accumulated by the old DR. FRIDTJOF NANSEN, and still continuously expanded by surveys with the new vessel, represent important historical evidence on the composition and abundance of fishery resources in shelf areas of the world. These data may be very valuable for further studies of the marine fisheries resources of several productive areas and further work should be encouraged.

During the editing of this document the book “Ecological Geography of the Sea” by Alan Longhurst was published in 1998. Longhurst (1998) provides an overview of biological productivity in all areas. The results of the surveys of the DR. FRIDTJOF NANSEN provide an interesting fisheries complement to Longhurst's review.

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APPENDIX I REPORTS ON DR. FRIDTJOF NANSEN SURVEYS, 1975–93

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APPENDIX II SURVEYS WITH THE DR. FRIDTJOF NANSEN, 1975–93

Cruise No.	Area or country	Year	Start date	End date	Cruise Reports	Summary Reports
1	**ARABIAN SEA** **GULF OF OMAN** **GULF OF ADEN**	**1975**	14 Feb.	14 Apr.	IMR, 1975	IMR, 1976b Gjøsæter, 1977 Kesteven *et al.*, 1981 IMR, 1977b
2	**ARABIAN SEA** **GULF OF OMAN** **GULF OF ADEN**	**1975**	19 Apr.	3 Jul.	IMR, 1975	IMR, 1976b Gjøsæter, 1977 Kesteven *et al.*, 1981 IMR, 1977b
3	**ARABIAN SEA** **GULF OF OMAN** **GULF OF ADEN**	**1975**	16 Aug.	24 Nov.	IMR, 1976a	Gjøsæter, 1977 Kesteven *et al.*, 1981 IMR, 1977b
4	**ARABIAN SEA** **GULF OF OMAN** **GULF OF ADEN**	**1976**	11 Jan.	1 Apr.	IMR, 1976c	Gjøsæter, 1977 Kesteven *et al.*, 1981 IMR, 1977b
5	**ARABIAN SEA** **GULF OF OMAN** **GULF OF ADEN**	**1976**	6 Apr.	25 Jun.	IMR, 1976d	Gjøsæter, 1977 Kesteven *et al.*, 1981 IMR, 1977b
6	**ARABIAN SEA** **GULF OF OMAN** **GULF OF ADEN**	**1976**	20 Aug.	24 Nov.	IMR, 1977a	Gjøsæter, 1977 Kesteven *et al.*, 1981 IMR, 1977b
7	**PAKISTAN**	**1977**	19 Jan.	11 Feb.		IMR, 1978a
8	**PAKISTAN**	**1977**	13 Feb.	5 Mar.		IMR, 1978a
9	**PAKISTAN**	**1977**	8 Mar.	8 Apr.		IMR, 1978a
10	**PAKISTAN**	**1977**	13 Apr.	15 May		IMR, 1978a
11	**PAKISTAN**	**1977**	18 May	20 Jun.		IMR, 1978a
12	**MOZAMBIQUE I**	**1977**	24 Aug.	4 Oct.	IMR, 1977c	Sætre & de Paula e Silva, 1979
13	**MOZAMBIQUE I**	**1977**	12 Oct.	2 Dec.	IMR, 1978b	Sætre & de Paula e Silva, 1979
14	**MOZAMBIQUE I**	**1978**	16 Jan.	30 Mar.	IMR, 1978c	Sætre & de Paula e Silva, 1979
15	**MOZAMBIQUE I**	**1978**	4 Apr.	19 Jun.	IMR, 1978d	Sætre & de Paula e Silva, 1979
16	**SEYCHELLES**	**1978**	13 Jul.	27 Jul.	IMR, 1978e	Sætre & de Paula e Silva, 1979
17	**SRI LANKA I**	**1978**	16 Aug.	27 Sep.		Sætre & De Bruin, 1979 De Bruin, 1979
	MAJOR OVERHAUL OF VESSEL IN NORWAY					
18	**SRI LANKA II**	**1979**	26 Apr.	19 Jun.		Blindheim *et al.*, 1979
19	**GULF OF OMAN (Mesopelagics)**	**1979**	4 Jul.	3 Aug.		Gjøsæter & Myrseth, 1979; Aglen *et al.*, 1982
20	**GULF OF ADEN (Mesopelagics)**	**1979**	8 Aug.	29 Aug.		Gjøsæter & Myrseth, 1979; Aglen *et al.*, 1982
21	**MYANMAR I**	**1979**	25 Sep.	18 Oct.		Nakken & San Aung, 1980; Strømme *et al.*, 1981
22	**MYANMAR I**	**1979**	23	18		Nakken & San Aung,

			Oct.	Nov.		1980; Strømme *et al.*, 1981
23	**BANGLADESH I**	**1979**	25 Nov.	12 Dec.	Chowdhury *et al.*, 1980	Sætre, 1981
24	**SRI LANKA III**	**1980**	7 Jan.	11 Feb.		Blindheim & Føyn, 1980
25	**MYANMAR II**	**1980**	5 Mar.	1 Apr.		Strømme *et al.*, 1981
26	**MYANMAR II**	**1980**	5 Apr.	27 Apr.		Strømme *et al.*, 1981
27	**BANGLADESH II**	**1980**	7 May	24 May	Chowdhury *et al.*, 1980	Sætre, 1981
28	**MALAYSIA, EAST**	**1980**	10 Jun.	25 Jun.		Aglen *et al.*, 1981a
29	**MALAYSIA, WEST**	**1980**	5 Jul.	14 Jul.		Aglen *et al.*, 1981a
30	**THAILAND, WEST**	**1980**	16 Jul.	3 Aug.		Aglen *et al.*, 1981b
31	**INDONESIA, NW**	**1980**	6 Aug.	30 Aug.		Aglen *et al.*, 1981c
32	**MOZAMBIQUE II**	**1980**	11 Oct.	28 Nov.	IMR, 1981	Brinca *et al.*, 1981
33	**KENYA I**	**1980**	8 Dec.	19 Dec.		Nakken, 1981
34	**GULF OF OMAN (Mesopelagics)**	**1981**	24 Jan.	13 Feb.		Aglen, Gjøsæter & Tilseth, 1981
35	**GULF OF ADEN (Mesopelagics)**	**1981**	17 Feb.	26 Feb.? 21		Aglen, Gjøsæter & Tilseth, 1981
36	**DJIBOUTI**	**1981**	2 Mar.	5 Mar.		Myklevoll, 1982a
37	**EGYPT**	**1981**	8 Mar.	12 Mar.		Aglen & Myklevoll, 1982a
38	**TUNESIA**	**1981**	19 Mar.	30 Mar.		Aglen & Myklevoll, 1982b
39	**ALGERIA**	**1981**	4 Apr.	11 Apr.		Aglen & Myklevoll, 1982c
40	**MOROCCO**	**1981**	25 Apr.	29 Apr.		
41	**CAPE BLANC-CAPE VERGA**	**1981**	30 Apr.	26 May		Strømme, 1983a; Strømme, Sætersdal & Gjøsæter, 1982
42	**CAPE VERGA-GHANA**	**1981**	2 Jun.	25 Jun.		Strømme, 1983a; Strømme, Sætersdal & Gjøsæter, 1982
43	**TOGO-P. NOIRE (CONGO)**	**1981**	7 Aug.	3 Sep.		Strømme, 1983a; Strømme, Føyn & Sætersdal, 1983
44	**BISSAGOS ISLANDS-CAPE BLANC**	**1981**	8 Sep.	28 Sep.		Strømme, 1983a; Strømme, Sætersdal & Gjøsæter, 1982
45	**CAPE VERDE ISLANDS**	**1981**	16 Nov.	1 Dec.		Strømme, 1983a; Strømme, Sundby & Sætersdal, 1982
46	**MAURITANIA**	**1981**	4 Dec.	14 Dec.		Strømme, 1983a; Strømme, Sætersdal & Gjøsæter, 1982
47	**CAPE BLANC-**	**1981**	15	19		Strømme, 1983a

	CAPE JUBY (outside 12 n.miles)		Dec.	Dec.		
48	**DAKAR-FREETOWN**	**1982**	8 Feb.	1 Mar.	IMR, 1982a	Strømme, 1983a
49	**DAKAR-CAPE BLANC**	**1982**	3 Mar.	17 Mar.	IMR, 1982a	Strømme, 1983a
50	**CAPE BLANC-CAPE JUBY**	**1982**	17 Mar	20 Mar.	IMR, 1982a	Strømme, 1983a
51	**CAPE JUBY-AGADIR**	**1982**	23 Mar.	3 Apr.	IMR, 1982a	Strømme, 1983a
52	**TANZANIA I**	**1982**	16 Jun.	8 Jul.	Myklevoll, 1982b	Iversen *et al.*, 1984
53	**KENYA II**	**1982**	12 Aug.	24 Aug.	IMR, 1982b	Iversen, 1984
54	**MOZAMBIQUE III**	**1982**	1 Sep.	9 Sep.		Brinca *et al.*, 1983
55	**MOZAMBIQUE III**	**1982**	14 Sep.	30 Sep.		Brinca *et al.*, 1983
56	**TANZANIA II**	**1982**	12 Nov.	3 Dec.	IMR, 1982c	Iversen *et al.*, 1984
57	**KENYA III**	**1982**	7 Dec.	15 Dec.	IMR, 1982d	Iversen, 1984
58	**GULF OF OMAN**	**1983**	4 Feb.	2 Mar.		Gjøsæter & Tilseth, 1983; Strømme, 1986
59	**OMAN Muscat-Salalah Island**	**1983**	2 Mar.	19 Mar.	Strømme, 1983b	Strømme, 1986
60	**KENYA IV**	**1983**	2 May	8 May	Iversen, 1983	Iversen, 1984
61	**TANZANIA III**	**1983**	11 May	26 May	IMR, 1983b	Iversen *et al.*, 1984
62	**MOZAMBIQUE IV**	**1983**	29 May	8 Jun.		Brinca *et al.*, 1984
63	**MADAGASCAR**	**1983**	16 Jun.	28 Jun.	IMR, 1983b	
64	**MALDIVES**	**1983**	17 Aug.	28 Aug.	Strømme, 1983c	
65	**PAKISTAN**	**1983**	5 Sep.	16 Sep.	Nakken, 1983	IMR, 1986f
66	**IRAN**	**1983**	23 Sep.	1 Oct.	IMR, 1983c	
67	**OMAN**	**1983**	7 Nov.	11 Dec.	Strømme & Tilseth, 1984	Strømme, 1986
68	**PAKISTAN**	**1984**	20 Jan.	2 Feb.	IMR, 1984a	IMR, 1986f
69	**YEMEN**	**1984**	14 Feb.	28 Feb.	IMR, 1984b	Blindheim, 1984
70	**SOMALIA**	**1984**	28 Feb.	4 Mar.	IMR, 1984b	Blindheim, 1984; Strømme, 1984d
71	**ETHIOPIA**	**1984**	11 Mar.	20 Mar.	IMR, 1984b	Blindheim, 1984
72	**OMAN**	**1984**	29 Apr.	17 May	Strømme, 1984a	Strømme, 1986
73	**IRAN**	**1984**	21 May	23 May	Ona, 1984a	
74	**IRAN**	**1984**	30 May	2 Jun.	Ona, 1984a	
75	**PAKISTAN**	**1984**	2 Jun.	12 Jun.	Ona, 1984b	IMR, 1986f
76	**IRAN**	**1984**	12 Jun.	15 Jun.	Ona, 1984a	

77	**YEMEN**	**1984**	12 Aug.	24 Aug.	Strømme, 1984b	
78	**SOMALIA**	**1984**	25 Aug.	30 Aug.	Strømme, 1984c	Strømme, 1984d
79	**YEMEN**	**1984**	1 Sep.	4 Sep.	Strømme, 1984b	
	BREAK DOWN OF MAIN ENGINE AND REPLACEMENT IN GREECE					
80	**EGYPT (Nile Delta)**	**1984**	12 Dec.	17 Dec.	Strømme, 1985	
81	**ANGOLA I**	**1985**	28 Jan.	26 Feb.	IMR, 1985a	Strømme & Sætersdal, 1986 & 1991
82	**CONGO-GABON I**	**1985**	2 Mar.	15 Mar.	IMR, 1985b	IMR, 1986c
83	**ANGOLA II**	**1985**	23 Apr.	28 May	IMR, 1985c	Strømme & Sætersdal, 1986 & 1991
84	**CONGO-GABON II**	**1985**	30 May	12 Jun.	IMR, 1985d	IMR, 1986c
85	**ANGOLA III**	**1985**	8 Aug.	10 Sep.	IMR, 1985e	Strømme & Sætersdal, 1986 & 1991
86	**CONGO-GABON III**	**1985**	14 Sep.	27 Sep.	IMR, 1985f	IMR, 1986c
87	**ANGOLA IV**	**1985**	5 Nov.	5 Dec.	IMR, 1986a	Strømme & Sætersdal, 1986 & 1991
88	**CONGO-GABON IV**	**1985**	7 Dec.	18 Dec.	IMR, 1986b	IMR, 1986c
89	**ANGOLA V**	**1986**	21 Jan.	10 Mar.	IMR, 1986d	Strømme & Sætersdal, 1986 & 1991
90	**ANGOLA VI**	**1986**	22 Apr.	5 Jun.	IMR, 1986e	Strømme & Sætersdal, 1986 & 1991
91	**SHERBRO-BISSAGOS ISLANDS Sierra Leone, Guinea, Guinea Bissau)**	**1986**	19 Aug.	27 Aug.	IMR, 1987a	Strømme & Sætersdal, 1987a & b
92	**SENEGAL-THE GAMBIA (intercalibrations)**	**1986**	28 Aug.	5 Sep.	IMR, 1987a	Strømme & Sætersdal, 1987a & b
93	**GUINEA-BISSAU (off-shore)**	**1986**	7 Sep.	9 Sep.	IMR, 1987a	Strømme & Sætersdal, 1987a & b
94	**THE GAMBIA (trawl)**	**1986**	10 Sep.	12 Sep.	IMR, 1986g	Strømme & Sætersdal, 1987a & b
95	**MAURITANIA**	**1986**	14 Sep.	17 Sep.	IMR, 1987b	Strømme & Sætersdal, 1987a & b
96	**AGADIR-CAPE JUBY (repeated surveys)**	**1986**	23 Sep.	4 Oct.	IMR, 1986h	Strømme & Sætersdal, 1987a & b
97	**AGADIR-CAPE JUBY**	**1986**	6 Nov.	13 Nov.	IMR, 1987b	Strømme & Sætersdal, 1987a & b
98	**GUINEA BISSAU**	**1986**	23 Nov.	12 Dec.	IMR, 1987a	Strømme & Sætersdal, 1987a & b
99	**THE GAMBIA**	**1986**	27 Nov.	29 Nov.	IMR, 1987a	Strømme & Sætersdal, 1987a & b
100	**SENEGAL**	**1986**	2 Dec.	7 Dec.	IMR, 1987a	Strømme & Sætersdal, 1987a & b
101	**MAURITANIA**	**1986**	7 Dec.	12 Dec.	IMR, 1987a	Strømme & Sætersdal, 1987a & b
102	**PANAMA-COSTA RICA**	**1987**	4 Feb.	20 Feb.	IMR, 1987c	Strømme & Sætersdal, 1988a & b
103	**NICARAGUA-HONDURAS-EL SALVADOR**	**1987**	20 Feb.	3 Mar.	IMR, 1987d	Strømme & Sætersdal, 1988a & b

104	**GUATEMALA-MEXICO**	**1987**	4 Mar.	13 Mar.	IMR, 1987e	Strømme & Sætersdal, 1988a & b
105	**COLOMBIA, PANAMA, COSTA RICA**	**1987**	23 Apr.	19 May	IMR, 1987f	Strømme & Sætersdal, 1988a & b
106	**NICARAGUA-HONDURAS-EL SALVADOR**	**1987**	20 May	1 Jun.	IMR, 1987g	Strømme & Sætersdal, 1988a & b
107	**GUATEMALA-MEXICO**	**1987**	4 Jun.	13 Jun.	IMR, 1987h	Strømme & Sætersdal, 1988a & b
108	**COLOMBIA, PANAMA, COSTA RICA**	**1987**	4 Aug.	28 Aug.	IMR, 1987i	Strømme & Sætersdal, 1988a & b
109	**NICARAGUA-HONDURAS-EL SALVADOR**	**1987**	28 Aug.	10 Sep.	IMR, 1987j	Strømme & Sætersdal, 1988a & b
110	**GUATEMALA-MEXICO**	**1987**	11 Sep.	23 Sep.	IMR, 1987k	Strømme & Sætersdal, 1988a & b
111	**COLOMBIA, PANAMA, COSTA RICA**	**1987**	28 Oct.	17 Nov.	IMR, 1987l	Strømme & Sætersdal, 1988a & b
112	**NICARAGUA-HONDURAS-EL SALVADOR**	**1987**	17 Nov.	28 Nov.	IMR, 1987m	Strømme & Sætersdal, 1988a & b
113	**GUATEMALA-MEXICO**	**1987**	30 Nov.	8 Dec.	IMR, 1987n	Strømme & Sætersdal, 1988a & b
114	**GUIANAS (I-1)**	**1988**	21 Jan.	7 Feb.	IMR, 1988a	Strømme & Sætersdal, 1989a & 1989b
115	**TRINIDAD (I-2)**	**1988**	9 Feb.	14 Feb.	IMR, 1988b	Strømme & Sætersdal, 1989a & 1989b
116	**VENEZUELA (I-3)**	**1988**	15 Feb.	3 Mar.	IMR, 1988c	Strømme & Sætersdal, 1989a & 1989b
117	**COLOMBIA (I-4)**	**1988**	3 Mar.	11 Mar.	IMR, 1988d	Strømme & Sætersdal, 1989a & 1989b
118	**GUIANAS (II-1)**	**1988**	8 May	22 May	IMR, 1988e	Strømme & Sætersdal, 1989a & 1989b
119	**TRINIDAD (II-2)**	**1988**	23 May	29 May	IMR, 1988f	Strømme & Sætersdal, 1989a & 1989b
120	**VENEZUELA (II-3)**	**1988**	30 May	14 Jun.	IMR, 1988g	Strømme & Sætersdal, 1989a & 1989b
121	**COLOMBIA (II-4)**	**1988**	14 Jun.	21 Jun.	IMR, 1988h	Strømme & Sætersdal, 1989a & 1989b
122	**GUIANAS (III-1)**	**1988**	11 Aug.	23 Aug.	IMR, 1988i	Strømme & Sætersdal, 1989a & 1989b
123	**TRINIDAD (III-2)**	**1988**	23 Aug.	28 Aug.	IMR, 1988j	Strømme & Sætersdal, 1989a & 1989b
124	**VENEZUELA (III-3)**	**1988**	29 Aug.	15 Sep.	IMR, 1988k	Strømme & Sætersdal, 1989a & 1989b
125	**COLOMBIA (III-4)**	**1988**	15 Sep.	23 Sep.	IMR, 1988l	Strømme & Sætersdal, 1989a & 1989b
126	**GUIANAS (IV-1)**	**1988**	29 Oct.	12 Nov.	IMR, 1988m	Strømme & Sætersdal, 1989a & 1989b
127	**TRINIDAD (IV-2)**	**1988**	13 Nov.	20 Nov.	IMR, 1988n	Strømme & Sætersdal, 1989a & 1989b
128	**VENEZUELA (IV-3)**	**1988**	21 Nov.	6 Dec.	IMR, 1988o	Strømme & Sætersdal, 1989a & 1989b
129	**COLOMBIA (IV-4)**	**1988**	6 Dec.	11 Dec.	IMR, 1988p	Strømme & Sætersdal, 1989a & 1989b
130	**GABON-CONGO V**	**1989**	25 Jan.	8 Feb.	IMR, 1989a	
131	**ANGOLA VII**	**1989**	13 Feb.	16 Mar.	IMR, 1989b	Strømme & Sætersdal, 1991
132	**ANGOLA VIII**	**1989**	23	29	IMR, 1989c	Strømme & Sætersdal,

			Apr.	May		1991
133	**CONGO-GABON VI**	**1989**	31 May	12 Jun.	IMR, 1989d	
134	**CAPE SAFI-CAPE BLANC**	**1989**	27 Aug.	18 Sep.	IMR, 1989e	
135	**CÔTE d'IVOIRE-GHANA**	**1989**	11 Oct.	20 Oct.	IMR, 1989f	
136	**ANGOLA IX**	**1989**	17 Nov.	13 Dec.	IMR, 1989g	Strømme & Sætersdal, 1991
137	**NAMIBIA I**	**1990**	25 Jan.	22 Mar.	IMR, 1990a	
138	**MOZAMBIQUE V**	**1990**	21 Apr.	14 May	IMR, 1990b	
139	**NAMIBIA II**	**1990**	27 May	20 Jun.	IMR, 1990c	
140	**MOZAMBIQUE VI**	**1990**	9 Aug.	1 Sep.	IMR, 1990d	
141	**NAMIBIA III**	**1990**	11 Sep.	6 Oct.	IMR, 1990e	
142	**MOZAMBIQUE VII**	**1990**	6 Nov.	15 Dec.	IMR, 1990f	
143	**NAMIBIA IV (Part 1, hake)**	**1991**	25 Jan.	28 Feb.	IMR, 1991a	
144	**NAMIBIA IV (Part 2, pelagics)**	**1991**	2 Mar.	22 Mar.	IMR, 1991a	
145	**ANGOLA X**	**1991**	4 May	19 Jun.	IMR, 1991b	
146	**ANGOLA XI**	**1991**	6 Aug.	18 Sep.	IMR, 1991b	
147	**NAMIBIA V (Part 1, hake)**	**1991**	23 Oct.	22 Nov.	IMR, 1991c	
148	**NAMIBIA V (Part 2, pelagics)**	**1991**	23 Nov.	16 Dec.	IMR, 1991d	
149	**ANGOLA (Part of Namibia V Part 2, pelagics)**	**1991**	26 Nov.	29 Nov.	IMR, 1991e (in IMR, 1991d)	
150	**MOROCCO**	**1992**	16 Jan.	10 Feb.	IMR, 1992a	
151	**MAURITANIA**	**1992**	11 Feb.	19 Feb.	IMR, 1992b	
152	**SENEGAL-THE GAMBIA**	**1992**	19 Feb.	4 Mar.	IMR, 1992c	
153	**GUINEA BISSAU**	**1992**	5 Mar.	11 Mar.	IMR, 1992d	
154	**NAMIBIA VI (Part 1, hake)**	**1992**	23 Apr.	22 May	IMR, 1992e	
155	**NAMIBIA VI (Part 2, pelagics) (incl. ANGOLA)**	**1992**	24 May	21 Jun.	IMR, 1992e	
156	**ANGOLA XII**	**1992**	5 Aug.	22 Sep.	IMR, 1992f	
157	**NAMIBIA VII (Part 1, hake)**	**1992**	20 Oct.	1 Dec.	IMR, 1992g	
158	**NAMIBIA VII (Part 2, pelagics)**	**1992**	? Dec.	16 Dec.	Draft only	
159	**NAMIBIA VIII (Part 1, hake)**	**1993**	20 Jan.	25 Feb.	IMR, 1993a	
160	**NAMIBIA VIII (Part 2, pelagics) (incl. ANGOLA)**	**1993**	28 Feb.	19 Mar.	IMR, 1993a	
161	**NAMIBIA IX (Part 1, hake)**	**1993**	21 Apr.	25 May	IMR, 1993b	

162	**NAMIBIA IX (Part 2, pelagics) (incl. ANGOLA)**	**1993**	26 May	19 Jun.	IMR, 1993b

APPENDIX III LIST OF PARTICIPANTS FROM COOPERATING COUNTRIES

The list contains 347 names based on records contained in the original cruise reports. The institutions which the participants represented were unfortunately not identified in these records.

FAO and other UN personnel (23) formed part of the scientific staff on a number of surveys, often contributing expert knowledge in special fields, in particular taxonomy. A list of these participants is included.

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Jorge Nieto
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Mario Quiros
Carlos Rodriguez

Côte d'Ivoire 1981–89
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El Salvador 1987
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Gambia, The 1986–92
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Guatemala 1987
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Malaysia 1980
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