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## THE SHOALING BEHAVIOUR OF PELAGIC FISH AND THE DISTRIBUTION OF SEALS AND GANNETS OFF NAMIBIA AS DEDUCED FROM ROUTINE FISHING REPORTS, 1982-1985

R. M. THOMAS† AND F. H. SCHÜLEIN\*

Detailed fishing reports of the Namibian pelagic purse-seine fleet were used to elucidate circadian, lunar and seasonal variations in shoaling patterns of the South African pilchard *Sardinops ocellatus*, Cape anchovy *Engraulis capensis* and recruiting Cape horse mackerel *Trachurus trachurus capensis* in the northern Benguela system over the period 1982-1985. Data on the distribution of Cape fur seals *Arctocephalus pusillus* and Cape gannets *Morus capensis* per fishing position were also evaluated. Pilchard and adult anchovy tend to form comparatively large and fewer shoals during the day than at night, but recruiting anchovy and horse mackerel showed no meaningful day/night differences in shoal sizes. Normally, pilchard and anchovy shoals descended during the day and horse mackerel during the night. Most pelagic fish catches were made in the coastal regions between 19 and 23°S, but the distributions of seals and gannets at sea differed somewhat and also were not the same as those of the fish.

Uitvoerige visvangverslae van die Namibiese pelagiese beursnetvloot is aangewend om die nagenoeg daaglikse, lunêre en seisoensvariasies in skoolvormingspatrone van die Suid-Afrikaanse sardyn *Sardinops ocellatus*, Kaapse ansjovis *Engraulis capensis* en rekruterende Kaapse marsbanker *Trachurus trachurus capensis* van die noordelike Benguelasisteam op te klaar, dekkende die periode 1982-1985. Gegewens oor die verspreiding van Kaapse pelsrobbe *Arctocephalus pusillus* en Kaapse malgasse *Morus capensis* per visvangposisie is ook getakseer. Sardyne en volwasse ansjovisse neig om bedags betreklik groot en minder skole te vorm as snags, maar rekruterende ansjovisse en marsbanker het geen betekenisvolle dag/nagverskil in skoolgroottes vertoon nie. Sardyn- en ansjovisskole neig om bedags af te sak, en maasbanker snags. Die meeste pelagiese vangste is in die kusgebied tussen 19 en 23°S gemaak, maar die verspreidings van robbe en malgasse ter see het ietwat van mekaar en ook van dié van die vis verskil.

The general shoaling behaviour of South African pilchard *Sardinops ocellatus*, Cape anchovy *Engraulis capensis* and juvenile Cape horse mackerel *Trachurus trachurus capensis* encountered in the Benguela system off Namibia has, in part, already been investigated by Agenbag (1973), Cram and Agenbag (1973) and Hampton *et al.* (1979). However, those findings, based on combined aerial, acoustic and catch measurements taken during comparatively short surveys, were aimed at assessing the size of particularly the pilchard stock.

Shoaling records have also been collected from the commercial fishing fleet. Such information is considered to be more comprehensive and continuous in respect of circadian, lunar and seasonal shoaling patterns of the available fish stocks. It can also yield information on occurrences of such predators as Cape fur seals *Arctocephalus pusillus* and Cape gannets *Morus capensis* at catch positions.

Collection of shoaling records commenced in 1971, when the Namibian purse-seine fleet consisted of up to 110 vessels, most of which operated from Walvis Bay (23°S) and Lüderitz (26°50'S). A few others

operated that year in conjunction with the factory ship M.S. *Willem Barendz* at around 21°S. Because of the volume and sometimes questionable quality of the older data, however, the present analysis is restricted to the period 1982-1985 only. During that period, the fishing fleet comprised some 45-57 modern vessels operating out of Walvis Bay, but covering the entire pelagic fishing grounds in the coastal area between 17 and 27°10'S.

The fleet used large nets capable of catching up to 500 metric tons or more of fish per set and capable of being deployed close inshore, sea bed permitting. Adult pilchard were caught mostly with nets of 28-mm mesh and smaller fish, such as anchovy, juvenile horse mackerel and juvenile pilchard, with nets of 11-mm mesh. Some of the larger vessels were also equipped with refrigeration facilities to keep pilchard catches fresh for canning purposes.

The number of catch reports analysed in this study varied between 1 500 and 2 500 per fishing season, each report providing detailed summaries on every set made per fishing trip. Consistency in the trends identified from these records has encouraged the

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# PELAGIC FISHING REPORT

## (B form)

	OM/EN 851
A FORM	05216
Nos.	05217

BOAT <i>Duinekus</i>				SKIPPER <i>J. N. De Castro</i>	
BOAT REG. No <i>L 11</i>				INSPECTOR <i>APC</i>	
TIME AT SEA	DAY	MONTH	YEAR	HOUR (a.m.)	HOUR (p.m.)
DEPARTURE	<i>14</i>	<i>Mar</i>	<i>1985</i>		<i>22h00</i>
RETURN	<i>16</i>	<i>Mar</i>	<i>1985</i>	<i>11h00</i>	

### INDIVIDUAL THROWS

No.	DATE	TIME	FISH SPECIES	TONS	CATCH POSITION	FATHOMS	DEPTH OF SHOAL
1	<i>15/3</i>	<i>22h00</i>	<i>Pilchardis</i>	<i>20</i>	<i>204 A</i>	<i>78</i>	<i>3 - 8</i>
2	<i>16/3</i>	<i>02h00</i>	<i>"</i>	<i>80</i>	<i>"</i>	<i>78</i>	<i>5 - 10</i>
3							
4							
5							
6							
7							
8							
9							
10							

MARK WHERE APPLICABLE	1 Anchovy net	1 Catch unrefrigerated	5 R.S.W. for bait
	2 Pilchard net X	4 R.S.W. for canned fish X	6 Unrefrigerated for bait

### OBSERVATIONS

TALLY:	BOLYN	(given)	(taken)	BOAT
NUMBER OF NEGATIVE THROWS	<i>0</i>			NUMBER OF POSITIVE THROWS <i>2</i>
NUMBER OF BOATS IN VICINITY	<i>4</i>			DIR: FISH SHOALS <i>SW</i> SPEED <i>2</i>
WIND: DIRECTION	<i>SW</i>			SPEED <i>2</i> (knots)
CONDITION OF SEA	<i>low swell</i>			VISIBILITY <i>good</i>
SEALS (number)	<i>40</i>			GANNETS (number) <i>100</i>

Fig. 1: An example of a skipper report completed for each trip of the Namibian purse-seine fleet

present study, even though it must be conceded that the data are subject to various biases and human error. However, in an attempt to smooth undetected errors, the data were averaged.

The duration of the pelagic fishing season during the period of this study was normally from March until August. Over these months, the annual migration- and capture-cycles of each fish species showed

recurring seasonal patterns. For instance, adult pilchard (for canning) are caught mainly during March and April together with small catches of adult anchovy and juvenile horse mackerel (used for fishmeal). Anchovy recruitment normally starts in May, and the species is frequently mixed with juvenile pilchard and juvenile horse mackerel. Adult pilchard and adult anchovy are encountered mainly

in the north (20°S) and recruits in the central regions off Walvis Bay (Schülein 1974, Butterworth 1980, Le Clus and Melo 1981, 1982, Thomas *et al.* 1982, Cruickshank 1983).

## METHODS

An example of a fishing report from the pelagic fishery of Namibia is given in Figure 1. The tonnages per set pumped into the purse-seiner's hold are estimated by the skipper. Skippers are supplied with charts in which the fishing grounds are subdivided into numbered pool areas of 20 × 20 nautical miles. For each set, they record the number of the appropriate area as the catch position. "Fathoms" refers to the depth of the sea bed at which each set is made and "depth of shoal" to the position of the shoal below the vessel's echo-transducer. Only the depths of the top of each shoal were used in the analysis. The direction of fish-shoal movement is only approximated. The numbers of seals and gannets are estimated subjectively, the same subjectivity being applied to each set made per fishing trip. The other entries on the reports were not utilized for the present study.

## DATA ANALYSIS

### Skipper reports

The skipper reports were computer-checked for error by means of validation programmes. Times and dates of sets were examined for consistency by comparing them with

- (i) the times and dates of departure and return,
- (ii) the average travelling time to and from the fishing grounds, and
- (iii) the expected total fishing period, the latter based on the number of sets made.

The species composition and tonnage were compared with official inspection reports completed at the landing point. First, the sea depths given for the catch positions were checked against valid bottom depths for appropriate pool areas. In about 2 per cent of the reports, details on the date, fishing time, species and the tonnage of fish captured per set were omitted. However, it was found that such entries could often be completed ashore taking the information from other vessels in the vicinity. Catch positions were not recorded on about 0.5 per cent of the reports and, in those cases too, they were derived from other boats with a similar catch composition discharged during

that day. In cases where skippers had failed to enter the direction of fish-shoal movement, no attempt was made to deduce it. The age of the moon (in days) was obtained from a nautical almanac for each catch date.

The validated records were entered into a relational database, and a suite of FORTRAN programs was used to extract and analyse information on circadian, lunar and seasonal variations in shoaling patterns of the fish. The average distribution patterns of commercial fish catches and of seals and gannets per pool area were compiled by means of computer programs with the facility to select years, months, moon phases, species, individual boats, catch positions, depths of sea bed and catches with one or more species. Where the data were extracted for single fish species, only clean catches were selected. For the present study, the aspects investigated are listed below.

*Number of sets per hour, and day/night differences* — Sets were grouped into hourly intervals to determine the hourly set frequencies for pilchard, anchovy and horse mackerel. Such set frequencies were further grouped into day (07h00–18h59) and night (19h00–06h59) periods to investigate, by means of a  $\chi^2$  test, whether there was a significant day/night difference.

*Mean tonnage per set per hour, and day/night differences* — The sets per species, grouped into hourly intervals, were further used to calculate mean tonnage caught per hour and to detect whether catches were heavier at certain times of the day. The day/night differences were tested for significance by means of a *t*-test.

*Number of sets and catch sizes per moon phase* — Sets per species were grouped into five phases of the lunar month to determine whether the shoaling pattern was also affected by the moon. Moon ages of 14–19 days correspond to full moon and 26–01 days to new moon.

*Frequencies of direction of fish-shoal movement* — The directions of fish-shoal movement per set were grouped according to the entries on the skipper reports (N, NE, E, SE, S, SW, W, NW), then used to determine the frequencies per direction. Directions recorded as "variable" were ignored.

*Mean shoaling depth per hour, and day/night differences* — Sets per species, grouped into hourly intervals, were used to calculate the mean shoal depth per hour and to detect whether the shoals migrated vertically at certain times of the day. Shoal depth, as already stated, referred only to the top of the shoal. Day/night differences were tested for significance by

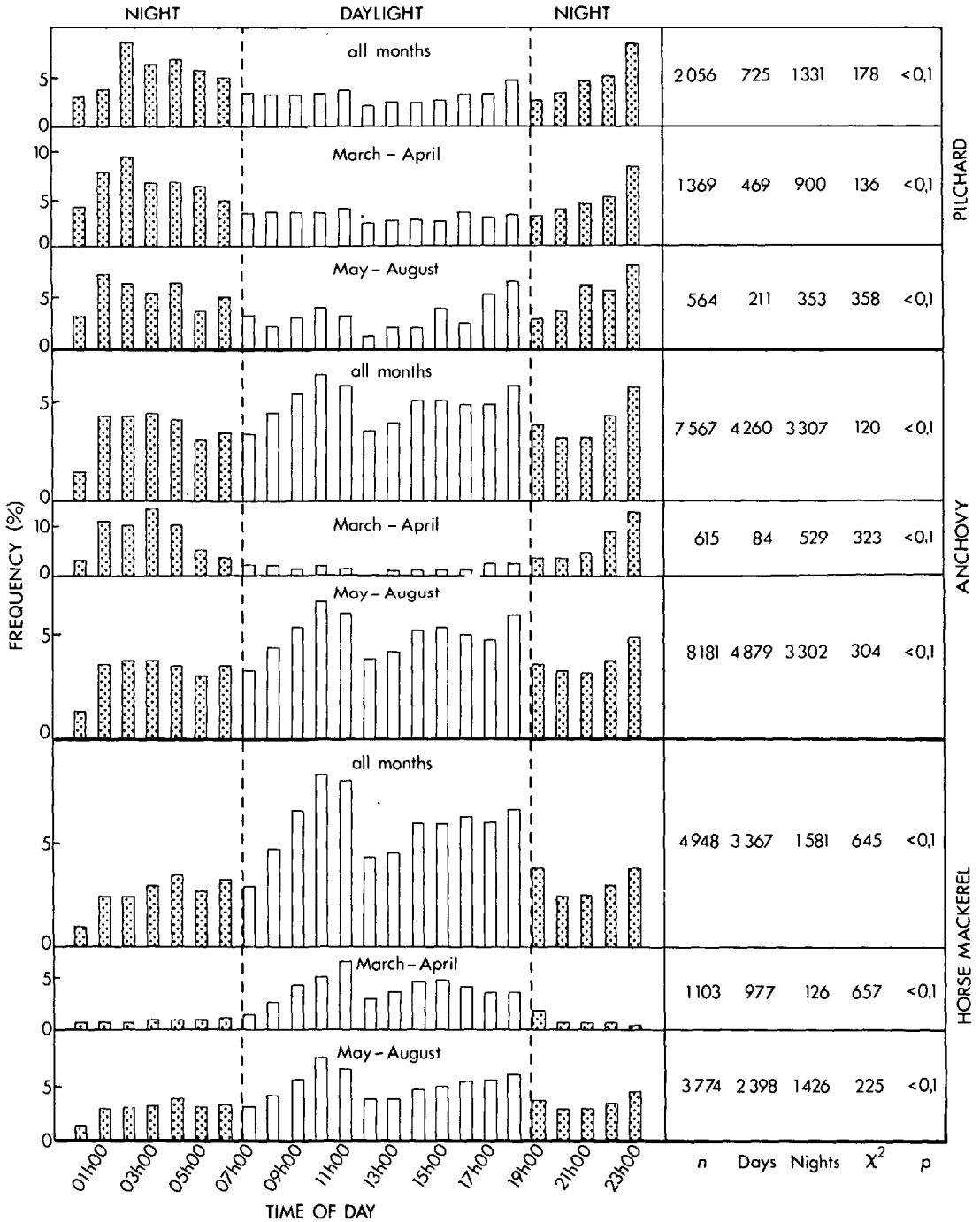


Fig. 2: Percentage frequency by time of day of catches of pilchard, anchovy and horse mackerel made by the Namibian purse-seine fleet for the 1982-1985 fishing seasons combined and for March-April (autumn) and May-August (winter) of the same years. Summaries of catch frequencies by day and night and  $\chi^2$  test results are listed

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means of a *t*-test.

*Catch frequencies per pool area* — The numbers of sets made per pool area were determined by direct addition of all catch returns available. The summaries were mapped and contoured for comparison with seal and gannet distributions over the same period.

*Seals per fishing area* — The estimated number of seals per fishing trip was applied to each set made during that trip. Averages were determined from totals per numbered pool area, then mapped and contoured for comparison with catch frequencies.

*Gannets per fishing area* — The gannet density was computed, mapped and contoured as for seals. However, only sets made by day were used because gannets are not usually active at night.

### Biases in the data

As it is very likely that fishermen vary in the accuracy with which they complete their catch reports, it is necessary to detect sources of possible systematic bias. For example, some skippers were suspected of having entered the times of sets at random or entered the same times on every trip. In order to check on this source of bias, a table of frequency per hour was compiled for each boat operating within a selected area over a given period when strong circadian variations were recorded by a large number of vessels. It was reasoned that skippers who habitually recorded random or unreliable catch times would differ from the total fleet. Odd records were then rejected.

It was also suspected that some skippers may have entered the same direction of fish-shoal movement on each report. To eliminate this bias, all direction entries of those skippers who gave an uninterrupted series or more than 50 per cent of the same direction were not incorporated in the calculations.

Estimating numbers of seals and gannets at sea is very difficult, and such records are inevitably subject to many uncertainties and other biases. Nevertheless, the data were used, but all entries of those skippers who gave the same number in more than 50 per cent of their reports were not incorporated in the calculations.

## RESULTS

During the four seasons from which these data

were drawn (1982–1985), the purse-seine fleet made 5 924 trips and 17 283 sets. The number of sets per trip varied only slightly each year, being highest at 3,00 in 1984 and lowest at 2,86 in 1983.

### Tests for bias

Analysis of the frequency of clean anchovy catches per hour during 1983 revealed that 86 per cent of the sets were made in daylight (1 706 of 1 990 sets). During that year, reports from 52 purse-seiners were examined and all gave a strong daytime peak, suggesting good reliability of the data.

Entries on the direction of fish-shoal movement were frequently omitted by some skippers, but none of the remainder gave only a single direction, suggesting that the records are fairly reliable. This conclusion was further confirmed by the fact that the entries of most skippers showed good correspondence in variations per time and area.

Depth of shoal was another parameter frequently omitted by skippers. Such cases were erroneously coded as zero, thereby being confused with the true zero recordings. This unfortunate mistake could not be rectified, but it was overcome by ignoring all zero codings, with the result that the mean shoal depth was biased downwards. However, no corrections were made for transducer depth, and the mean shoal depth was therefore compensated upwards (by about one fathom).

On the usefulness of seal numbers recorded, only 24 sets of data were considered acceptable on the basis of the criterion stated previously. Likewise, for gannets, only 23 data sets were considered usable, though these were not the same sets as for seals.

### The data

#### NUMBER OF SETS PER HOUR, AND DAY/NIGHT DIFFERENCES

The numbers of sets per hour for each species during the period 1982–1985 are shown in Figure 2, together with the same details for March–April (autumn) and May–August (winter).

Pilchard catch frequencies were significantly higher at night than in the day ( $p < 0,1$ ), both in autumn and in winter (Figs 2a–c). Catch frequencies of anchovy and horse mackerel, on the other hand, were more frequent by day ( $p < 0,1$ ), showing peaks at about 10h00 and again at 17h00 for the data for all months combined (Figs 2d, g). However, in autumn, the catch frequency of anchovy was significantly higher

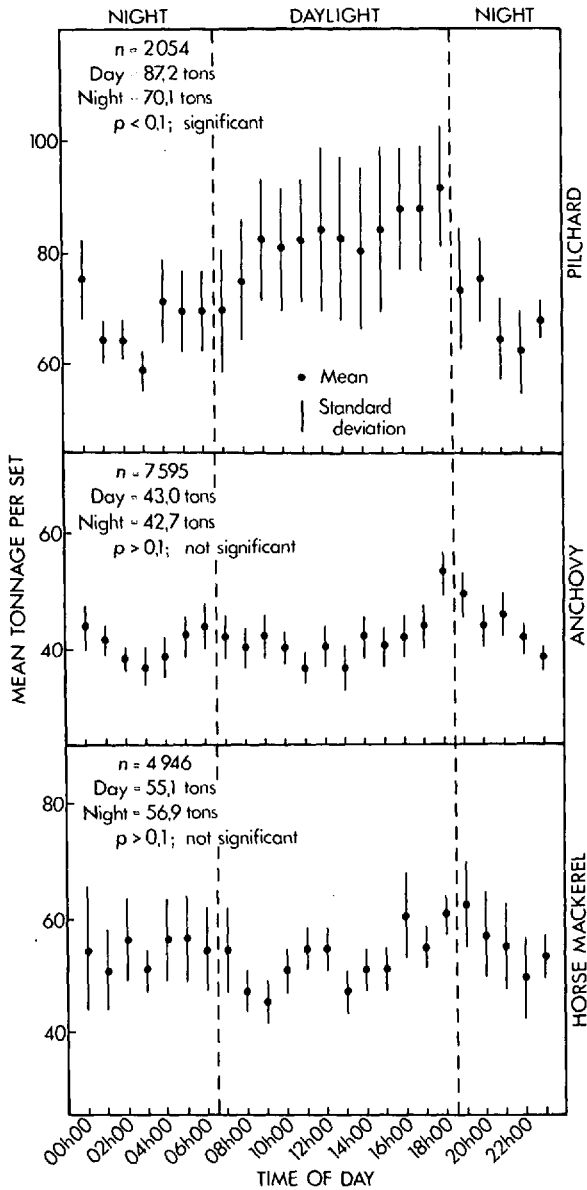


Fig. 3: The mean catch per set by time of day of pilchard, anchovy and horse mackerel of the Namibian purse-seine fleet, 1982-1985. Summaries of average catch sizes by day and by night are listed

at night ( $p < 0,1$ ) whereas, in winter, most sets were made by day ( $p < 0,1$ ) — Figs 2e, f.

Apparently, few catches were made at midnight, but on comparing such declarations with those for the periods shortly before and after midnight, the

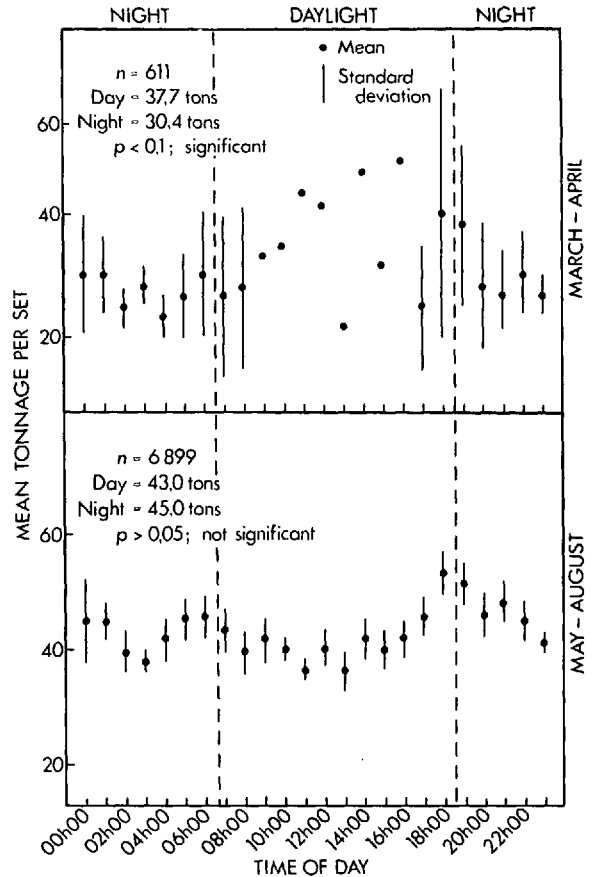


Fig. 4: The mean tonnage per set by time of day of anchovy catches by the Namibian purse-seine fleet for autumn (March-April) and winter (May-August), 1982-1985. Summaries of average catch sizes by day and by night and statistical test results are listed

conclusion was reached that there is a bias against reporting midnight as the time of set.

MEAN TONNAGE PER SET PER HOUR, AND DAY/NIGHT DIFFERENCES

The largest catch sizes were for pilchard (76,1 tons, s.d. 51 tons), followed by horse mackerel (55,7 tons, s.d. 55 tons) and anchovy (42,9 tons, s.d. 37 tons).

The mean tonnage per set throughout 24 hours is shown in Figure 3. Pilchard catches were significantly larger by day than by night ( $p < 0,1$ ). On the other hand, catches of anchovy and horse mackerel showed no significant day/night differences ( $p > 0,1$ ). Never-

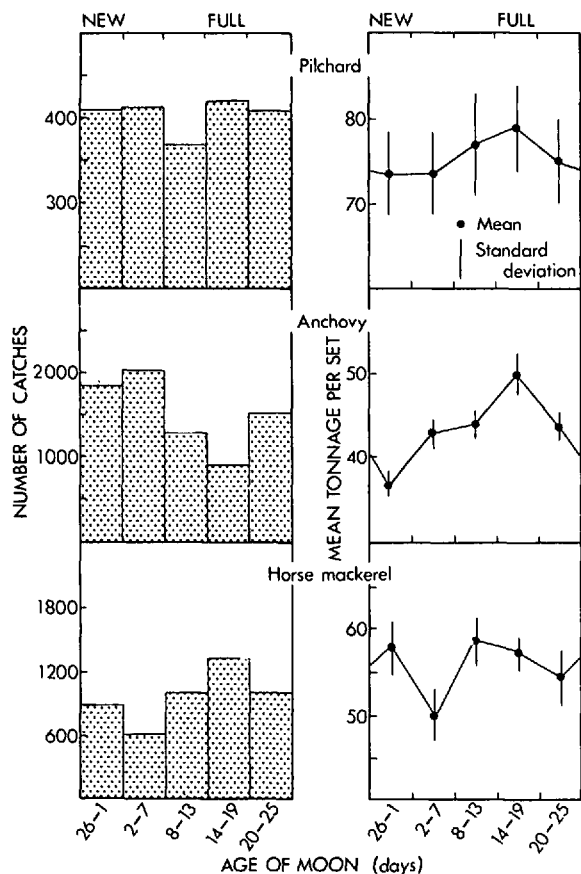


Fig. 5: The number of catches and mean tonnage per set per moon phase for pilchard, anchovy and horse mackerel captured by the Namibian purse-seine fleet, 1982-1985

theless, for anchovy, there was a significant rise in daylight catching during autumn ( $p < 0,1$ ), though no meaningful day/night difference for winter ( $p > 0,5$ ) --- Fig. 4.

NUMBER OF SETS AND CATCH SIZES PER MOON PHASE

Mean catch frequency and mean tonnage per set per species at five different phases of the moon are shown in Figure 5. It seems that pilchard catches tend to be slightly larger and more frequent during full moon than during the other phases. Anchovy catches appear to be scarcer but larger and juvenile horse-mackerel catches most frequent at full moon. However, mean tonnages display a rather irregular

Table I: Frequencies of direction of pelagic fish-shoal movement off Namibia, 1982-1985

Direction	Frequency (%)
N	3,6
NE	7,6
E	3,0
SE	31,7
S	27,0
SW	20,1
W	2,0
NW	5,0

$n = 14\ 597$

pattern per set during the different phases of the moon.

FREQUENCY OF DIRECTION OF FISH-SHOAL MOVEMENT

The frequency of direction of fish-shoal movement is shown in Table I. The most common course was SE, and 79 per cent of fish shoals were moving in a southerly direction.

MEAN SHOALING DEPTH PER HOUR, AND DAY/NIGHT DIFFERENCES

The results of the analysis of shoaling depths per species by time of day (Fig. 6) reveal that pilchard shoals were usually nearest the surface at 02h00, 07h00, 17h00 and 20h00 (3 fathoms) and deepest at 12h00 and 13h00 (5 fathoms). The day/night differences were, however, insignificant ( $p > 0,05$ ). Anchovy shoals tended to be nearest the surface between 20h00 and 06h00 (2 fathoms) and deepest between 10h00 and 14h00 (7 fathoms). The day/night differences were highly significant for this species ( $p < 0,001$ ).

Finally, the positions of horse-mackerel shoals in the water column fluctuated erratically, though the deepest recordings were usually made at night and those closest to the surface by day. The day/night differences were also highly significant ( $p < 0,01$ ).

CATCH FREQUENCIES PER POOL AREA

Analyses of catch frequencies per pool area (Fig. 7) reveal that pelagic fish were caught along almost the entire coast between the Cunene River ( $17^{\circ} 10'S$ ) and the Orange River ( $28^{\circ} 30'S$ ), mostly within 20 miles of the coast. However, no catches were made between Lüderitz ( $26^{\circ} 40'S$ ) and Chamais Bay ( $28^{\circ} S$ ) during the period of this analysis. Comparatively high catch



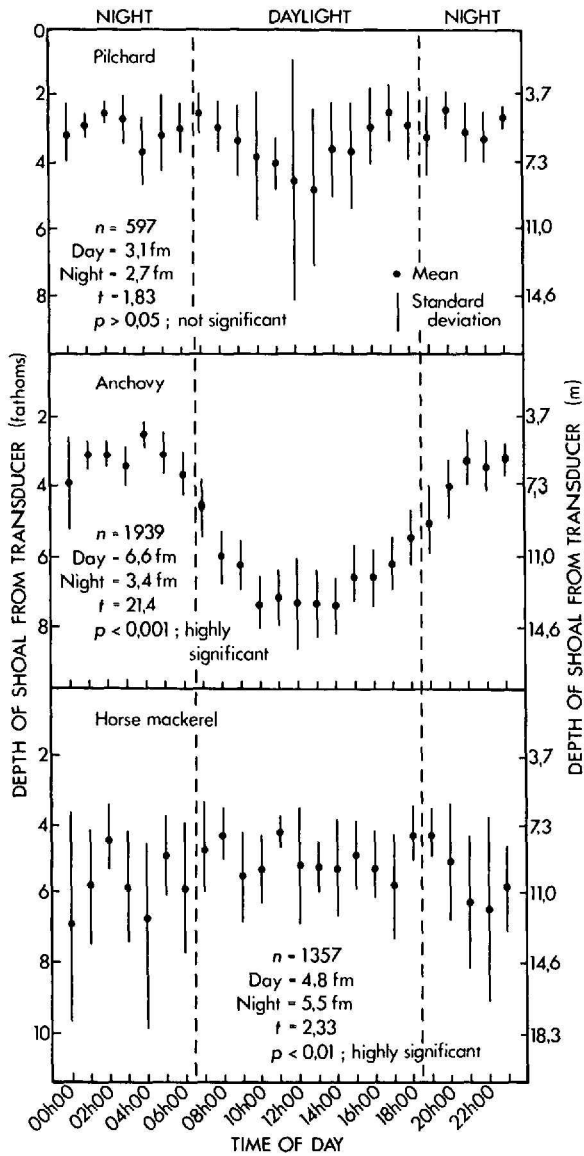


Fig. 6: The mean shoaling depth by time of day of pilchard, anchovy and horse mackerel captured by the Namibian purse-seine fleet, 1982-1985, summaries of average depths of the shoals by day and by night, and results of the statistical tests

frequencies, > 200 sets per pool area, were recorded inshore between Cape Frio (18° 30'S) and Cape Cross (21° 30'S), between Henties Bay (22° S) and Conception Bay (24° S), and around Hollams Bird Island (24° 30'S). Catches decreased in frequency north of Cape Frio, south of Hollams Bird Island and progres-

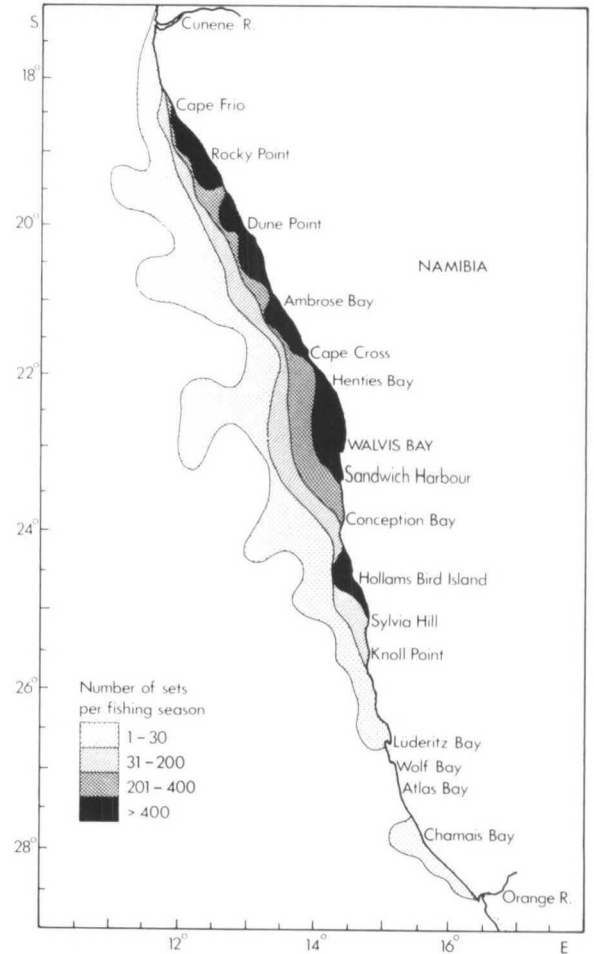


Fig. 7: The distribution of catch frequencies of pelagic fish per area by the Namibian purse-seine fleet, 1982-1985

sively offshore, though isolated catches were made up to 110 miles from the coast.

SEALS PER FISHING AREA

Available data on the relative numbers of seals at fishing sets within each pool area (Fig. 8) show that seals were common along the entire coast, though between Lüderitz and Chamais Bay no sets were made and so their occurrence there cannot be deduced. The highest concentrations (≥ 300 seals per set) were in an extended area starting offshore 30 miles south of Cape Cross, spreading northwards over a wide area (both inshore and offshore) off Ambrose Bay (21° S) and ending in a broad belt at

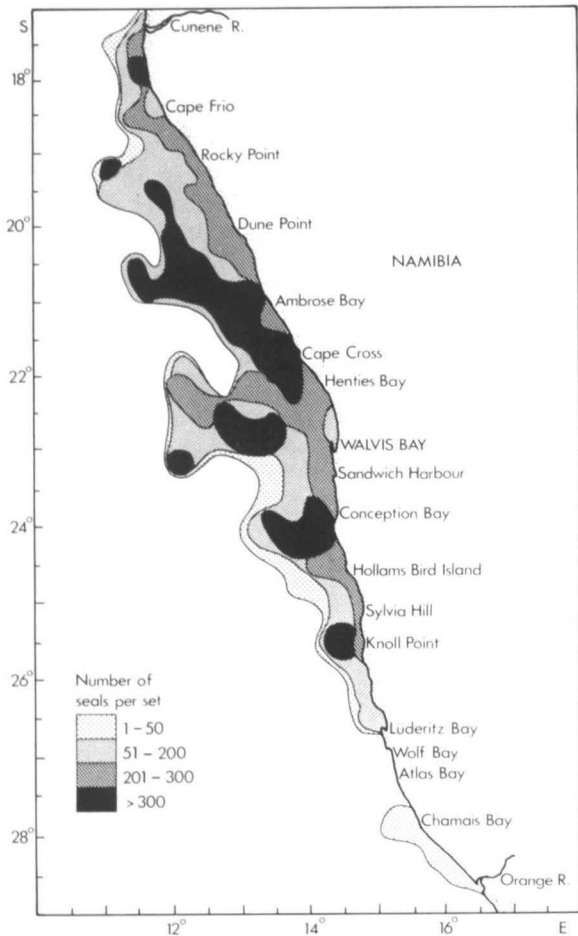


Fig. 8: The distribution of estimated seal numbers per set made by the Namibian purse-seine fleet, 1982-1985

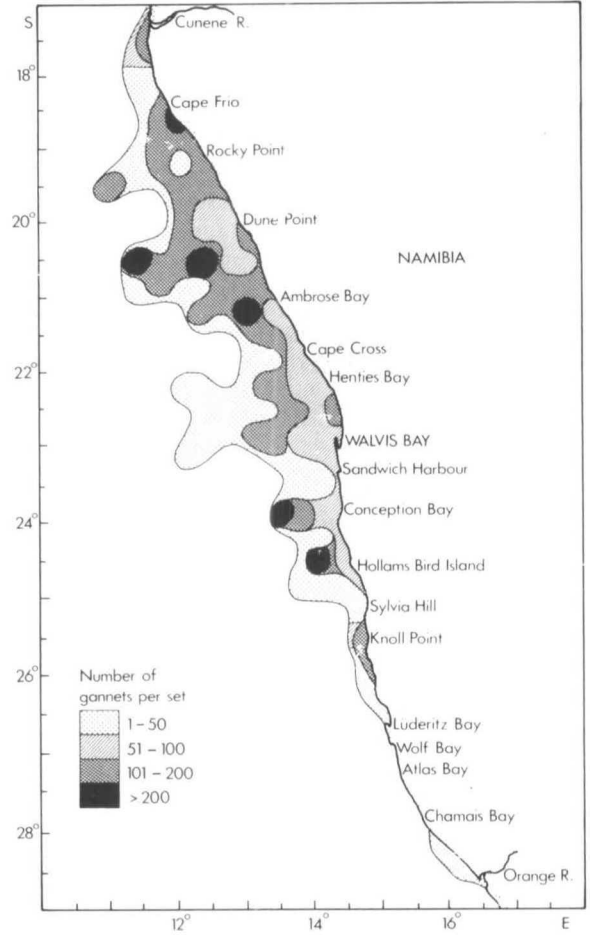


Fig. 9: The distribution of estimated gannet numbers per set made by the Namibian purse-seine fleet, 1982-1985

about 19°30'S at a distance between 30 and 60 miles from the coast. High densities were also found inshore near the mouth of the Cunene River, offshore off Walvis Bay, off Conception Bay and off Knoll Point (25°30'S). In general, densities tended to decrease offshore, but they were still fairly high offshore between Rocky Point (19°S) and Dune Point (20°S), off Ambrose Bay, off Walvis Bay and off Conception Bay. Their numbers were comparatively low in the south, between Chamais Bay and the mouth of the Orange River.

#### GANNETS PER FISHING AREA

The chart of relative numbers of gannets per pool area (Fig. 9) shows that these predators too were

present along the entire coast between the Cunene and Orange rivers. Again, of course, no statement can be made for the region between Lüderitz and Chamais Bay, because no sets were made there. The highest concentrations ( $\geq 200$  per set) were in small, isolated patches along the entire coast. There seem, also, to have been more gannets offshore than inshore (Hollams Bird Island — north of Dune Point) except in the extreme north between Rocky Point and the Cunene River, where the densest concentrations were near the coast. Not surprisingly, the offshore contour of their distribution displays the same indentations as those of the catch and seal records. Also, there were comparatively few gannets in the south, between Chamais Bay and the Orange River, the same as for the catch records and seals.

## DISCUSSION AND CONCLUSIONS

The results presented have shown that routine fishing reports of skippers of a large fleet operating continuously and synoptically have a potential use as a data source for comprehensive studies on the shoaling behaviour of pelagic fish stocks. However, it must be conceded that such studies cannot provide full details on the general behaviour pattern of an entire commercial stock because fishing skippers normally first attempt to catch the largest shoals nearest their home port. Further, findings based on commercial records would obviously be affected by such factors as catch restrictions, varying fishing regulations and techniques, differences in vessel and net sizes, and most likely also by the personal attitudes of skippers towards the completion of data forms. Such variables were not evaluated in this study because the emphasis was on reviewing validated catch returns. Nevertheless, the entries on the skipper reports showed good similarity and consistency of synoptic events, suggesting a high level of reliability.

Entries on the catch times must be biased because each successful set may take between one and two hours (or more if problems are encountered) and skippers are not in the habit of checking their clocks at the moment of setting the net. Also, the fact that catch rates apparently dip at midnight (00h00) and midday (12h00) suggest that skippers are averse to entering these times in particular; hence the crepuscular appearance of these results.

Reported tonnages per set are considered fairly reliable because most skippers are well aware of their vessel's hold capacity. Also, tonnages per set may well approximate the actual shoal size because, during the period under review, most shoals were, in fact, small. Analysis of such catch data would therefore create no spurious trends in diurnal shoaling patterns of these fish.

### Distribution of sets by time, tonnage per set and day/night differences

Catch frequencies of pilchard (Figs 2a–c) and their average size (Fig. 3a) lead to the conclusion that this species tends to form scattered and small shoals by night and dense, large shoals by day. Of course, this catch pattern may, in some respect, be ascribed to the fact that larger catches take slightly longer to pump aboard than smaller ones, thereby allowing more smaller catches to be made at night. However, fish can be pumped aboard rapidly once a net has been

hauled (100 tons takes only some 20 minutes more to pump than 50 tons), so differences in catch size are concluded to be an unimportant factor in this analysis.

The mean pilchard catch was 87,2 tons per set by day and 70,1 tons by night (Fig. 3a). This day/night difference has also been discussed by Hampton *et al.* (1979), who showed that the packing density of pilchard shoals off Namibia increased by a factor of 4,3 during daylight, implying that these shoals were more compact during the day than at night. Other clupeoid stocks display the same behaviour. For example, the Japanese sardine *Sardinops melanosticta* forms compact shoals in daylight and scattered surface shoals at night (Hara 1985).

Anchovy catches tended to be more frequent but slightly larger by day than by night, but the diel differences were rather insignificant over the period reviewed. Most of the largest catches were made at 18h00, and the most frequent catches of smaller shoals were made at 10h00–11h00 (Figs 2d, 3b). The apparent shoaling pattern would appear to conflict with observations on other anchovy stocks. For example, shoals of *Engraulis anchoita* off Argentina normally aggregate by day and disperse by night (Matsumiya and Hayase 1982). The same applies to *E. mordax* off California (Squire 1972, Mais 1977) and *E. japonicus* off Japan (Aoyama and Mimoto 1970, cited by Matsumiya and Hayase *op. cit.*). However, in autumn, anchovy off Namibia seem to follow the same trend as that of other anchovy stocks (Figs 2e, 4a). It is therefore only in winter (Figs 2f, 4b) that the Namibian anchovy stock seems to display unusual shoaling trends.

Catches of anchovy in autumn tend to be smaller than in winter, and the peak times are different too, 16h00 in autumn and 18h00 in winter (Fig. 4). Autumn catches are usually dominated by adult anchovy (9–12 cm standard length  $L_c$ ), netted inshore north of Ambrose Bay, and winter catches by small recruits (5–10 cm), captured near Walvis Bay and farther offshore (Schülein 1986). Therefore, the seasonal shift in the circadian shoaling pattern of the anchovy stock may well be directly associated with an annual recruitment cycle which normally dominates the overall picture (Fig. 2d).

Adult *E. capensis* also show the same shoaling pattern as those of the anchovy stocks off Argentina and California. However, there is no information in the cited literature on length or age of anchovy in the other two areas, though Matsumiya and Hayase (1982) do state that the Argentinian catch was mostly adults. Findings on the shoaling patterns of anchovy off California were on the basis of aerial (Squire 1972) and acoustic monitoring (Mais 1977), i.e. more

indirect techniques than actual catch data.

The apparent differences in the circadian shoaling behaviour of adult and juvenile anchovy in the northern Benguela system may perhaps be ascribed to differences in feeding habits. King and Macleod (1976) have shown that juveniles (< 8 cm) are particulate zooplankton feeders, whereas large recruits and adults feed mainly on phytoplankton. Thus, anchovy would normally change their basic feeding habit and possibly also their shoaling pattern at a length of some 8 cm. However, feeding studies by James (1987) on anchovy in the southern Benguela system have shown that selective feeding is dominant over filter-feeding in each length and age group. James also found that juveniles feed mostly between 19h00 and 21h00 and adults at about 16h00 and between 23h00 and 09h00. It consequently seems that adult and juvenile *E. capensis* have similar feeding patterns, and therefore the differences in their shoaling cycles should be ascribed to other ecological factors.

Horse mackerel caught by the purse-seine fleet are usually juveniles (<20 cm  $L_c$ ), which normally feed on zooplankton (Venter 1976). They are caught mainly in daylight throughout the fishing season (Fig. 2g). Larger catches tend to be made at 16h00 and 19h00, and the small ones at about 09h00 and 13h00 (Fig. 3c). It would therefore appear that juvenile horse mackerel usually form large shoals in the late afternoon and early evening, but that they scatter into smaller shoals by day. The fullest stomachs and the highest percentage of undigested gut contents are usually recorded between 12h00 and 16h00, implying that most feeding is in daylight (Venter op. cit.) when the shoal sizes seem to be smaller. Adult horse mackerel are not caught by purse-seiners, because they move offshore into mid-water, where they apparently feed at night (Venter op. cit.).

#### Number of sets and catch sizes per moon phase

Pilchard catches tend to be more frequent and the shoal size larger during a full moon than during a new moon (see Fig. 5). The smallest catches tend to be made shortly after new moon, after which the shoals seem to aggregate, a conclusion drawn from the finding that catches are less frequent but larger during the phase prior to full moon. Anchovy catches tend to be less frequent but noticeably larger during full moon than during new moon. It is assumed therefore that shoal size is usually larger during full moon. The catches and shoal sizes of juvenile horse mackerel tend to be largest during new moon and again shortly before full moon. Catch frequencies

seem to peak during full moon, when the mean catch sizes are still comparatively large.

It is concluded that all three species form comparatively large shoals during full moon. Pilchard possibly show the least response to the lunar cycle, horse mackerel the most erratic and anchovy a clearer response. The reasons for such trends and differences warrant further investigation.

#### Directions of fish-shoal movement

The pelagic fish shoals off Namibia move mainly in a south-easterly, a southerly or a south-westerly direction (Table I). Fishermen have consequently claimed that these fish may eventually recruit to the South African fishery (Anon. 1983, Duffy and Boyd 1983). However, studies by Newman (1970), Newman and Schülein (1973), Cruickshank (1983) and Schülein (1986) have indicated that the stocks of pelagic fish off Namibia are distinct from those off the Western Cape, though a small degree of intermingling does occur. Therefore, virtually all south-moving fish would ultimately return north, possibly as scattered fish or outside the fishing season.

The consistent southward movement of fish reported by skippers may, to some extent, also be explained by the technique employed to catch them. Skippers commonly approach their targets from the leeward side in an attempt to scare the shoal *towards* the prevailing wind direction. This is done to ensure that the shoal moves into the net while it is encircled, and that the vessel will not drift over the net while pursuing, hauling and pumping. As the coastal winds off Namibia are predominantly from the south, the direction of shoal movement could thus be manipulated into a southerly direction prior to and during the set operation.

#### Mean shoaling depth per hour, and day/night differences

Agenbag (1973) found that pelagic fish shoals descend from about 7 m by night to about 15 m by midday. However, these findings are not wholly supported by the result of the present investigation.

Comparison of commercial fish shoaling records in Figure 6 shows that pilchard apparently undertake no significant vertical migration, although most tend to shoal at a depth of about 4 m during the night, dawn and dusk (at 02h00, 07h00, 17h00, 20h00 and 23h00), or at about 8 m during the day (12h00–13h00). Anchovy do undertake a significant vertical migration under average conditions, being found

shallowest at about 6 m at night (21h00–05h00; 7,3 m at 00h00 ignored) and at their deepest of about 13 m at midday (10h00–14h00). Anchovy have been recorded down to 130–260 m off California (Mais 1977), but shoals at such depths have not been observed off Namibia. Horse mackerel perform a most erratic, but still significant, diel migration pattern. The shoals nearest the surface at about 7 m are usually recorded during the day (at 08h00, 11h00 and 18h00) and the deepest ones at about 12 m by night (21h00–22h00, 00h00 and 04h00).

### Distributions of catches and predators

The data presented in Figure 7 show that most pelagic fish shoals were caught within 20 nautical miles of the coast and between 18°30' and 24°S. Seals and gannets tended to be farther offshore and between 17 and about 26°S (Figs 8, 9). Of course, the distribution maps apply to the fishing seasons only (March–August each year), and such records are further based on averages of rough estimates for observations at catch positions only. However, the shortcomings with regards to their appropriateness are considered to be largely overcome by averaging the vast number of available records, thereby providing at least a useful picture for comparison with the catch records in Figure 7.

Seal colonies are located at Cape Cross (22°S, c. 20 000 pups per year), Hollams Bird Island (24°40'S, < 3 000 pups), Lüderitz (26°50'S, < 3 000 pups), Wolf Bay (27°S, > 35 000 pups) and at Atlas Bay (27°10'S, > 70 000 pups) — Butterworth *et al.* (1987). Pups are born mostly during November and weaned in about June, and nursing females spend most of their time on land over this period (Rand 1959). Non-breeding colonies are located at False Cape Frio (18°30'S, 3 000 seals) and Pelican Point (23°S, < 50 seals) — Shaughnessy (1987). Seal distribution at sea therefore reveals no obvious relationship with the location of their colonies ashore. The high numbers occasionally recorded offshore suggest that they are being attracted by fish aggregations not readily available to the commercial purse-seine fleet. These fish were mostly pilchard, anchovy, horse mackerel or occasionally juvenile hake (*Merluccius* spp.), which usually form very small shoals close to the sea surface in the deep (pers. obs.). Seals (and gannets) are, of course, also attracted by fishing vessels.

Gannets breed at Mercury (25°30'S), Ichaboe (26°30'S) and Possession islands (27°S) off the coast of Namibia. Their main egg-laying season is August–December, and some of their chicks are fed until

March or even until April (MacLean 1985). Juvenile and non-breeding gannets, as well as a few breeding birds during foraging trips, may spend nights at sea, and the foraging distances of breeding birds may range up to 300 km from their nest, depending on the availability of food (A. Berruti, Sea Fisheries Research Institute, pers. comm.). Gannets north of 21°S off Namibia would therefore be mostly non-breeders and juveniles. Cape gannets have been recorded north of the equator (Broekhuysen *et al.* 1961, Crawford *et al.* 1985).

The distribution of gannets at sea determined from the present study (Fig. 9) confirms a prey preference for pilchard and anchovy in the north, a conclusion drawn from the fact that they do not exploit the resource of pelagic goby *Sufflogobius bibarbatulus* located between 22 and 27°S or near their breeding locations in the south (Crawford *et al.* op. cit.). Gannet numbers have declined drastically since the collapse of the Namibian pilchard stock during the 1970s (Crawford *et al.* 1981, 1983), after which the remnants of the pilchard stock were found mostly north of Walvis Bay (Thomas 1986). The general distribution pattern of gannets at sea is similar to that of seals for the same period, suggesting a similar diet for at least parts of the stocks of these predators.

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