where these were presented on the same scale. There was continuous critical interaction between the participants. A tape-recording was made of the entire proceedings and a transcript is now being prepared.

The purpose of the Workshop was to compile maps which listed, with all the rigour possible in July 1979, the reuniting of the now separated fragments of Gondwanaland—especially the fit between West and East Gondwanaland. Newly acquired marine data promised important advances.

Drs M. McElhinny and B. Embleton brought to the Workshop tables listing the latitude and longitude of the palaeomagnetic poles (at the specific times 30, 40, 53, 65, 80, 127 and 160 Myr ago) for each of the Gondwanaland continents; in some cases such data were not readily available, but for many of the continents they can be interpolated. When a topic such as the India-Africa fit was analysed it was introduced by marine geophysicists who (using ocean magnetic anomaly and fracture zone data) retraced the movement of India relevant to Africa for the time interval 'present day' – 30 Myr; thus the marine geophysicists define a specific pole and angle of rotation. The 30 Myr Indian palaeomagnetic pole (from the McElhinny/Embleton tables) was then rotated with India and its new latitude and longitude listed.

From the closeness of fit of the 30 Myr African and (rotated) Indian palaeomagnetic poles the Workshop was able to assess the mutual consistency of the seafloor spreading and palaeomagnetic data. This same operation was repeated for the time-bracket 30 → 40 Myr ago, then for the time-bracket 40 – 53 Myr ago and so on. Then the Workshop moved to the next pair of continents (India/Australia).

The most important single result of the Workshop was the demonstration that current available palaeomagnetic data are consistent with the history of Gondwanaland dispersal recorded in a forthcoming paper by I. O. Norton and J. C. Sclater and, in very general terms, with the Smith-Hallam reconstruction. When the seafloor spreading data are rigorously followed, there is an outstanding problem in regard to the 'overlap' of the Antarctic Peninsula and the Falkland Plateau. There was continued evaluation of data from the southernmost part of South America and from West Antarctica, in the light of the meagre seafloor data from the Weddell Sea and the previously contiguous portions of the Mozambique Basin and environs. The consensus of the Workshop was that reassembly of this specific region of Gondwanaland could best be achieved by splitting West Gondwanaland into three sub-plates, termed Filchner, Ellsworth and Mariebyrd fragments, respectively.

The Workshop took the decision (on 6 July 1979) to continue work by assembling a map, on the scale 1:10 000 000, which will be called Gondwanaland Reunited. It will be a geologic map, with tectonic trends and (where possible) geochronology and resource data added. Coordinators were appointed for this very great task and it is hoped that the first draft will be available for review at the Gondwanaland Conference in New Zealand in February 1980.

A further practical result was the definition of a number of key areas in the ocean basins separating the fragments of Gondwanaland, where there is an urgent need for geophysical and IPOD drilling data. The meeting recognised that, in the precise fitting of West Gondwanaland against East Gondwanaland, there were major problems which were still unsolved. Nevertheless the gains which would come from a geologic map of Gondwanaland would surely justify the great effort needed to produce it.

The meeting also decided to assemble a map, using the present outlines of the continents and the relevant seafloor data, which highlights the state of Gondwanaland dispersal 65 Myr ago. It will probably be on the scale 1:20 000 000 and will be published with a slim volume recording the proceedings of the Workshop and explaining the maps.

Dr J. C. Sclater made a sage remark, after conclusion of the Workshop: 'Speed of publication is essential. At present we do not know a great deal about the shelves and hence the proposed geologic and geophysical construction has great merit. It is essential that the proposed reconstruction predates and "sets the framework" for this work. If not, it will not be very useful, that is, it will be fundamentally outdated, before being published.' □

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Man's Impact on Estuarine Environments

John R. Grindley and Allan E. F. Heydorn

In South Africa, as in many other countries, widespread disruptions of the natural functioning of estuarine ecosystems have been caused by human activities. In the 'Overview of present knowledge on South African estuaries and requirements for their management',[1] one of us has outlined the scope of the problems. The need for the compilation of existing knowledge of South African estuaries so that it can lead to better management has been stressed. It has also been suggested that more research needs to be done on the dependence of marine organisms on estuaries, the value of estuaries in relation to human activities, and management options for disturbed estuarine ecosystems.

In reviewing the papers relating to estuaries which were presented, or appeared as poster papers, at the symposium and particularly the discussion arising from them, man's impact has been given special consideration. We have also attempted to draw particular attention to the practical value of findings relevant to human impact on estuarine environments. These 35 contributions, representing as they do the greatest number of papers on estuaries to have appeared at such a symposium in South Africa, suggest a growing interest in estuarine problems. This apparent increase in research effort is certainly to be welcomed. It might be argued that the need to put existing knowledge into practice in improving management and conservation of our estuaries is greater than the requirement for further research. Perhaps this is so. But certainly we do not have all the answers. Research leading to an improved understanding of the natural functioning of estuaries and, even better, of the malfunctioning of disturbed estuaries will be most valuable in the future.

Conservation and management

Several papers dealt directly with conservation and management problems such as siltation and water control.

W. J. R. Alexander, of the Department of Water Affairs, discussed the causes and effects of sedimentation of estuaries. During the Pleistocene, when sea level fell to more than 100 m below the present level, river valleys cut correspondingly lower. When sea level rose at the end of the Pleistocene, creating drowned valleys, natural sediments started to accumulate. Current concern is related to the accelerated sedimentation that has taken place during the present century. Changes in the morphology of river channels and adjacent floodplains, due largely to the denudation of vegetation, has resulted in great sediment erosion. It was shown that most coastal rivers have a capacity for sediment transport in excess of the sediment load generated by their catchments. While agricultural mismanagement in the catchment may increase sedimentation, it appears that bank erosion associated with changes in the geometry of river channels is the major cause of sedimentation in estuaries. Various erosion control measures were suggested. During the ensu-

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ing discussion the problem of marine sand intrusion was noted. Where dams limit flood flows, normal flushing is reduced or eliminated, allowing the penetration of marine sand.

Dr A. E. F. Heydorn (N.R.I.O.) noted that it was a pity Mr Alexander had not considered the effects of dams. The altered flow regimes resulting from the building of barrages eliminated peak flows and allowed sediment input from the sea which could not be removed. Alexander agreed that dams affected large floods particularly. He discussed the way that the flood hydrograph was affected. As waters rose, first the river bed was filled and then the banks were flooded and finally overtopped, and bank erosion took place. He noted that the effect of a dam was to attenuate the flood peak and prolong the flow at lower levels so as to accelerate bank erosion. This tends to produce a widening of the river channel and makes it shallower if the banks are not sufficiently protected by vegetation. The presence of a dam results in less frequent and smaller floods. The form of a river channel is established primarily by the median flood of the kind that occurs every two years. When a dam has been constructed, floods of this magnitude may appear only every five or ten years. Flows less than a median flood have little influence on channel morphology.

Professor Per Bruun (Technical University of Norway) agreed that it was important to consider dams as their effects were well known. He referred to the situation in California as an example. The elimination of the first flow allows the formation of sediment barriers in estuaries. He criticised Alexander's suggestion that it is the river regime which controls the estuary mouth. The current bypass mechanism at the mouth plays an important role. If the longshore current is in the same direction as the outflow and they run parallel to the beach for some distance, sediment output is increased, reducing the tendency for the mouth to close.

Mr Alexander pointed out that if the estuary mouth is in equilibrium with an almost flat gradient there will be a long channel, while when the mouth has a steeper gradient it will be maintained by deposition of sediment. He agreed that ocean hydrology might have an effect but stressed that it is the river regime which establishes the nature of the mouth. Alexander also remarked that sediment transport caused by turbulent flow was a complex question and referred to Einstein's famous comment. Einstein's son was a civil engineer who specialized in sediment transport, although his father said he found turbulent flow too difficult to understand!

Mr J. Zwamborn pointed out that Alexander had concentrated on major floods and asked about low flow conditions. South African rivers tend to have low flows most of the time and the effect of dams may be greatest under such conditions. Alexander quoted the Umgeni as an example of a river with three dams in place and another being considered. He pointed out that despite this there had been no changes in the estuary and suggested the reason was that there was a heavy sediment load in a stable situation. Where there is a lighter sediment load he considered that this tended towards an unstable situation where the development of a dam might have greater impact.

Dr Heydorn noted that water from the catchment was vital for an estuary and in particular that high flow conditions were required for the all-important scour mechanism of the mouth. Alexander took a different view and noted that although a dam intercepts lower flows during critical periods, this can be overcome by regulating discharge from the dam. He said that one of the possibilities for the problematical Umfolozi dams was the provision of water to reduce hypersaline conditions in St Lucia during drought periods. A mismanaged dam can have adverse ecological effects, while a well managed one can help to maintain viable conditions during a drought. He considered that although floods are less frequent, they do still occur and that while an estuary might have been flushed open two or three times a year in the past, this might, after the construction of a dam, occur only every two years. If an estuary needs floods to maintain its biological balance this could be a problem, but he questioned whether this is so. Some of the biologists present obviously felt differently. Road embankments and other barriers also limit high flows, although they do not affect low flows.

Bruun noted that the Amazon was not the largest river in the world in terms of flow volumes. There are greater flows in those found on the coast of Iceland. In July the glacial meltwater from Gletner has twice the flow of the Amazon. The bed load transport has a grain size of 10 to 20 tonnes! Following a volcanic eruption the sediment output created a spit 2.5 × 3 km in water 100 m deep in two weeks! Huge sediment outputs occur every spring (summer is usually a Friday in August, he said!).

Professor Rooseboom (Pretoria University) noted that although agricultural activity and overgrazing were reputed to augment sediment loads, that of the Orange River had dropped by half in recent times. Perhaps development does not increase sediment loads as badly as was believed. Mr Alexander commented sadly that 'it's already gone, it's all been washed away'.

Mr J. Reddering (University of Port Elizabeth) agreed with Heydorn that reductions in flood flows were causing changes. He stated that recent research in the Bushman's River estuary had revealed that marine sands had pushed 4 km upstream from the mouth. The mineralogy and surface nature of the sands under the electron microscope confirmed their marine origin. This penetration of marine sand was apparently caused by lack of flushing, for there had not been a really good flood since 1954. The marine sands which had migrated up the estuary had covered *Zostera* and *Upogebia* beds and impoverished the lower reaches. Alexander was sceptical and said that from a hydrological point of view that would be a miracle. How would the sediments get upstream? What would be the mechanism? It was quickly pointed out that tidal flow was obviously the mechanism, for the Bushman's estuary is tidal for many kilometres.

One speaker remarked that in the east coast rivers of New South Wales it had been found that marine sediments had come to occupy every estuary for some distance upstream of the river mouth. This problem has not yet been solved. Although great boulders are washed down by floods in the upper rivers, the marine sediments are no longer removed. Where a tributary enters a river below a dam the sediments introduced by the tributary tend to accumulate as the original peak flows no longer occur. Rooseboom confirmed that this effect had also been observed in South Africa. Alexander stated that one action of a dam is to trap sediment, and particularly relatively coarse material. What water spills over the barrage will have much less suspended sediment and mainly the fine fractions. This, however, does not affect the transport of sediments in the lower river or estuary where sediment accumulation is becoming a problem in many parts of the world.

The fundamental question of water control and its relationship to estuarine management was considered in abstract by G. W. Begg of the Oceanographic Research Institute. The Siyai, which is a small river draining a 21.4 km² catchment just south of Mtunzini in Natal, is a case study. Twenty to thirty years ago it used to be a relatively deep, clear stream which ended in a quiet lagoon much frequented by the local community for boating and swimming. Today the river is a sand-filled, turbid, stormwater drain, and the lagoon has become choked with reeds. This is typical of the condition of many estuaries today. The transformation in this instance is entirely due to sugar farming, since there is no activity other than the growing of sugar cane in the catchment. Natural resources have been lost. It is now in the national interest to remedy such situations if possible. Begg and others see in the Siyai possibilities of pioneering restoration action. Improved water management, increasing infiltration and reducing runoff in the catchment will limit excessive loss of soil, improving both the agricultural land and the aquatic ecosystem. It was proposed that a land-use plan for the area be developed and implemented. The results will then be monitored and documented with a view to establishing the practicability of implementing similar action on a wider scale. Cost-benefit implications will require study to assess the potential of this pilot experiment.

In the Swartvlei estuary Dr C. Howard-Williams (Institute of Freshwater Studies, Rhodes University) had examined the influence of bridges and the artificial opening of the mouth on changes in the ecosystem. Changes in physico-chemical conditions and various biological parameters had been monitored on either side of the road and rail bridges crossing the Swartvlei estuary both when the mouth was open and when it was closed by a sand bar. Over a period of several years, variations in the Swartvlei ecosystem were followed, including the effects of periodic tidal penetration when the mouth was open. These data have been evaluated in conjunction with a hydrological model developed at the N.R.I.O.

Dr R. D. Beaumont and P. J. Heydenrych described the effects of development on the Diep River estuarine system near Cape Town. Major physical changes have occurred in the regime over the last 170 years and their effects upon the tidal flow and frequency of river mouth closure have been notable. Man's impact has included accelerated siltation, a weir later demolished, bridges and, in the early 1970s, proposals for a marina linked to the sea. The marina did not materialize but the studies required for it provided a clear understanding of the system. In discussion following the paper, Beaumont noted that the tidal prism would have been increased by a factor of about 20 if the marina had been dredged, returning Rietvlei to its original estuarine condition.

Professor J. R. Grindley said he was interested in the suggestion that the Rietvlei area of the Diep River system had been estuarine. It certainly used to be much deeper but historical records provide little evidence of its nature. Cores taken from the Rietvlei have been analysed for their pollen content by Dr Schalke of Leiden University, but no mention has been made of the presence of diatoms in the cores. The recording of freshwater, estuarine or marine diatoms would have provided evidence of the past nature of the system. The studies made by Dr Cholnoky of diatoms in cores at St Lucia had provided an interesting record of past environmental fluctuations, including previous hypersaline periods.

Beaumont noted that they had not analysed the sediments for microfossils and that their conclusions about the earlier estuarine character of the area were based on accounts of boats being able to sail up as far as Vissershok, combined with the low-lying nature of the area. With most of the region less than 2 metres above mean sea level and minimal river input in summer, one would expect tidal inflow. It is known from Schalke's work that in earlier geological times there were channels opening to the sea west of Rietvlei. The system was then perhaps a tidal lagoon but that was many thousands of years ago.

A paper given on behalf of Dr D. Baird (University of Port Elizabeth) discussed the influence of a marina canal system on the ecology of the Kromme estuary. A short history of the construction and development of the complex, one of the few marinas in South Africa, was given. Two intensive surveys had been conducted in the area of the marina as well as in the main estuary, and it was concluded that the marina had increased the habitat area for plankton, macro-invertebrate fauna and fish, and that it had not had an adverse effect on the ecology of the estuary.

In discussion it was suggested that the good water conditions might have been associated with a non-linear rectification of the tidal flow inducing a nett circulation. This would be very favourable even if slow. Dr J. F. K. Marais (University of Port Elizabeth) noted that there was a mean flow and that at the bridge in the main canal surface currents were 46 cm/s on the ebb and 33 cm/s at the flood. Such a pattern provides far more effective flushing than a simple flow in and out of a single inlet. It was agreed that the two entrances to the canals were important.

Grindley noted that in a study he and Dr A. McLachlan had carried out in this marina about ten years ago, they had made similar observations, while investigating the rate of colonization of the canals by estuarine fauna. One difference from the present study was the high plankton biomasses recorded in the canals. Perhaps the reduced abundance of plankton now was caused by the improved circulation, as a causeway had been replaced by a bridge. Concern had been expressed before the bridge was erected about the build-up of biogenic particulate matter and dense black, deoxygenated sediments on the canal bottom in some areas.

Mr T. Wooldridge, who had carried out the more recent plankton study, found that the plankton in the main canal was similar to that observed in the lower estuary and came from the sea. In the back canals, typically estuarine plankton was found but the Mysidacea were not breeding. Plankton biomasses ranged from rather low to reasonably high in the canals.

Professor Bruun indicated that the statements about marine flushing were not only important but perhaps more important than had been realized. Flushing is necessary to improve the environment of estuarine animals and it can be increased by introducing two entrances. In South Carolina a system was developed with two tidal gates so that the flood tide entered one and the ebb passed out the other, causing a loop of flow through the 22 km of canals. Previously, the tidal flushing had been inadequate as the tidal inlet was rather small and conditions, including salinity, had fluctuated. At that time only three species of fish inhabited the canals and they were not in good condition. After the introduction of the two entrances, 13 species of fish appeared in the system and everything seemed to be fine. Part of the trouble originally had been the leaching of fertilizer from a golf course in the area and Bruun was concerned that this might now pollute the sea. However, while eutrophication is a common problem in inland waters, it is unlikely to cause trouble in the sea.

Perhaps the best known problem area when it comes to estuarine management in Southern Africa is the St Lucia lakes. Fluctuations in water level and salinity have created great stresses for the biota, while siltation has required the maintenance of a dredger for many years. Mr A. Berruti (Percy FitzPatrick Institute of African Ornithology, University of Cape Town) has discussed the effects of changing water levels on water birds. Water levels and salinities depend upon the amount of fresh water entering the lakes. During drought cycles the lakes may be hypersaline for several years. At such times species richness, abundance and the productivity of the biota are greatly reduced. After floods, when the water level is falling, invertebrate and plant food concentrates in shallows and the numbers of birds increase. The management implications are that a seasonal flooding cycle creates optimal conditions for the water birds.

Wise planning is the fundamental prerequisite for successful management of estuarine ecosystems. With this in view, N. D. Geldenhuys (Department of Environmental Planning and Energy) presented a poster paper outlining guidelines for the future utilization of the Knysna estuary. A description was given of the most important problems which are presently being experienced in the estuary, such as the intrusion of developments into the intertidal zone, the detrimental effect of the causeway on Thesens Island by tidal exchange, the large number of boats in the area, and the lack of effective zoning for different recreational uses.

One aspect of planning that requires particular attention is the setting aside of certain estuaries as nature reserves. Professor R. Siegfried (Percy FitzPatrick Institute of African Ornithology, University of Cape Town) discussed criteria for the selection of estuaries as nature reserves. A national programme for the conservation of estuaries in South Africa should include guidelines for the selection of specific estuaries of scientific importance, and for the choice of alternative sites for other legitimate kinds of land-use. An ecologically determined classification of South African estuaries is necessary. An index derived from data on the richness and abundance of bird life allows the classification of estuaries along an environmental gradient. This is a useful guide in assessing particular estuaries as representatives of types of ecosystems.

A long list of proposals for estuarine reserves had been prepared by the Council for the Habitat and published earlier in the year. These recommendations had been submitted to the Department of Environmental Planning and Energy. Professor Grindley asked to what extent these proposals met the criteria based on avian species richness. Siegfried replied that there appeared to be close correspondence between the proposals and his criteria. Rooseboom said that as a civil engineer he found these proposals very valuable. He stressed, however, that when planning the conservation of an estuary it was necessary to look carefully at the catchment as a whole. With present economic and political pressures certain areas would have to be developed to such an extent that it would be impossible to conserve an estuary in such parts satisfactorily. People are often concerned about the effects of bridges but these are relatively innocent structures. The greatest changes in estuaries are caused by the character of the water and land-use in the catchment. He suggested that for reserves we must think in terms of estuaries with relatively small catchments and examine the nature of the whole catchment. Professor Siegfried agreed that it was the job of the ecologist to establish which factors had the greatest consequences. Estuarine ecology is strongly influenced by river and sediment input. Heydorn endorsed the comments made by Professor Rooseboom and agreed that we must look at the functioning of entire drainage basins rather than just certain aspects of an estuary. It is only when we look at a system holistically can we gain a proper understanding.

Biological productivity

The remarkable productivity of estuaries has made them important to man since prehistoric times. An understanding of that productivity and its controlling factors is fundamental to the management of estuarine ecosystems.

D. Baird and P. E. D. Winter (University of Port Elizabeth) have investigated aspects of energy flow in the salt marshes of the Swartkops estuary near Port Elizabeth. Annual mean standing crops were determined for five species and the net production of *Spartina capensis* was measured. Net primary production in energy terms was 10 380 $kJm^{-2}yr^{-1}$, but of the 602 g $m^{-2}yr^{-1}$ produced it is estimated that only about 376 g $m^{-2}yr^{-1}$ accumulates as detritus. The remainder is apparently deposited elsewhere in the estuary or carried out to sea. Productivity of several species of macrofauna and meiofauna was also determined. It is not yet known how much of the secondary production is utilized by predators and how much of the animal production goes to the decomposer-scavenger food chain.

G. M. Puttick and Professor W. R. Siegfried (Percy FitzPatrick Institute of African Ornithology, University of Cape Town) have considered the feeding ecology and energetics of the curlew sandpiper, *Calidrus ferruginea,* at Langebaan lagoon. They examined its energy requirements in relation to the carrying capacity of the lagoon. It is the most abundant wading bird in South African lagoons and estuaries and is particularly common at Langebaan. It was found that the mean energy requirements of the free-living bird was 125 kJ/d, while mean energy intake was 180 kJ/d. It was estimated that the birds took 12.9% of the gross production of benthic invertebrates potentially available to them. Mr McQuaid commented on the large amount of benthic fauna consumed by the birds in the lagoon. He asked whether they selected large-sized individuals and thus affected the reproductive potential of those populations. Miss Puttick replied that the evidence was somewhat equivocal.

Professor J. R. Grindley (University of Cape Town) presented a paper on the general ecology of Verlorenvlei, which is a coastal lake and reed-swamp system connected to the sea by a small estuary at Elands Bay, 180 kilometres north of Cape Town. General ecological studies were begun in 1975 and have continued for the following four years with the collaboration of graduate students in environmental studies. Professor R. Pienaar was interested in the epiphytic communities in the system and asked about the extensive *Phragmites* beds. Grindley noted that there was little epiphytal growth on the *Phragmites* but that there were rich growths on *Myriophyllum* and that in the estuarine area there were also extensive micro-algal growths on other substrates. Dr Forbes asked what information there was on larger burrowing benthic organisms such as bivalves and *Callianassa*. Grindley pointed out that it was remarkable that in a system as rich as this there was very little infauna, quite unlike typical estuaries and lagoons. Much of the bottom of this coastal lake is covered by a thick layer of deoxygenated biogenic sediments. A few large dead bivalves have been recorded but they appear to be a relic of an earlier time when there was a greater marine influence. Dr Heydorn asked if there was any *Zostera* or other estuarine aquatic macrophytes such as *Ruppia* or *Potamogeton*. Grindley confirmed that there are several species. In the estuarine part of the system where salinites are somewhat higher, *Myriophyllum* tends to be replaced by *Potamogeton*. *Zostera* is currently absent, although apparently was formerly present for the archaeological excavations carried out in the vicinity by Professor J. Parkington have contained remains identified as *Zostera*. Layers of dried *Zostera* were apparently used as bedding by cave dwellers. Heydorn asked why *Zostera* should have disappeared, to which Grindley replied that the violently fluctuating environment and a periodically closing mouth produced conditions ranging from hypersaline to fresh water and so had made the estuarine area unsuitable for *Zostera* at present.

Miss S. V. Ansell (Sea Fisheries Branch) presented a poster paper on mathematical models of the Langebaan lagoon ecosystem. Three models have been developed describing the amounts, rates and pathways of energy flows in terms of sets of ordinary differential equations.

Sedimentation

The accumulation of sediments in estuaries is such an important matter that it is pleasing to see how much attention is being given to the subject today. Ten of the 35 papers presented related directly to aspects of sedimentation and several other papers included references to sedimentation problems.

Professor A. Rooseboom discussed the fundamentals of riverine mechanics in relation to sediment transport. New theoretical approaches enable us to calculate sediment carrying capacities of rivers with greater accuracy and to analyse the deformation of water courses with more confidence than before. His paper dealt mainly with theories of stream power which have been developed locally and overseas. In the processes by which river courses are formed, currents tend continually to minimize their initial impetus. As a result, the sediment carrying capacity is also minimized, which leads to river course stabilization.

Professor Bruun discussed the stability and dredging problems. The former is a subject of increasing importance. The study of tidal inlets along the littoral drift shores has recently developed into an exact science based on the results of physics and hydraulics. Bruun gave an overview of inherent stability criteria which had resulted from his work and that of others. Mr J. Moes of N.R.I.O. asked whether this was the ideal way to proceed. Was it not wise to deviate from the empirical approach and to go to mathematical modelling to determine the stability of tidal inlets? Bruun agreed and indicated that his basic criteria had been derived from mathematical calculation. He stressed that in considering the scouring of an entrance channel, we must combine a knowledge of sediment transport with the effects of wave action in the mouth. The ratios concerned are based on hydrodynamic considerations and are not really empirical. He advocated moving from empiricism towards basic physics in this field,

J. Moes also gave consideration to the computation of the stability of tidal inlets. Empirical stability relationships can be applied or physical models developed. Both approaches are subject to severe limitations. In order to overcome these, a one-dimensional mathematical model has been developed.

A. v. B. Weaver (Hydrological Research Institute, Pretoria) considered the effects of flow restriction on selected grain size parameters of the sediment of the Bushman's River estuary. The dredging of rubble from the western arch of the Bushman's River bridge provided an ideal opportunity to study the effects of flow restriction on estuarine hydraulics. The results of this study showed that a reversal in sedimentation trends had occurred due to artificial changes in channel geometry. The usefulness of grain size measures as indicators of energy conditions in estuarine environments has become apparent.

Dr J. Rogers (Geological Survey, Belville) described the dispersal of sediment from the Orange River along the Namib Desert coast. The largely episodic Orange River transports sediment eroded from Karoo shales and sandstones in its upper catchment. It was reported that annual discharges of sediment and water average 60.4×10^6 tons and $9.30 \times 10^9 m^3$, respectively. The Orange delta is at the ocean-dominated extreme of the deltaic spectrum. Wave energy from the Southern Ocean's stormbelt is so high that the delta is almost totally submarine. Littoral drifts driven by southerly gales cause sand to be blown inland, forming trains of barchan dunes. North of Lüderitz, where wind velocities decline, the sand is deposited in the giant barchanoid megadunes of the Namib Desert sand sea.

Pollution

Pollution is less of a problem than excessive sediment accumulation in most South African estuaries and it is not yet as serious a threat as misuse of the land. As a result, a relatively small proportion of the national research effort on estuaries is concerned with pollution.

Drs A. D. Connell and D. D. Airey (National Institute for Water Research, Durban) presented a paper on the chronic effects of fluoride on the estuarine amphipods *Grandidierella lutosa* and *G. lignorum*. Professor Stewart (Institute of Ocean Sciences, Canada) asked whether examination of the tissues of the affected experimental animals had been done. He mentioned that there had been problems at an inlet in northern Canada where there was fluoride input from an aluminium factory. It appeared in preliminary observations that some mussels had developed what appeared to be abnormal neoplasms. Dr Connell answered that he had not yet examined his specimens for abnormal growths. He had assessed effects on the basis of changes in population and fecundity. Professor Grindley asked whether any of the people who had worked on other organisms in the area had found anything comparable to the observations in Canada but it appeared that no abnormal features had been noted yet. Dr H. Hennig (N.R.I.O.) mentioned experiments he had carried out on the effects of cadmium on algal growth, in which he obtained an increased harvest at 1 ppm cadmium. Connell remarked that it is often found that low levels of heavy metals produce enhanced growth, whereas the opposite is true at higher concentrations. He mentioned that in the amphipod experiments there had been increases of greater than 100%. Hennig added that in his algal studies he had obtained double the normal production at 1 ppm cadmium. Connell noted that some Canadian work had indicated that there was actually a physiological need for small concentrations of fluoride and that with algae there had been no evidence of toxicity at concentrations up to 125 mg/l.

Various speakers discussed the prevention and combating of oil pollution at Knysna. A number of studies had been made of ways of preventing oil pollution in the event of an oil spill at sea. Attention was focused on the possible use of oil booms to prevent the entry of oil and their probable effectiveness at various locations was evaluated using field and model data. It was concluded that if oil did enter between the Knysna Heads, commercially available oil barriers would only be effective in preventing further oil penetration during favourable conditions such as neap tides. At spring tides, the currents in the estuary are too strong for oil booms to operate effectively. Grindley was concerned that the calculations of the catchment for oil had been assumed to be an area outside the Heads with a radius of one nautical mile. He asked whether the continual replacement of water in that area by the inshore countercurrent would not provide an equivalent new area for each flood tide. Professor G. de F. Retief (Stellenbosch University) agreed, but noted that wind effects were so important that intermediate deposition on beaches would complicate the picture. It was only possible to get rough estimates of the amounts of oil that might be involved. Professor Parsons (University of British Columbia) suggested that it would be inappropriate to consider the costs and benefits of putting up an oil boom. He suggested that if the public demanded that something be done, the demand will have nothing to do with science or economics! Retief agreed but noted that it was difficult to make rational recommendations that would satisfy the public in the event of an oil pollution crisis.

T. P. McClurg (National Institute for Water Research, Durban) described the effects of industrial development on *Penaeus indicus* at Richards Bay. *P. indicus* is the most abundant littoral penaeid prawn on the east coast of South Africa. Its life-cycle entails spawning and larval development in the sea, followed by an extended period of growth in estuaries. During the past eight years, Richards Bay has been transformed from a relatively undisturbed subtropical estuary into a major harbour with associated industries. Substrate preference was determined for *P. indicus* and a strong attraction to silty mud was found to exist. The attraction appeared to be nutritionally motivated, so changes in sediment quality away from silty mud appear to be potentially detrimental to the animal. However, despite extensive dredging operations involved in harbour construction, no decrease in the abundance of prawns has been observed.

As elevated fluoride levels are apparent in parts of Richards Bay, toxicity and bioaccumulation experiments were carried out to assess the response of *P. indicus*. A high resistance to acute poisoning by fluoride was found. Bioaccumulation experiments revealed a rapid uptake of fluoride, approximately 10 days being required to reach equilibrium. Fluoride appears to accumulate almost entirely in the carapace and is lost with moulting.

Estuarine plankton

There were four papers on estuarine plankton including one on ichthyoplankton. R. Melville-Smith and D. Baird (University of Port Elizabeth) presented a poster paper on the abundance, distribution and species composition of fish larvae in the Swartkops estuary near Port Elizabeth. Nineteen species were found to be represented. Certain groups dominated the picture and the Gobiidae and the clupeid *Gilchristella aestuarius* together accounted for more than 90% of all fish larvae sampled.

Professor Grindley discussed the plankton of west coast estuaries. The study encompassed twenty different systems ranging from open bays through lagoons and open estuaries to closing estuaries and pans of various kinds. When the systems were grouped in this manner, it was found that the highest mean biomass of zooplankton was in open bays and that there was a decreasing trend with the lowest biomasses in pans. However, the trend was not consistent, for Wadrifsoutpan, unlike the other pans, had a remarkably high biomass. Large numbers of flamingoes, terns and other birds frequent the place. It was remarkable that maximum diversity appeared to be associated with maximum biomass, which is unusual. Professor Pienaar asked whether phytoplankton biomasses showed a pattern of distribution similar to that of the zooplankton. Grindley explained that although phytoplankton had been sampled in every estuary together with the zooplankton, the present study was related only to the zooplankton. The phytoplankton collections have not been studied.

T. Wooldridge (University of Port Elizabeth) presented a poster paper on aspects of the ecology of two estuarine species of *Acartia* (Copepoda). Both *Acartia natalensis* and *A. longipatella* are common in eastern Cape estuaries and there appear to be cycles of dominance related to temperature, salinity and competition between the two species. On a floodtide for example, *A. natalensis* responds in such a way that it is carried further upstream to waters of lower salinity.

Wooldridge also presented a poster paper on a study of the sandy beach mysid *Gastrosaccus psammodytes*. This is not really an estuarine organism for it lives in the sand of the surf zone of sandy beaches. However, at night part of the population becomes planktonic and they are commonly encountered in the sandy mouth areas of estuaries.

Estuarine fish

Fish usually evoke more interest than other estuarine organisms, so it is not surprising that nine of the papers related primarily to them. Professor J. Heeg and S. J. M. Blaber (University of Natal, Pietermaritzburg) presented a paper on the biology of filter-feeding teleosts in Lake St Lucia, Zululand. Three common species, *Gilchristella aestuarius, Hilsa kelee,* and *Thryssa vitrirostris,* were studied in detail. The composition and fluctuations in abundance of the zooplankton which forms their food was also studied. The estuarine copepod *Pseudodiaptomus stuhlmanni* formed more than 70% of the calorific value of the zooplankton, while the mysid *Mesopodopsis africana* and the amphipod *Grandidierella lignorum* were also abundant. The dependence of the fish on the zooplankton was apparent from the close correlation between the zooplankton cycles and those of the fish. The importance of the zooplankton, and particularly *P. stuhlmanni,* to the ecology of St Lucia is substantial, for the predatory fish *Argyrosomus hololepidotus* and *Elops machnata* depend upon the filter-feeding fish and thus indirectly upon the zooplankton.

Dr Wallace noted that in the past there had been major changes in the abundance of fish in relation to the great salinity fluctuations that had occurred. When the northern areas had become hypersaline, there had been a marked reduction in the fish fauna and a movement south as the hypersaline area expanded. He commented that much more was known now about the food of predatory fishes and that many in the juvenile phase of their life-cycle also fed on *Pseudodiaptomus* and *Mesopodopsis*. Professor Grindley reported that one of the factors causing increases in the abundance of estuarine plankton was the influx of flood waters. There is some evidence that organic detritus and its associated micro-organisms form the basis for subsistence of many estuarine zooplankton species. Wooldridge noted that their work had suggested that *Pseudodiaptomus* might be regarded as 'pioneer' species as they were able to exploit new waters after floods. In the absence of competition from marine zooplankton they can become very abundant in a remarkably short time. They tend to be most abundant in summer and this sometimes appears to be related to inflows of river water.

R. P. van der Elst (Oceanographic Research Institute, Durban) presented a paper on changes in populations of estuarine-dependent sport fish in Natal. The importance of estuaries as nursery areas for fish is widely recognized. Of the 32 species of teleosts most commonly caught by anglers from the shore of Natal, 15 live in estuaries in their juvenile stages. Analysis of 22 years of anglers' catch returns provided a basis for assessing the changes in estuarine fish populations that have taken place. The availability of certain species has declined along the whole coast. The riverbream *Acanthopagrus berda* has declined particularly seriously. It was noted that among the predatory species 'olfactory' feeders had become more plentiful relative to 'optic' feeders. This might be related to increasing turbidity as a result of siltation. It would seem that degradation generally has adversely affected the nursery function of many Natal estuaries, resulting in reduced catches.

Professor Margaret Smith commented on van der Elst's suggestion that the time had come to undertake tagging studies. She said she thought the time had passed a long time ago and suggested that the community of biologists should prevail upon the SANCOR authorities to make funds available for such work. The groups of scientists in Durban, Port Elizabeth and elsewhere working in this field need financial support for technicians and boats so that tagging can be carried out. Observations such as the apparent greater abundance of spotted grunter at Knysna when St Lucia was closed can be explained only by tagging. Dr Heydorn noted that there was now a committee to co-ordinate sport fish research, or line fish research as it is called. It is hoped that this group will arrange a workshop meeting within a few months and they must then follow up the points made by Professor Smith.

A. K. Whitfield (Rhodes University) presented a quantitative study of the trophic relationships within the fish community of the Mhlanga estuary. The importance of benthic floc (detritus and associated micro-organisms), zoobenthos, zooplankton and epiphytic flora and fauna as energy sources for the fishes was studied. Benthic floc was found to be the most important food resource, with an annual standing crop of 161 kJ/m^2. More than 90% of the fish population utilized this energy source. It seemed that the biological productivity of the estuary was closely linked to the fringing *Phragmites* swamp which produced much of the detritus on which the system depended. The fauna was found to be richest when the estuary was closed by a sand bar.

Dr D. Baird, Dr J. F. K. Marais and P. E. D. Winter (University of Port Elizabeth) presented a paper on seasonal abundance, distribution and diversity in eastern Cape estuarine fish populations. Monthly sampling in the Swartkops revealed 42 species and in the Sundays estuary 41 species. Changes in abundance and diversity were systematically analysed. The greatest numbers and diversity occurred in spring and summer.

Mr A. Kok (Port Elizabeth Museum) has studied the juvenile fish fauna of two Cape estuaries, Knysna and Swartvlei. The former is large and permanently open to the sea and has a richer fish fauna than Swartvlei, which is only intermittently open to the sea. Limited contact with the sea leads to reduced species diversity and curtails recruitment of juveniles into the Swartvlei system.

Drs J. F. K. Marais and D. Baird presented three poster papers on the fishes of the Swartkops estuary. The first of these was an analysis of anglers' catches from the estuary over the period from April 1972 to March 1978. *Pomadasys commersoni,* the spotted grunter, completely dominated catches, making up 83% of the total biomass concerned. *Lithognathus lithognathus,* the white Steenbras, *Argyrosomus hololepidotus,* the kob and *Lichia amia,* the Leervis were also abundant. It is remarkable that this estuary, completely surrounded as it is by the metropolitan area of Port Elizabeth, is still so well conserved.

Another paper from this group was on aspects of feed intake, feed selection and alimentary canal morphology of *Mugil cephalus, Liza tricuspidens, L. richardsoni* and *L. dumerili.* Adaptations of the alimentary tracts and teeth of these four species of mullet were found to be related to their respective diets.

A third paper was on seasonal abundance, distribution and catch per unit effort of gill net catches in the Swartkops estuary. Various species of mullet made up 42% of the catches, while the most abundant individual species was the spotted grunter.

The overview of present knowledge on South African estuaries[15] presented by Dr Heydorn stimulated the final discussion. One of the most important aspects of estuarine ecology, which requires investigation, is the extent to which juvenile fishes utilize nursery areas in the sea. As this is unknown, it is difficult to assess how dependent they are on estuaries. In the past we have had to rely on divers' observations and occasional netting in accessible areas. This has barely penetrated the problem. What is needed is work with a small trawler off a rich estuary with radiating transects. Equipment which includes beam trawls and blanket nets must be used and this will require more funding than has been available for this kind of work in the past. Dr Heydorn acknowledged that the need was recognized and that these problems were being given consideration.

The discussion came round to the fundamental problem of human numbers. The rapid growth of human populations lies behind most environmental problems. Until we are able to limit human populations effectively we will not be able to solve the environmental problems of our estuaries. It was pointed out that the apparent conflict depends on different approaches to the management of limited resources. On the one hand there are certain ecological requirements that have to be met to ensure the maintenance of natural systems, while on the other there are economic forces demanding utilization of resources. There are long-term and short-term benefits and economic pressures favour the short term. However, ultimately, sustaining development will become the fundamental problem for both developers and conservationists.

1. See page 544.

Distribution of Organisms in the Sea around Southern Africa

A. C. Brown

This section of the symposium was originally planned to deal with Biogeography but as some of the papers received did not fall strictly under that heading, the subject was broadened to include all aspects of distribution. The important biogeographical works on the region are those of Ekman[1] and the long series of papers by Stephenson and his colleagues, summarized in ref. 2. Brown and Jarman[3] were able to add to our knowledge of the phytogeography of Southern Africa and included sandy beaches in their zoogeographical considerations for the first time. Other recent papers have dealt with specific areas or single taxa, though one should not overlook the important work of Heydorn *et al.*,[4] which cuts across many groups and presents new concepts as far as the distribution of organisms in the Agulhas Current region is concerned.

In view of the large amount of work done and the already detailed coverage of much of the coast, it is inevitable that new discoveries of value will emerge only slowly and erratically and that most of the papers given at symposium session will be relatively trivial. It was thus refreshing to find the papers read in the present section to be not only of a high standard but also to incorporate a great deal of profound thought, displaying a thorough grasp of the subject and its attendant problems.

R. K. Brooke, speaking on the place of South Africa in the world of sea birds, convinced his audience that, as far as marine zoogeography is concerned, birds should be considered along with aquatic vertebrates and invertebrates in arriving at a broad distributional picture. None of the authors listed above included the birds in their considerations, a somewhat serious oversight. T. M. Crowe and his co-workers are busy attempting to apply various therories of island biogeography to intertidal rock pools, a new and enlightening concept, though as the work is still in progress, no final conclusions can be reached.

The paper by M. J. Penrith, and the discussion which followed, drew attention to one of the most important questions in zoogeography—the ability of fish and other organisms to cross temperature boundaries, such as that presented off the Cunene River. Virtually all existing work on this problem, from all over the world, remains theoretical, conceptual and highly tenuous. Professor R. N. Pienaar's paper on the nanoplankton of South Africa's east coast was of great interest to the audience as this is one of the fields in which our knowledge is still extremely slight and nanoplankton, like birds, have nearly always been omitted from biogeographical considerations.

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Dr D. E. Pollock showed us very clearly how the distribution of one organism (rock mussels) can limit the distribution of another (the lobster *Jasus lalandii*) and further showed how the occurrence of sediment limited the distribution of the mussel. He did not, however, fall into the trap of being simplistic, and other limiting factors, such as oxygen lack, were considered. This is the sort of work that should be extended to other organisms if an understanding of our coastal ecology is to be achieved.

G. J. B. Ross presented the results of eleven years' work on records of stranded small Cetacea on the south-east coast, work which requires considerable patience and dedication but is adding immeasurably to our knowledge of the distribution of these animals. The last paper, by Professor D. Boltovskoy, on the zooplankton of the south-western Atlantic, seemed from its title to be out of place in a symposium dealing with Southern Africa. However, the talk proved highly relevant, there being many parallels and common problems between the two regions.

The section as a whole gave the assured impression that our knowledge of biogeography and of the distribution of organisms around the South African coast is progressing steadily, particularly with regard to certain groups, and that we are gaining greater insight into the factors determining that distribution.

1. Ekman, S. (1953). *Zoogeography of the Sea*. Sidgwick & Jackson, London.
2. Stephenson, T. A. and Stephenson, S. (1972). *Life between Tidemarks on Rocky Shores*. Freeman, San Francisco.
3. Brown, A. C. and Jarman, N. (1978). Coastal marine habitats. In *Biogeography and Ecology of Southern Africa*, edit. M. J. A. Werger, 1239–1277. Junk, The Hague.
4. Heydorn, A. E. F. *et al.* (1978). Ecology of the Agulhas Current region: an assessment of biological responses to environmental parameters in the south-west Indian Ocean. *Trans. R. Soc. S. Afr.*, 43, 151–190.

The First GARP Global Experiment: A View from Inside *

Robert W. Stewart

At the time of speaking, we are approaching the final months of what is probably the largest concerted international effort ever undertaken in any field of science. This is the giant meteorological observing and analysis programme variously called The First GARP Global Experiment, or The Global Weather Experiment. Virtually every country in the world, not so torn by internal dissention as to be incapable of action, is taking part. It is impressive that despite the fact that 1979 is a time of widespread financial difficulty unforeseen when planning was undertaken, nearly all nations have found the resources to carry out their commitments, and some have managed to exceed them. Even more remarkable is the fact that the experiment, the cost of which will run to hundreds of millions of dollars, was conceived and for the most part designed by university professors around the world.

The notion of a period in which the global atmosphere would be intensively observed jelled in the mid-1960s: first, so far as I am able to ascertain, in the mind of Jule Charney of the Massachusetts Institute of Technology. He recognised that with the coming of the satellite it was soon going to be possible to observe the entire atmosphere with enough detail to describe its synoptic-scale behaviour. Further, the rapid development of fast computers with huge memories would enable the collected data to be absorbed and analysed in a way which would be sufficiently complicated that there would be some hope of reproducing the most important features of the atmospheric circulation.

With respect to observations, Charney's original enthusiasm was