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Scientific Inputs to Fishery Management: International Implications

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SCIENTIFIC INPUTS TO FISHERY MANAGEMENT: INTERNATIONAL IMPLICATIONS

This paper was prepared by Alan Longhurst, Director General of the Bedford Institute of Oceanography, Dartmouth, Nova Scotia, Canada, at the request of IOC, as part of the IOC's contribution to the Technical Phase of the FAO World Conference on Fishery Management and Development, to be held in Rome, 10-19 October 1983. The views expressed herein are those of the author and do not necessarily coincide with those of the IOC.

* Translated into French and Spanish.

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ABSTRACT

This essay reviews ecological and oceanographic science relevant to fisheries management; it suggests the nature of the links between the oceanographic and fishery science communities, and how the oceanographic institutes and similar research organizations should be encouraged to participate in international programmes in fishery science.

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INTRODUCTION

The management of sea fisheries, like any other resource enterprise, requires not only economic and energy inputs to the cropping process but also intellectual inputs. It has taken the industrial fishing nations almost a century to move from a concept of an ocean infinitely productive of fish to one in which the interactions between the crop and its environment are sufficiently understood to begin to enter into the management process.

The practical manager, with his team of fishery scientists and economists, now has at his disposal a formidable array of tools developed since the early quantifications of Baranov and Graham, through the mathematical flowering of the 1950's and 1960's, to the current management models which begin to admit of inter-specific and environmental interactions with the target-crop species. This array of fisheries management techniques undoubtedly represents the most complete analysis system that currently exists for understanding the growth and mortality of any animal population.

These techniques have been progressively developed by fishery scientists over the last half-century in response to the year-to-year demands for information, and in response to a developing understanding of the biological and economic principles involved, and they continue to evolve actively within the fishery science community. The purposes to which they are put differ from fishery to fishery, and from country to country, but a set of simple principles governing restriction of effort and capitalization, the establishment and allocation of seasonal quotas, and the manipulation of market supply and demand, has emerged as a consensus; apart from political impediment and any problems inherited from past laissez-faire periods of management, management of no fishery need now be constrained by shortcomings in management techniques, at least over the short term.

Nevertheless, the history of exploited fish stocks contains a saga of unexpected events, preventing sustained cropping at an anticipated level, and occasionally apparently destroying the usefulness of the stock 1/. Such events appear to fall into several classes: the short-term uncertainty concerning the numbers of recruits to be anticipated from reproduction in any one season; the unexplained dwindling away of a resource over a span of years in an apparently uncontrollable fashion; and the changing composition of stocks in a region again in an unpredicted and uncontrollable fashion, often to replace desirable with undesirable species. Different though these phenomena may be, they share a single characteristic -- that they represent the consequence of factors beyond those which have come to be regarded as the particular concern of fishery management scientists, working to produce quota advice against seasonal deadlines.

Ecological relationships between fish stocks and their biotic and physical environments comprise a set of scientific problems occupying the attention of not only fishery scientists but also a wider population of research organizations than those mandated to produce management advice. The problems range from the development of ecological theory to the investigation of ocean-atmosphere coupling in driving climatic change: the output from such research is an evolving understanding of processes as complex as any under investigation in science today, and we can hope for a sequential uncovering of important questions to be answered: this serves as an essential but largely unprogrammable input to fishery science in the strict sense.

A simple recent example will illustrate how this process can work, and will illustrate its international character. The availability of satellite infra-red sensing of sea-surface temperatures in the last ten years showed how important and predictable large-scale temperature fronts were on continental shelves; oceanographers in Britain derived a simple relationship between water depth, strength of tidal currents and the stratification of water in the summer over continental shelves which -- at a stroke -- both explained the existence of fronts, and finally made sense of continental shelf oceanography 2/. Computer simulation predicted the location of such fronts on a variety of North Atlantic continental shelves and ecological studies explained why they should be sites of high and sustained biological production during the summer 3/. One of the shelves simulated to predict residual tidal currents and the location of fronts by Canadian oceanographers was that of the Bay of Fundy and Gulf of Maine, to predict the consequences of building a tidal barrage there 4/. Finally, to close the circle, Canadian fishery scientists found that the distribution of the fronts explained the distribution of spawning grounds for herring and were able to postulate a mechanism for the retention of herring larvae in the biologically productive frontal areas 5/. Since herring management demands attention to the spawning success of many individual stocks, each apparently site-specific in its spawning location, a new tool has consequently come to the hands of Atlantic herring managers.

There are several lessons to be learned from this simple example: that the intellectual input used in the management of a fishery may come from many sources, frequently beyond the control of those managing the fishery; that synergism, and sensitivity of fishery scientists to progress in fields beyond their own special competence, both have an important role to play in the evolution of scientific inputs to fisheries management; that while formal planning of research, both nationally and internationally, is obviously essential it will not accomplish everything that is needed.

Perhaps, however, it is even more important to recognize that it is impractical to attain this level of understanding for all managed stocks and that practical management (which ought to be as cheap to do as possible) can neither await such results nor even pay for the research needed for each stock. As was pointed out several years ago 6/, fishery

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managers mu.' .. prepared to act on the basis of incomplete scientific evidence; this point is inherent in the latest stock-recruitment models which attempt to extract as much information as possible by empirical analysis of statistical data on catches and population structure, recognizing that this is but a simple model for a complex ecological process 7/.

With all this in mind, we can now proceed to examine the realities of how marine science in general functions as an input to fisheries management, what the practical possibilities are, and how to strengthen the flow of information from the wider scientific community to fishery scientists and managers. A great deal of general marine science is justified to the funding agencies as being a necessary input to fisheries but how this is actually supposed to happen is frequently ignored.

ANNUAL-SCALE RECRUITMENT VARIABILITY

It has come to be regarded as a truism that one of the most urgent problems to be solved in fisheries science is the prediction of the recruitment variability that determines levels of abundance in some species. Like all truisms, it should be regarded with caution and will certainly be modified by experience and an increased understanding of the mechanisms involved.

The present pre-occupation with environmental mediation of variable recuitment has its roots in the failure of a purely mathematical analysis of stock-recruitment relationships adequately to predict recruitment. Detailed ecological studies of those parts of a species' life history when mortality rates were highest, and when success or failure of the year-class most likely to be established, have pre-occupied some of the best teams of fisheries ecologists in recent years; very significant advances have been made, so that for several stocks we have a first-order model of a possible mechanism for the physical process that may determine year-class success. However, it has also become clear that no single mechanism is capable of explaining the process in all stocks (though some unwarranted claims have been made, at least informally), and we now realize that such research will not provide a universal new weapon for the armoury of managers.

More realistic fisheries scientists recognize that while such studies must continue very actively, other avenues must also be explored. Firstly, we must remember that practical fisheries biologists have no difficulty in measuring the population of young fish prior to their entry to a fishery by at least one season: pre-recruit surveys are part of the established practice of most comprehensive management schemes, and probably will always be needed. Secondly, it has been pointed out that our present pre-occupation has diverted attention from the remarkable stability of recruitment (considering the enormous reduction in numbers from spawning to

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recruitment), and from the fact that feed-back mechanisms are sufficiently complex as to prevent the catastrophic reproduction and stunted populations such as may occur in ponds and lakes with young, simple ecosystems 8/. Thirdly, we now understand enough about the complex biological mechanisms that determine larval survival that we can return to a renewal of studies of the stock-recruitment relationship itself, and hope that it will prove more reliable than previously; recent studies have suggested that time-series of data for stocks which have suffered recruitment overfishing contain sufficient information to capture the general form of the stock-recruitment relationship and to determine the approximate appropriate values for its parameters 9/.

All this being said, there is no serious movement to abandon the current emphasis being placed by fisheries oceanographers on the study of mortality and survival mechanisms of fish during their sensitive periods, usually during their planktonic existence. Although such research must lean very heavily on the development of an understanding of biological systems, both internal physiological mechanisms and ecological relations, the critical node that determines success is the interaction between ocean physics and biology. Fortunately, this is well recognized, and successful research teams have had no difficulty in integration of the necessary disciplines.

Perhaps the best explanation of the way such research must go, if it is to be successful, is to briefly consider a successful example -- the now-classical elucidation of a mechanism apparently capable of determining survival in larval anchovies in the California Current. Success came only after an integrated study by a team of fishery scientists extending over more than ten years; the first step was to develop techniques for on-demand spawning of anchovies in the laboratory 10/ as a *sine qua non* for experimental work on their behaviour and physiology; after their bioenergetics and behaviour patterns were fully worked out with artificial diets, it was possible to start testing survival potential of laboratory-spawned larvae at sea with natural food conditions existing at various locations and at different depths in the water column 11/. From this point, it was a relatively minor step to an integration of larval behaviour, available food sources and local oceanographic variability to support a hypothesis concerning water column stability and larval survival. Subsequent hindcasting of year-class strengths against ocean conditions tended to confirm the hypothesis 12/.

The structure of this successful research programme is a good model for any such programme. It shows how success can only come by a very deliberate establishment of successive objectives, each of which demands a different mix of disciplinary inputs. It shows also that the effort required to solve the recruitment problem in one stock -- at least as far as understanding the mechanism is concerned -- is massive, and likely to require a scientific team of five or ten people for as many years, together with all appropriate back-up, including research vessel time. There are probably no short cuts, and the derivation of generalities is uncertain.

It is also necessary to remember that the variety of skills and tools that are called for is very wide, and the example chosen probably succeeded largely because the team was situated at a major oceanographic institution, with many people to call on for advice and a very wide range of available equipment. Such research is on the border-line between fishery biology and oceanography and needs inputs from both communities; it is particularly true that it depends entirely, at least in its later stages, on the direct participation of physicists.

This example carries a final lesson: that a successful test of a simple hypothesis -- in this case that a sufficient density of food organisms determines larval survival -- may actually conceal complexity. Although the limiting food density hypothesis appears to have been validated for one stock by these studies, they did not test an alternative hypothesis, that predation is the determinant of year-class survival, although there is plenty of evidence to suggest the great importance of this process 13/. Nor did the study address the significance of other possible food-aggregating mechanisms 14/. It is easy to over-emphasize the dogmatic significance of such a clear validation of an ecological hypothesis as this: by analogy with the rest of natural science we must expect uncertainty progressively to invade what initially seems clear and unequivocal.

DECADAL-SCALE POPULATION FLUCTUATIONS

Although the variability of year-class strength is linked to it, it is useful to discuss the long-term waxing and waning of populations as a special case. It is here, also, that an explanation will not be found by biologists without the intimate participation of oceanographers and meteorologists.

The literature on variability in fisheries abounds with examples of long-term population fluctuations 15/. The case-histories of cod at west Greenland, herring in the Baltic and North Seas, sardines off Japan, South Africa and California are all familiar stories which do not need repeating here. In some cases, it is intuitively obvious that the phenomenon is a natural population fluctuation in response to changing environmental conditions; in other cases, especially where a once healthy fishery appears inexorably to be diminishing in potential, it is often very obscure whether this represents a natural fluctuation or the consequences of a fishery.

Thus, it has always seemed obvious that events such as the range expansion and contraction of Greeland cod, the changes between a herring-dominated and a sardine-dominated ecosystem at Plymouth, and the cyclical abundance of Baltic herring should be attributed to natural changes. But what are we to make of the collapse of the Peruvian anchovy? Or the replacement of useful species by Balistes in the Gulf of Guinea 16/? Or the collapse of the eastern Mediterranean sardine 17/? All have apparently simple explanations, yet the more closely we examine these events, the more complex they appear to be, and all will demand an integration of fishery population dynamics with various branches of oceanography for their final explanation.

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The collapse of the Peruvian anchovy population, linked with El Niño events and heavy fishing pressure, has become a classical study, and the relative importances of heavy fishing and environmental change have been integrated reasonably satisfactorily into a unified hypothesis. Currently, the West African Balistes explosion and the collapse of eastern Mediterranean sardine are attributed to environmental changes -- the Sahelian drought and the Aswan dam, respectively. But it is probable that the Balistes phenomenon was related to prior heavy modification by fishing pressure on the West African demersal fish population and the Mediterranean sardine population was already declining before the closure of the Aswan dam 18/. Evidently, an explanation of such events must await the completion of an amount of research appropriate to the complexity of the problem -- as for Californian anchovy larvae. Satisfactory resolution of the enigmatic disappearance of Peruvian anchovies was only resolved by the efforts of a large, multidisciplinary Peruvian research team over a period of about ten years, in this case supplemented by heavy support from foreign oceanographic institutions in Europe, the USA and Canada, and the Soviet Union.

An understanding of the major fluctuations of fish populations also requires a sufficient input from oceanography to support the fish population experts; perhaps the demand is even more imperative than for larval ecology -- understanding of the clupeid species replacements in the western English Channel, or the fluctuations of Greenland cod, or of Japanese sardines, has required studies of oceanographic and meteorological phenomena linked as systems on a hemispheric scale. An understanding and prediction of the El Niño phenomenon, now within our grasp, would be impossible without understanding links between circulation anomalies in the ocean and atmosphere over the whole Pacific Ocean between 45°N and 45°S. This is a task that has occupied much of the effort of the Pacific oceanographic community over the last ten years.

SECULAR-SCALE GENETIC EFFECTS OF FISHING

A natural fish population exists because, over very long periods of time, it has evolved a certain distribution of genotypes and a certain age-frequency structure that are sufficiently attuned to the natural environmental changes to which the stock is exposed that it can respond by modifying its range suitably and can maximize its population size by appropriate reproductive strategies.

We may assume that the artificial pattern of mortality imposed by a fishery will modify the distribution of genotypes, and we know that the age structure of a population changes immediately fishing pressure is applied. Neither fisheries scientists nor general marine ecologists have addressed themselves seriously to these problems, and the practical analysis of population from as many as 20 important year-classes to one containing less than ten is simply not addressed in a serious manner. It is possible that if we seriously considered the effects of the recurrence of anomalous conditions that may recur once a century we might conclude that the basic assumption that management for some level of indefinitely sustainable yield is not as realistic as we presently assume it to be.

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These topics are still hardly being worked on today in the context of our principal commercial species, but investigations on the changing genotypes of exploited populations of some marine invertebrates, in several laboratories, may possibly uncover information of fundamental importance to the renewable resource concept of fisheries.

ECONOMETRIC MODELS

More fisheries have failed through an application of inappropriate economic policies to the catching and marketing sectors than to an absence of adequate scientific advice. Indeed, at the extreme, short-cut techniques for setting quotas are perfectly valid and give results a great deal better than no management at all, requiring only very simple and easily obtained biological information on the fish stocks 6/.

Perhaps reflecting this situation, a characteristic of the last decade or so has been a flowering of effort to integrate biological aspects of fishery management with socio-econometrics. Unfortunately for such planning, economic and political forecasting is inherently even less successful than biological prediction so that there is a danger in trying to overcome such stochastic variability by forcing increasingly complex economic models on the fishery. In fact, concepts such as effort limitation are by no means new, are simple to apply in theory, though difficult politically and especially as a remedial measure.

The profitability of over-capitalized fisheries in a world of expensive energy inputs and contracting markets is becoming marginal, and much effort must be put into closely refining the establishement of quotas and their allocation to enterprises: a few thousand tons of fish valued at several hundred dollars a ton at the dockside may make the difference between profit and loss for an entire fishery, yet is within the error bar of biological estimates on which quotas must be based.

So there are two almost unresolvable difficulties in achieving the ideal world represented by bio-econometric models: the political perturbations of the economic system are not trivial and are entirely unpredictable, and biological predictions cannot be as precise as we need for maximum profitability of an enterprise. These two paradoxes remain unresolved.

POPULATION ANALYSIS BY BIO-ENERGETICS

The sophisticated population dynamics routines used in fisheries management and developed as a set of techniques internally by fisheries scientists must be consistent with ecological theory. Fish populations must be understood as bio-energetic systems as well as numerically by such techniques as virtual population analysis; only thus can closing conditions be set for levels of production, growth and recruitment. While new attempts to establish direct statistical approximations to generalized stock-recruitment relations are essential to management in the short-term, bio-energetic models of the stock and recruitment relationship give the best hope for real understanding of the complex

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interacting processes that control recruitment. Such a model, recently developed by marine ecological research, suggests that recruitment is a two-step bio-energetic process: a stock-dependent component by which individual fecundity increases with reducing population size and a density dependent component by which pre-recruit survival is reduced at high population densities. Such a self-regulating model proves to be sensitive to the different reproductive strategies of both clupeids and gadoids 19/.

Unlike most numerical population analysis techniques, bioenergetic analysis has the merit that most variables are either directly observable or can be measured experimentally. Much progress has been made in recent years in the analysis of the relationship of growth, ration and energy expenditure in a variety of fish as the starting point for an understanding of the dynamics of multispecies fish populations utilizing a common food base. Not only for fish, but also for marine mammals, a bioenergetic approach to predictions of population response, based on such measures as individual and population biomass, surface area or gill volume, are a powerful adjunct to numerical population analysis.

Already, this kind of research is able to support holistic analysis of the relationships between growth and mortality parameters with environmental conditions, which are valuable in short-cutting lengthy studies, especially in multispecies fisheries. Undoubtedly, the continuing deepening of our understanding of how fish stocks relate to their environment will entail further investigation of the energetics of foraging behaviour and prey availability, the accumulation of energy surplus to maintenance requirements, and the selection of reproductive strategies to maximize the amount of energy available for reproduction.

OCEANOGRAPHIC PROGRAMS

Much of what has been written above demonstrates a need not only for the investigative oceanography that has characterized our work over the last twenty or thirty years, but for also what has come to be called operational oceanography -- a description in real-time, or with a short delay, of the physical and biological state of the ocean in the same way as meteorological reporting describes atmospheric variability.

This is easily and frequently said, and the methods required are in fact already in place or could readily be implemented, but operational oceanography remains in a very undeveloped state. Certainly, from the various national and international marine data networks (including IGOSS)* that have evolved for military and civilian purposes since the early 1960's, we have some capability for monitoring ocean circulation and biological changes, but both are very slight compared with atmospheric monitoring for weather forecasting.

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* A List of Acronyms is appendixed to this document.

Integration of satellite imagery with data from voluntary observing ships already gives us some ability to follow circulation changes in the ocean for limited areas, and to know that anomalies are occurring in the mean circulation; some examples relevant to fishery science are the charts which describe the population of eddies in the vicinity of the Gulf Stream 20/ and Pacific Ocean temperature anomalies 21/, and the upwelling indices devised for the Pacific coast of North America 22/. Operational oceanography has as its main civilian objective the development of ocean circulation patterns, and for long-range weather predictions such as those which so successfully predicted the anomalous winter of 1982-83 in North America 23/; however, such products are also the most visible part of a much larger data network essential for understanding the kinds of change in the ocean that mediate long-term fish population changes.

There are extremely few comparable data sets that describe how the biological environment varies from year to year. Monitoring of fisheries-independent biological data is restricted to a very few long time-series: the majority of such monitoring programmes have endured for very few years. The North Atlantic plankton recorder programme 24/ and CalCOFI 25/ are almost the only exceptions capable of describing long-term changes in the biotic environment of fishes over wide areas. This is not a matter of lack of know-how, but rather because of decisions that the expenditure of resources on monitoring process improperly understood is less cost-effective than trying to understand the process better.

It is critical that monitoring programmes and the development of new operational oceanographic products should be initiated only in response to a real need: because sea-surface temperature analysis and the localization of ocean fronts are useful products for warm-water tuna fisheries 26/ does not, of itself, indicate that such products would be cost-effective in all fishery regions and that science resources should be diverted to their production. Establishing global or even regional systems for operational oceanography carries the very real danger of expending resources on the generation and distribution of products of no real utility. International and national agencies must constantly guard against this danger in the allocation of resources, for some such examples already exist.

It should also be remenbered that some of the variables that have importance for larval survival, for instance, can be obtained indirectly and more cheaply. Derivation of indices of water-column stability, and hence of larval survival for some stocks of fish, could be made from wind-stress data and generalized sea-surface temperature information: it may not always be necessary to make direct measurements of the key phenomena. This is probably as true for large-scale processes as for these examples.

It is perhaps fortunate for fishery science that the oceanographic community is increasingly pre-occupied with circulation, and its variability, on a global scale within the World Climate Programme of WMO 27/.

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The principal objectives of several WCP projects, such as the World Ocean Circulation Experiment, will produce understanding useful for fisheries purposes though actually having quite different objectives.

INTERNATIONAL IMPLICATIONS

Above all things, the planning of international programmes in science must be realistic and must recognize what are the limitations to action for the international bodies concerned, and how their actions can really enhance the work of the dispersed scientific community. Perhaps the next most important single consideration is that the simplification of objectives required for an international programme should not lead to dogmatization of the current hypothesis concerning a very complex and dimly understood process: this is perhaps one of the most effective ways of actually constraining progress.

Taken together, these two considerations suggest that the most important preliminary activity is the assimilation of a sufficient knowledge of the state of the art by the sponsoring international organization, whether it be a permanent one like FAO or IOC, or a temporary one like the MODE secretariat established for a single activity. Fortunately, review and consultation have been a hallmark of fisheries science and of oceanography in relation to fisheries, perhaps as a consequence of the repeated crises in the industry over the last decade. There are, in consequence, many excellent compilations reviewing the current understanding and programmes of research in fisheries science; the most recent of these is the series of consultations undertaken during the development of the International Recruitment Programme (IREP) with the IOC programme of Ocean Science in Relation to Living Resources (OSLR) initiative 28/. Not only is the work of the SCOR-ACMRR Working Group No. 67 available 29/, but also a series of nationally sponsored workshops in the USA, and an internal FAO consultation 30/. On the larger plan, the interaction between ocean circulation changes and population abundance of marine organisms has been the subject of many modern reviews and symposia 31/. There should be no difficulty in assessing any initiative against current priorities and concepts.

In the development of international scientific programmes for a discipline as diverse as fisheries science, work plans cannot be initiated in any detail by national or international scientific agencies; what is required is sufficiently different from the oceanography needed for climate prediction that the top-downwards planning which characterizes the meteorological agencies is not appropriate. This comparison can, in fact, profitably be carried also to the next step: it is unlikely that any successful international experiment in fishery science, as IREP is hoped to be, will involve the mounting of a large and complex multiagency, multiship exercise comparable to the major international physical oceanography programmes. While regional activities will certainly be proposed and appropriate, the bulk of the work will surely comprise national or even institutional programmes performed within the framework of, and contributing to, the international programme. This has been the pattern for all successful international biological programmes and is unlikely to change in the near future 32/. The programme can be led, or facilitated, by international agencies, but they do not have the capability to direct it.

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Much has been made in recent years of the new opportunities afforded to coastal states for their fisheries as a result of the UN Convention on the Law of the Sea, but we must be careful that expectations are not set too high. Over the last twenty or thirty years conventional fisheries resources have been exhaustively surveyed, not only by exploratory fisheries expeditions but also by the scouting of commercial fleets: it would be unreasonable to expect that any significant stocks remain unrevealed. We can therefore be realistic about the resources available to Third World nations that have newly acquired jurisdiction over their EEZ's. In most cases, the potential of their stocks is quite well known, and in some cases is very well known: the tropical ocean is not, as some would have it, a Mare Incognita.

On the contrary, not only have some of the most careful and extensive fishery surveys anywhere been performed in the tropics 33/, and some tropical stocks as carefully and well managed as any in the oceans 34/, but our knowledge of biological processes in tropical seas is particularly complete 35/. Finally, we should bear in mind that the attention of physical oceanographers working on circulation variability and the global heat budget have come to understand the workings of the tropical ocean-atmosphere mechanism more completely than perhaps anywhere else on earth.

Though the means for performing research is still very unevenly distributed, the level of expertise in the Third World, and of understanding fishery problems on a global scale are both much more generously distributed than ten years ago. It is now much less likely than previously that the application of science from the developed countries in attacking the problems of tropical fisheries will blunder in with inappropriate concepts and parochial, if sophisticated, vision.

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LIST OF ACRONYMS

CalCOFI	California Co-operative Oceanic Fisheries Investigations
FAO	Food and Agriculture Organization of the United Nations
IGOSS	Integrated Global Ocean Station System (of IOC and WMO)
IOC	Intergovernmental Oceanographic Commission
IREP	International Recruitment Programme
MODE	Mid-Ocean Dynamics Experiment
OSLR	Ocean Sciences in relation to Living Resources
WMO	World Meteorological Organization