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RECENT ADVANCES IN OCEANOGRAPHY AND NEW PERSPECTIVES IN FISHERIES MANAGEMENT

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ABSTRACT

The *reason de etre* for the swing back to an empirical approach in fisheries management as an interim measure towards developing a truly rational method is discussed. The importance of physical oceanographic and meteorological factors especially at meso- and micro- scales as well as biological processes taking place at these levels and their role in controlling the broad strength as evidenced from many publications are briefly reviewed. Recent advances in Oceanography have given conclusive evidence of the need for understanding the processes at these scales on real time basis for a proper elucidation of trophic relationships and bioenergetics of fish larval development in the pelagic environment. It also shows the new direction in which biological oceanographic research is orienting itself largely due to the vital role played by hydrodynamic processes in biological variability in the sea linking also behavioural, physiological, bio-chemical and molecular processes making the whole approach a multidisciplinary one.

Key-words : Fishery management, modelling.

INTRODUCTION

In a recent paper Krishnan Kutty (1985) has briefly reviewed the biological basis on which the modern theory of fishing is developed. The concept of growth overfishing has been the most popular and widely accepted basis for constructing population models for the exploitation and management of marine fishery resources. Fishery Scientists thus gave greater importance to the adverse effects of fishing pressure on the contribution of growth to the population biomass than to the contribution of recruitment in formulating ehe theoretical basis of fisheries management. They therefore developed population models assuming constant recruitment and natural mortality to arrive at optimum fishing pressure and age of exploitation to take maximum advantage of growth to the biomass. The data from demersal fishery in the European waters on which the above premises originated gave considerable evidence in support of this theory. Since demersal populations in cold temperate waters are more stable and found to withstand heavy fishing pressure without showing clear symptoms of biological overfishing it was considered adequate to devise methods aimed to maximise the long term average yield by treating annual fluctuations in the fishery as purely random events. Analytical steady state population models thus became the most commonly employed tool for the judicious exploitation of marine fish populations. The classical work of Beverton and Holt (1957) brought together and systematised all the earlier studies on the dynamics of exploited fish populations while making their own significant contribution. For the first time it gave hope to fishery scientises in many parts of the world to deal more effectively with the challenging task of marine fisheries management. Their contribution sparked off fresh enthusiasm in tackling this problem and the study was undertaken with renewed vigour all over the world from various angles as well as from a holistic approach for more than quarter of a century. Excellent reviews of the mathematical treatment of the problem such as that of broad spectrum analysis of Emlen (1984) and the more specific studies confining to fish populations by Haley (1981) are referred to assess the progress made along theoretical lines and how they are applied to the actual situations. In this paper the problem of fisheries management is discussed in terms of the possibilities of a fresh approach opened up by some of the latest advances made in oceanography and marine biology.

THE NEED FOR A FRESH LOOK INTO THE PROBLEM OF FISHERIES MANAGEMENT

Despite all the advances made in mathematical modelling and techniques employed for estimation of population parameters and the recent emphasis given to holistic or systems approach, lot more is to be achieved in the predictive ability, reliability of the various measures adopted for maximising the landings and in obtaining even partial freedom from annual fluctuations in the landings. Failure of the existing models to manage the coastal pelagic fisheries beset with extreme annual fluctuations and catastrophic failures in certain years despite all efforts of scientific management fully substantiate the need to look for new ways of managing these resources. There is high degree of inherent instability in the various estimated population parameters arising from intrinsic factors that determine the resiliency of the population as well as biotic and abiotic extrinsic factors. Even if one is fortunate to deal with populations where the estimated parameters can be considered reliable, successful prediction and management is made frustratingly difficult by the multiplicative effect of the vagaries of the environment on the spawning success even in years with adequate spawners. Apart from these problems faced by all fishery scientists the situation is further complicated in the tropics by various hurdles peculiar to tropical fish populations and ecosystems. In recent years both these major aspects of fisheries management have received proper attention and much progress have also been made in both the spheres. Pauley (1979) and Pauly and Murphy (1982) have ably reviewed the developments and improvements in the techniques to suit single and multispecies fisheries in the tropics while Ursin (1984) has dealt the ecological peculiarities and limitations of the marine tropical ecosystem emphasising the need to make detailed ecological studies in relation to the various fisheries. These aspects are not touched upon in this article. The following account is largely confined to the impact of certain revolutionary insights gained recently into the factors governing the erratic fluctuations in the spawning success of marine fish populations.

RECENT INSIGHTS INTO THE OCEANOGRAPHIC PROCESSES OF THE PELAGIC ENVIRONMENT

The progress made in our understanding of the variations in the major oceanographic processes at their meso– and micro– scale levels is perhaps the most useful information in understanding the fluctuations of marine fish populations. No longer the averaged values collected from widely spaced stations at discrete points over space and time is considered to be representative values to understand the descriptive and dynamic aspects of the oceanic environment and on their basis formulate generalisations. The significance of meso– and micro– scale variations in the physical, chemical and biological aspects of the environment are now fully taken into consideration in examining almost every oceanographic processes. Such refinements in our scientific approach is the result of both the cumulative increase of our knowledge of the ocean and the use of finer instruments by steadily increasing their limits of resolution in space and time as well as the detectable limits of concentration of the chemical composition of the ocean — a rich dividend from the progressive advancement of science and technology. Studies on mesoscale processes like eddies, rings, fronts and upwelling were much emphasised in the 1970s. Variety of processes whose sizes are on the centimetre scale are now known to accompany the stirring and mixing across the fronts (WHOI Ann. Rep. 1982).

The pivotal role of hydrodynamic processes in Biological Oceanography.

Legendre and Demers (1984) after a survey of recent literature on plankton and fish larval investigations have shown the role of hydrodynamic processes as the driving force of aquatic ecosystems whose physical, chemical and biological factors act as proximal agents through which hydrodynamic variability is transmitted to aquatic organisms. It is the high biological variability seen at the meso– and micro– scales in shelf and lake waters based on small scale sampling in contrast to the conventional oceanographic surveys that led in the 1970s to a study of the hydrodynamic control of biological processes. The causes of phytoplankton patchiness are found to be different at different scales. The authors based on investigations by various experts conclude that zooplankton distribution and biomass at the mesoscale (1–100 km) in upwelling regions depend on its intensity; that often bands are developed along the coast and that zooplankton maxima, although overlaps chlorophyll maxima, need not be the result of *in situ* grazing and growth but can be the result of physical transport and behavioural aggregation. Similarly on the 1 m to km scale structures in zooplankton biomass or species composition depend very much on hydrodynamic features such as coastal fronts, internal waves, tides etc. With respect to fish larval abundance, several theories have been postulated and it is generally accepted that it is the food that largely determines larval survival. Many recent studies have established the important role of physical oceanographic processes utilising larval food as the proximal agency in determining larval survival.

Angel et al. (1984) have also pointed out that it is biology more than any other oceanographic field that has benefitted most from the advances made in marine physics and technology especially in the upper 100 to 200 metres — how turbulence, eddy diffusion, thermal stratification etc. have a major role in the supply of nutrients which determines the productivity of the ocean. The following treatment of the recent advances in biological oceanography will make the great bearing physical oceanography has in tackling fisheries management problems even more clear.

Microscale plankton patchiness and micro-ecosystems.

Studies on patchiness of planktonic communities occurring at scales of 1 mm to 1 cm by scuba diving (Harbison, 1982) and Goldman's theory (1983) of the spinning — microbial food chain within a discrete microenvironment maintained by small autotrophs, protozoa and bacteria around minute floculated masses of organic material in the open ocean previously described as nutrient poor biological deserts are two major biological revealations gained by looking at marine ecology from levels not done hitherto. His theory is not contradicted by any of the major recent findings in biological oceanography. In fact he brings them together including the revolutionary insight recently made into the functioning of the oceanic food chains that the microheterotrophic processes involving protozoa and bacteria play a significant role in regulating the flow of energy and nutrients beyond the autotroph step. The traditional concept is that this role is largely played by macro-zooplankton grazing. To account for recycling of 80–90% of nutrients in the euphotic zone very low in their concentration and in the biomass he suggests a tight coupling between phytoplankton and grazer components and maximum rates of phytoplankton cell growth, their grazing as well as nutrient regeneration so that the growth of individual phytoplankton cells is not limited by nutrient availability but by how fast the above process goes on.

Goldman's findings of a major short-circuiting in the nutrient cycle brought by such micro-associations of these minute organisms and their importance in the oceanic food chain may also have relevance with respect to open ocean fishery resources. However meaningful research along this line may have to wait until more is known of the food chain in such micro-environments. Recent researches again by Woods Hole Scientists (WHOI Ann. Rep., 1982) on the possible role especially of smaller planktonic ciliates ($<$ 30 microns in size) as an important trophic link between very small phytoplankton (picoplankton or ultraplankton of $<$ 2 microns and nanno-plankton — 2 to 20 microns), the crustaceans and other larger zooplankton also indicate the complimentary role played by them in the dynamics of the planktonic food chain. Without such links, crustacean zooplankton cannot efficiently graze these minute phytoplankters whose ultra small size as pointed out by Longhurst (1983) allows unusually efficient use of solar energy for primary production and rapid uptake of nutrients and are now known to account for the bulk of the primary productivity in the oceans. Ciliates may also serve as food to larval fishes. Although the planktonic biomass of ciliates is comparatively small compared to that of copepods, their occurrence in large numbers. size dependent high metabolic requirements and feeding rates per unit biomass may enable them to play a significant role in the planktonic food chain. The above studies have also brought to light the importance of these microorganisms, because of their ability to use very small nutrient concentrations and hence their vital role in supporting life in apparently barren sea as well as in the nutrient cycling and regeneration at the pelagic level. These aspects, though equally relevant, are not discussed here to avoid digression from the main topic.

Microlayering of plankton and survival of newly hatched fish larvae.

Microlayering of plankton and the role of environmental perturbations in the bioenergetics of fish larval development is perhaps the most important of all recent studies in the field of biological oceanography that is of major interest in the exploitation and and management of marine fish populations. According to Blaxter and Hunter (1982) it is the disparity between the threshold density of food requirement and their average density in the sea that led to the discovery of the importance of small scale plankton patchiness in fish larval survival and the various aspects of the dynamics of larval feeding which established starvation as the major cause of larval mortality.

As early as 1914 Hjort based on his studies on Atlantic herring concluded that magnitude of the fluctuations in the year class strength of fish populations is largely determined by the availability of food during their early larval phase. He therefore emphasised research in fisheries hydrography in relation to spawning success. Until recently however studies along this line were concentrated for studying the movements of the adult population in their exploitable phase to permit efficient fishing. Experimental and field studies by Blaxter and others (Blaxter ed. 1974; Blaxter and Hunter 1982, O'Connell and Raymond 1970) especially on the feeding habits and behaviour of clupeoid fishes and of Lasker and his colleagues (Lasker 1975, 1978, 1981a, b, Hunter 1981) on the distribution of planktonic food organisms in relation to hydrodynamic disturbances in recent years have opened up the possibilities of achieving an ecological breakthrough in understanding the dynamics of the fragile larval phase of fish populations.

It has been generally accepted that the most critical period in the larval phase is during the first twenty-four hour period immediately after the absorption of the yolk sac. Blaxter and Hunter (1982) and Lasker (1978) based on experimental and field studies have shown that during the first few days proper food should be available in concentrations above a minimum threshold level so that the larvae come in contact with the food without any active searching, and that 230 food particles of 50 μm diameter is required daily to meet the high metabolic requirement of first feeding northern anchovy, *Engraulis mordax*. Raymond, Beinfang and Hanson (1974) have found that if in its first 4 or 5 attempts the larvae fail to get the food they cease further seeking and choose to die. Species succession of planktonic organisms in the upwelling region, differences in the nutritive value of food of right size occuring in proper abundance, the clear distinction in the feeding regimes required for survival as against growth, increasing ability to withstand adverse effect of starvation and progressively increasing searching ability of the older larvae are some of the major findings of Lasker (1981 b) and others that provide certain basic biological framework for predicting the quality of the environment for survival of anchovy larvae and also some guidelines for research with respect to other important species.

Studies by Haury and Wiebe (1982), Fasham (1978) and others have also shown that zooplankton patchiness is greater than that of phytoplankton when oceanic fine structure is more homogeneous and that at this time their patchiness is determined mainly by biological interactions like grazing, predation, social and reproductive behaviour etc. According to Lasker (1978, 1981 b) there are times and places in the sea having the required food aggregation favourable for larval survival and that a study of the temporal and spatial picture of the micro- and macro- environment of the larvae will give the clue on the spawning success. Lasker and his group clearly established the micro-layeering or small scale stratification of phyto- and zoo-plankton and their dilution by environmental perturbations brought by oceanographic and meteorological conditions.

Behavioural, physiological and molecular processes in the organisms occupying these oceanic microniches have also become an integral part of the investigations at these scales. Wood (1982) has argued the case for a better understanding of the metabolic capabilities of marine organisms from the angle of marine pollution and that by ignoring the biochemical processes in the sea we will only be oversimplifying the biological cycles. Legendre and Demers (1984) mention that under moderate vertical mixing, changes in environmental conditions are slower than physiological adaptation of phytoplankton and hence the cells are able to adjust their metabolic activities when conditions change. But when vertical mixing is intense the cells can only acclimate to mean environmental conditions. They also quote Cox, Haury and Simpson (1982) and others to show that in addition to studies on biomass characteristics such physiological rates as grazing, respiration etc. and their corresponding enzyme activities are also to be understood. The necessity for studying feeding behaviour, physiological effects of starvation etc. and their relevance on larval survival are also seen from the above account.

THE NEW APPROACH IN FISHERIES MANAGEMENT

The brief review given above of some of the recent developments more directly concerned with fisheries management has clearly shown that hydrodynamic disturbances modify not only every aspect of the oceanic environment but even the intrinsic physiological mechanisms of oceanic life through the organism's response to a change in its environment. It is also made equally clear that definition of the phrase environmental perturbations should not be restricted to physical perturbations alone but to the environment as a whole although hydrodynamic variations may play an important role in introducing the multitude of fluctuations seen in the aquatic environment especially at the meso- and micro- scales. We have seen that aquatic life in the ocean are in much greater intimacy with their environment than in the land; that oceanic environment is not as homogeneous as often considered and that as in terrestrial habitats, pelagic environment is also comprised of a "mosaic of microhabitats" liable to short term dynamic changes. The processes taking place at these dimensions are quite complex and play a major role in the distribution and abundance of marine organisms. Our understanding of the biological processes in the sea can therefore be taken beyond the limits of our present comprehension only by adopting a multidisciplinary approach and as clearly expressed by Legendre and Demers (1984) "on a spatio-temporal scale that is comparable with the phenomenon at hand". This indicates the new direction the biological oceanographic research is going to take in the coming years. Fisheries management problems however cannot wait until all major causal factors in understanding the larval abundance and survival are investigated. The catastrophic decline and sudden resurgence of many major pelagic fisheries of the world reported by Bakun, Beyer, Pauly Pope and Sharp (1982), Longhurst (1983), Lasker (1981 b), Lasker and MacCall (1983) and others have made many fishery scientists realise the need to adopt a more "common-sense" approach than giving too much reliance on over-simplified population models. To the most pressing question raised by Gulland, "Can a study of stock and recruitment aid management decisions" and his pessimistic answer, "No", Lasker (1975) suggested an approach not previously attempted in fisheries research, which on the basis of subsequent research by his own group and others have given new hope in managing the exploited fish populations. Lasker suggests that larval studies in the sea on the basis of the findings on their ecological requirements, limitations etc. based on intensive laboratory studies will unfold the link between marine food chain and stock and recruitment predictions in fisheries. While we are still far away from the solution they have made a major dent into the problem from the ecological angle and is undoubtedly another major advance just as Beverton and Holt's (1957) significant contribution to the problem by representing the population by mathematical models was considered in the 1960s. The latter authors convincingly argued the relevance of population models as the most effective tool in the management of marine fish populations over the earlier crude empirical models. While one cannot deny the impetus given by Beverton-Holt model in leading fisheries research along the lines it has taken in subsequent years or to the phenomenal ecological advances made since then resulting in the current trend to go back to more empirical mathematical methods on the basis of the common sense approach, this change in the trend is only a passing phase in the attempt to make management of marine fisheries as realistic as possible just as the development of the Beverton-Holt model was a similar attempt in the 1950s. *Bakun and Parrish (1982)* Bakun, Beyer, Pauly, Poue and Sharp (1982) and Pauly and Tsukayama (1983) are perhaps the most ardent proponents of this new approach. Their reasoning in adopting this approach on the basis of the findings of Lasker and others of the micro-layering of plankton and food aggregates in relation to hydrodynamic disturbances is that monitoring of food factors controlling their aggregations etc. are difficult, time consuming and expensive and for which suitable techniques are yet to be developed. Hence a rational cause — effect approach is not possible until the complex linkages between environmental processes and biological interactions could be properly understood and measured quantitatively. As a practical interim measure to meet the urgent need of evolving a method more efficient in predicting the fishing success than the existing simplistic models these authors have suggested this alternative approach of utilising the oceanographic and meteorological parameters that control the extent of the "larval retention areas" or "survival windows" which in turn determine the spawning success to a considerable extent. It is a combination of empirical and cause-effect approach. If the upwelling coincides with the spawning season, as it often does, knowledge of the extent of the upwelling alternating with calm period is important, the former for the adult stock and the latter for larval survival and this is again to be linked with the duration of the critical period of the early larvae. Their method is thus much different from the old approach of plotting annual average values of certain oceanographic factors with recruitment or annual landings. Instead daily wind run, direction of wind, Ekman transport and turbulent indices etc. along with other major oceanographic parameters are collected. From the length frequency data recruitment pattern is obtained and also the absolute time when spawning actually occurred by means of latest techniques such as otolith daily annulus counts. Using the data thus collected on real time basis a multiple regression equation is then constructed taking spawning stock size and major environmental parameters as the variables. Bakun, Beyers, Pauly, Pope and Sharp (1982) mention that this approach in essence is a Ricker type function (Ricker, 1975) modified by environmental terms. It is still early to say to what extent these refinements of the old empirical approach, on the basis of mounting evidence that fish eggs and larvae are very much a part of the local physical processes, will improve the predictive ability of the equation.

Another important aspect to be considered here is, with all that is said and done about this new approach in fisheries management problems and its *reason de etre*, the current thinking in answering the basic question raised by Gulland and cited above is oriented only towards developing a predictive tool to determine the annual spawning success. With so much insight gained into the major biological processes in the sea, and the role of physical processes at the micro- and macro- scales in controlling them, it is also time to think how to dampen the magnitude of the fluctuations in spawning success while also permit maximum fishing pressure. Current methods of fishery regulation, especially because of the introduction of highly efficient gears and fish finding techniques, result in progressively reducing the fishing season and effort. As suggested by Krishnan Kutty (in press) oceanographic and meteorological data collected from satellite may be of use in looking at the problem from this angle as well, without which no complete solution to the fisheries management problem will ever be possible. Detailed information in meteorological data such as wind speed, direction, the level of the wind, extent of cloud cover, cloud free regions, all can be extracted from satellite data for even small areas through enhancement process by persons specially trained for it. Once spatio-temporal distribution of favourable areas of larval survival can be obtained in this manner on real time basis it may be possible at least in certain fisheries to restrict fishing in these areas alone so as to ensure maximum larval survival and minimum fishing restrictions. The objective here is to obtain freedom from density dependent stock-recruitment relationship and from the effect of environmental factors on recruitment. The concept still is in the science fiction stage but many such hypotheses have later become realities.

I am happy to make this compilation for the felicitation number of Mahasagar to be issued on the occasion of the sixtieth birthday of Dr. V.V.R. Varadachari, Director, National Institute of Oceanography, India. I hope the compilation will benefit many others at least as much as it has benefited me.

REFERENCES

Angel, M. et al., 1984. Life in the Ocean, In: *Ocean Science in the Year 2000.* p. 61–73. UNESCO, Paris.

Bakun, A., J. Beyer, D. Pauly, J.G. Pope and G.D. Sharp, 1982. Ocean Sciences in relation to living resources. *Canadian Journal of Fisheries and Aquatic Sciences* **39**: 1059–1070.

Bakun, A. and R.H. Parrish, 1981. Environmental inputs to fishery population models for eastern boundary current regions, In: *IOC Workshop Report* G.D. Sharp (ed.) No. 28, p. 67–104. UNESCO, Paris.

Beverton, R.J.H. and S.J. Holt, 1957. On the dynamics of exploited fish populations. *Fishery Investigation, London*. Ser. II, **19**: 533 pp.

Blaxter, J.H.S. (ed) 1974. *The early life history of fish.* Springer-Verlag, New York, 765 pp.

Blaxter, J.H.S. and J.R. Hunter, 1982. The biology of clupeoid fishes, In: Advances in Marine Biology, J.H.S. Blaxter, F.S. Russell and M. Yonge (eds) Academic Press, London, **20**: 1–123.

Cox, J.L., L.R. Haury and J.J. Simpson, 1982. Spatial patterns of grazing-related parameters in California coastal surface waters, July 1979. *Journal of Marine Research* **40**: 1127–1153.

Emlen, J.M., 1984. Population Biology. The Coevolution of Population Dynamics and Behaviour. Collier Macmillan Publishers London, 547 pp.

Goldman, J.C., 1983. Oceanic nutrient cycles. In: Woods *Hole Oceanographic Institution Annual Report,* p. 17–18.

Haley, K.B., 1981. Applied operation research in fishing. NATO Conference Series II : Systems Science, Vol. 10, Plenum, New York, 490 pp.

Harbison, G.R., 1982. The structure of planktonic communities, p. 17–33, **In** : *Oceanography. The Past and Future.* Brewer, P.G. (ed) Springer-Verlag, New York, 392 pp.

Haury, L.R. and P.H. Wiebe, 1982. Fine scale multi-species aggregations of oceanic zooplankton. *Deep-Sea Research* **29** : 915–921.

Hjort, J., 1914. Flucutuations in the great fisheries of northern Europe. *Rapports Conseil International Pour L 'Exploration De La Mer,* **19** : 1–228.

Hunter, J.R., 1981. *Feeding ecology and predation of marine fish larvae, In: Marine Fish Larvae. Morphology, Ecology and Relation to Fisheries.* Lasker, R. (ed) College of Ocean and Fishery Sciences, Univ. Wash. .Seattle, p. 34–77.

Krishnan Kutty, M. 1985. Some thoughts on the exploitation and scientific management of the fishery resources in the seas around India. **In** : *The Oceans: Realities and Prospects,* R.C. Sharma (ed). Rajesh Publications, New Delhi, 304 pp.

Lasker, R., 1975. Field criteria for survival of anchovy larvae: The relation between inshore chlorophyll maximum layers and successful first feeding. *U. S Fisheries Bulletin,* **73** : 453–462.

Lasker, R., 1978. The relation between oceanographic conditions and larval anchovy food in the California current : Identification of factors contributing to recruitment failure. *Rapport Conseil International Pour L'Exploration De La Mer,* **173** : 212–230.

Lasker, R., 1981a. Factors contributing to variable recruitment of the northern anchovy *(Engraulis mordax)* in the California current: Contrasting years, 1975 through 1978. *Rapport Conseil International Pour L'Exploration De La Mer,* **178** : 375–388.

Lasker, R., 1981b. The role of a stable ocean in larval fish survival and subsequent recruitment, p. 80–87, In': *Marine Fish larvae Morphology, Ecology and Relation to Fisheries.* Lasker, R. (ed) College of Ocean and Fishery Sciences, Univ. Wash. Seattle, 131 pp.

Lasker, R. and A. MacCall, 1983. New ideas on the fluctuations of the clupeoid stocks off California. *Proceedings of Joint Ocean Assembly.* 1982. Gen. Symposia. Ottawa, Ont. 110–120.

Legendre, L. and S. Demers, 1984. Towards dynamic biological oceanography and limnology. *Canadian Journal of Fisheries & Aquatic Sciences,* **41** : 2–19.

Longhurst, A.R., 1983. Summary — Biological Oceanography. Proceedings of the Joint Ocean Assembly 1982. *General Symposia. Canadian National Commission on Oceanic Research.* Ottawa, Ont. 143–146.

O'Connell, C.P. and L.R., Raymond, 1970. The effect of food density on survival and growth of early post yolk-sac larvae of the northern anchovy *Engraulis mordax* Girard in the laboratory. *Journal of Experimental Marine Biology and Ecology.* **5** : 187–197.

Pauly, D., 1979. Theory and management of tropical multispecies stock : a review, with emphasis on the Southeast Asian demersal fisheries. *ICLARM Studies and Reviews* **1** : 35 pp.

Pauly, D. and G.I. Murphy, 1982. Theory and management of tropical fisheries. *ICLARM Conference Proceedings.* **9** : 360 pp.

Pauly, D. and Tsukayama, I., 1983. On the seasonal growth, monthly recruitment and monthly biomass of Peruvian anchoveta (*Engraulis ringens)* from 1961 to 1979. Paper presented at the FAO Expert Consultation to Examine Changes in Abundance and Species Composition of Neritic Fish Stocks, San Jose, Costa Rica, 18–19 April, 1983.

Raymond, L.R., P.K. Bienfang and J.A. Hanson, 1974. Nutritional consideration of open sea mariculture, In : *Open Sea Mariculture Perspectives, Problems and Prospects.* Hansen, J.A. (ed), Dowden, Hutchinson & Ross. Inc. Srandsburg, Pennsylvania, USA, p. 129–182.

Ricker, W.E., 1975. Computation and interpretation of biological statistics of fish populations. *Bulletin of Fisheries Research Board of Canada* **191 :** 382 pp.

Ursin, E., 1984. The tropical, the temperate and the arctic seas as media for fish production. Dana, **3 :** 43–60.

Woods Hole Oceanographic Institution, 1983. Annual Report, 1982. 64 pp.

Wood, J.M., 1982 Molecular processes in the marine environment, In : *Oceanography. The present and future.* Brewer, P.G. (ed.) Springer-Verlag, New York, p. 3–15.