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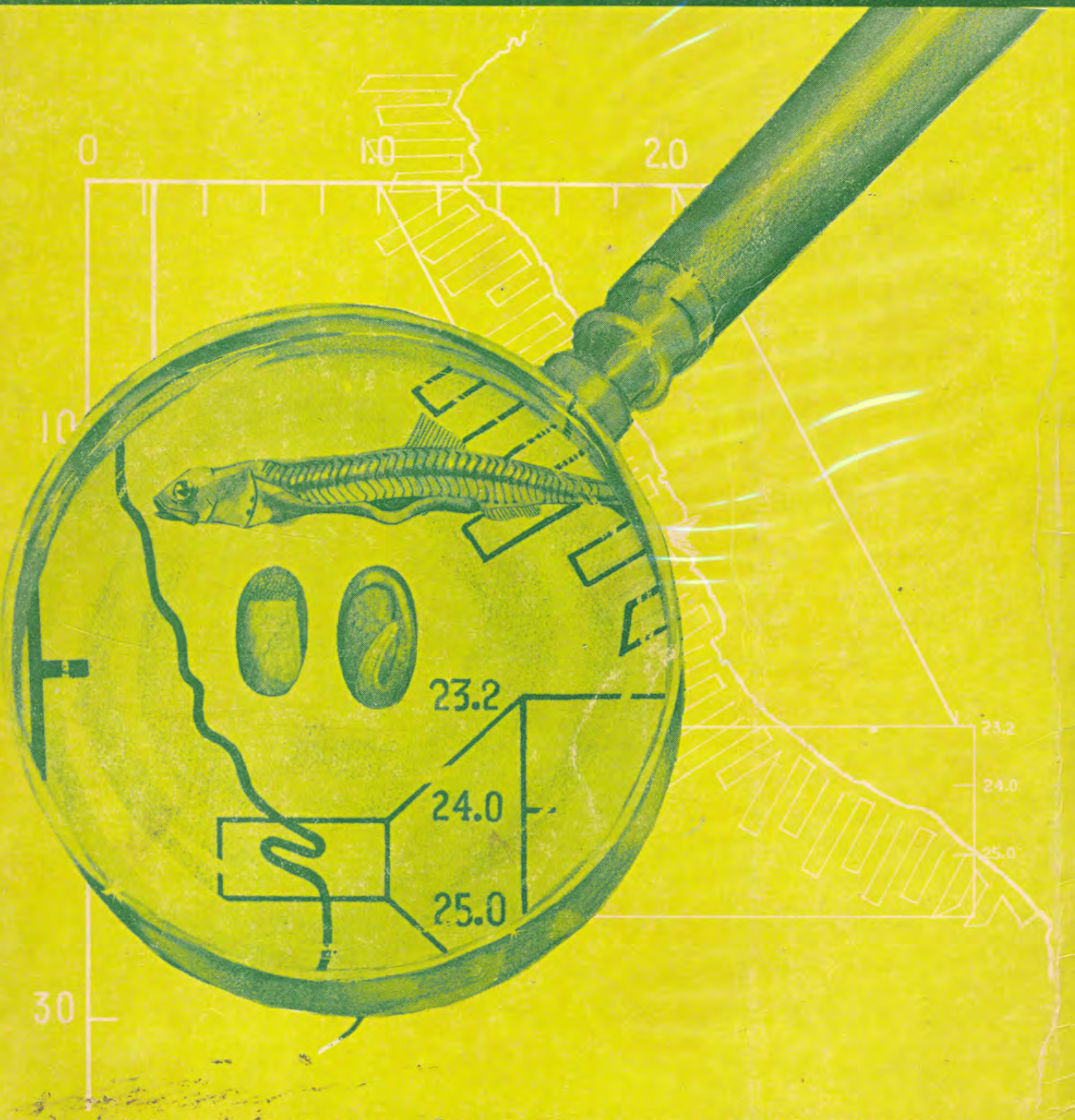

INVESTIGACION COOPERATIVA DE LA ANCHOVETA Y SU ECOSISTEMA -ICANE- ENTRE PERU Y CANADA

CALLAO 1981 PERU

INVESTIGACION COOPERATIVA DE LA ANCHOVETA Y SU ECOSISTEMA (ICANE) BETWEEN PERU AND

CANADA

A SUMMARY REPORT

by

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INTRODUCTION

It is well known that one of the major difficulties to start a proper scientific management of a fishery is the lack of previous studies on unit population, reliable biomass estimations, biological and behaviour characteristics of the resource to be exploited. Given this lack, if the first investments in the fishery are gratifying then it generally follows a boom which causes the fishing effort also to boom to uncontrolable levels in a few fishing seasons with unhealthy consequences for the resource. The anchoveta fishery in the coastal eco-system off Peru is a point in case since from a few hundreds of thousands of anual tons at the end of the fifties several millions of tons per season were caught at the beginning of the sixties. It is only in this lapse that collection and analysis of catch and effort started together with an effort to know some of the population characteristics; these studies are by nature time consuming; meanwhile, the building of fishing boatas increased rapidly. Thus, by 1965 the fishing fleet comprised 1000 boats efficiently equiped while the research work resulted only in a model to estimate the maximum sustainable catch assuming that environment and recruitment remain constant.

In 1965, coinciding with one occurrence of the climatic phenomenon known as El Niño, which brings great changes in the biological and physical environment of the anchoveta, IMARPE, the Peruvian institution in charge of fishing research in Peru, seeing that the existing effort put in danger the resouce, proposed a closure of fishing activities as an indirect means of courtailing the effort; however, this kept growing so that by 1970 the fleet that caught 12.5 million tons was potentially large enough to fish one and one half times the world's production of fishes.

The excessive exploitation together with a very severe occurrence of El Niño determined a drastic diminution of the stocks of anchoveta in 1972 reflected in the low levels of catch since 1973 which at best reached only to 4 millions of tons in 1975 and 1976.

The management of the fishery in this remarkable system has been the responsibility of the government of Peru. But because of the special nature of the system, such management has necessarily been carried out under the full glare of interest of the world fishing community. Many other countries alone, and collectively through the FAO, have tendered their help and the Peruvian government has accepted and made use of this assistance both in its national interest and in keeping with its sense of responsibility and participation in the world community. On all these accounts is has been clear that an assessment of the change in the anchoveta ecosystem and the extent to which manipulation of the fishery might play a role in it were questions of utmost importance, both to this fishery, and to the management of fisheries throughout the world.

The extent of the changes taking place during the 1970's can only be judged in retrospect. They could not be fully appreciated at the time. However, it was evident that they were very extensive (Valdivia, 1978) and economically very important even in 1976 when the Gobernment of Peru approached the Government of Canada with a view to exploring ways in which new methods of study in fisheries and oceanography being developed in various places of the world, might be transferred to the Peruvian situation. The aim of the proposal was to assist the Peruvian scientific group to enlarge its capacity to interpret and predict events in this system on time scales relevant to the needs for management of the fishery.

In this volume is recorded the results of many of the scientific projects which were eventually undertaken by the scientific community and supported by the two governments. This record is an easily understood testimony to the variety and technical complexity of the ensuing operations. For those familiar with the technical problems it will also be evident that much new information and new understanding emerged in a remarkably short time as a result of dedicated and concerted efforts of the individual scientists.

What is perhaps especially remarkable for a scientific venture is the appearance of concrete results of benefit to management. Scientific investigation is, by its nature, a very high-risk undertaking for short-term "pay-off". It is partly on this account that scientific planners generally aim at support of a wide range of individual projects. Many new techniques and many new sampling and experimental projects were initiated in this ICANE study. But in general the scientific community focuses its attention on the much more certain long-term benefits. It must therefore be counted as an especially satisfying surprise that the combined short-term results in this instance resulted in new insight into the relative importance of the mechanisms controlling population changes. These results permit immediate modification of fishery management models towards increased reality and significantly improved precision.

It is our hope that this introductory summary report will assist the reader in gaining a sense of the new potential that has resulted from the total project.

THE OBJECTIVES AND OPERATIONAL PLAN

Project ICANE, requested by the Gobernment of Peru through the agency of the Instituto del Mar del Peru, was based on the concept that improved advice on the management of the fishery depends on better scientific understanding of mechanisms underlying the dynamics of the fish populations. At the time the project was initiated it was becoming clear that the anchoveta stock was in an unprecedented state, and for this reason it was considered critical to rapidly expand the suite of observations of the anchoveta populations and their ecosystems. The purpose of this expansion was to find methods which would measure the relative importance of environmental and fisheries influences on the recuitment to the fished population. It was also considered necessary to explore techniques which could assist in an assessment of the stability of the new state of the stock.

It was clear that in this new situation such information was essential if we were to be able to judge the usefulness of fishery management techniques for creating and maintaining any desirable configuration of the populations making up the resource stock.

Upon formal agreement of the project in late 1976 by the Governments of Canada and Peru, the Gobernment of Canada, through the Canadian International Development Agency (CIDA) arranged for Dalhousie University in Halifax, N.S. and the Bedford Institute of Oceanography in Dartmouth, N.S. to jointly develop and carry out the Canadian obligations under the program. Following consultations among the directors of the responsible laboratories in Canada and Peru a scientific advisory committee was set up, consisting of senior scientists from the three institutions: The Institute of Oceanography, Dalhousie (IODAL): The Bedford Institute of Oceanography (BIO): The Instituto del Mar del Peru (IMARPE). It was the task of this committee to formulate an operational program.

From the start the advisory committee aimed at a program which would consider at least exploratory observations of a very wide range of potential predictors for the ecosystem. The experience of the Peruvian scientists established that a major effort would need to be directed towards a field program, using new and sometimes technically sophisticated equipment. The primary need appeared to be for an examination on small time and space scales of many of the physical and biological phenomena which had been identified on larger, coarser scales by the earlier survey programs of IMARPE. Parameters related to some of these phenomena were already being utilized by IMARPE in providing management advice. Observations on the smaller scales might be expected to yield information on the mechanisms involved.

The earlier programs of IMARPE had also established that the northern coast of Peru consistently supported a major fraction of the commercial production of anchoveta and was by far the most regular and important area of egg production and larval growth. Accordingly it was agreed that the field operations should concentrate on the upwelling area off Chimbote where the Peruvian continental shelf also reaches its maximum width.

It was also clear that an explanation of the dynamic state of the anchoveta stocks would require extensive information on the physiological ecology and energetics of various life history stages of the anchoveta and associated species. Scant facilities existed in Peru for such work. A major effort was thus required for the development of suitable experimental facilities and of the laboratory techniques required to provide the information.

With this background the scientific advisory committee invited scientists from the three institutions to submit specific proposals for experimental work on the productivity of the anchoveta ecosystem. From these proposals the committee selected a suite which appeared capable of providing new insight into the basic structure of the ecosystem, the foodchains operating in it, and the dynamics of the processes linking the structural elements. In some cases the initial proposals were modified by the scientists in the light of the scientific planning discussions. In a few instances it was felt that proposals arising within the three institutes left significant gaps in needed information. In such cases certain scientists from other laboratories, chiefly in Canada and the United States, were invited to participate. The advisory committee found it necessary to restrict the numbers of participants to within limits dictated by the financial budget. But within this constraint scientists were encouraged to give full range to their proposals with a particular view to the formation of joint projects between Peruvians and Canadians.

The number of such joint projects in the final program justified the committee's expectation that the scientific backgrounds of a number of individuals in the various laboratories were strongly complementary.

Finally, in midsummer of 1977, when the main elements of the proposed program had been identified, an introductory scientific seminar was organized at Dalhousie University. By this time the ship preparations had begun, and the main items of required scientific equipment were in process of design, construction or purchase. At this seminar some of the principal participants in the project outlined the rationale for their programs. An important element in this proceeding was the participation, in both presentations and discussions, of scientists from the United States who had been working in the Coastal Upwelling Ecosystems Analysis (CUEA) programa funded by the United States National Science Foundation. The experience of these scientists in the San Juan upwelling on the south coast of Peru provided many of the future participants in ICANE their first opportunity to learn in detail about scales of environmental phenomena and of the practical problems associated with measuring them. The results of this seminar were considered by the scientific advisory committee in the final revisions of individual proposals and in the consolidation of an agreed operating plan and schedule.

In all, the final plan called for the participation of some 80 scientific workers, three research vessels (the Canadian Scientific Ship "Baffin" and the Peruvian research vessels "SNP-1" and "Unanue"), a commercial bolichera (an anchoveta purse-seiner) and shore-based temporary laboratory, which was eventually established in Samanco Bay just south of Chimbote. In addition, an array of special equipment was assembled for the field and laboratory programs, and several special instruments were constructed for permanent installation in IMARPE facilities in Callao, including a special "aquatron" (a controlled open-circulation sea-water and fish holding system) to permit IMARPE scientists to continue with experiments initiated in the scientific program. Further details of the field and laboratory operations, which began with the sailing of the CSS "Baffin" from the Bedford Institute of Oceanography on October 17, 1977, are given in the operational report compiled by the cruise manager and its appended individual reports, written by the participants (Doe 1978).

Following the initial field and laboratory operations, a period of exchanges of scientific personnel between Peru and Canada was initiated. These exchanges were for the purpose of reviewing the results of the initial operations, for setting up new cooperative experiments where indicated, for reviewing or in some instances learning new techniques for experiments or data analysis, for modifying or repairing equipment, and particulary, for preparing scientific reports of the results.

The culmination of this analytical phase of the project was a scientific workshop held at IMARPE from Nov. 19-23, 1979. At the workshop, leaders of the various research exercises reported on their progress and where possible presented their conclusions based on the data available to them. As a result of the ensuing discussions many of the scientists involved have undertaken revisions or new analyses of their work. A number of these have been submitted as scientific papers and reports to a small editorial committee appointed by the workshop. The editors have been responsible for reviewing the papers and ensuring review by colleagues as well as general editing. A number of projects have seemed to be of rather general scientific interest and have been submitted or published in the periodical scientific literature.

This volume, which marks the final step in the ICANE project, has aimed at presenting a collection of reports of all of the most important research projects undertaken. The first section consists of original reports of work considered by the editors to be of primary relevance to the project aim. Also included are reprints of a number of scientific papers which have appeared elsewhere, but were considered of such importance to the program to justify us in seeking permission for reprinting here. In this introductory summary we attempt an interpretation of the compiled findings and seek to present for a general, non-scientific audience an assessment of the importance of the scientific results in relation to the project aim.

RESULTS

The results of the ICANE project are appropriately considered in four separate parts. The main purpose of the work was to deepen the scientific understanding of the mechanisms underlying the anchoveta production in order to improve its recomendations for the resources administration. First place is therefore given in this report to progress in compiling new models of the anchoveta ecosystem and in measuring the power of the mechanisms as predictors in them. Second, we consider the improvement in precision and practicability of various sampling techniques necessary to estimate parameters for these predictors in the models. Third, we deal with problems of technology transfer associated with the new analytic and sampling techniques. Finally, we consider the impact of this combination of factors on future research programs of IMARPE.

(A) DEVELOPMENT OF MODELS

(1) Anchoveta Production and Yield: Because the main purpose of the investigation was to deepen the knowledge in order to advice more properly the fishery management, it is appropriate to begin with discussion of models of the anchoveta stocks themselves. The work is brought into focus by the reports of Csirke and Ware **et al.** Csirke has shown how the earlier general models of the fishery, which had provided the basic background structure for management advice, failed after 1972 due to the abrupt changes in the estate of the stocks. Csirke proposed that environmental information, which had been excluded from the general models, might provide the main key to their improvement. His analyses, which were carried out in parallel with the ICANE suggested that an appropriate reformulation using a combination of fishery and environmental indices could explain on the order of 80o/o of the total variation in recruitment from 1961 to 1976, that is, including the period of the drastic change in stock size. Such precision would clearly re-establish a useful management model, provided that the reliability of the correlation system could be tested. Unfortunately the data series on which the environment index was based was unavailable after 1976.

The ICANE work of Ware and his associates at IMARPE provides considerable support for the belief that Csirke's prediction system might be both tested and improved. In the first step in this process Ware and Tsukayama propose the application of a model developed by Ware based on his experience with Canadian east coast fisheries. In it, the process of production from adult stock to subsequent recruitment is divided into two main parts: (1) adult stock to anchoveta egg production, and (2) eggs to recruits. The first part of this system may be investigated by a combination of field observations on egg abundance and stock size together with laboratory studies of fecundity and the energetics of food and growth. Preliminary work of this sort including comparative data on anchoveta and sardines was begun at Samanco and was reported at the workshop by Tsukayama, Villavicencio and associates and Sanchez. Ware's preliminary calculations using the acquired data suggest that phenomena associated with spawning stock and egg production account for somewhat less than half of the observed variation in the stock-recruit ratios.

The second phase of this model is concerned with survival from egg to recuits, but, particularly of the intermediate larval stages, since there has been much evidence from various fish populations in the world that heaviest mortalities take place in the larval stages. It is often considered that the most important factor affecting larval survival is food availability at the time of first feeding, although there has also been much speculation that drift to "unsuitable" regions or predation on larvae by various predators, including in this situation adult anchoveta, may be of equal importance.

The ICANE plan included a number of projects devoted to the subject of larval distribution, feeding, survival and predation, both in the field and the laboratory. Reports by Ware, Mendiola, Newhouse and their associates show that the larvae of the Peruvian anchoveta are somewhat similar to the Californian species, but that there seems to be greater plasticity in the Peruvian anchoveta. This plasticity would make the latter species better able to adapt to the range of feeding conditions it encounters when its yolk-sac food reserves are exhausted. The larvae may nevertheless prefer particular food species and will therefore survive and grow more successfully when these are present (Ochoa and Mendiola).

The field studies of Sameoto with the BIONESS sampler showed that larval distributions are strongly associated with the thermocline, although larvae of anchoveta and of sardines appeared to show a significant difference in vertical distribution. Work by Herman with the "Batfish" sampler and Mackas and associates with the vertical plankton pump and counter showed that suitable larval foods were also strongly associated with the thermocline. Interestingly enough, however, this was also the focal point of occurrence of zooplankton which to some extent are competitors of first-feeding fish larvae. This strong conjunction of many forms at the thermocline is evidence for dynamism which exceeds prior expectations and makes predictive modelling of this phase of the anchoveta life-history dependent on futher measurement. It suggests, however, that the simple arguments respecting cannibalism of the eggs and larvae by adults are subject to question. There is no doubt that adult anchoveta and probably sardines eat quantities of anchoveta larvae when they are present, but the work of Alamo shows that the adults also consume significant quantities of zooplancton which are the competitors and predators of the larvae. Unfortunately the intention of ICANE to measure the larval survival rates directly was frustrated by the unexpectedly early termination of anchoveta spawing in November 1977 (Dickie).

It must be tentatively concluded that density-dependent mortality functions stronger than those employed by Ware **et al.** for the second part of their model can not be justified by the data. In the present study Ware et al. have employed Csirke's index of environmental change in the second part of the model, from which it appears that this larval survival phase accounts for more than half of the year to year variation in anchovy recruitment. Overall, the results therefore suggest that we have information which provides the same overall explanatory powers as was allowed by Csirke's model, but which, in addition, appears to explicitly identify the main mechanisms underlying recruitment variation. That is a new model, employing Csirke's correction, provides at least a method for checking management indices derived from existing methods and may even be a basis for replacing them.

The results of the ICANE project have thus amply confirmed Csirke's hypothesis concerning the necessity of including environmental parameters in the management models. Indeed, on general grounds one would expect that the longer the term over which a natural resource system such as the anchoveta ecosystem is observed, the larger must be the "universe" included in any model which purports to predict for it. The significant fact of Csirke's intervention in the Peruvian case was his recognition that incorporation of a parameter reflecting environmental change significantly improved prediction of a very large population change which, at that time, almost everyone concerned with the management of the fishery was prepared to blame on the fishery. With the perspective of a few more years it appears that assignment of the yield change to fishery or environmental effects alone is too simple a view. At this stage of our understanding it seems clearly necessary to implicate both. The question for management then becomes: "What is the relative importance of these two powerful forces?"

It is of special importance to an assessment of the ICANE project that the models conceived and tested during the experiment offer the first possibilities of answering this fundamental question. The two parts of the model applied by Ware and Tsukayama have different sensitivity to these two major influences. The stock size, used directly in the first part of their model is clearly influenced by the fishery. By contrast, the larval survival rates of the second part of the model are to a first approximation fishery independent. Of cource the first part of the model is also subject to environmental effects and the independance of the second might have to be modified slightly if cannibalism is found to be very important. However, even with these reservations, we can say that the power of the sotck-egg production relation circumscribes the first order effects of the fishery. The way is therefore open to a study of the relation of these two variables to variations in yield of successive fish generations. The way is then open to an assessment of the sensitivity of the models to management procedures over time.

No attempts have yet been made to develop the study of the system to this point. In our view this must still be regarded as a subject for further research, in which a new derivation of an index like that proposed by Csirke must assume a high priority. However, the prospects for successful study are now there, and a model which permits us to examine the relative effect of the fishery is clearly a key step to understanding the importance of fishery control as an element in overall management.

In concluding this subject, it is important to draw attention to the overall predictive power of these models. The parameters identified so far leave unexplained an unspecified though small amount of the total variation in recruitment. But even this small component could contain effects that are very important even if infrequently manifested. For example, the field data assembled by Santander and Sandoval suggest that the most recent period, 1975 through 1977 may have been a newly critical period in the history of the fishery. An encouragingly successful spawning in 1975 seems to have been cut short by the recurrence of an El Niño perturbation in 1976. This seems to have been followed by a rapid encroachment of northern species and perhaps more importantly of sardine on former anchoveta territory. By 1979 there was wide-spread sardine spawning and unprecedented confinement of anchoveta spawning to small localities along the coast. The events were heralded by features of the ICANE sampling in November 1977, Santander.

It is still too early to assess the significance of these observations, as will be evident from discussions in the following sections. It is likely that if long-term shifts in species dominace between anchoveta and sardine, such as have occurred elsewhere, are in progress off Peru, then the models discussed here are insufficient to account for them. Acoording to present theories, the likely course of such change would necessitate including in the models some mechanism whereby the biomass of sardines and other pelagic species affects anchoveta recruitment. Predation and cannibalism would provide such a mechanism, and it is tempting to speculate on possible formulations. What seems apparent from the information available to date, however, is that any such relationship must operate rather weakly in the Peruvian situation. The very wide changes in conditions which have already been observed seem **a priori** to provide ample opportunity for profound change. The historical resiliency of the basic configuration of this system does not yet provide grounds for rejecting the hypothesis that it is a natural production area with unusual if not unique properties which in some fashion contribute to its long-term stability.

(2) **General Productivity**: In attempting to understand the larger picture of general production on the Peruvian shelf, there is a need to identify and measure mechanisms affecting the entire complex of species. These may be indexed by factors in the trophic system or the environment. A considerable part of the ICANE field work was directed to exploratory sampling of these phases of the system.

Essentially the broader question of prediction for the entire production system invokes such further questions as, "why has this area been such a special producer in comparison with upwelling systems elsewhere in the world?" ICANE papers by Platt, Harrison, Pocklington, Sheldon and others address this question, in some cases by direct comparison with other regions. It is clear from their analyses that the explanation is related to the physical configuration of the Peru coast and the impact on it of water and meteorological circulation events on the larger time scales of weeks, or even of months, seasons and years. Certainly the primary production indices developed by Platt and Harrison show that the production characteristics of the organisms themselves are not unique. The vertical and horizontal structuring in the water column may be. Sheldon's results support Herman's observations of important vertical structuring. The peculiarities of the horizontal distributions and their relation to physical upwelling are illustrated by the papers of Zuta **et al.** (1978) and Guillen (1977, and personal communication) based on extensive earlier sampling. Thus there is no doubt that horizontal and vertical circulation on these scales has an important bearing on the distribution of eggs and larvae (Santander and Sameoto), of zooplankton (Santander, Boyd, Herman and Owen), and of the adults themselves (Canales).

It is the analyses of Towill who examined the available physical oceanographic data, which confirms our expectations that phenomena on larger scales may account for a significant fraction of the physical variance observed in time. His results imply the presence of important and possibly remote environmental forcing functions for the entire system. Unfortunately the ICANE plan to recover a CUEA current meter moored a short distance south of the ICANE area 10 months earlier failed. It appeared that the mooring must have been lost or fouled or that the release mechanism malfunctioned. A valuable source of information on the power and periodicity of the longer term environmental influences was thus lost.

Despite these short-comings of the larger scale data records, the existing information permits the perception of what may be important effects in the environment of the fishes. One such preliminary model of the primary production system was briefly previewed for the ICANE workshop by Guillen. By making provisional assumptions about the data on both primary production and food requirements of the recruits, he found indications that the food available for the recruits may itself be a limiting factor in some years. In particular, his results suggested that there may have been food deprivation for the larvae for a period beginning in 1971, prior to the time that the abrupt decline in the adult stocks was observed. Such suggestions would be of first order importance to any coprehensive predictive models and, whether or not they provide short-term predictors for the fisheries system, they support inferences from many sources from nutrients to fish abundance data that there is an interdependent balance of production among different phases of the trophic structure.

The likelihood of population balance among the various fish stocks, further demonstrated in Jordan's workshop review of recent compensatory-like changes in the landings and estimated biomasses of pelagic fish species occurring on the shelf. An attempt by the ICNAE program to check these indications over the longer term by the collection and analysis of geological cores failed. Five cores were obtained on the shelf area, of which only one was wholly suitable for analysis, and two others provided questionably useful data (Vilks, Rashid and Delgado). The complete core showed that there has been extensive **in situ** reworking of the sediments, some of catastrophic proportions possibly related to earthquakes. Comparisons among the cores show that even closely spaced samples may reflect different depositional conditions: The potential importance of a coring record justifies new efforts to improve the information by sampling other sites. Even if long, continuous, depositional series are difficult to find, shorter ordered sequences would be valuable. At the moment we are totally dependent for indices of population balance on the relatively short fishery and environmental history and on comparison with other areas.

A further potentially important area in which environmental variance is amply demonstrated was provided by studies of the zooplankton. The reports of Alamo, and Ware and Mendiola confirm that zooplankton are important food organisms at various times in the life history of fishes. Past studies in other areas have shown both vertical and horizontal structuring of the concentrations and complexes of zooplankton species and sizes at any given site. The ICANE sampling of Sameoto, Boyd, Herman, Santander and Dickie all confirm this, as well as verifying what appear to be significant diurnal, longer term and spatial patterns. In some instances these were related to obvious features of the physical environment and of the phytoplankton.

Of particular interest in the ICANE project was Boyd and Smith's application to Peru distribution data of a model of zooplancton production developed by Boyd and his associates. The resulting patterns permit for the first time an appreciation for the significance of the oceanographic front evident in the zooplankton distributions. While the technique is in its early stages of development, the suggestion of a coincidence of high secondary production with the areas of deposition of anchoveta eggs is of interest. Confirmation of effects of this sort would strengthen the hypothesis that growth-supporting characteristics of the water masses are of primary significance to the fish populations, outweighing the cannibalistic and competitive aspects of zooplankton occurrence. Such information supplies an important setting for predictive fishery models.

This inference further underlines the likely significance of the spatial heterogeneity of the whole anchoveta producing area, and the possible signficance of the local topography in determining important features of along-shore structuring of the ecosystem. This spatial structuring is clearly an important determining influence, a fact which has already been recognized by the anchoveta survey and sampling programs of IMARPE and was taken into consideration when the ICANE field project was set for the Chimbote area. The presence of such structuring suggests that further understanding of the smaller scale factors controlling fish production may be enhanced in future programs by the adoption of deliberate comparative ecological design of sampling and analysis between geographical sub-systems.

(B) ASSESSMENT OF NEW TECHNIQUES TESTED DURING ICANE

The projects and results discussed in the foregoing section are concerned with two classes of processes: distributive processes which determine the occurrence of physical, chemical and biological properties in space and time and which seem generally to occur along the coast in discrete, more or less coupled sub-systems or water masses; and continuous bioenergetic processes which comprise the dynamics within the subsystems and will be involved in any measurement of coupling among them. In general the former processes have to be described by field sampling. The latter are generally subject to laboratory study and rarely can be satisfactorily measured without laboratory facilities. The ICANE project involved both classes.

The distributive properties were the subject of investigation by the research vessels involved in the cruise. It was only the availability of the CSS Baffin that made some of the more sophicticated work possible. While it is scarcely useful to list all of the operations, the exploratory work on geological coring, the operation of the Batfish, of BIONESS, and of the Guildline CTD were dependent on the Baffin from the rigging for overside handling to electrical power supplies for recording and computer facilities. It is a tribute to the ship's complement as well as the scientific teams that the unusually large variety of equipment was made to function efficiently and smoothly in unfamiliar waters far from home base. Measurements were made of a large array of physical, chemical and biological properties on a finer and more intense scale than had ever been possible before.

Three items of special equipment operated in ICANE are of particular interest because they directly concern future IMARPE programs. A plankton counter for vertical and horizontal distribution studies of phytoplankton and zooplankton was constructed at IODal for donation to IMARPE. The electronic, recording and computing phases of this equipment all functioned faultlessly during the cruise. Unfortunately the jury-rigged pump and collection system, which was new to the Baffin operation, did not, and the excellent data collected was at the expense of considerable efforts and extra time of the ship's crew. A more satistactory arrangement has been made for installation of the equipment on the Peruvian Scientific Ship "Humbolt", now nearing completion.

A second item of sophisticated equipment supplied from Canada was an underwater TV camera for use in connection with acoustic measurement of fish abundance an behaviour. No suitable shelf items were available so the equipment and a housing system for it were especially constructed and assembled at Halifax. This equipment also functioned faultlessly during operations on SNP-1 and has since been successfully used at IMARPE as a recording system in connection with laboratory studies of fish activity.

The third item was the computerized Echo Counting System (CECS) which had been developed at BIO and was shipped to Peru on the Baffin, trans-shipped to SNP-1 and used uscessfully for two weeks in tests in parallel with the Echo Integrator System regularly used in Peru for carrying out surveys for fish abundance. A series of experimental survey patterns was completed using the two systems linked in various ways. Unfortunately, the Canadian data could not be processed in time for the workshop. The cooperating teams have been working in close touch during the data processing and continue to identify analysis and interpretation problems which make direct comparisons of results uncertain. It was hoped that echo-counter information would be able to provide the much desired direct data on the relation between accoustic returns and actual fish abundance under different conditions of fish length, within school density and depth. Such information would be particularly useful in extension of IMARPE acoustic survey techniques to the other species now appearing in abundance along the Peruvian coast. There are however persistent problems of interpretation of single fish as opposed to multi-fish echos. The further processing of the data is continuing without further charges to the ICANE budget.

Not all of the field trails were with sophisticated equipment. A simple neuston sampler (i.e. for sampling organisms very close to the surface) was developed at BIO and tried in Peru waters on the ICANE cruise. Its use confirmed practically and in a simple fashion the very superficial distribution of the juveniles of anchoveta and sardine by collecting them in significant amounts. This simple device has been reproduced by IMARPE for possible routine use on the Peruvian Eureka cruises.

In addition to this special equipment, a variety of sampling devices and nets which have been used in the past by IMARPE workers was used on the Baffin for comparative purposes. The results, taken together, demonstrate some differences in the efficiency of particular gear for capturing different size ranges and types of organisms. Detailed comparisons of the data sets are likely to continue for some time as more and more analyses of the basic information are undertaken. While the results to date generally confirm that the conventional equipment performs well under specified conditions, it is also obvious that such samplers cannot be used to measure certain features of the fine structure which may be significant in future research. We return to this subject in the final section of this report.

Perhaps the most obvious impact of the ICANE exercise on developing new techniques has been in connection with the second class of processes which we have called continuous bioenergetics processes. During the project a running sea water and fish-holding system (aquatron) was designed and the parts constructed and collected at Dalhousie University. Initial units were shipped to Peru on the Baffin with others following by commercial transport. The entire system was assembled at IMARPE by Dalhuousie personnel in facilities provied by IMARPE. After some initial difficulties related to the unknown and unexpected water conditions encountered, the system has begun to function highly satisfactorily. It appears that it is impossible to overcome some of the problems of low oxygen or small red-tide organisms that occur sporadically in summer so that long-term holding of animals in the system is risky. However, the forseeable desirable experiments on physiological and energetics parameters of various species and life history stages are relatively simply adapted to avoid these condtitions. The work which has already been done in these facilities, and using other laboratory equipment supplied in the project, goes a long way towards justifying the effort involved in the installation.

(C) TECHNOLOGY TRANSFER

The Instituto del Mar del Perú was founded in 1960 with the expectation that its primary function would be the compilation of information about the fishery in scientific detail which would provide a strong base for management advice. As we have seen, with time events affecting the stock have led to an understanding that the base of scientific advice must be broadened and observations need to be made on a scale that was not regarded as necessary 20 years ago. This change in point of view respecting the Peruvian fisheries parallels experience in fisheries management throughout the world, but is perhaps clearer in Peru because of the powerful and catastrophic effects of the El Niño phenomenon and the past heavy dependance of the fishery on a single species.

The ICANE excercise was therefore conducted in a system which was already well known, and was under active and sophisticated study by welltrained, experienced scientists. Because of the former importance of the fishery in world terms, IMARPE has also been a cross-roads of fisheries scientists from many countries and from International Agencies interested in studying the system and promoting its effective management. The invitation from Peru for participation by Canada reflected a mutual interest in applying advanced field and laboratory techniques in an effort to improve what was already a high level of observation and understanding.

The success of the ICANE exercise is agreed by all the participants involved precisely because it clearly involved an important mutual increase in the knowledge of the two main groups of participants. This in turn resulted in a significant overall increase in appreacition of the factors which affect the fishery and of the methods for measuring or indexing them.

On the Peruvian side the main feature of the technology transfer was therefore the aquisition and instruction in operation of equipment which was not available locally and for which a local design or construction capacity did not exist. In all cases the equipment involved as donation to IMARPE was used by IMARPE personnel during the main period of activity in late 1977, or was used in special meetings at Callao and Halifax/Dartmouth during 1978.

Subsequent to the operation of the field and laboratory equipment, a period of personnel exchanges was undertaken in which the principal activity was the analysis of ICANE or previous IMARPE data, jointly by Canadian and Peruvian scientists. In this process it was intented that new techniques of analysis should be introduced where there was a need or opportunity indicated by the data, and in a number of cases this was done.

The scope and result of the experiment is indicated by the workshop results which demonstrated a high degree of success in the application of novel techniques and in the assessment of the results. In retrospect it appears certain that the possibilities for joint analyses were far from exhausted. There is little doubt that the level of mutual understanding achieved could be usefully utilized in further steps in the process of building a more reliable and precise management advice system.

(D) IMPACT ON FUTURE PROGRAMS

In theory any predictor for a system must not only have certain characteristics of precision and reliability, but must be based on fewer data than were requiered for its original formulation. This logical process is often difficult to observe in prediction for ecosystems as is illustrated by the evolution of management advice for the Peruvian anchoveta. Experience of recent years indicates that the range of variables to be taken into account is wider than fisheries theory of the 1950's believed necessary. As a consequence the Peruvian scientists at IMARPE have since 1971 necessarily evolved a variety of new indices of the state of the population, including acoustic surveys of adult stocks, egg and larval surveys and recruitment surveys. These are applied in an annual sequence intended to improve the precision of the measurement of the present state of the stocks as a basis for setting up a "Total Allowable catch" for the fishery in the forthcoming year.

In the 1960's the extent of survey information judged appropriate was small, since the data collected were thought to reflect parameters in a general model which should have provided an index of long-term directions in stock and fishery changes. The occurrences of 1972-73 and more recently of 1976-77 destroyed this framework and necessitated a rather large increase in the needed amount of observational data if even short term assessment was to be undertaken. The concern with a new model was therefore in the expectation that it would make possible a reduction in the costs of monitoring at the same time as it increased reliability and precision.

The present state of our knowledge of the anchoveta ecosystem does not yet enable a safe reduction in the density or extent of survey information. In logical terms, it must be recognized that our present theories of the dynamics of this system have utilized all the information which was available and could be processed by the ICANE participants. The models need to be verified on other data. What is important in this context, however, is that as a result of the cooperative efforts, the basic structure of at least one new model of the system has emerged and others are implied in the analyses. The model of Ware et al. hast the advantage over previous models that at least parts of it are expressed explicitly in terms of the mechanisms underlying them. To this extent it is therefore testable at a level which is more immediate than would be the long process of checking its validity by adding one new point per year to the correlation diagrams.

It is in this sense of verifying the mechanisms and identifying the scales on which they operate that the ICANE results will have the most immediate impact on IMARPE programs. It is clear, for example, that the operation of the model would imply certain physiological compensation of the fecundity rates. To verify this would need special new research efforts, rather than a reduction in what is already done. In similar fashion, the data on food habits and food preferences of the adults, especially as they relate to cannibalism, are still very scanty and circumstantial. Laboratory and field observations in combination will be needed to verify the importance of this mechanism. Guillen's general model of feeding is strongly dependent on estimates of grazing rates of larvae and juveniles and similar information on comparative grazing rates of anchoveta, sardine and other species at various stages in their life history will be required in any more general biomass models of the system. All of these phenomena will require further study.

The foregoing does not, however, imply that a future predictor of the anchoveta ecosystem, or even of the whole fishery ecosystem will necessarily involve the monitoring of all these phenomena. This is already apparent from the effectiveness of Csirke's index of environmental influence. It was developed by Csirke from data on seasonal changes in fishing success and appears to reflect a concentration of the spawning stocks into a small part of the potentially habitable coastal area. The index appears to measure a response to envrionmental influence, and its effectiveness as a correction term in Ware's model may result directly from the effect of stock concentration of the mechanism may then mean that Csirke's index, or some substitute index based on other data, will provide a simple, inexpensive and sufficiently precise predictive parameter of a complex mechanism. The analyses of Ware et al. even suggested that Csirke's index was strongly correlated with deviation of temperature from the optimal spawning temperature, a parameter which would be relatively easily estimated. It is clear thar research devoted to the exploration of the Csirke index and development of a substitute for it (possibly from acoustic survey data, for example) may be one of the most efficient uses of research time.

The ICANE results suggest two additional features which must be taken into account in future programs. It is clear from all the data that the ICANE sampling area was only one of several production sub-systems that are related to the geography of upwelling. There is a strong likelihood that these areas may operate slightly differently and at different times. In particular, they are probably differentially sensitive to environmental perturbation. Efforts to establish whether or not these separate producing areas also support partially separate populations of juveniles and adults would be justified. Should the degree of interdependance or mixing of the adult spawning stocks be measurable, it would be possible to set up tests of predictors for the sub-systems separately thus speeding up the process of verification and implementation.

Finally it must be pointed out that while we must subscribe to the view that the biological system is ultimately dependent on the physical environment, we have very little precise information about the physical variations or of the factors controlling them on the Peru shelf. Most of the biological tests described above assume that the important responses of the organisms to the environmental factors can be described by rather small-scale observations. However, there is a significant probability that important features of perturbation and response may be taking place outside this framework. To construct models which affectively encompass the size of system actually in operation, requires at the very least, a spectral analysis of the environmental events from the order of days to months, and eventually to years. A powerful device for obtaining this information would be an array of current meters anchored at appropriate locations along the shelf. Given data of this sort it may then be possible to extend the analysis into larger scales by judicious use of wind records or detailed records of tidal levels at shore stations. It is essential to learn at what frequencies the energy expressed in the total variance is being dissipated. It would appear that this kind of information should be considered as of high priority in programs directed to resource management on the Peruvian coast. Such data would be especially important in studies directed towards an understanding of the overall stability of the new stock complex.

Finally, we return to the subject of geological study of the deposition patterns on the continental shelf off Peru. Although the first attempt at sampling showed vigorous reworking of sediments in some areas, it is likely that in other areas, particularly where there is low oxygen in the water, there will be periods of greater stability. Cores have been taken by other groups on the continental slope and the results are suggestive of orderly sequences of deposited material. Further attempts should be made to identify and sample such localities in the region of the anchoveta production system. The data would provide the most immediate index of long-term productivy and stability of patterns of producers.

CONCLUSIONS

In proposing a project such as ICANE, which is dependent on the development and application of scientific knowledge to a large practical problem, there is inevitably a set of imponderables. In the first place it cannot be confidently forecast just what kinds of observations will be needed, and only a very general idea of what information a particular technique will yield. In the second place we cannot know what kind of changes the system itself will undergo. Finally, we cannot foresee the contributions that will be made by individual scientists which might permit significant new synthesis relevant to application.

The ICANE project is no exception to these generalizations. The scientific advisory committee, which chose the detailed program, necessarily operated on very general rules for judgement of the scientific merit of proposals and the capabilities of the personnel. It will be clear from a comparison of the preliminary statements included in the manager's progress report (Doe 1978) with the results described here that not all of the projects met the expectations of their authors. Others that were successful on a logical basis, were found not to be immediately related to the main objectives of the program. Yet others may be found to be relevant when further analyses are undertaken. In almost every case it can be recognized that reanalysis from different points of view is possible. In the workshop proceedings themselves there was hardly an exception to the realization by individuals that even minor reworking of their previous analyses would make clearer the relation of their results to those of others. Most of the reports presented in this bulletin have been re-worked from the versions presented at the workshop as a result of discussions there. Other projects failed to yield the hoped-for information because the system itself was differente from expectations.

Of particular importance in the case of the ICANE project, however, was the change in the anchoveta ecosystem itself. The original terms of reference of the cooperative project stressed the central importance of the anchoveta, partly because the concern of management had been with possible recovery from the drop in 1972-73, and partly because the 1975-76 events suggested the possibility that the system might revert to its former state if there were judicious restriction of the fishing. While all involved were aware of the remarkable changes in species composition in other pelagic upwelling elsewhere in the world, the high productivity of the Peru coast in the 1970's seemed to set it apart from these others. It was therefore not until the data for 1979 were assembled that we could begin to appreciate the extent of the change. Now questions as to the stability or transience of this new configuration are of first importance.

It is likely that a fore-knowledge of the possible extent of change in the Peruvian system would have made some difference in the approach to the problems addressed by ICANE participants. In particular, sampling patterns might have been more widely distributed and a greater proportion of the field effort might have been expended offshore. However, it is of the nature of scientific work that it begins from description of its system and works toward generalization which can then be focussed on the particular. In this instance it must be recognized that the models applied to the anchoveta were first developed in other contexts and generalized in such a way that it appeared useful to fit them with specific anchoveta parameters. This process involves some adjustments and corrections. For the results discussed here, for example, the basic fishery model might well be applied to the sardine or the jurel, but our sampling indicates a slightly different distribution of sardine eggs and larvae. It is thus possible that Csirke's environmental index developed from observed anchoveta distributions might not work in quite the same way for the sardine. That is, the work on the anchoveta and its ecosystem is probably equally useful for an analysis of the sardine populations, but it is necessary to be alert to the possbility that this may involve more than a simple matter of substituion of parameter values for another species.

The principle difference between a project planned in 1976 and in 1979 would likely be found in the comprehensiveness of the approach. The present concern is with the interaction between the two species rather than either one separately. This difference will certainly be reflected in any further work of such groups.

What the foregoing implies is that one of the main fruits of this kind of exercise must be the development of the capacity of the management advisory groups to adapt to changing conditions and problems in what we call the "real world". A perfect predictor for the anchovy system alone would be of limited practical use in the system with which management is now dealing.

From this point of view, there can be very little question of the success and significance of the ICANE project. That is, in addition to specific results, it has developed a capacity for understanding of ecosystem dynamics which is at the same time broader and more specific than existed at the beginning. While this fact will only be fully demonstrable in future management advice, the evidence for it was clear in the broad participation in workshop discussions and will be clear to a reader of the reports of analysis included in this bulletin.

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