Intergovernmental Oceanographic Commission

Workshop Report No. 66

IOC Workshop Report of the Expert Consultation on the Sardine/Anchovy Recruitment Programme (SARP)

La Jolla, California, USA, 30 October - 1 November 1989

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40 Suppl.	OC Workshop on the Technical Aspects of Tsunami Analyses. Prediction and Communications, *Submitted Papers* Sidney, B.C.. Canada. 29-31 July 1985	E
41	First Workshop cd Participants in the Joint FAO/IOC/WHO/IAEA/UNEP Project on Monitoring of Pollution in the Marine Environment of the West and Central African Region (WACAF/2) Dakar, Senegal, 28 October - 1 November 1985	E
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44 Suppl	IOCIFAO Workshop on Recruitment in Tropical Coastal Demersal Communities *Submitted Papers*, Ciudad del Carmen, Campeche, Mexico, 21-25 April 1986	E
45	IOCARIBE Workshop on Physical Oceanography and Climate Cartagena, Colombia, 19-22 August 1986	E
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47	IOC Symposium on Marine Science in the Western Pacific The Indo-Pacific Convergence Townsville, I-6 December 1986	E
48	IOCARIBE Mini-Symposium for the Regional Development of the IOC-UN (OETB) Programme on "Ocean Science in Relation 10 Non-Living Resources (OSNLR)" Havana, Cuba, 4-7 December 1986	E. S
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54	Workshop on Sea-level Measurements in Hostile Conditions, Bidston, UK. 28-31 March 198(	E
55	IBCCA Workshop on Data Sources and Compilation, Boulder, Colorado, 18-19 July 1988	E
56	IOC/FAO Workshop on Recruitment of Penaeid Prawns in the Indo-West Pacific Region (PREP) Cleveland, Australia, 24-30 July 1988	E
57	IOC Workshop on International Co-operation in the Study of Red Tides and Ocean Blooms Takamatsu, Japan, 16.17 November 1987	E
58	International Workshop on the Technical Aspects of the Tsunami Warning System. Novosibirsk, USSR, 4.5 August 1989	E
58 Suppl.	Second International Workshop on the Technical Aspects of Tsunami Warning Systems, Tsunami Analys~e. Preparedness, Observation and Instrumentation. *Submitted Papers* Novosibirsk, USSR, 4-5 August 1989	E
59	IOC-UNEP Regional Wórkshop to Review Priorities for Marine Pollution Monitoring Research, Control and Abatement in the Wider Caribbean. San Jose. Costa Rica. 24-30 August 1989	E, R, S
60	IOC Workshop to Define IOCARIBE-TRODERP Proposals Caracas. Venezuela. 12-16 September 1989	E
61	Second IOC Workshop on the Biological Effects of Pollutants, Bermuda. 10 September 2 October 1988	E
62	Second Workshop of Participants in the Joint FAO-IOC-WHO-IAEA-UNEP Project on Monitoring of Pollution in the Marine Environment of the West and Central African Region, Accra, Ghana, 13-17 June 1988	E
63	IOC/WESTPAC Workshop on Co-operative Study of the Continental Shelf Circulation a the Western Pacific, Bangkok. Thailand, 31 October - 3 November 1989	E

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1. OBJECTIVES OF THE EXPERT CONSULTATION

The SARP proposals formulated in La Jolla in 1984 are now perceived ambitious since they have not received the necessary financial support. The proposals concentrated on a 'within-year' study of variation in mortality determined from otolith studies, and the relation of mortality to environmental events. The aim of this Expert Consultation was therefore to refocus SARP onto objectives having a higher likelihood of being carried out.

The objectives of the Consultation were therefore:

(i) To review the state of the regional SARP projects.

(ii) To outline future SARP activities including

a) reconcile the temporal versus spatial investigation strategies;
b) suggest a uniform methodology;
c) incorporate new technology; and
d) determine the role of SARP in assessing the impact of global climate change.

(iii) Recommend a feasible SARP strategy for the future.

2. THE ROLE OF SARP AND IREP IN THE OSLR PROGRAMME

There is certainly a need to bring about a much closer interaction between oceanographic research and marine biology. Several recent national and international initiatives show that the time is ripe for coupling these two branches of marine science. One initiative towards this goal is the "Ocean Science in Relation to Living Resources" (OSLR) programme which is co-operatively sponsored and formulated by the Intergovernmental Oceanographic Commission (IOC) of Unesco and by the Food and Agriculture Organization of the United Nations (FAO). This programme was under discussion for several years in the early 1980's and was initiated officially in 1983 by an international workshop in Halifax, Canada. The formulation, development and implementation of the Programme is carried out and guided by the Guiding Group of Experts for OSLR, the members of which come from the fields of marine biology and physical oceanography. The Scientific Committee on Oceanic Research (SCOR), and the International Council for the Exploration of the Sea (ICES), have permanent representatives in this group. The Group reports to the governing bodies of IOC and FAO. The purpose of OSLR is to promote improvement in scientific understanding which will lead to more effective development, management and conservation of the marine living resources of coastal nations. So far, OSLR has concentrated its efforts in the field of fish recruitment.

The variability of fish recruitment is considered to be the most important unsolved problem in fishery population dynamics. To processes controlling the variability of fish recruitment are the subject of the "International Recruitment Project" (IREP) of OSLR. Fisheries management could be improved considerably if recruitment success or failure could be anticipated or if, at least, it be known if recruitment failure of a fish stock is due to natural or man-made causes, such as over-fishing or pollution. A variety of physical oceanographic phenomena on the macro- meso-and micro-scale, such as currents, upwelling, turbulence, Langmuir circulations, surface slicks, are known to affect fish at all life stages, particularly in the highly vulnerable larval or early juvenile phase. However, their net effect at the population level are poorly understood. The result is large unexplained inter-year variability in recruitment which, besides being a major source of uncertainty to those involved in fishing and associated industries, is typically so extreme as to largely obscure essential signals needed to foresee and manage the long-term effects of fishery exploitation, habitat alterations, global climate change and other vital concerns in a scientific

manner. The need to develop the means to filter the inter-year "noise" in order to resolve the crucial underlying signals is perhaps the most important argument for promoting research on the recruitment problem.

IREP has been initiated by two pilot projects, the "Sardine/Anchovy Recruitment Project" (SARP) and the "Tropical Demersal Recruitment Project" (TRODERP). Within the context of SARP, the principal biological and physical factors causing mortality of early life stages, including the early juvenile phase, are intensely studied, as it is commonly assumed that recruitment strength is determined at these stages.

Several regional SARP projects have been formed. Sprat recruitment in the North Sea is studied co-operatively by the UK, Denmark and the Germany. Sardine recruitment in Iberian waters is investigated in a bilateral project by Portugal and Spain with some US support. A multinational project on the recruitment of the Southwest Atlantic anchovy with scientists from Argentina, Uruguay, Brazil, Germany and Sweden will begin in November 1989. Similar studies will be initiated in 1990 on anchovies and sardines in the upwelling region off the Chilean coast. A major aspect of the SARP scientific rationale involves application of the comparative method of science whereby the multiple expression of the problem afforded by various species groups inhabiting different regional ecosystems may facilitate the sorting out of the complex interacting mechanisms involved in recruitment variability.

Another growing sphere of activity within IREP focuses on the demersal resources of the tropical band through the "Tropical Demersal Recruitment Project" (TRODERP). TRODERP has been initiated in Southeast Asia in the form of a Penaeid Prawn Recruitment Project (PREP) involving Australia, Brunei, Indonesia, Malaysia, Papua New Guinea and the Philippines. In the western tropical Atlantic area, the IOCARIBE Sub-commission of IOC has defined 3 focal research areas under TRODERP:

(i) Fish Estuarine/Deltaic Recruitment (FEDERP);
(ii) Penaeid Prawn Recruitment (PREP); and
(iii) Coral Reef Demersal Recruitment (CORDERP).

A schematic presentation of OSLR and its various regional components is given in Figure 1.

A second sub-programme of OSLR to be launched now will focus on Red Tides and Ocean Blooms.

3. ICES INITIATIVES IN IREP

The meeting heard a report on current ICES activities in relation to IREP from the ICES representative at the Expert Consultation (M. Heath). A summary is presented in Annex II.

At present, ICES is not co-ordinating any recruitment programmes. However, there are several international research programmes underway in ICES member countries which investigate the processes of recruitment, mainly in the north Atlantic. The role adopted by ICES has been to suggest avenues for research and review activities through the formation of Study Groups. Recently, a more active co-ordinating role has been suggested by the Larval Fish Ecology Working Group, and the Intercommittee Recruitment Group have proposed to investigate the fundamental basis of recruitment concepts by establishing a modelling study group.

4. PRESENT STATE AND SYNTHESIS OF REGIONAL SARP STUDIES

Individual SARP projects were reviewed by participants in the meeting. Presentations included descriptions of work carried out and planned for the future on sprat in the North Sea, sardines and sardinella off Spain and Brazil, anchovy, off the Argentinian coast, and sardine and anchovy off Portugal, Chile, Mexico (Gulf of California), Japan and the USA (California). Individual reports from each of these studies are contained in Annex III.

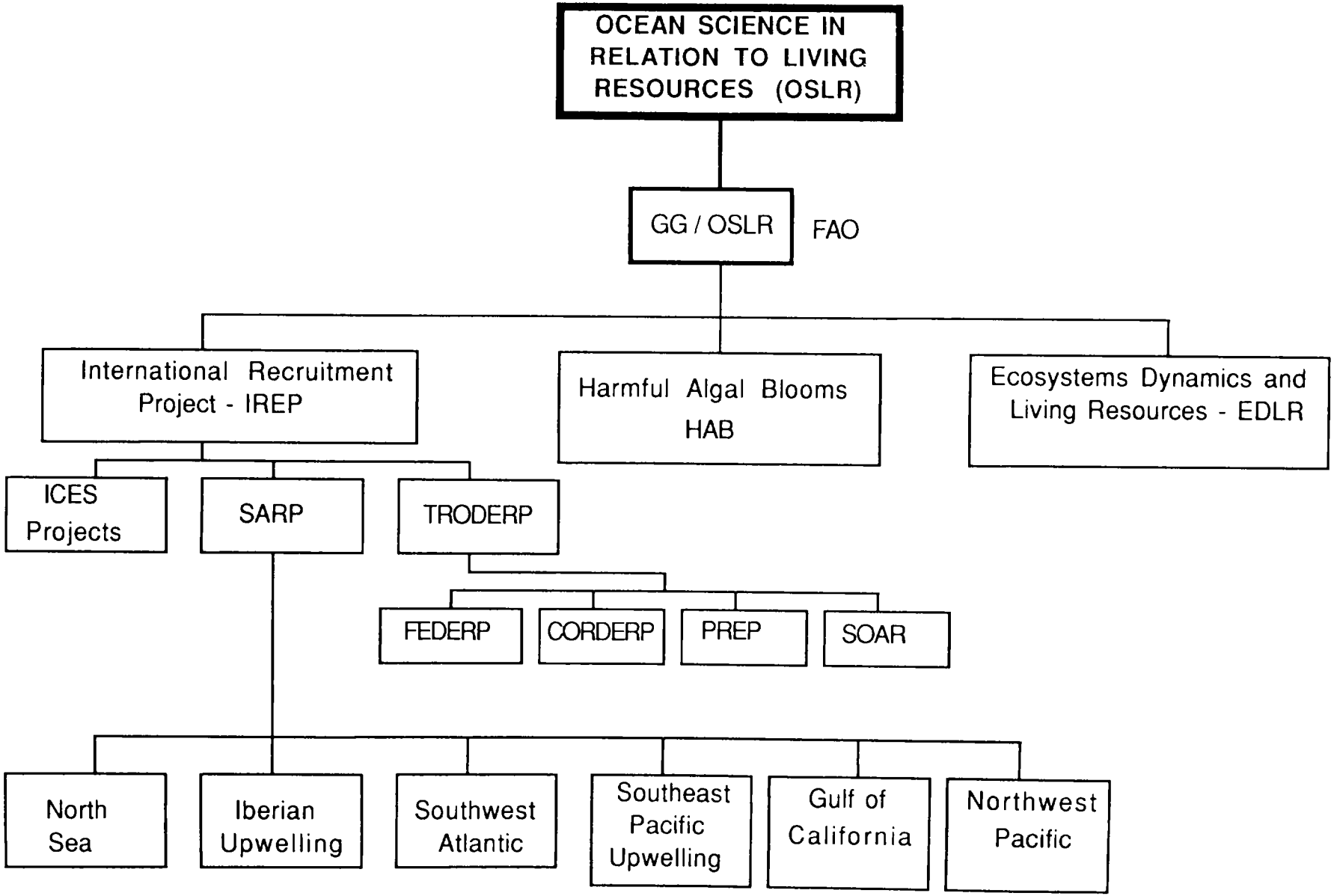

Fig. 1 OSLR and its components

Some of the investigations reported to the meeting were primarily devoted to the determination of adult spawning biomass by the egg production method. Other studies concentrated on the processes likely to affect egg and larval survival. There were no studies involving juveniles.

A wide range of techniques were in use by researchers, particularly in relation to assessing the condition of larvae and detecting predation. Of particular interest were the biochemical and histological methods to determine the recent feeding history of individuals. Predation studies were less common, only two instances being cited - cannibalistic consumption of anchovy eggs by adults, and predation on eggs and yolk-sac larvae by euphausids.

All the projects had a broad multidisciplinary basis. Leaving aside investigations focussing on the egg production method (Iberian and Californian sardine/anchovy) there were two main approaches to investigating egg and larval survival. First, the interrelations of mesoscale oceanography, the spatial distributions of eggs and larvae, and year class strength were investigated in the southwest Atlantic, off the Iberian coast and around Japan. Studies of this type are planned in the Gulf of California. Secondly, regional or sub-regional differences in plankton production and biomass were related to larval condition in the North Sea (sprat), off the Iberian coast and in the southeast Pacific. Similar studies are planned in the southwest Atlantic and in the Gulf of California.

Advective processes were an important consideration in the Japanese sardine investigations. It is likely that the widespread and extended duration of spawning by most of the populations under investigation in SARP has inhibited the development of advection studies in other areas.

Taken overall, the investigations described to the meeting were focussed on testing the early larval starvation-mortality hypothesis. In addition, many of the important mesoscale processes governing the population characteristics have been successfully elucidated by the application of comparative and spatial investigations.

5. NEW METHODS APPLIED TO SARP STUDIES

The meeting heard presentations on 4 aspects of methodology. First, techniques for assessing the condition of larval anchovy by measurement of triacyl glyceride (TAG) and sterols in individuals were described. Data were presented which indicated that the method was able to resolve differences in condition between habitats.

Secondly, an immuno-assay for the presence of fish eggs and yolk-sac larvae in the stomachs of invertebrates was described to the meeting. The initial motivation for developing the technique arose because the predator involved (euphausid) macerated its prey so that items were not recognizable in the stomachs. Antibody to anchovy yolk protein was developed and an enzyme linked spot immuno-assay on euphausid stomach contents performed on nitrocellulose membrane filters. The method provided presence/absence data on the incidence of feeding on anchovy eggs/yolk-sac larvae and was sufficient to estimate predation mortality, provided that gut residence times and the duration of diurnal spatial coincidence of predator and prey were known. The method could not be used to detect fish predation on eggs or larvae due to cross-reaction with predator proteins.

A new histological method for detecting starvation in larvae was also described. The height of mid-gut cells in sections of larvae was taken as an index. The method had the advantage that material could be collected from standard ichthyoplankton tows, formalin preserved, and the cells visualized with standard haemotoxylin and eosine stains.

Finally, the meeting heard a presentation on the Plymouth version of the Longhurst-Hardy Plankton Recorder (LHPR) which can be used for investigations of the vertical distributions of eggs, larvae and plankton.

Details of each of these methods are given in Annex IV.

6. APPLICATIONS OF MODELLING AND SATELLITE IMAGERY IN SARP AND RECRUITMENT STUDIES

The meeting heard two presentations illustrating the role of modelling in recruitment studies, and the interface between biological investigations and physical oceanographic studies.

First, an account of the Autumn Circulation Experiment (ACE) was presented to the meeting. ACE was a multidisciplinary study of water circulation and larval herring growth, drift and survival in the North Sea. An important part of the study was the development of a 3-dimensional numerical model of larval advection. Flow fields from a 3-dimensional (horizontally and vertically resolved) water circulation model of the European shelf seas governed the horizontal transport and dispersion of simulated tracer particles.

The consequences of different climatological conditions for the advection of larvae were evaluated using the model and finally, the implications of advection variability for subsequent mortality due to predation by demersal fish were investigated by field sampling.

The second presentation was an example of the application of satellite imagery and flow modelling in recruitment studies. In this case, surface flow fields in eddy structures were interpreted from the lateral displacements of distinctive features in sequential satellite images of sea surface temperature. Satellite derived flow vectors were transferred to curvi-linear co-ordinates to resolve the flow over the area of interest, and in recent developments the subsurface flows have been derived from these data. This work is typical of that presently carried out under the SOAR project (Satellite Ocean Analysis for Recruitment) - a sub-component of the IOCARIBE-TRODERP initiative of OSLR.

Data on the distribution of walleye pollock eggs and larvae in the Alaskan Coastal Current were presented as an example of the application of satellite derived flow fields. Field sampling detected the presence of a persistent patch of pollock eggs and larvae in Shelikof Sound, Gulf of Alaska. Independent analysis of satellite images showed that at this time northwesterly winds induced the formation of an eddy in the Sound, and the surface flow fields indicated that this structure had effectively trapped the pollock, when under other circumstances they might have been carried rapidly through the sound by the Coastal Current.

The two modelling approaches described in the presentations on ACE and Alaskan pollock studies represented very different but complementary approaches. The oceanographic model used in ACE simulated shelf wide circulation but at a relatively low horizontal resolution (20 km). The satellite imagery produced high spatial resolution data, but only for short periods over a small area of the shelf and under particular circumstances. The two approaches were clearly complementary in that the detailed satellite derived structure could be nested within the shelf wide flow model for particular applications. These areas of research represent an important interface between biology and physical oceanography, and should be included in future recruitment research programmes.

Descriptions of ACE and the satellite derived flow field method are contained in Annexes V and VI.

7. THE COMPARATIVE APPROACH TO RECRUITMENT RESEARCH

The experimental method and the comparative method have been called the two great methods of science (Mayr 1982). The experimental method is the method of choice when experimental conditions can be readily controlled. The comparative method offers an alternative in cases where experimental controls may be impractical. As an example of its power, Mayr credits "nearly all the revolutionary advances in evolutionary biology" to the comparative method.

The ocean-atmosphere system is largely uncontrollable. Moreover, the mixture of scales of motion in the ocean makes it virtually impossible to maintain the integrity of the volume of water in which an

experiment is taking place unless it is artificially contained in some manner. However, artificial containment restricts the scales of crucial dynamic processes and also presents anomalous interfaces and substrates which can alter essential mechanisms. Besides, because of the enormous reduction in numbers that occurs, survival of an individual to the age at which recruitment occurs is a very rare event compared to the fates of the overwhelming majority of hatchlings. Thus, the results obtained for most samples of larvae may be quite irrelevant to eventual recruitment at the population level. Thus, experiments should ideally be performed at the population level. If experiments on small population segments are difficult, the problems of performing experiments at the population level are overwhelming.

Thus the comparative method would seem a natural way to address the problem of recruitment variability in marine populations. In fact, it seems surprising that the comparative method has not been more widely employed in fishery-environmental science, which appears to have been more preoccupied with diversity than with synthesis, and prone to view each local situation as unique (Bakun 1985).

Some recent applications have been informative. By comparing geographical and seasonal aspects of spawning habits to those of environmental processes and characteristics, Parrish et al. (1983) found a pattern of simultaneous avoidance of offshore transport and of storm-induced turbulent mixing that implicated these processes as major detrimental factors affecting reproductive success of sardines and anchovies of eastern ocean boundary upwelling systems. Time series analysis of reproductive success of the Peruvian anchoveta (Mendelssohn and Mendo 1987) and of larval mortality of the northern anchovy off California (Peterman and Bradford 1987) tend to corroborate this result. Cury and Roy (1989) compare time series models of a number of eastern boundary sardine and anchovy populations and conclude that an "optimal environmental window" for reproductive success may exist between wind speeds too low for sufficient upwelling to enrich the trophic pyramid and wind speeds so high that turbulent mixing may destroy fine-scale food concentrations essential to successful larval feeding and offshore transport may sweep surviving larvae away from the favorable coastal habitat. Examination of the habitat climatology of the Sardinella of southeastern Brazil (Bakun and Parrish, in Press) indicates that this population has a reproductive strategy tuned to solving essentially the same environmental problems as its eastern boundary counterparts, in spite of its dynamically quite different western ocean boundary location and its much more tropical temperature situation.

On the more biological side, studies in 4 countries (USA, Peru, Argentina, and South Africa) indicate that anchovy cannibalism accounts for a significant fraction of the natural egg mortality (about 20-30%) over a wide range of stock conditions and habitats from the virgin Argentinean stock to the heavily exploited Peruvian stock. Collectively, these findings establish cannibalism as a key regulatory mechanism in anchovy populations, whereas no single study would have had such an impact. Along similar lines, biomass estimation using the egg production method conducted under SARP has provided estimates of the natural mortality of eggs and larvae of sardine and anchovy in California, Peru, and Spain. Because the nets and estimation procedures were identical in these studies, a direct comparison of egg and larval mortality rates is possible. Striking differences between the Peru and California systems provide insight into the coupling between productivity and recruitment processes.

Another important function of the comparative method will be the validation of models. The history of recruitment research has been that correlations between the physical environment and recruitment ultimately break down. The process is probably far too complex for simple correlations to hold, and success will most likely be realized through the development of more complex models. The most effective means of validating these models would be their successful application in different regions of the world. In fact, such a comparative approach may be the only way that such models can be validated over the short term.

We have an impressive recent example of co-operative data assembly and integrative analysis in the recent multilateral study of the ecosystem of the Peruvian anchoveta (Pauly and Tsukayama 1987; Pauly et al., in Press). Similar efforts in other areas around the world would serve to facilitate broad application of the comparative method. By so offering its experience and results for incorporation in a wider comparative context, each local effort could expect to realize enhanced scientific utility in terms of

its own local fishery concerns, while in turn expanding the available suite of potential comparative analogues and thereby contributing to the general scientific benefit of all the associated regional efforts.

8. CONCEPTUAL DESIGN OF SARP STUDIES

The SARP high temporal resolution "within-year" exercise, developed under the leadership of Ruben Lasker and his colleagues at the Southwest Fisheries Center, has been identified as a uniquely promising process-oriented approach for addressing the mechanisms and impact of short term temporal variability in larval survival (Anon. 1983, 1984, 1987). A particular attribute is that it addresses these aspects at the population level, rather than addressing the fate of typical or "average" larvae which, as discussed above, may be irrelevant to net reproductive success. It does this by relying on the capture of survivors, i.e., members of the successful subset, at a later life cycle stage and then reconstructing its birth date from daily marks carried in the bony structures (Pannela 1971, Methot 1983, Campana and Neilson 1985). These would then be compared to short term variability in environmental processes and conditions to reveal linkages and causal mechanisms. Another promising element is its use of newly-developed technological tools such as the larval birthdating methodology, histological measures of starvation (Theilacker 1986) and immunoassays of predator stomach contents (Theilacker et al. 1986).

Implicit in the concept is a loss of spatial resolution within the larval habitat because the animals may undergo substantial movements during the period between birth and capture. This may not be a crucial drawback because the most energetic sources of short-term environmental variability (atmospheric storms, etc.) have large spatial scales. In fact, any source of increased mortality that did have both a short temporal scale and a small spatial scale, could not have any substantial effect on net annual recruitment to fish populations whose spawning is distributed on a regional scale over an extended spawning season.

In order to produce a valid "survival index" from larval birthdate frequencies it is necessary to have documentary evidence of the short term variability in larval production. Since larval production can vary on small spatial scales as well as on small temporal scales, a full SARP "within-year" exercise requires detailed monitoring of larval production over the entire habitat at short intervals over an extended period. This represents one of the most demanding aspects of the operation. Because of the extensive ship time and other operational resources required, no full SARP "within year" exercise has been completed to date. In view of this, the Ad Hoc SARP Consultation participants agreed that the SARP concept should be broadened to include other types of high-resolution (both temporal and spatial) studies. The original SARP "key phrases": high-resolution, new technologies, and interregional comparative studies would continue to characterize SARP activities.

Technologies for indicating short term variability in larval growth rates, both biochemically (Buckley 1984) and by measurement of otolith increment width (Gutierrez and Morales-Ninn 1986) are available. Starvation and predation appear to be the major sources of larval mortality (Hunter 1981). These are both associated with growth rate. Starvation represents the extreme of minimal (negative) growth rate. Vulnerability to predation appears to be size dependent (Hunter 1981) and so growth rate would affect predation mortality. A focus on factors controlling growth rate variation would provide a high temporal resolution verification field without the onerous necessity for the detailed specification of larval production (Bakun, in Press). Also, since the very recent growth may be determined, spatial resolution is restored. The availability of spatial resolution allows many new hypotheses to be addressed. These would include effects of topographically-controlled hydrodynamic structures and frontal formations, effects of eddies and current meanders, etc., and all the associated hypotheses concerning larval retention (Sinclair 1987), local enrichment, convergence, advection, etc.

9. CORE QUESTIONS FOR FUTURE SARP STUDIES

In view of the proposed refocussing of SARP objectives it was considered essential that the meeting should provide a range of future research options. These should reflect the broadening of the scope of the programme and provide the basis for investigations at various levels of activity. The list of

research questions presented below should not be regarded as exhaustive, but represents those which the meeting considered to be important for future SARP studies. In each case, the appropriate methods have been indicated, together with an assessments of the relevance of the question for the comparative ecosystem approach to recruitment research, and the feasibility taking into account both scientific and financial considerations. The meeting considered the first 7 questions to be of highest priority for future SARP studies. The prototype SARP "within-year" exercise should continue to be an important aspect of the SARP and is included in the list of options (item 7).

9.1 ARE THERE EPISODIC, DYNAMIC FEATURES THAT GEOGRAPHICALLY RETAIN LARVAE OR DISPERSE THEM?

Methods: Interactive multidisciplinary ichthyoplankton and hydrographic surveys using drifting buoys, satellites and acoustic current profilers and models to track water currents.

Comments: The objective is to investigate the co-distributions of larvae and oceanographic features such as fronts, eddies, filaments and coastal currents which may be characteristic features of shelf ecosystems. The approach is therefore very valuable for ecosystem comparisons.

Feasibility: Highly feasible at many levels of sophistication.

9.2 HOW DOES THE VERTICAL MIGRATION BEHAVIOUR OF LARVAE AFFECT THEIR ADVECTION AND DISTRIBUTION?

Methods: Vertical distribution sampling of larvae with high time resolution using opening and closing nets or acoustics. Concurrent measurements of vertical distributions of horizontal velocities and hydrographic parameters (e.g., using acoustic doppler current profiler and CTD systems). Accurate measurements of subsurface light intensity.

Comments: This question represents a key interface between biology and physics and should be a high priority project. The approach is especially valuable for the comparative ecosystem approach.

Feasibility: Highly feasible.

9.3 DOES STARVATION MORTALITY EXIST AND OVER WHAT LIFE STAGES? WHAT FRACTION OF TOTAL NATURAL MORTALITY IS ACCOUNTED FOR BY STARVATION?

Methods: Field sampling of larvae and subsequent analysis of individuals to detect incidence of starvation. Total mortality measured by sequential ichthyoplankton surveys and otolith aging.

Comments: Only histological methods (e.g., height of gut epithelial cells) are true probes of starvation. Biochemical methods are correlates of growth. Regional comparisons of starvation mortality are particularly valuable when assessed in the context of measurements of food availability.

Feasibility: Detection of starvation very feasible, dependent on availability of expertise. Interpretation of starvation mortality requires laboratory calibration of observations. Measurement of total mortality less practical and results subject to high uncertainty.

9.4 DOES CANNIBALISM EXIST AND AT WHAT LIFE STAGES? IS A SIGNIFICANT FRACTION OF TOTAL NATURAL MORTALITY ACCOUNTED FOR BY CANNIBALISM?

Methods: Trawl sampling for adults and plankton sampling for eggs/larvae. Examination of stomach contents and/or immunoassay techniques. Gastric evacuation rate measurements. Total mortality measured by sequential ichthyoplankton surveys and otolith aging (for larvae).

Comments: Cannibalism on eggs has been investigated for some species of anchovy by inspection of stomach contents, but for other species the eggs are very fragile and do not survive ingestion. The problems are severe for yolk-sac larvae. The immuno-assay method has promise, but cross reactions with predator proteins may cause problems. Laboratory studies of gastric evacuation rates are required.

Feasibility: Highly feasible for eggs of some species. Low feasibility for yolk-sac larvae, and unknown for older larvae. Qualifications for total mortality estimates as in 3 above.

9.5 IS THERE SPATIAL OR TEMPORAL STRUCTURE IN CONDITION FACTORS, GROWTH AND MORTALITY? CAN SUCH PATTERNS BE LINKED TO PHYSICAL AND BIOLOGICAL STRUCTURES AND DYNAMICS?

Methods: Field surveys of ichthyoplankton, plankton and hydrography for example, within and without spatial structures, or before and after storms. Analysis of larval condition (correlates of growth) by for example RNA/DNA, TAG/sterol ratios, morphometrics, growth rate, mortality, incidence of starvation.

Comments: The approach is valuable for studying processes within an ecosystem, but difficult to conceive as an in-between system comparative method. The approach could be integrated with question 9.1 above, and should include subsurface profiling of physical and biological measurements.

Feasibility: The methods have all been carried out and are highly feasible. However, a fully integrated programme requires a large ship and could therefore be costly.

9.6 WHAT ARE THE PREDATORS OF EGGS, LARVAE AND JUVENILES? WHAT IS THE COINCIDENCE IN SPACE AND TIME?

Methods: The predators of eggs and larvae can be identified from stomach sampling programmes for vertebrates and immuno-assay surveys for invertebrates. Coincidence in space and time can be investigated by concurrent directed sampling for both predators and prey.

Comments: Identification of eggs and juveniles in vertebrate stomachs is relatively easy, but larvae are very hard to detect. In cases where both predator and prey are captured with the same gear, cod-end feeding may be a problem. The approach is very valuable for ecosystem comparative studies.

Feasibility: Identification of predators is highly feasible, except for those consuming larvae. Estimating coincidence is highly feasible for zooplankton predators, but requires a multidisciplinary ship for fish predators.

9.7 IS THERE SHORT TERM RADICAL VARIABILITY IN SURVIVAL OF LARVAL STAGES OVER SIGNIFICANT AREAS? IS THERE SMOOTH OR STOCHASTIC VARIABILITY IN BIRTHDATE DISTRIBUTIONS FOR SURVIVING LARVAE AND EARLY JUVENILES?

Methods: Sequential surveys of eggs and larvae to estimate time distribution of larvae production. Sampling of late larvae and/or early juveniles, and examination of otoliths to determine birthdates of survivors. Comparison of production with survivor birthdates to determine within season variations in mortality which may be related to, for example, storm events.

Comments: The first approach is the 'classical SARP' within-year experiment. The second approach is a "short-cut" method in which a smooth change in production over time is assumed so that and "stochastic" variability in back-calculated birthdates of survivors could represent within season variability in mortality. However, this approach should be undertaken cautiously since the analysis would be time consuming and the results may contain bias or be misinterpreted. A valuable approach for ecosystem comparisons.

Feasibility: The first approach is technically feasible, but rarely carried out, due to cost. The second approach only requires sampling of late larvae/early juveniles and so is more feasible.

9.8 WHAT ARE THE RELATIONS BETWEEN VERTICAL MIGRATION BEHAVIOURS OF LARVAE, PREY AND PREDATORS?

Methods: As in 9.2 above but with additional sampling of other biological components.

Comments: The objective is to estimate the encounter rate between larvae and their prey and predators, initially in a 1-dimensional frame of reference (vertical). With increasing sophistication a 3-dimensional approach could be developed by combining with question 9.2. The 1-dimensional approach has limited value for the ecosystem comparisons.

Feasibility: Highly feasible.

9.9 DOES A RELATIONSHIP EXIST BETWEEN LARVAL GROWTH AND EITHER THE ABUNDANCE OR QUALITY OF THEIR FORAGE?

Methods: Field sampling of zooplankton abundance, size distribution, biochemical composition and physiological rates (measures of condition). Concurrent sampling of larvae for measurements of growth by otolith analysis, size at age, RNA/DNA. Modelling studies to relate growth to prey density.

Comments: The approach is valuable for investigating within region variations in growth, and especially applicable to late larval stages. The results are not intrinsically valuable for ecosystem comparisons.

Feasibility: The approach is very feasible and has been carried out several times.

9.10 DO TOXIC ALGAL BLOOMS HAVE A SIGNIFICANT EFFECT ON SURVIVAL?

Methods: Laboratory assays of toxicity, and opportunistic field sampling of bloom organisms and larvae, aided by satellites.

Comments: Laboratory assays are not well understood or readily available. Targeted sampling is difficult to achieve. Of local significance but little value for ecosystem comparisons.

Feasibility: The approach is being carried out in some areas and is very feasible.

9.11 DOES POLLUTION AFFECT THE SURVIVAL OF EGGS AND LARVAE?

Methods: Considerable controversy over methods (e.g., embryo development as an index of pollution stress). Few methods available.

Comments: Principle problem is to distinguish variability due to pollution from natural variability. There are few convincing studies where this has been achieved. The approach is of little value for ecosystem comparisons.

Feasibility: Very low feasibility with present technology.

9.12 HOW DOES THE STRUCTURE AND PHYSIOLOGICAL CONDITION OF THE SPAWNING POPULATION AFFECT REPRODUCTIVE OUTPUT AND THE QUALITY OF SPAWN?

Methods: Trawl sampling of adults for fecundity versus age measurements and age composition of adult stock. Fat content measurements on adults to assess condition. Measurements of egg size, yolk content and hatching success to assess egg quality.

Comments: Annual fecundity of migratory species may be determined during the feeding migration. Fat accumulated during the feeding phase may be related to total fecundity and/or egg quality. It is possible that industry records of fat content could be utilized for time series studies of condition once the detailed interrelations have been worked out.

Feasibility: Moderately feasible - diverse sampling and analysis methods required. May be difficult to obtain samples of adult fish at the appropriate time of year for some species. Attractive but not an essential element of a comparative ecosystem study.

9.13 AT WHAT LIFE STAGE DOES ACTIVE HORIZONTAL MOVEMENT BECOME SIGNIFICANT (i.e., BECOME QUASI-INDEPENDENT OF WATER CIRCULATION)?

Methods: Ecological interpretation of organo-genesis. Laboratory measurements of swimming speed and stamina. Observations of the onset of schooling behavior and changes in diel vertical movements.

Comments: This question may be important in some areas, for example, where current measurements may cut off pockets of larvae. The question is vital for advection modelling studies to determine at what stage the model becomes invalid for describing larval distributions. However, the methods are indirect and inferential and of low value for ecosystem comparisons.

Feasibility: The approach is highly feasible.

9.14 WHAT IS THE ROLE OF GENETICS IN DETERMINING GROWTH AND SURVIVAL?

Methods: No well established methods.

Comments: The question is very challenging and is an important area of fundamental supporting research with many sub-questions.

Feasibility: Not generally feasible with present technology.

9.15 IS PARASITISM A SIGNIFICANT CAUSE OF MORTALITY?

Methods: Opportunistic observations of parasite incidence, followed up by laboratory evaluation of consequences for survival.

Comments: Has been demonstrated to be a significant factor in some circumstances. Not generally of high value for ecosystem comparisons.

Feasibility: Highly feasible if the situation arises.

10. FUTURE ROLE OF MODELLING AND SOAR IN SARP

10.1 MODELLING

Within OSLR, the components of IREP (i.e., SARP, TRODERP and CORDERP) are process-oriented research initiatives that require larger theoretical and empirical frameworks for the interpretation and full exploitation of their individual results. For example, the within-year experiment defined as the core of SARP attempts a detailed comparison between the larval production at peak spawning and the birthdate distribution of juveniles at a later date within the same population. In order to interpret the observed patterns in terms of causes and effects, a rather detailed characterization of the environment is needed, and a model (or models) relating differential larval survival with environmental variability at different spatial and temporal scales is required.

The recognition of recruitment as the missing link for understanding the ecology of benthic coastal marine populations has received renewed attention in the ecological (non-fishery) literature, and recruitment in general has been widely recognized as the key ecological process for the prediction of highly variable marine populations. Models that incorporate recruitment and advection into age structured marine populations have been published and further theoretical developments are expected. Furthering the understanding of recruitment as a process is one of the main goals of the new GLOBEC initiative.

Modelling, at least conceptually, remains an integral part of IREP. However, it should be identified and singled out as a specific task within the programme. The modelling exercises being undertaken within the ICES countries (ICES Modelling Study Group) could provide a focal point for developing an IREP modelling initiative. Because of the highly structured intellectual environment that a modelling exercise generates, it provides a very efficient means for transferring knowledge and multidisciplinary methods of investigation from developed to developing countries.

10.2 SOAR

Satellite derived information has been successfully used for defining the mesoscale structure of environments where important fish populations spawn. This technology is a very cost-effective way of solving major observational restrictions in recruitment studies. Sequences of satellite images not only allow better allocation of sampling effort at sea, but can also be used in conjunction with oceanographic models to predict the trajectories of eggs and larvae within complex structures such as coastal currents, plumes, filaments and eddies. The study of recruitment in tropical estuaries and coral reefs (PREP, TRODERP and CORDERP) would also benefit from a more systematic use of satellite oceanography. Several developing countries already possess facilities to retrieve and process satellite imagery, and local capabilities are developing very fast.

11. ROLE OF SARP IN ASSESSING THE IMPACT OF GLOBAL CLIMATE CHANGE

The International Geosphere-Biosphere Programme (IGBP): A study of global change, attempts to understand the interactive physical, chemical and biological processes which regulate the total Earth system with particular emphasis on those that are most susceptible to human perturbation. Major global climatic changes are expected to take place in the next decades as the result of the accumulation of CO_2 and other greenhouse gasses in the atmosphere. In this context, the world oceans function as both a source and sink for CO_2 through a combination of physical and bio-geochemical processes.

The International Global Oceans Flux Study (IGOFS) of the Scientific Committee on Oceanic Research, an independent component of IGBP, has focused on the role of the oceans in regulating the climate system and its rate of change in response to the greenhouse effect.

On land, climatic change will not only affect natural terrestrial ecosystems but also impose regional constraints on agriculture and forestry. These impacts are widely recognized and models are currently being designed for predicting changes and assessing strategies for alleviating the consequences. However, prediction of the impact of climate change on marine ecosystems has not yet received so much attention even though it may have significant consequences for states whose economies depend on the exploitation of living marine resources.

The impact of climate change on marine ecosystems was discussed during the IGBP Southern Hemisphere Workshop held in Mbabane, Swaziland, in December 1988 (IGBP Report No. 9). It was proposed that research should be carried out in a limited number of marine pelagic ecosystems which might be expected to be strongly affected by global climatic change. It was recommended that ecosystems should be selected according to the following criteria:

(i) the magnitude of the potential impact of climatic change on their structure and function;

(ii) the importance of their main biotic components as renewable resources;

(iii) the feasibility of conducting comparisons and sensitivity analyses of goal orientated single process models to global climate change;

(iv) the potential for developing a generic coupled-process model, that on the basis of the high level of commonality of oceanographic and ecological processes structuring them, could increase the basic understanding of their dynamics, in an effort to predict their response to global climate change.

The nature of this research calls for an extensive use of the comparative approach developed within OSLR, and since recruitment of pelagic fishes was identified as one of the sensitive processes, it provides a natural focal point for collaboration and integration among both programmes.

12. IMPLICATIONS OF SARP FOR FISHERY MANAGEMENT

The meeting discussed the likely applications of the products from SARP for fishery management, and concluded that there are two main roles. First, to assist in the estimation of spawning stock size and secondly to provide scientific underpinning of long term management objectives. SARP studies should be regarded as being an adjunct to stock assessment which focuses attention on biological issues, increasing awareness and the ability to interpret signals logically when changes occur. These issues will become more important as the world human population increases and it becomes necessary to harvest fish stocks which are presently under-exploited.

The socio-economic objectives of fishery management may vary considerably from nation to nation. Nevertheless, the target of exploiting stocks at a level which does not incur unacceptable risk of recruitment failure should be one which is encouraged. At present, there is little scientific basis for

defining such a target for any stock in the world. Very often, the target is determined from a simple examination of historical data. However, this approach cannot take into account trends in the environmental conditions controlling early life survival, or changes in the distribution and abundance of other organisms which may reduce or enhance predation pressure on the target species. An objective of SARP should be to provide the scientific understanding of fisheries ecology necessary to objectively determine target levels of exploitation.

13. RECOMMENDATIONS

The ad-hoc Expert Consultation on SARP recommends:

(i) Broadening the objectives of SARP by complementing the within-year experiment approach defined previously by the addition of other process-oriented recruitment research relevant to a comparative approach.

(ii) That the SOAR (Satellite Ocean Analysis for Recruitment) project presently proposed under IOCARIBE-TRODERP be raised to the IREP sub-project level in the OSLR organizational structure.

(iii) That the on-going recruitment research initiatives on Japanese sardine and Mexican research on anchovies and sardines in the Gulf of California be included in SARP.

(iv) That IOC should seek regional participation by OSLR in the new ICES Study Group on Models of Recruitment Processes to be held in 1991 in Paris.

(v) The development of closer contact between OSLR and especially SARP activities and those of the ICES Recruitment Processes Working Group. An increased level of representation at the Working Group meetings is recommended.

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ANNEX I

AGENDA

1. OBJECTIVES OF THE EXPERT CONSULTATION

2. THE ROLE OF SARP AND IREP IN THE OSLR PROGRAMME

3. ICES INITIATIVES IN IREP

4. PRESENT STATE AND SYNTHESIS OF REGIONAL SARP STUDIES

5. NEW METHODS APPLIED TO SARP STUDIES

6. APPLICATIONS OF MODELLING AND SATELLITE IMAGERY TO SARP AND RECRUITMENT STUDIES

7. THE COMPARATIVE APPROACH TO RECRUITMENT RESEARCH

8. CONCEPTUAL DESIGN OF SARP STUDIES

9. CORE QUESTIONS FOR FUTURE SARP STUDIES

   9.1 ARE THERE EPISODIC, DYNAMIC FEATURES THAT GEOGRAPHICALLY RETAIN LARVAE OR DISPERSE THEM?

   9.2 HOW DOES THE VERTICAL MIGRATION BEHAVIOUR OF LARVAE AFFECT THEIR ADVECTION AND DISTRIBUTION

   9.3 DOES STARVATION MORTALITY EXIST AND OVER WHAT LIFE STAGES? WHAT FRACTION OF TOTAL NATURAL? MORTALITY IS ACCOUNTED FOR BY STARVATION?

   9.4 DOES CANNIBALISM EXIST AND AT WHAT LIFE STAGES? IS A SIGNIFICANT FRACTION OF TOTAL NATURAL MORTALITY ACCOUNTED FOR BY CANNIBALISM?

   9.5 IS THERE SPATIAL OR TEMPORAL STRUCTURE IN CONDITION FACTORS, GROWTH AND MORTALITY? CAN SUCH PATTERNS BE LINKED TO PHYSICAL AND BIOLOGICAL STRUCTURES AND DYNAMICS?

   9.6 WHAT ARE THE PREDATORS OF EGGS, LARVAE AND JUVENILES? WHAT IS THEIR COINCIDENCE IN SPACE AND TIME?

   9.7 IS THERE SHORT TERM RADICAL VARIABILITY IN SURVIVAL OF LARVAL STAGES OVER SIGNIFICANT AREAS? IS THERE SMOOTH OR STOCHASTIC VARIABILITY IN BIRTHDATE DISTRIBUTIONS FOR SURVIVING LARVAE AND EARLY JUVENILES?

   9.8 WHAT ARE THE RELATIONS BETWEEN VERTICAL MIGRATION BEHAVIOURS OF LARVAE, PREY AND PREDATORS?

   9.9 DOES A RELATIONSHIP EXIST BETWEEN LARVAL GROWTH AND EITHER THE ABUNDANCE OR QUALITY OF THEIR FORAGE?

ANNEX II

ICES RECRUITMENT INITIATIVES

This review has been prepared by the Chairman of the ICFS Recruitment Processes Working Group (M. Heath) and does not necessarily represent the views of the Council itself.

1. Background

Following the initiation of OSLR and IREP by the IOC and FAO in 1983, ICES responded by forming a study group to consider the development of an ICES contribution to IREP. The group met in 1985 but was unable to produce firm recommendations. THis interdisciplinary steering group on IREP met in 1986, 1987 and 1988, reporting on the concepts and possible courses of action for recruitment research.

During 1984-1988 various ICES member nations had been carrying out their own recruitment investigation programmes. In a few cases these had developed into international co-operative efforts, although not co-ordinated through ICES. However, many of the initiatives had been discussed and carried out by members of the ICES Larval Fish Ecology Working Group (LFEWG).

In 1988 the IREP Steering Group was changed to the Intercommittee Recruitment Group and its activities scaled down to a meeting during the ICES Annual Statutory Meeting. At the same time, the IFEWG was given additional responsibility for recommendations on recruitment studies. Both the LFEWG and the IRG met during 1989.

2. Current Recommendations on Recruitment Research

The latest recommendations of the LFEWG and the IRG are contained in ICES CM 1989/L:22 and CM 1989/A:8 respectively. Both the groups agreed that there are fundamental conceptual difficulties hindering the development of hypotheses and investigations of recruitment. The LFEWG perceived that theory and practice should develop simultaneously as a ymbiotic relationship and favoured the comparative ecosystem approach for identifying the important processes. The LFEWG concluded that the comparative approach required a co-ordinated initiative and proposed to take steps towards developing the theory and practice of such a programme. The IRG has recommended the setting up of a study group to examine recruitment modelling.

The recommendations of both the IRG and the LFEWG (now renamed the Recruitment Processes Working Group) were accepted by the ICES delegates meeting in October 1989.

Both the IRG and Recruitment Processes Working Group will meet again in 1990.

ANNEX III

PRESENTATIONS OF REGIONAL SARP STUDIES

NORTH SEA/IRISH SEA SPRAT

by
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A co-operative series of investigations on sprat (Sprattus sprattus) have been initiated in European waters by the Plymouth Marine Laboratory (S. Coombs), the Alfred-Wegener Institut fur Polarforschung, Bremerhaven (J. Alheit), the Institut fur Hydrobiologie und Fischereiwissenschaft of Hamburg University (W. Nellen) and the Danish Institute for Fisheries and Marine Research (P. Munk). These studies are essentially independent projects which are united under the common theme of the study of recruitment processes of sprat. Where possible there is co-operation in sampling and analysis to provide a broader base for interpretation of the results. The investigations do not constitute a SARP experiment as such but include many of the components of a SARP-type study.

A common aim of all the studies is to compare the condition and survival of sprat larvae with hydrographic and plankton measurements. Included in the various analyses for larval condition are growth-rate determinations from otolith-ring counts, RNA/DNA ratio (both FRG and MAFF, Conwy Laboratory), gut enzyme, histological and histochemical assays, C and N elemental analysis and several biochemical methods applied by CNRS laboratories in France for lipids, amino-acids, protein and vitamin C measurements.

The work of the Plymouth Marine Laboratory (PML) is organized within the framework of a 4-year programme (1987-1991) to investigate reasons for the observed relatively low fish production per unit area of the Irish Sea compared with the North Sea. The focus of this study has been an examination of food availability in relation to condition and survival of fish larvae. Included in the programme are hydrographic and primary and secondary production studies for overall comparisons between areas. Broad-scale sampling methods have included UNDULATOR tows, Coulter-Counter measurements of particle abundance and more conventional net sampling for microplankton. More detailed sampling is then carried out at representative stations using LHPR systems for studies of vertical structure and standard net tows to obtain larvae for condition analyses.

Sampling for sprat larvae by the Alfred-Wegener Institute (AWI) has been concentrated in the German Bight of the North Sea to study the condition of sprat larvae in relation to tidal and river-plume fronts and
plankton distribution and abundance. In June 1989, a 2-ship exercise was conducted between AWI and PML involving detailed vertical profiling for physical and biological measurements followed by depth-stratified vertical sampling to obtain larvae for condition analyses.

Similar sampling has been conducted by Hamburg University but including O-group sprat as well as over-wintering adults with sampling extending from the German Bight to the western English Channel.

The Danish research programme took place later in the year (August 1989) so that greater emphasis was placed on sampling for larger post-larvae. As well as studies of larval condition in relation to hydrographic and plankton conditions a principal aim was to relate differential survival of larvae to advection and the environment into which larvae were transported.

Future work of all the laboratories will continue to refine analytical methodologies for the assessment of larval condition. Preliminary bioassay techniques employed in 1989 to measure the feeding potential of different areas and to validate condition indices will be expanded to limited laboratory based experiments to improve these techniques.

SPANISH SARDINE

by
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Background

The Iberian sardine, Sardina pilchardus, is the target species of an important fishery off the Atlantic coast of the Iberian Peninsula, in terms of both economic and social value. Research on the biological aspects of this species began in the 1950's, based mainly on studies of reproductive parameters, growth and stock and/or population differentiation through meristics. In the early 1970's and throughout the decade, several ichthyoplankton surveys to define seasonality and spawning areas were begun by Spain and Portugal. From 1979 onwards, research was in support of management of the fishery by means of a continuous joint assessment by both countries considering the stock as a unit. The evaluation of the sardine stock is currently being done by Virtual Population Analysis and periodic acoustic surveys.

On the other hand, investigation of hydrographic conditions and biological oceanography emphasizing the upwelling ecosystem off the Iberian peninsula began as early as the 1960's. The investigations of physical oceanography by Fraga, in Spain and Fiuza, in Portugal, and most recently, by North American and Spanish scientists within the FOG (Fisheries and Oceanography of Galicia) co-operative programme provided some background knowledge of the hydrographic conditions of the area. The programme "Ciclos"
(Planktonic Production Cycles) carried out by Portugal during 1985-1986 also supplied background information on the biological and oceanographic aspects of the eastern coast of the Iberian peninsula and on the areas and seasonality of sardine spawning.

The first contacts between Spanish and American scientists within the SARP framework began in 1984 at the La Jolla SARP meeting, which configured the main lines of a SARP study on the Iberian sardine. Later, these lines were specifically defined for the Iberian SARP project in a seminar held in Vigo in October 1985, which led to the submission of a SARP proposal to the USA-Spain Joint Committee for Scientific and Technological Co-operation.

This project contemplated a 3-year programme according to the following schedule:

(i) The first year was mainly based on training the involved scientists in some of the SARP techniques (data management, plankton sampling quality, batch fecundity and spawning frequency estimation, starvation, daily otolith reading, etc).

(ii) During the next 2 years the efforts were addressed to: a) establish the spawning seasonality and areas; b) study the hydrographic conditions off the Iberian peninsula; c) validate the results of the methods applied; d) evaluate the spawning stock by using the Egg Production Method (EPM); and e) determine the birthdate distribution through daily otolith growth ring analysis.

Since the Iberian sardine is distributed over all the upwelling system of the peninsula, and Portugal was also carrying out similar studies, collaboration between the 2 countries began in July 1986, to co-ordinate the studies on the early life history aspects of sardine as well as on physical and biological oceanography and hydro-climatology.

In December 1986, a course on Egg Production Method was given by Dr J. Alheit, with support of the International Oceanographic Commission (IOC) in the oceanographic laboratory of Vigo with the participation of several Portuguese scientists.

Within the SARP framework, 2 Fullbright Fellows from Portugal visited the Southwest Fisheries Center in 1987 in order to learn plankton quality control and data management, aging of post-ovulatory follicles and daily otolith growth ring analysis.

Also in 1987, Portugal submitted a 3-year programme to the National Committee for Scientific and Technological Research (JNICT) with the aim of establishing a basis for a sardine recruitment study.

The possibility of using the aquaculture laboratory at the Centro Costero de Vigo, Instituto Espanol de Oceanografia, and their personnel support, allowed them to carry out studies on sardine embryonic development in relation to temperature, validation of the age criteria of post-ovulatory follicles and larval starvation experiments.

Sardine spawning biomass in the Atlantic coast of the Iberian peninsula was estimated in 1988 both by the EPM and by acoustic survey. The acoustic method provided a very useful tool for the EPM in determining sardine distribution.

The 3-year USA-Spanish collaboration in SARP is coming to an end. Results of this research have been presented at the ICES meeting held in 1989 at The Hague, Netherlands, where the papers on EPM for sardine spawning biomass estimation were presented at the pelagic sessions. Following this, amini-symposium on spawning stock estimation using the various different methods has been proposed for ICES in 1991. Another mini-symposium on recruitment processes is also planned for 1991.

Finally, we would like to stress on the importance of the role of the former principal investigator of the USA-Spain SARP project, the late Dr. R. Lasker, on promoting and supporting the Iberian SARP and developing the scientific ties between Spain and Portugal.

Daily Egg Production

The Iberian-SARP project had a calendar of activities which depended largely on the success of the evaluation in 1988 of the size of the sardine spawning stock using the Egg Production Method (EPM). This method is used for estimating daily egg production and requires a strong sampling effort covering the entire spawning area if a result is to be obtained with an acceptable degree of precision.

Since sampling effort could be reduced during the periods of maximum spawning intensity, 2 years of the SARP project (1987 and 1988) were devoted, among other activities, to establish the spawning peaks in different areas off the Iberian peninsula. For this purpose monthly sampling was established along several representative transects located in the 3 sardine spawning areas off the Atlantic coast of Spain and Portugal. Two of the transects were located off the southern coast of Portugal, another 3 off the west coast of the peninsula and a further 2 off the north of Spain.

Additionally, the offshore limit of the spawning grounds of the Iberian sardine were determined during the period of maximum spawning. This was achieved as part of a series of co-ordinated cruises between Spain and Portugal in April 1987, in the Atlantic coast off the Iberian peninsula. The sampling design of the cruises was established with the same criteria, and similar methodologies were used by the 2 countries.

Another requirement for daily egg production estimation is a knowledge of the rate of embryonic development with temperature. In Portugal, aging of the eggs was performed taking into consideration information on the duration of embryonic stages at 16°C, the time the sample was collected and the time of spawning. The possibility of using the aquaculture laboratory in Vigo, Spain, allowed the fitting of an equation for sardine embryonic development as a function of temperature. These studies were performed on eggs obtained by inducing adult sardines to spawn in the laboratory and then by rearing the eggs at different controlled temperatures.

According to the results, the maximum intensity of spawning occurs in Portuguese waters during the Winter months and in the Cantabrian sea during early Spring. Spawning areas seem to be restricted to the continental
shelf in the south and off the west coast of the Iberian peninsula, while in the north they extend further offshore mainly in the western Cantabrian Sea.

In 1988, using the above information, sardine spawning biomass was estimated in Portuguese waters in March, and in April/May off Spain. The cruises were planned jointly to meet a $\pm$ 30% precision on the daily egg production and were carried out concurrently with an acoustic survey.

In general, the sardine egg distributions matched the distribution of adults mapped by the acoustic survey. However, the results on daily egg production does not seem to be very precise in Portuguese waters showing some evidence of under sampling of the youngest egg stages (II, III and IV). This has not been observed with the Spanish egg data which included high numbers of these stages.

The accomplishment of the EPM method is considered to be a successful initial experience which will enhance its future application in Spain and Portugal. With the experience gained the sampling design can be improved to achieve more precise estimates of daily egg production in the sea.

The co-operative research between Spain and Portugal has been developed within the framework of this project. We would like to stress the achievements obtained with this co-operative study on the better understanding of the biology of the sardine stock over the Iberian peninsula. This was made possible only through joint collection and analysis of data sets gathered in the project.

SPANISH ANCHOVY

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AZTI-SIO is developing a research programme in the Bay of Biscay on anchovy aiming at knowing the actual state of the stock. THis programme includes some SARP like activities:

(i) yearly estimates of spawning stock biomass (SSB) using the Daily Egg Production Method.

(ii) studies of egg and larval mortality at small spatial scales and with a high temporal intensity (patch studies).

Daily egg production method

DEPM surveys were initiated in an experimental way in 1987, using information on egg production from an egg survey during the peak of spawning over the perceived full spawning range of the species. Information was collected on adult parameters from a sampling scheme performed on board the purse seiners of the fishing fleet. A similar strategy was used in 1988, achieving a better coverage of the anchovy spawning range. During 1989 and 1990, these activities were performed within the frame of the EEC (FAR programme). In addition to routine egg surveys to estimate daily egg production in the sea, independent adult fishing surveys are carried out to estimate daily egg productionj of the adult population. Furthermore, two different DEPM surveys are being implemented in each of these two years in order to calibrate the possibility of estimating separately the SSB of the adult population (2+ year old anchovies), with an earlier peak spawning in May, and the SSB of first spawners recruiting to the fishery (1-year old ahcnovy), with peak spawning in late May and June.

Results of these surveys are being published within the frame of ICES, after presentation to the Working Group on Sardine, Horse Mackerel and Anchovy.

Anchovy embrionic and larval mortality studies

During 1987 and 1988, two sea surveys were carried out during the peak spawning period of anchovy (May-June) aiming at studying egg and larval mortality in relation with hydrobiological and biological features. High intensity sampling in time was performed near a driftinb buoy (Davis) deployed in a patch of anchovy eggs and larvae.

Otholit microstructure studies (daily ring increments) are being tried in collaboration with Dra. Palomera (ICM Barcelona), using material from these surveys.

Some preliminary results had been internally presented. The information collected is being worked out in AZTI-SIO within the frame of PhD studies.

PORTUGUESE SARDINE AND ANCHOVY

by
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The sardine (Sardina pilchardus) fishery of Portugal is one of the country's most important fishing activities, yielding about 50% of total fish landings at an average of 102,000 metric tons (MT) over the period 1985-1987. The Spanish fishery, utilizing what is believed to be the same stock, took an average of 83,000 MT per year over the same period. Acoustic surveys indicate that there is an average biomass of about 340,000 MT (1985-1987) in Portuguese waters and a total of 550,000 MT in ICES areas VIIIc and IXa which include Portugal and Spain.

The sardine fishery in Portugal, which harvests mainly young fish, (one and 2-year olds), is concentrated in upwelling areas off the western Portuguese Coast. Anchovy (Engraulis encrasicolus) is also an important resource in Portuguese and Spanish waters. This species spawns preferentially in estuaries and "rias" along the western Iberian Peninsula.

Over the period 1985-1989 the dynamics and possible relationships between environmental conditions and sardine recruitment variability have been studied in Portugal with the emphasis on reproductive behavior and the occurrence, distribution and survival of sardine eggs and larval stages. Spawning biomass was evaluated using the Egg Production Method and the results compared with those obtained by Virtual Population Analysis and acoustic methods. Studies on advection during the spawning season and upwelling structures along the continental shelf and their consequences were also conducted. This multidisciplinary project was implemented in co-operation with similar studies carried out by Spanish, American and Norwegian institutions.

Several more restricted areas had previously been studied off Portugal (1978-1983) mainly in connection with sardine and anchovy egg and larval ecology. These focused on occurrence and distribution patterns, rhythms of activity such as larval vertical migration patterns and swim bladder inflation/deflation, larval growth based on otolith micro-growth increments, egg and larval mortality, larval feeding and egg and larval transport and retention areas.

More recently (from 1985), the ecology of the planktonic phase of the anchovy was studied in Portuguese estuaries. These studies are mainly concerned with the occurrence and distribution patterns of egg and larval stages, tidal transport of eggs and larvae, retention areas and mechanisms of retention, larval feeding and predation on eggs and larvae.

In the future it is intended to continue these studies and also to emphasize other activities such as studies on egg and larval mortality, egg and larval predation, egg cannibalism, egg and larval retention areas, larval condition and larval growth.

BRAZILIAN SARDINELLA

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Since 1985, several SARP-related activities have been developed in Brazil and some results obtained. Three kinds of activities have been developed: (i) Meso- and Micro-scale distribution of sardine eggs and larvae and their relation to biotic and abiotic factors; (ii) Larval rearing experiments; and (iii) Egg Production Method.

The first 2 activities have been developed within an integrated oceanographic investigation of the coastal ecosystem which was started in October 1985. Field observations have been conducted using 3 sampling techniques: (i) Horizontal meso-scale distribution of sardine eggs and larvae using Conical-cylinder net and CalVET net; (ii) Vertical distribution of zooplankton, eggs and larvae using Motoda nets and closing net; and (iii) Vertical profiles of chlorophyll-a and phytoplankton using closing net, Van Dorn bottle and spectral photometer.

Larval rearing experiments were carried out to investigate: (i) Feeding behaviour; (ii) Validation of daily growth rings; and (iii) Growth rate.

The first Egg Production Method (EPM) was conducted in January 1988 in the main spawning area of Brazilian sardine. The survey cruise covered the entire spawning area using CalVET and Bongo nets. At the same time an echo-sounder was used to detect sardine shoals. Unfortunately, the spawning in the summer 1987-88 season was not successful - no significant catches of sardine eggs were made. Only one adult sample was taken during the cruise. The results of the first EPM cruise can be summarized as follows:

(i) Out of 770 CalVET net samples, only 12 stations were positive for sardine eggs (1.6%) and the total number of eggs taken was 79. This figure is very low when compared with the results of previous investigations of sardine spawning.

(ii) Based on one adult sample taken in the Sta. Catarina, tentative fecundity estimates were made. 90% of females had ripe ovaries and 60% had ovaries with migratory nucleus stage oocytes. Only 9% of females had the same stage of post-ovulatory follicles. Using the stereometric method, the batch fecundity was estimated for 35 females giving a mean value of 31,772.

(iii) Contrary to the sardine, significant numbers of anchovy eggs (Engraulis anchoita) were collected. The main spawning area was concentrated in the southern part of the survey area near the edge of the continental shelf.

Previous investigations on the coastal oceanographic structure of the Brazilian region showed that during the Summer, the South Atlantic Central Water (SACW) which flows northwards along the continental slope under the Brazil Current penetrates in a bottom layer over the continental shelf extending to near the coastal region. Because of this cold and nutrient rich water at the bottom and heating of surface water, strong stratification forms in the middle layer. During Winter the SACW retreats to the margin of the continental shelf and the water column in the coastal region becomes homogeneous.

During 5 years of investigation on the coastal ecosystem it was found that biological processes in the Summer were started from injection of nutrients from the SACW into the euphotic zone. This occurred in 2 ways: in the coastal region (down to the 50 m isobath), the SACW penetrates to the euphotic zone by a similar process to coastal upwelling; in the neritic region (50-150 m isobath), clockwise frontal eddies induce localized upwelling and bring nutrients inside the core up to the euphotic zone. It was also found that the intensity of penetration of the SACW and formation of frontal eddies changed from year to year. Thus, primary production of the coastal and neritic regions depended on the intensity of penetration of SACW and on the presence of eddies. This seems to imply that the spawning success and

survival of sardine in the coastal and neritic region may be influenced by the annual variation of penetration of the SACW and meandering of the Brazil Current.

SOUTHWEST ATLANTIC ANCHOVY

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Background

Information on anchovy eggs and larvae in the Southwest Atlantic has been collected over the last 25 years. A synopsis on the reproductive biology and early life history stages of Engraulis anchoita and related environmental conditions in the sea off Brazil, Uruguay and Argentina, has been prepared recently (IOC Workshop Report No. 65).

The Southwest Atlantic anchovy is distributed and spawns over a wide latitudinal range from 24°S to 47°S, in a variety of hydrographic structures including upwelling areas, estuarine and shelf-break fronts, and tidal mixing systems. South of 34°S, in waters off Argentina and Uruguay, the anchovy spawns all year round and, in general terms, spawning and nursery grounds are located in the same areas. An exception to this pattern occurs during the colder months of the year when at least some of the larvae drift to warmer waters off Brazil.

The stocks off Argentina and Uruguay which have been assessed several times both by acoustic survey and by classical ichthyoplankton methods, showed a remarkable consistency (biomass estimates between 2-4 million tons) when compared to other large Engraulis stocks elsewhere. Although several parameters of the Egg Production Method (i.e., daily egg production, embryonic developmental rates, embryonic mortality) have been estimated, the method as such has not yet been applied, since we have not been able to determine accurately the adult reproductive parameters, in particular the batch fecundity, due to the difficulties in catching hydrated females either from exploratory cruises or from the coastal commercial fleet.

Recent studies based on an historical data base (1966-1988) of about 5,000 samples collected in the sea off Argentina, yielded information on broad-scale variations in the monthly patterns of distribution, abundance, and length composition of the early life history stages of the species. The occurrence and seasonality of anchovy eggs have been related to physical characteristics of the environment such as temperature, water depth, distance from shore, proportion of different water masses, and stratification of the water column. Monthly variations in the sampling probability distribution of eggs, and degree of aggregation of larvae of the species, have also been studied.

At least 2 stocks and 3 spawning sub-populations of anchovy inhabit the Southwest Atlantic south of 34°S. Recent studies have focused on the spawning strategies of the species in response to different environmental conditions, and their implications for larval growth and survival. These studies lead to an interpretation of the final fate of anchovy larvae after metamorphosis in relation to existing knowledge on circulation and oceanographic processes in the Argentine shelf and slope, and to a characteri of the different nursery grounds in terms of their carrying capacity and potential for egg and larval survival.

In this respect, the most interesting results refer to the reproductive activity of the species in the tidal-frontal system of the Patagonian region, with characteristics similar to those of the spawning grounds of the North Atlantic herring. This front which separates well-mixed from stratified waters, provides the physical mechanisms, which include baroclinic and tidal residual circulation, contributing to larval retention of this stock. Differences between the Patagonian and Buenos Aires stocks have been reported in relation to some meristic characteristics, and adult population attributes such as growth, mortality and the length/age at first maturity. Results also indicate enhanced embryonic and larval survival in the Patagonian region, higher larval feeding incidence and better larval nutritional condition.

Future activities in relation to SARP

From 17 November to 18 December 1989, a joint co-operative cruise, to study processes relevant to the understanding of recruitment of the Southwest Atlantic anchovy, will be carried out on RV METEOR of the Federal Republic of Germany, with the support of IOC-Unesco and the participation of European and South American scientists of Brazil, Uruguay and Argentina. This cruise will be a starting point for a regional SARP project for E. anchoita, which is by weight, the largest potential fish resource in the area.

The rationale of this cruise is to study processes which are believed to have an influence on the species recruitment in relation to the different hydrographic structures found in the area. As a working hypothesis it is assumed that survival of anchovy larvae depends crucially on the physical and biotic characteristics of those structures, as they influence growth and metabolic rates, the development of larval food and the occurrence of predators. Intensive sampling will be carried out in 3 areas of interest, one off each South American country: an upwelling area off Santa Marta, Brazil; the estuarine plume and the shelf break off Uruguay; and the Patagonian tidal system (Figure 1). In all cases the sampling strategy will tend to optimize the spatial resolution, while simultaneous and post-cruise surveys by each South American country will try to solve the problem of temporal resolution. Real-time images of the sea surface temperature in the area of the study area will be obtained daily from NOAA satellites 10 and 11 by the National Weather Service of Argentina and transmitted to the ship with details of the hydrological structures of interest. All images will be processed by the Remote Sensing Laboratory of the Rosenstiel School of Marine and Atmospheric Science, University of Miami, while flow conditions will be derived by the Department of Oceanography, Texas A & M University.

Each of the 3 areas will be divided into a different number of transects (2-4) each of which will be sampled repeatedly (4 times: 1 hydrographic + 3 hydro-biological legs). In addition, on passage between the 3 areas, additional biological sampling stations will be occupied to gain supplementary information from other environments which cannot be studied intensively. Each complete hydro-biological station will include:

(i) Physical oceanographic studies: CTD, rossette water sampler; luxometer and current meter.

(ii) Continuous fluorometry determination;

(iii) Vertical phytoplankton sampling;

(iv) Egg and larval sampling with MOCNESS and BONGO nets;

(v) MULTINET casting for larval feeding studies;

(vi) Micro-distribution studies of anchovy larvae and food particles with LONGHURST HARDY RECORDER;

(vii) Juvenile sampling with RMT and Young Fish Trawl; and

(viii) A CTD cast to close the station.

Additionally, information on adult age composition and reproductive biology will be obtained from some 60 samples with a pelagic fish trawl.

The most important techniques to be incorporated in this cruise are:

(i) The assessment of nutritional condition of individual larvae by histological methods, enzyme activity and RNA/DNA ratio determination;

(ii) Age and daily growth rates from counts of daily rings and determination of distances between rings on anchovy larval and juvenile otoliths;

(iii) Microscale studies on larval distribution;

(iv) Vertical distribution of eggs and larvae in relation to circulation patterns and velocities;

(v) Determination of crustaceans predation on anchovy eggs and pre-larvae by means of immunological techniques;

(vi) Experimental aquaria of the RV METEOR, will be used to attempt to assess the impact of ctenophores on anchovy eggs and larvae, and to raise larvae to the point of yolk-depletion in order to obtain basic specific data for calibration of the starvation methods.

Future SARP activities in the area should include the application of the Egg Production Method to the different spawning sub-populations, the evaluation of juvenile abundance in relation to egg and larval production in different spawning and nursery grounds and, particularly in the Patagonian tidal system, the assessment of the impact of red-tide toxic dinoflagellates on larval survival.

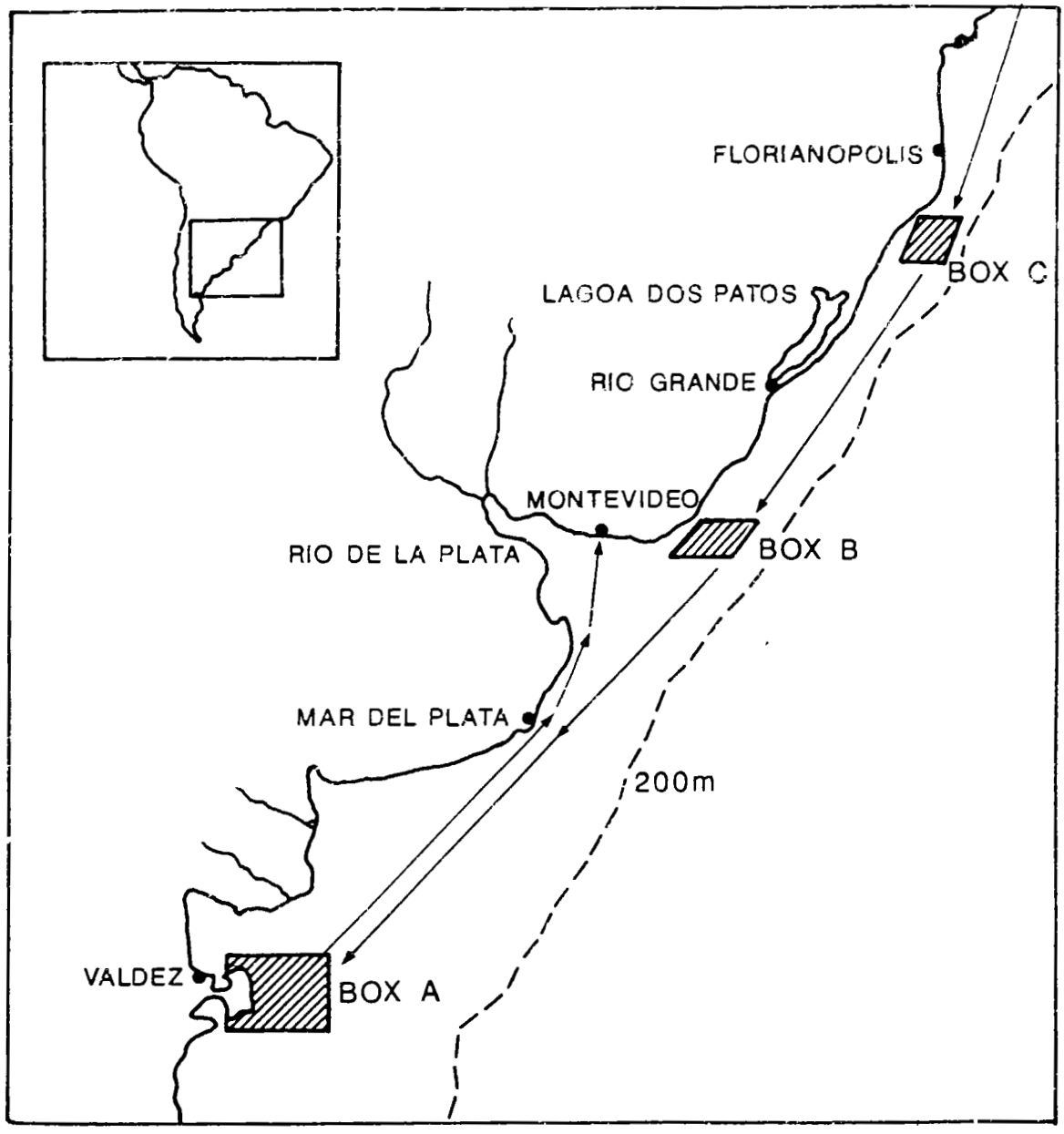

Fig.1 Positions of the 3 Main Sampling areas of the 1989 METEOR Cruise.

CHILEAN SARDINE AND ANCHOVY

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Background

Early in the development of OSLR-IREP, the south-east Pacific was identified as the region with the highest potential for implementing a full within-year SARP experiment for 3 reasons: 1) Interest in the scientific and developmental impact of the programme by countries with large pelagic fisheries, i.e., Peru, Chile and Ecuador; 2) The comparatively high level of local expertise available in the region; 3) The interest of other member countries of IOC to collaborate in the execution and contribute to the funding of such efforts.

In November 1984, a special meeting was convened at the US Southwest Fisheries Center in La Jolla, with the purpose of generating SARP proposals for the eastern Pacific, the priority area identified at the 1983 Halifax workshop on IREP. In addition to the US-Mexico SARP proposal, 2 other experiments were planned: the Central Peru SARP experiment and the Northern Chile SARP experiment. Full proposals were developed during 1985 and several training activities took place within and outside the region related to the egg-production, the daily-ring technique and environmental monitoring methods.

However, the large amount of ship-time needed to conduct within year comparisons of larval production and juvenile birthdate distributions made these experiments expensive to the point where they could not be supported without additional funding from outside the region. Despite several national and international initiatives, final funding for these experiments did not materialize and to this date no within-year experiments have been conducted in the south-east Pacific.

Research completed

Nevertheless, the countries in the region have pursued different IREP/SARP related activities supported by local funding. In Peru, the egg production method and larval production estimates have been obtained for the major central stock of anchovy (Engraulis ringens).

In Chile, several projects have been funded by the national research agency (FONDECYT, universities, the public sector and by the Swedish Agency for Research in Developing Countries (SAREC).

Using the daily-ring technique studies have been made for single species (Sardinops sagax and Engraulis ringens) to ascertain larval growth rates in different areas and seasons and to compare growth rates of co-occurring populations of 2 different species.

In central Chile, off the Gulf of Arauco (36 ¦ S), local populations of sardine (Sardinops sagax), anchovy (Engraulis ringens) and 2 other clupeoids (Clupea strangomera bentickii and Ethmidium maculatum) have been studied for determining larval condition by histological analysis of tissues and assessment of the impact of starvation as a cause of mortality
in the field. These studies also attempt to define conditions with regard to the concentration of particles and chlorophyll, abundance of zooplankton and physical structure of the coastal environment.

In the same area, the Gulf of Arauco, a study to look into the factors controlling the formation/destruction of layers of high concentration of particles (larval food) was conducted using the GISMO instrument developed at the Oceanografiska Institutionen (Gothemburg University, Sweden). This instrument uses an acoustical current meter and an in situ fluorometer, providing a very fine vertical resolution of horizontal velocities and chlorophyll concentration. This information allows the distinction between physical and biological processes in the formation/destruction of these layers. As part of this

study, the physical response of the Gulf to wind forcing was ascertained and the generation of trapped Kelvin waves detected.

Other studies have tried to define the level of organic production and horizontal structure of this coastal ecosystem. Production-orientated studies include the measurement of primary production, bacterial biomass and production, and the abundance of the different components of the small-sized spectrum of particles in the water column. Special attention has been paid to the abundance and distribution of larval food (microzooplankton). Ecological studies of food selection and electrivity by fish larvae has been also conducted for anchovy and sardine.

Future Prospects

An effort to create in Chile a consortium of private and public research institutions and fishing industries, with the purpose of attempting a larger scale recruitment study, did not materialize. However, the fishing industries based in the Talcahuano area, have established a research corporation which attempts to contract specific research projects, some of which fall within the general scope of IREP/SARP.

On a more general framework, the new political climate prevailing in the region in the early 1990's should promote the interest of countries from outside the region to collaborate and contribute to new international co-operative initiatives within OSLR/IREP.

MEXICAN SARDINE AND ANCHOVY

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The Pacific sardine, Sardinops sagax caeruleus, in the Gulf of California comprises one of the major pelagic fisheries in Mexico and represents about 29% of total Mexican landings. The northern anchovy, Engraulis mordax, is fished mostly off the northern coast of Baja California and has recently represented about 10% of total fishery landings; this fishery is actually based on the southern portion of the large Central sub-population of northern anchovy, whose distribution is centered further north off Southern California, USA. A new stock was identified in the Gulf of California in 1986 (Hammann and Cisneros-Mata, 1989), but has not yet been exploited.

The increase in Pacific sardine landings observed during the 1970's, and especially the early 1980's was due to industrial development of the fisheries and to an increase in the size of the fleet. A sharp decrease in landings in 1984 was attributed to the 1982-83 El Niño event which was the strongest of the century. Recent yearly landings of Pacific sardine in Mexico have exceeded 400,000 metric tons giving concern of over-exploitation.

Inter-annual variability in Pacific sardine landings in the Gulf has been related to the inter-annual cycles in sea-level and surface temperature due to the El Niño/Southern Oscillation. Changes in landings may be due either to distributional fluctuations which change the stock's availability to the fishing fleet, typically centered off Guaymas, Sonora, or to changes in recruitment (see Lluch-Belda et al., 1986 and Hammann et al., 1988). It has even been proposed that recruitment was enhanced by the El Niño because the average length of landed sardine decreased one year after the event suggesting a strong year-class of recruits.

The El Niño phenomena may affect recruitment by compressing the sardine's spawning habitat northward and shortening their spawning season. During compressed habitat conditions with an El Niño event, eggs and larvae may co-occur with the adults for a longer period of time, thus increasing cannibalism. The juvenile habitat may also be reduced, increasing food competition and affecting juvenile mortality, growth rate, and their future fecundity (Hammann et al, op. cit).

Of additional importance is the fact that since 1986 a stock of northern anchovy has been found in the Gulf of California, and appears to be increasing in abundance (Hammann and Cisneros-Mata, op. cit.). Spawning of this species was confirmed in 1987. Thus, our recruitment programme will include the northern anchovy. We feel that this is especially interesting when compared to the CALCOFI programme because we can study the interactions of these 2 species at population levels that were previously not available: a large sardine population and a small anchovy population in the Gulf, versus the small sardine and young anchovy population of the California current during the 1940's and 1950's. Furthermore, we feel that because the Pacific sardine population is fairly constrained in the Gulf of California, we should be able to measure relevant environmental variables better than when working in an open coast system.

At CICESE we have initiated a programme on the dynamics of recruitment of Pacific sardine in the Gulf of California. In this programme, we will collect eggs, larvae and juveniles of Pacific sardine and northern anchovy and samples of the biotic and abiotic environment in which they live. Associated with this research is a study on the historical abundance of sardines and anchovies in the Gulf using fish scales preserved in varves from laminated sediments collected from the Guaymas Basin.

Our first recruitment cruise in planned for January-February 1990 when, depending on time available, samples will be collected to achieve as much as possible of 5 different experiments. Because spawning is mostly in the Central Gulf, we will be concentrating our efforts initially in that region. In the first experiment we will determine the live/preserved length conversion factor and the egg and larval retention factors from different sized nets to calibrate our historical egg and larval data base (distribution, abundance, mortality and production). Second, we will collect samples for larval and juvenile condition studies (RNA/DNA, LDH activity). Third, late larvae and juveniles will be collected for feeding studies, where with the particulate size distribution (Coulter-Counter), biochemical composition, and caloric content determined from water samples filtered and separated into the same size-classes. Fourth, is the determination of larval and juvenile growth rates using otolith daily ring techniques. Fifth, we will determine the egg and larval distribution, abundance, transport and mortality in relation to the environment.

Other institutions in Mexico will be collaborating with our SARP efforts. The Centro de Investigaciones Cientificas y Tecnologicas de la Universidad de Sonora (CICTUS) in Hermosillo will be working with larval taxonomy and primary production. The Centro de Investigaciones Pesqueras del Instituto Nacional de Pesca (CRIP-INP) in Guaymas will be assisting with the juvenile distribution. Other institutions have expressed interest, but their roles have not yet been clearly defined.

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CALIFORNIAN SARDINE

by
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The Pacific sardine population off the west coast of North America declined from an estimated 4 million short tons in the 1930's to levels thought to be as low as 5,000 tons by the 1970's. A moratorium on fishing was enacted in 1974. Signs of a recovery of the sardine resource became evident in the early 1980's. The California Department of Fish and Game (CDFG) is required to monitor the population. CDFG can allow a small fishery while the population is at least 20,000 tons, and can increase the quote as warranted.

In co-operation with the National Marine Fisheries Service, the CDFG has been conducting surveys since 1985 to evaluate the extent of the spawning area, using a modification (Wolf and Smith, 1985 and 1986; Wolf, Smith and Scannell, 1987) of the egg production method (Lasker, 1985). The modified technique compares the observed spawning area with the spawning area expected from a specified spawning biomass, given likely rates of egg production and adult reproductive parameters. Full egg production method (EPM) surveys were conducted in 1986, 1987 and 1988. These surveys have covered the waters off southern California, and in some years, central California and northern Baja California, Mexico.

In general, the spawning area of Pacific sardine, as described by plankton tows which contain sardine eggs, has increased steadily from 1985 (observed spawning area of 670 nautical miles^2) through 1989 (observed spawning area of 3,680 nautical miles^2). Based on this information, the spawning biomass of sardines has been considered to be greater than 20,000 tons, and a small annual fishery has been permitted.

The EPM surveys have resulted in spawning biomass estimates ranging from 8,000 to 17,000 tons. Although estimates of adult reproductive parameters have been fairly consistent and reasonably precise, our estimates of egg production rate have been highly variable and imprecise. We attribute this to an insufficient number of positive samples of eggs. As a result, efforts are currently being focussed on improving egg sampling.

In 1989, no adult collections were made, and sampling effort was limited to egg collections only. Plans for 1990 are similar, and included only a survey to collect sardine eggs. In addition, the Instituto Nacional de la Pesca (INP) of Mexico plans to conduct egg surveys that will coincide with the CDFG survey. Data from the INP survey will be used with CDFG data to evaluate the extent of the spawning area of sardines off southern California and northern Baja California. This work is being conducted under the auspices of MEXUS-Pacifico, a bilateral co-operative fisheries research programme between the United States and Mexico.

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JAPANESE SARDINE AND ANCHOVY

by
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A multidisciplinary study on the recruitment process of Pacific sardine is being carried out by the Ocean Research Institute of the University of Tokyo in collaboration with the BIOCOSMOS project of the Fisheries Agency.

The approach combines numerical modelling of recruitment and field sampling. Factors under investigation include pre-spawning condition of adults, spatial/temporal variations in egg production, transport mechanisms, and causes of egg and larval mortality.

In December 1988, field observations on the reproduction and recruitment mechanisms of Japanese sardine were conducted in Tosa Bay in the south of Shikoku (Figure 1). This area was the main spawning ground when the sardine stock increased rapidly over the period 1972-75. Results from part of this work have been prepared for presentation at the international symposium on "The Long-Term Variability of Pelagic Fish Populations and their Environment", 14-17 November 1989, Sendai, Japan.

Future work includes a one week cruise by R/V TANSEI-MARU in March 1990 and a 6-week cruise by R/V HAKUHO-MARU in February-March 1991 to investigate the present main spawning ground (Satsunan) of Japanese sardine off the southern Kyushu.

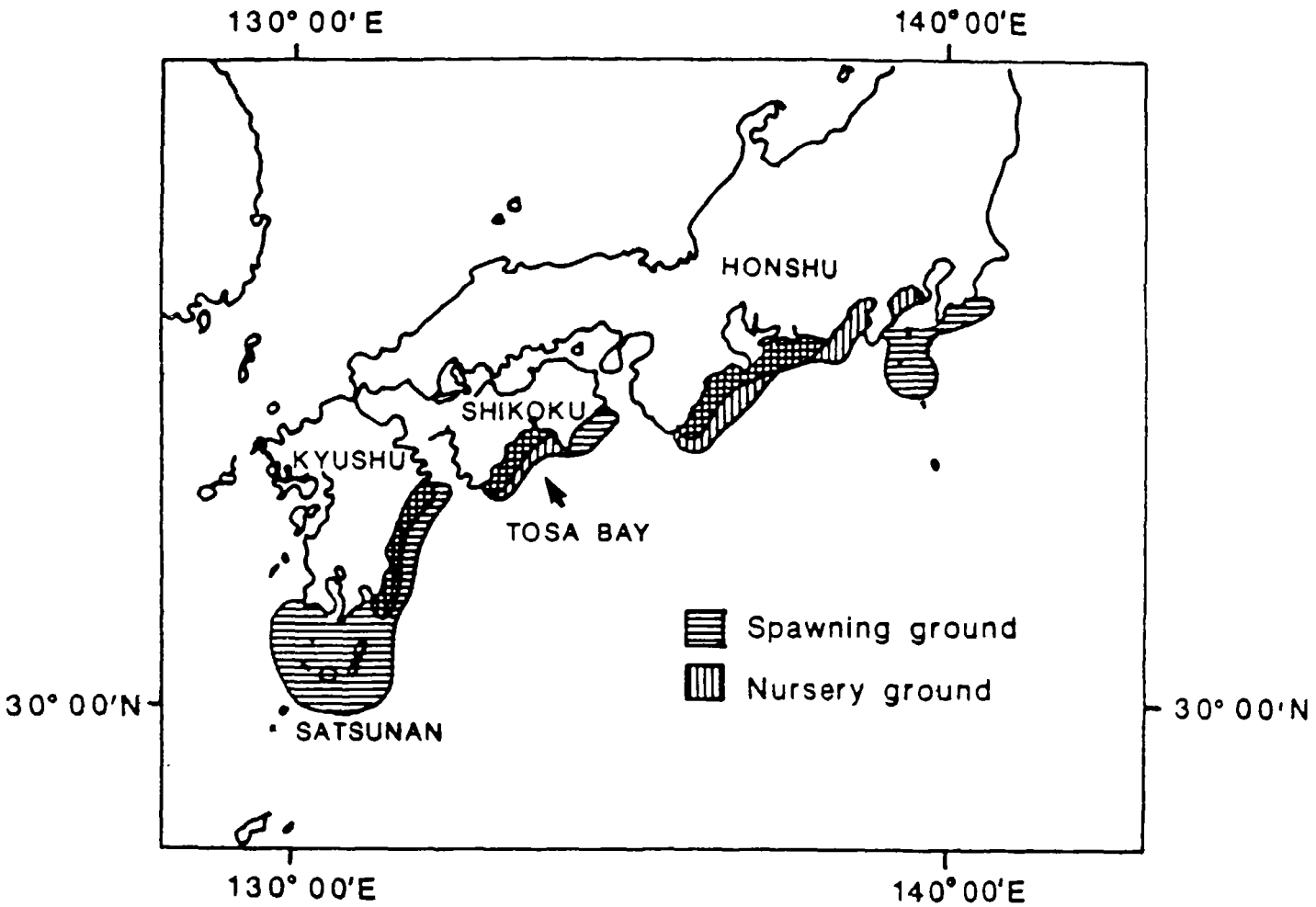

Fig.1 Spawning & Nursery Grounds of Japanese Sardine

BIOCOSMOS

by
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Resurgence of the Japanese sardine Sardinops melanosticta is one of the most dramatic events in fish population dynamics. The total catch of fish was as small as 9,000 metric tons in 1965. The population was so small that it was almost unfishable. However, it did have a reproductive potential to give rise to a formidable 1972 year class. Although the Japanese government did not set any moratorium on the sardine fishery during the years of the minimum population, the total catch increased radically after 1973 and exceeded 4 million metric tons in 1984, an almost 400-fold increase in 12 years (Figure 1). The sardine population is now at the second peak in this century. The spawning biomass has been estimated by the Japanese egg production method, which employs egg abundance and age, specific annual fecundity as estimation parameters, to be as much as 20 to 40 million tons in the northwestern Pacific. In the current year however, sardine fishermen in Japan are complaining about small catches of 1987 and 1988 year classes. They are concerned about the sardine stock if the small catch is a signal of a population collapse as we had in the 1940's.

One of the most interesting features observed with the population fluctuation is the east-west shift of the spawning grounds. At the previous peak in the 1930's, spawning of the sardine concentrated in the waters off the Kyushu Island in the western part of Japan (Figure 2). The total annual catch of the sardine in Japan was 1.5 million metric tons in those years, even though the sardine fishing boats were not as large and fishing gear were not as effective as what we have today.

In the early 1970's when the stock level was a minimum, the sardine spawning was observed only in a limited area along the Shikoku Island (Figure 3). The annual catch was about 10,000 metric tons. The stock began to increase after the appearance of a huge 1972 year class. The spawning area extended to the east with the stock increase and the main spawning ground was formed in the waters off Tokyo in eastern Japan in the late 1970's (Figure 3).

In the second period of the stock increase after 1980, the spawning ground gradually shifted to western Japan off the Kyushu Island (Figure 3), though the increasing rate of the stock did not change, as steeply as the late 1970's. When the stock reached the maximum level in 1984-1986, intense spawning ground was formed in the waters off the Kyushu Island again, as in the last stock peak of the 1930's (Figure 3).

The spawning area seems to be shifting to the east again since 1987 (Figure 3). This shift might have something to do with the small catches of the 1987 and 1988 year classes.

Another interesting feature is a change of population structure, I would say population quality, with a quantitative change of the population. During the small population period, 4 sub-populations existed, Japan Sea, Kyushu, Ashizuri and the Pacific sub-populations (Figure 4). Migrating areas of each sub-population are limited around their spawning ground and their stock levels fluctuated independently. With the increase of the sardine population, 2 sub-populations in the Japan Sea side and the Pacific side fused with each other and formed the Pacific and Japan Sea strain. Further increase of the population resulted in a coalescence of the 2 strains and made a unified large population (Figure 4). Their migration area extended further north to Hokkaido Island. It seems as though they had changed their life phase from a locally inhabiting phase to an extensively migrating phase. We might be able to call this phase variation a qualitative change of the population.

The cold Oyashio waters east of Hokkaido Island is a very productive area and provides sardines with a rich forage. Sardines get fat by feeding on zooplankton, and reserve energy for reproduction. It

seems likely that reproductive potential of the sardine is more or less determined by how much energy storage they get in the Oyashio waters.

An important oceanographic environment of the Japanese sardine, when we investigate the causes and effects of this spawning ground, shift and phase variation, is the presence of a dominant western boundary current Kuroshio (Figure 3). The Kuroshio current transports eggs and larvae at a speed of 2-4 knots (90-180 km/day) in its axis area (Figure 5). It produces gyres, eddies and streamers, which makes the oceanographic structure of the spawning grounds complicated. The spawning grounds of the Japanese sardine is more like a stream, than a pond. Transport of the eggs and larvae by the Kuroshio current is an important factor for their survival and recruitment.

Although there are some empirical explanations for the causes of drastic change in the sardine population, for example, correlations between shifts of the Kuroshio axis and population fluctuations, little is known about a sequence of biological processes from maturation of adult fish to recruitment of their offspring, to the stock, and differences of this sequence between the maximum and minimum population years. Since the sardine makes up one-third of the 12 million annual production of fisheries and aquaculture in Japan and it constitutes the major part of aquaculture baits and fish meal materials, collapse of the sardine stock will surely cause serious damages to aquaculture and fisheries and their associated industries. Fisheries scientists are now strongly required to answer the question, "What is going to happen to the Japanese sardine stock?"

We have just started the 10-year research project on sardine population dynamics from April 1989. The goal of this project is to answer the question, "What controls the sardine population"? We need to construct an elaborated prediction method to give an accurate forecast of the sardine population. We are certain that fish population fluctuations are influenced by the dynamics of their environmental biota, and that these biota are affected by the physical and chemical events of the sea. Therefore our research team is composed of physical and fisheries oceanographers, fisheries biologists, population dynamists, genetic analysts, biochemists and modelers, which should work effectively in making a breakthrough in the investigation of fish population dynamics. In the initial 4 years, we will examine possible causes of the sardine population fluctuation by conducting 14 experiments (Table 1) under the following 3 hypotheses.

Early Mortal Hypothesis : Growth and mortality in the early life stages to determine recruitment levels of individual years. Several consecutive years of good or poor recruitment results in drastic increase or decrease of the population.

Adult Fecundity Hypothesis : Fecundity of the adults and the quality of their sexual output, which are critically affected by biotic environments in the premature stage, determine the recruitment level and population size.

Phase Variation Hypothesis : Phase variations or changes of the population structure cause density independent explosion or the collapse of the sardine population.

The expected results of the above experiments and the time series of spawning biomass, egg and larvae abundances and the data catch of "shirasu" (post yolk-sac larva), juveniles of the year and 1-4 year old fish will be incorporated in developing a composite simulation model of sardine population dynamics.

We exploit mackerels Scomber japonicus and S. australacicus, Pacific saury Cololabis saira, Japanese anchovy Engraulis japonicus, jack mackerel Trachurus japonicus other than the sardine and these fish constitute the pelagic fish community in waters around Japan. We do not have an experiment on interspecific relationships of pelagic fishes in this project. This is not because we make light of interspecific competitions in the pelagic fish community but because we believe we had better concentrate our efforts in understanding the biology of the sardine in relation to biotic and abiotic environments. Investigations of these pelagic species have been conducted at the National Fisheries Research Institutes of Japan as ordinary research activities and they are to be continued. The results of our project, together

with the results from the ordinary researches, will contribute to understanding interspecific interactions of fish in the pelagic community.

The Sardine Anchovy Recruitment Project (SARP) is now practicing in many different types of ecosystems in the world. SARP is not a full guiding principle of our project, but our project has many points in common to the original SARP in hypotheses and methods. We believe we could distribute to the worldwide SARP experiments in understanding pelagic fish population dynamics.

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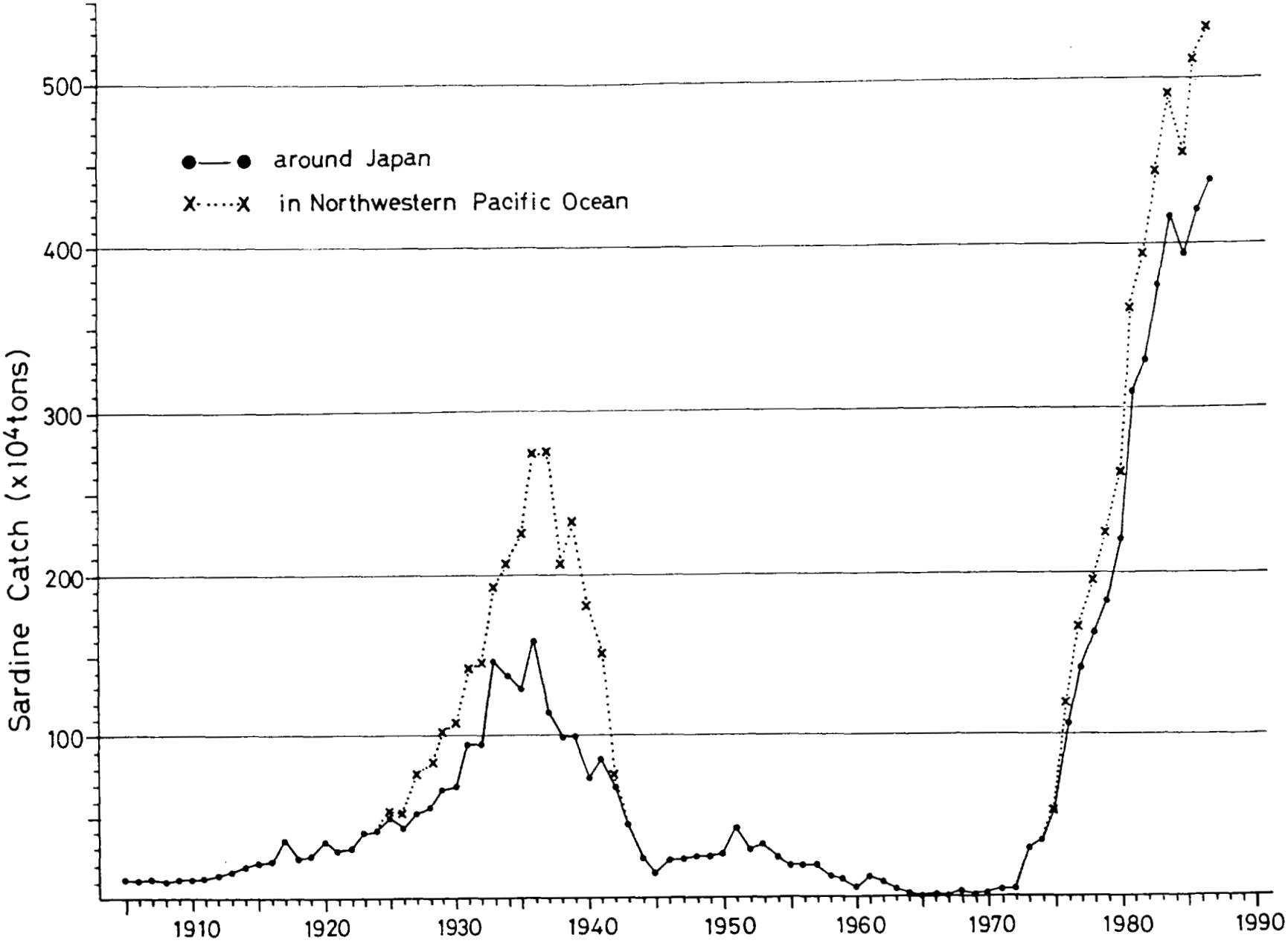

Fig.1 Long-term changes of the annual total catch of the Japanese sardine (after K. Kuroda unpublished data).

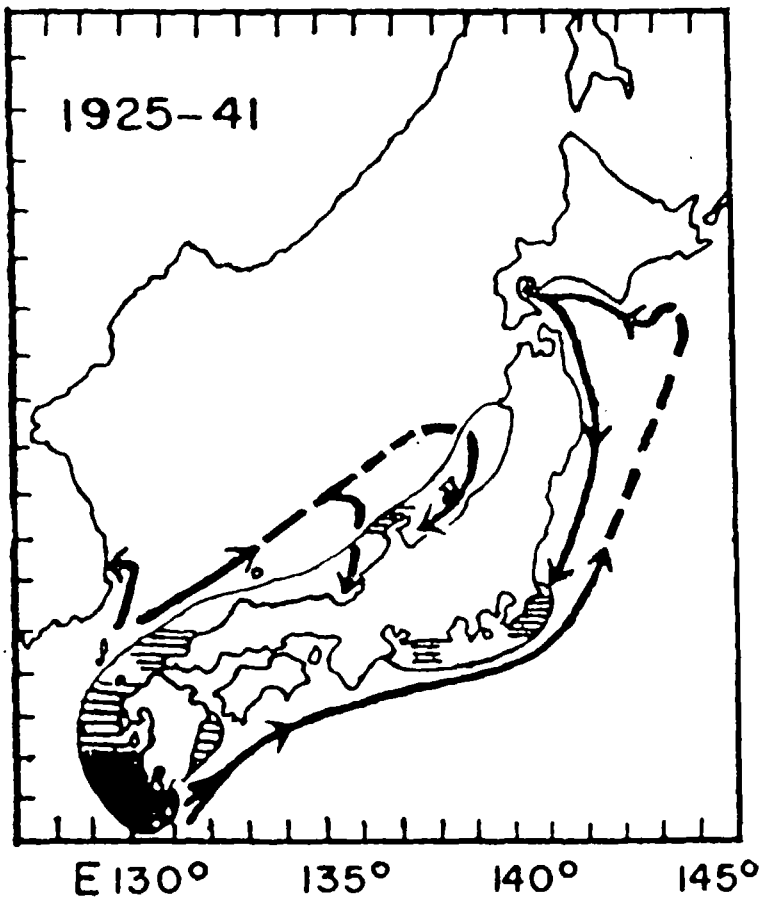

Figure 2. Spawning ground and migration routes of the sardine in the 1930's when the population was at its maximum (after Z. Nakai 1962).

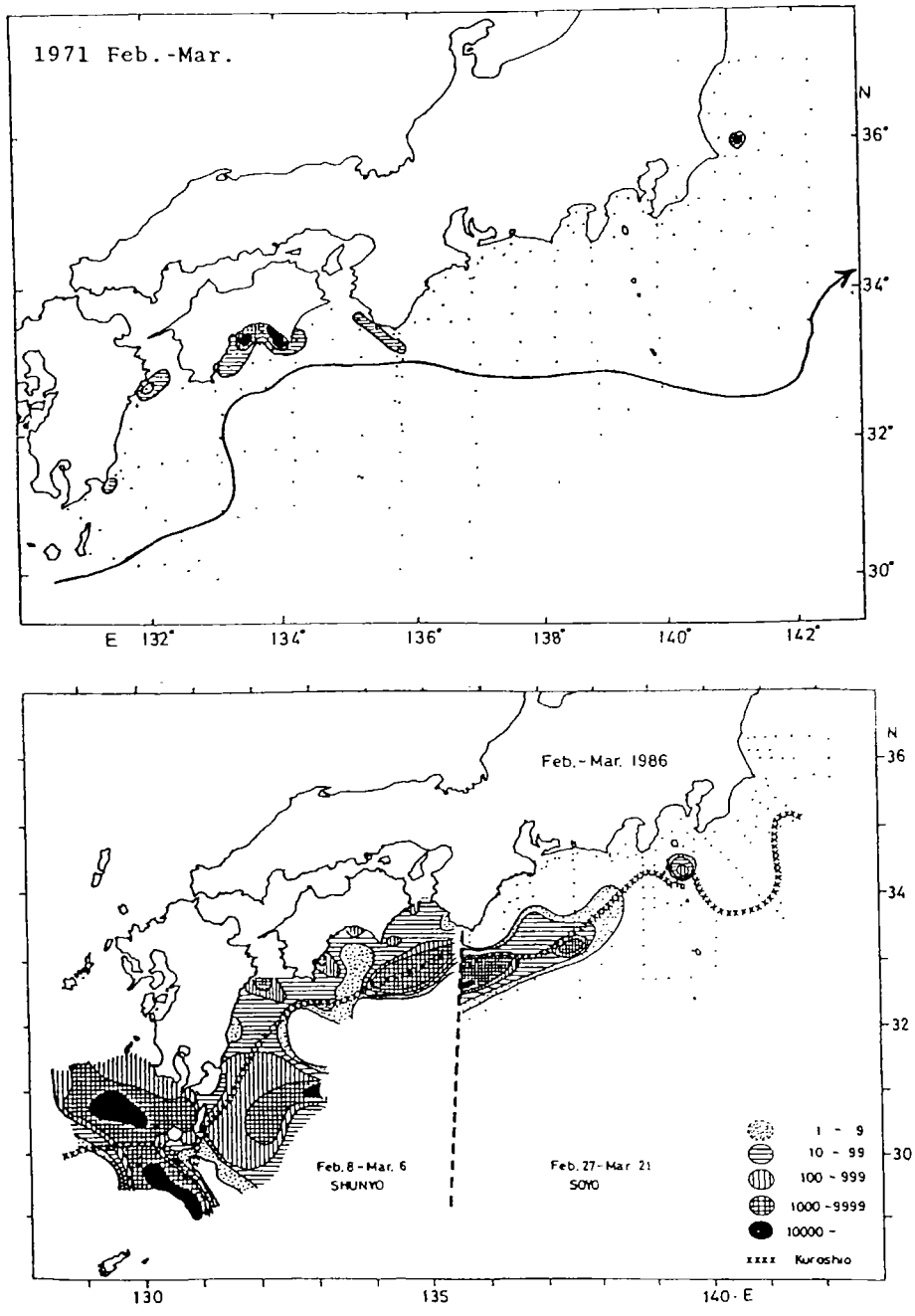

Figure 3a. East-west shifts of spawning grounds of the Japanese sardine along the Kuroshio current (indicated by arrows) with population fluctuation. Top, 1971, when the population was minimum. Bottom, 1986, when the population was at its maximum. (Data by the National Research Institute of Fisheries Science and Nansei National Fisheries Research Institute, Japan).

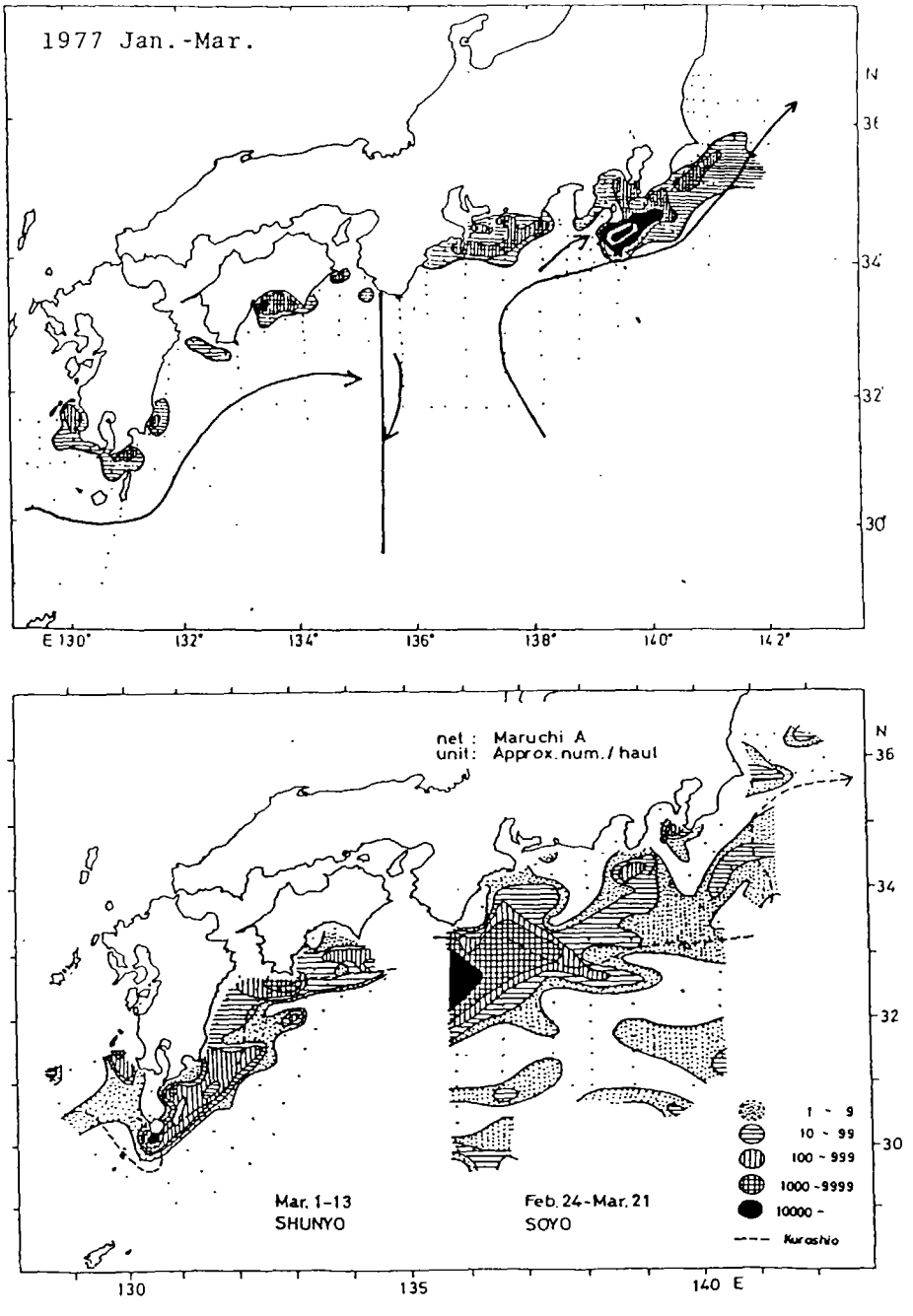

Figure 3b. East-west shifts of spawning grounds of the Japanese sardine along the Kuroshio current (indicated by arrows) with population fluctuation. Top, 1977, when the population was increasing; Bottom, 1989, when the population seemed to be showing a sign of decreasing. (Data by the National Research Institute of Fisheries Science and Nansei National Fisheries Research Institute, Japan).

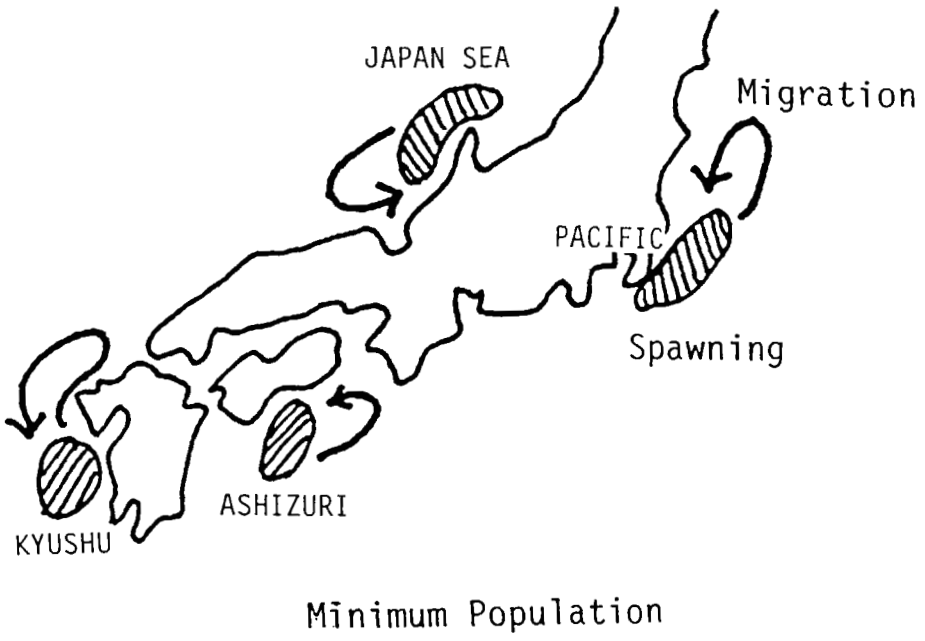

Figure 4a. Spawning grounds and migration routes of the sardine at minimum population levels. Four separated subpopulations (Japan Sea, Kyushu, Ashizuri and Pacific) with limited migration areas, exist in minimum population years.

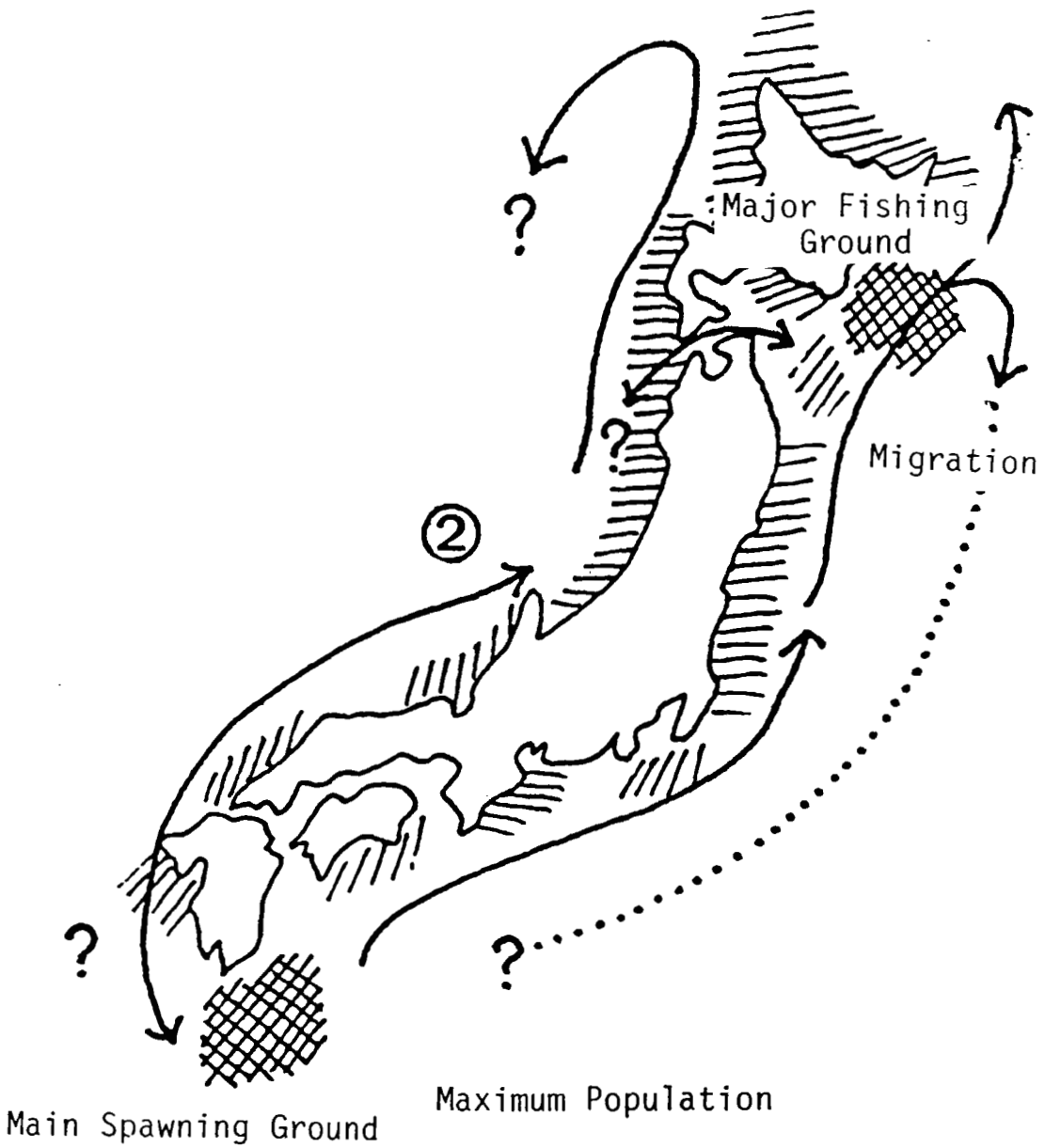

Figure 4b. Spawning grounds and migration routes of the sardine at maximum population levels. In the maximum population years, the subpopulations fuse with each other and form a large unified population which migrates further to the north.

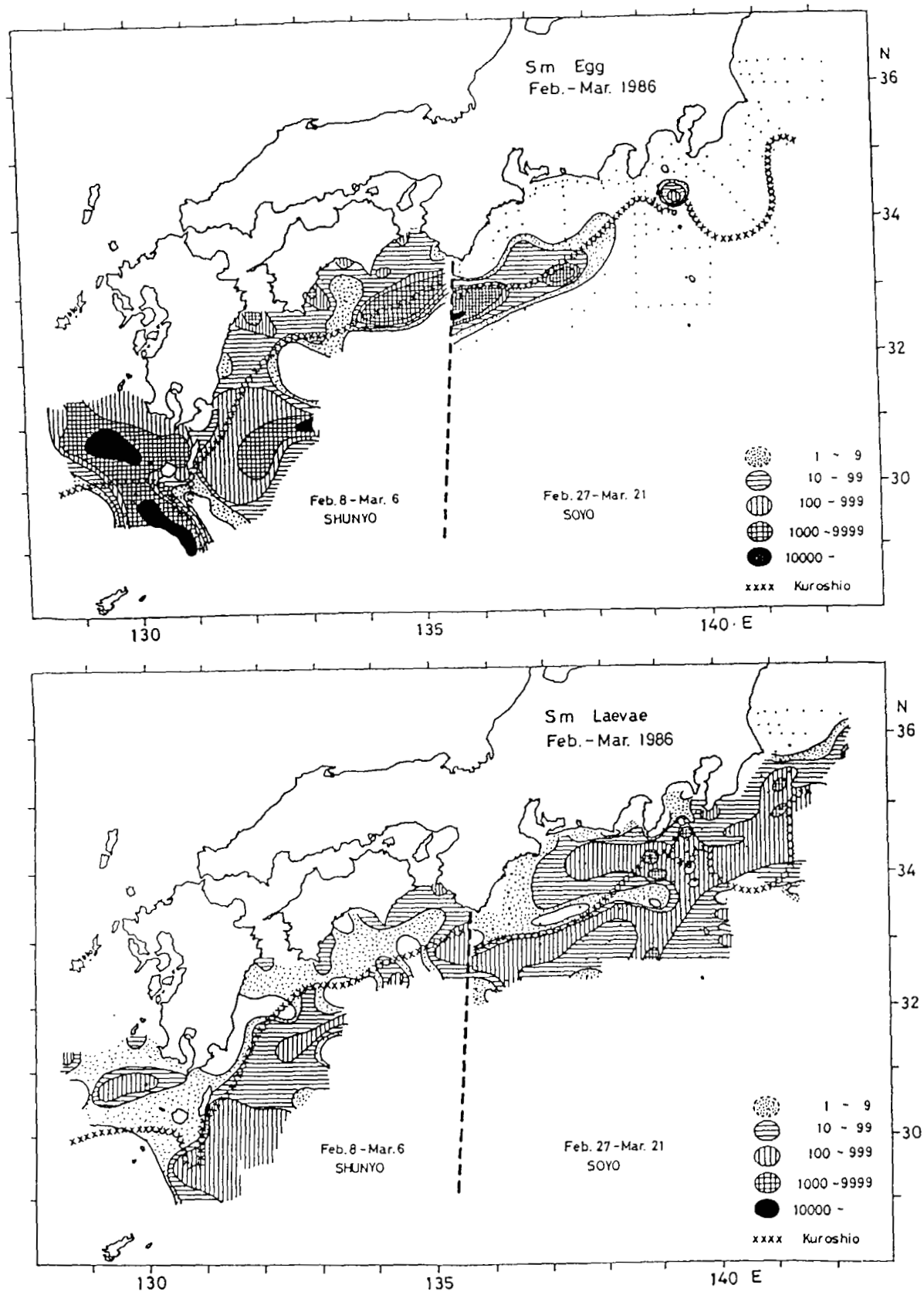

Figure 5. Transport of eggs and larvae by the Kuroshio current (indicated by arrows) shown by the difference of the distribution pattern of eggs (top) and larvae (bottom). (Data by national Research Institute of Fisheries Science and Nansei National Fisheries Research Institute, Japan).

TABLE I

Early Mortality Hypothesis

Exp-1: Morphological and functional development of larvae in terms of feeding and swimming activity, by the Seikai National Fisheries Research Institute.

Exp-2: Feeding strategy of larvae; an experiment in aquaria under controlled conditions, by the Marine Laboratory of the University of Kohchi.

Exp-3: Transport of larvae by the Kuroshio Current and migration of juveniles toward the Oyashio area for feeding, by the Tohoku National Fisheries Research Institute.

Exp-4: Larval mortality estimation by tracing a cohort by means of water mass labeling with drifter equipment, by the Nansei National Fisheries Research Institute.

Exp-5: Evaluation of recruit supply from different cohorts by comparing larval mortality among different time and space cohorts, by the National Research Institute of Fisheries Science.

Exp-6: Growth rate and birth date analyses of larvae and juveniles by otolith daily ring readings, by the Tohoku National Fisheries Research Institute.

Exp-7: Production of food organisms for larvae in the Kuroshio fronts, by the National Research Institute of Fisheries Institute.

Exp-8: Transport of eggs and early larvae from main spawning grounds by the Kuroshio current, by the Seikai National Fisheries Research Institute.

Adult Fecundity Hypothesis

Exp-9: Nutritional conditions and fecundity of mature adults in spawning grounds, by the Nansei National Fisheries Research Institute.

Exp-10: Triggers of oocyte maturation and spawning incidence by rearing maturing adults under controlled conditions, by the National Research Institute of Aquaculture.

Exp-11: Carrying capacity of the Oyashio area and the sardine population dynamics, by the Hokkaido National Fisheries Research Institute.

Exp-12: Evaluation of the Oyashio water as a feeding ground of the sardine and other pelagic migratory fishes; Variations of the plankton community, by the Hokkaido National Fisheries Research Institute.

Phase Variation Hypothesis

Exp-13: Genetic structure of the sardine population, by the National Research Institute of Aquaculture.

Exp-14: Variation of growth rate and maturation among subpopulations, by the Japan Sea National Fisheries Research Institute.

Modelling

Mdl-1: Composite model of the sardine population dynamics, by the Ocean Research Institute of the University of Tokyo.

ANNEX IV

PRESENTATIONS OF METHODS APPLICABLE TO SARP

LIPID ANALYSIS

by
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Northern anchovy larvae (Engraulis mordax) were reared in the laboratory under a variety of food regimes and the triacylglycerol, cholesterol and polar lipid content of individual larvae were measured with the latroscan TLC/FID system, as indicators of their nutritional condition. The technique is sensitive enough to analyze the lipids of a single young anchovy larva and allows 50 samples to be analyzed per day on a sustained basis. The technique has the advantage that otolith readings can be made on de-fatted fish larvae. Thus, the nutritional condition as well as the age and growth rate can routinely be determined for the same individual larva.

A comparison with field-caught larvae, which were otolith-aged and analyzed for lipid content, showed that a 'standard' laboratory rearing produced larvae of much too high lipid content. Larvae could be reared in the laboratory to have a length-specific lipid content similar to the field animals, but this required a very low food concentration. When groups of larvae were starved, the triacylglycerol component was most labile and decreased first.

Anchovy larvae were collected on 5 cruises covering the Southern California Bight between 1984 and 1986, and analyzed for lipids. There was a significant difference in each of the length-specific lipid components between the stations for 4 out of 5 cruises. This indicates that all the ocean habitats within a cruise were not equal in promoting growth (and presumably survival) in the anchovy larvae. There were also differences between cruises, where the percentage of the larvae judged to be in very poor condition varied from 8% to 27%.

Canonical correlation analyses showed a significant relationship in most cases between the larval fish parameters and the station data that were taken at each occupied station. Cholesterol was the component in the larvae that was most important for the relationship. For the station data, the most important parameter was the short-term energy storage component in the particle-grazing copepod Calanus pacificus (triacylglycerol).

References:

Hakanson, J. L. 1989a. Analysis of lipid components for determining the condition of anchovy larvae, Engraulis mordax. Marine Biology, 102, 143- 151.

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IMMUNOLOGICAL AND HISTOLOGICAL TECHNIQUES

by

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Limited information is available on predation of fish eggs and larvae by carnivorous crustaceans because crustacea macerate their prey and the remains cannot usually be visually identified. A new technique using ELISPOT immunoassay gives direct evidence of predation. Using this method, the presence of anchovy yolk protein was detected in the guts of euphausiids. Off California euphausiids were found to be significant predators of larval anchovy.

An additional diagnostic index has been developed in conjunction with Y. Watanabe (Tohoku National Fisheries Research Institute, Japan) to assess starvation-induced mortality rates of larval anchovy. This index, the height of midgut mucosal cells, yields reliable estimates of feeding history, is resistant to autolysis, and is dependable in formalin-fixed specimens. Thus, the special ichthyoplankton tows and special preservatives required for previous histopathological methods are not needed when the midgut index is used. The midgut index is as sensitive to nutritional conditions as the histopathological criteria and does not require the rigorous calibration needed for the morphormetric evaluation of condition. Because of these features, the midgut index is practical for routine estimations of starvation rates of larvae in the sea. In addition, unlike previous methods, the duration of the tow is not a constraint because the character does not degrade with time and a sample representative of the water column can be taken.

LHPR SYSTEM

by

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One requirement for implementation of the SARP proposal is information on the vertical distribution of fish larvae and their food.

The Longhurst-Hardy Plankton Recorder (LHPR) is a multiple sample plankton system designed for vertical distribution studies. The basis of the system is a cod-end unit which contains two rolls of filtering gauze. These are advanced at intervals to give a consecutive series of plankton samples along a tow. Results from analysis of these samples are used to give the vertical or horizontal distribution of each organism together with a profile of any physical or biological variables measured concurrently.

The original single net system has been developed into a double net system (e.g., 280lm and 53lm) to take up to 80 concurrent samples of fish eggs, larvae and larger zooplankton (coarse net) and microzooplankton (fine net) forming the diet of fish larvae. Other additional features are provision of cored-cable operation with real-time computer display of all sampling functions and control of sample acquisition. An integrated computer programme stores the sampling data for combining with the results of the plankton analysis (input via speech-recognition keyboard) to give vertical distribution profiles.

ANNEX V

ACE PROJECT ON NORTH SEA HERRING

by
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The Autumn Circulation Experiment (ACE) was both an oceanographic and biological study. The field biological part of ACE was co-ordinated by the Marine Laboratory, Aberdeen and carried out with the participation of the Danish Institute for Fisheries and Marine Research, and the Fisheries Laboratory, Lowestoft. Approximately monthly field observations of the distribution and biological characteristics of herring larvae in the North Sea were collected between September 1987 and March 1988. Distributions were compared with those simulated by a 3-dimensional transport model. Growth and feeding rates of larvae were interpreted in relation to primary and secondary plankton production measurements carried out during the studies.

The transport of herring larvae is controlled by the vertical distribution of the larvae and the horizontal water currents. A model of vertical distribution patterns was developed from field observations. The vertical distribution model then dictated the computer simulated behavior of tracer particles in a transport model. The horizontal flow data for the model were provided by a 3-dimensional water circulation model of the North Sea and European Shelf developed at Hamburg University. The horizontal grid size of the circulation model was 20 km and the time step 40 min. The model was forced by the M2 tide, climatological mean stratification and density fields, and 3-hourly surface wind stress and air pressure fields. The larval transport model was used with some success to account for the changes in the horizontal distribution of larvae in the North Sea during the ACE study period.

Circulation in the North Sea is wind driven during the Winter. During ACE anomalous atmospheric conditions caused a reduction in water transport relative to the long-term climatological mean. As a result, the model predicted that larvae from the northern North Sea and west of Scotland spawning areas failed to reach the juvenile nursery areas off the Danish coast. This result was confirmed by the results of the monthly field survey data collected during ACE. It is likely that these larvae were carried out of the North Sea by the north-flowing Norwegian Coastal Current, and would therefore be unavailable to recruit to the North Sea stocks in future years.

The investigations of vertical migrations of herring larvae in the North Sea during ACE indicated a complex interaction with light and the turbulent mixing environment. The underlying relationship was diurnal - larvae ascend towards the surface during daylight and descend at night - but this could be modified by the effects of tidal shear. The field investigations combined state-of-the-art biological and physical sampling techniques in the form of opening and closing nets, and an acoustic doppler current profiler. The results suggest that the simple model of vertical migrations used in the advection modelling part of ACE, was not fully adequate to account for the vertical distributions of larvae over the whole North Sea.

Field studies of phytoplankton and zooplankton productivity (the latter measured by copepod egg production) were combined with investigations of the diet of larvae assessed from stomach contents, and prey capture modelling to study regional variations in the growth potential of herring larvae in the North Sea. Growth was measured by direct observations of length changes over time, and by otolith ring increment studies. Significant primary and secondary production continued throughout the Winter in the central North Sea, and this was reflected in higher growth rates of larvae than in the northern North Sea.

The diversity of prey items was substantially lower during the overwintering period than in the Autumn, but this was not entirely reflected in the zooplankton populations.

Earlier studies had shown that overwinter advection of larvae into the eastern North Sea was a necessary but not sufficient condition for survival and subsequent good recruitment. Populations having long advection routes appeared to suffer greater variance in survival than those where there was overlap between egg and juvenile distributions. ACE indicated the origins of variability in advection and growth, but could not provide information on why transport to the eastern North Sea resulted in greater survival.

During follow-up investigations to ACE carried out by the Aberdeen Marine Laboratory, the gadoid species Merlangius merlangus (whiting) was found to consume selectively metamorphosed herring larvae (small O-group having scales and pigmentation) from a population composed of pre- and post-metamorphosis individuals. Data from the International Young Fish Surveys (IYFS) in the North Sea indicated that whiting size classes capable of consuming >40 mm herring were concentrated in the western North Sea. Therefore, herring larvae which are advected into the eastern North Sea before metamorphosis should avoid the substantial predation potential exerted by whiting.

The collapse of North Sea herring populations during the mid-1970's is believed to have been due to a period of several years of low recruitment coupled with high fishing activity. Predicting variations in recruitment in advance of fishery legislation will be essential for future management of fish stocks. However, such predictions are extremely difficult. The results from ACE suggest that a better understanding can be achieved with the aid of environmental modelling methods. The studies indicate the large potential for environmental interaction with multi-species predator/prey systems.

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ANNEX VI

APPLICATION OF SATELLITE IMAGE ANALYSIS FOR RECRUITMENT STUDIES POTENTIAL OF SOAR

(Satellite Ocean Analysis for Recruitment)

by
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Satellite observation presently provides a data base that is unique and pertinent to fisheries recruitment. Remote sensing of the sea surface by NOAA satellite AVHRR instruments in visible and infra-red bands yields regional area coverage with one kilometer resolution. Temporal sampling rates are normally 12 hours and are shorter when more than one satellite is in operation. With this information, satellite analysis methods can generate surface temperature patterns and associated vector flow regimes that are quasi-synoptic estimates over 12- or 24-hour periods. Regions studied in this manner show sub-mesoscale (10 km) and mesoscale (100 km) physical features that can pervade fishery environments.

Physical processes have the potential to dominate marine ecological phenomena when phasing and scales of environmental features match those of biological processes. Satellites can detect events and observe dynamic evolution in such cases and joint measures of ecosystem response can be obtained by coincident ship and satellite surveys. Satellites present an opportunity to together evidence for joint environmental and biological variability and to examine the relationship with interannual recruitment variability.

Recent results for a walleye pollock (**Theragra chalcogramma**) fishery near Shelikof Strait, Alaska demonstrate the application of satellite analysis (Vastano, et al., in preparation). The spring recruitment in 1986 was studied by ship and satellite observation. Bongo sampler tows were used to survey the distribution and abundance of larvae and satellite images gave sea surface temperature and flow distributions. Figure 1 shows the relationship of the vector flow estimates and larvae. High abundances occurred in the waters passing over the hatching area and forming a wind-driven plume in response to gap winds off the Alaskan Peninsula. Closed circulation features are being studied for their relation to larval retention and successful transport to the nursery grounds southwest of Kodiak Island.

ANNEX VII

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65	Second IOC Workshop on Sardine/Anchovy Recruitment Project (SARP) in the Southwest Atlantic, Montevideo, Uruguay, 21-23 August 1989	E
66	IOC *ad hoc* Expert Consultation on Sardine/Anchovy Recruitment Programme, *La Jolla, California, USA, 1989*	E
67	Interdisciplinary Seminar on Research Problems in the IOCARIBE Region, Caracas, Venezuela, 28 November - 1 December 1989	E
68	International Workshop on Marine Acoustics, Beijing, China, 26-30 March 1990	E
69	IOC Workshop on Sea-Level Measurements in the Antarctica Leningrad, USSR, 28-31 May 1990	E