History of International Co-operation in Research on Small Pelagic Fishes

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Over the last 25 years, since about 1980, international co-operation in research on small pelagic schooling fish with pelagic eggs, such as anchovy, sardine, sprat and sardinella focussed first on processes determining recruitment variability and, then, since the mid-1990s, on the impact of climate variability on ecosystems dominated by small pelagics. Recruitment research was carried out to a large extent under the umbrella of the Sardine-Anchovy-Recruitment-Programme (SARP) within the Ocean Science in Relation to Living Resources Programme (OSLR) run jointly by IOC and FAO and the Climate and Eastern Ocean Systems project (CEOS) conducted by a variety of research institutions.

Lack of scientific understanding of the mechanisms regulating recruitment was widely recognized in 1980s (and still is) as the key unsolved scientific problem currently hindering effective management of small pelagic fish populations. Their collapses such as the Californian sardine or the Peruvian anchovy have had enormous negative economic and social
effects on fishing nations which might have been avoided had there been the opportunity to predict recruitment. Consequently, several international and national initiatives were started in the 1980s to understand the relationship between environmental processes and fish recruitment. At this point, Ruben Lasker’s “stable ocean hypothesis” (Lasker 1975, 1978) had suddenly caught the attention of the fisheries scientific community, and provided a major conceptual basis for motivating and planning the early activity. Simultaneously, two new technologies, the “Daily Egg Production Method” (DEPM) (Lasker 1985) and a technique for daily age and growth estimates based on measuring and counting daily marks laid down on larval fish otoliths (Methot 1983), were under development in Lasker’s laboratory. By increasing the temporal resolution of demographic studies on fish larvae, these appeared to offer promising new ways to seek improved understanding of fish recruitment variability.

At its 11th Assembly in 1979, the Intergovernmental Oceanographic Commission (IOC) passed resolution XI-17 to promote development of plans for major oceanographic studies of the physical-ecological interactions of importance to fishery resource-related problems, including the formation of a “Group of Four” experts (Bakun et al. 1982) to advise on programme formulation. FAO and SCOR were asked in the resolution to develop a comprehensive scientific programme for OSLR. SCOR and the ACMRR of FAO responded to the IOC request forming Working Group 67 on “Oceanography, Marine Ecology and Living Resources” was formed with the aim to develop a proposal for an international recruitment experiment to investigate the relationships between environmental variability and fluctuations of living resources (Barber et al. 1982). The same year, coincidentally, the “Fish Ecology III Conference” in the USA developed a conceptual framework for REX a “recruitment experiment” (Rothschild and Rooth 1982). In the meantime, a “Workshop on the Effects of Environmental Variation on Survival of Larval Pelagic Fishes” (IOC 1981) was organized in Lima as a contribution to OSLR by FAO and the Peruvian-German technical aid
The DEPM is a fisheries-independent method to estimate the spawning biomass of small pelagics, including the associated statistical precision of the estimated value. It was developed at the Southwest Fisheries Science Center in La Jolla under the leadership of Ruben Lasker (Lasker 1985). The breakthrough for its development was the finding of Hunter and Goldberg (1980) that the age of postovulatory follicles can be used to estimate the daily proportion of spawning females. After its first application to the Californian anchovy in 1980, it was successfully carried out for the Peruvian anchovy (Santander et al. 1984) and is now widely used in South America, South Africa and Europe (Alheit 1993, Stratoudakis et al. 2006). The application of this method for spawning biomass estimates requires extensive knowledge of reproductive parameters such as batch fecundity, spawning frequency and daily egg mortality and has, consequently, as a by-product, furthered international co-operation in recruitment research.

The Lima Workshop in 1980 (IOC 1981) brought together an international group of recruitment researchers with scientists working on reproduction and recruitment of the Peruvian anchovy and allowed comparisons of recruitment processes between small pelagics in the Humboldt and California currents. Important outcomes of this meeting were the first quantitative estimate of egg cannibalism (MacCall 1980) and the first sketch of the "Basin Model", an attempt to explain population dynamics of small pelagics based on an “optimal free distribution” interrelationship between geography, movement and growth dynamics at the population level (MacCall 1990). It also produced an early comprehensive review (Bakun and
Parrish 1980) of empirical and conceptual frameworks for applying available environmental
data to inferring the primary causative factors in recruitment variability, including the
suggestion for the formulation that became known as “Lasker windows” (Pauly 1989,
Peterman and Bradford 1987).

A most authoritative account on the ecology of marine fish larvae with a focus on anchovy
and sardine was published in 1981 by four eminent fish larval researchers from the Southwest
Fisheries Center in La Jolla, R. Lasker, J.R. Hunter, H.G. Moser and P.E. Smith (Lasker 1981). It contains a thorough discussion of the role of larval starvation and predation on fish
larvae for recruitment and was a pacemaker for the SARP project.

The 12th Assembly of IOC in 1982 adopted the OSLR concept as a long-term programme. It
promoted co-ordinated regional research projects to elucidate factors determining recruitment
to fish populations with the International Recruitment Project (IREP) as the initial main focus
of OSLR. The Assembly established a Guiding Group of Experts for the OSLR Programme
and initiated the “Workshop on the IREP Component of the IOC Programme on Ocean
Science in relation to Living Resources” in Halifax, Canada, in 1983 (IOC 1983). This
workshop, under the chairmanship of R. Beverton, recommended (i) direct investigations of
the early life history, particularly the Sardine-Anchovy Recruitment Programme (SARP)
including, inter alia, the otolith ring method, the DEPM and relevant oceanographic
measurements (IREP Minimum Plan) and (ii) indirect (inferential) approaches by making
available the wealth of long-term time series, including relevant information, normally
peripheral to the marine field, such as climatic and meteorological data that could help to
elucidate the physical and biological coupling controlling recruitment at different scales.
At its first meeting in Paris in 1984, the Guiding Group of Experts for OSLR recommended SARP as the pilot programme for IREP. The basic SARP concept involved repeated surveys of larval production during the extended spawning season of small pelagic fish. These surveys were coupled with a comprehensive physical and biological oceanographic sampling programme designed to determine variations in conditions related to larval starvation (Lasker 1981), predation (Lasker 1981), advection, physiological stress and other factors leading to mortalities of early life stages. Later in the season, surviving juveniles were to be sampled and their birthdate frequencies determined using daily otolith growth rings (Methot 1983). These frequencies, when compared with the observed larval production rates corresponding to the various birthdates, provide an index of variation in survival rate of early life stages. This is compared to variations in environmental processes to identify the mechanisms that best explain the observations. The SARP concept therefore, while basically an empirical field approach, offered a major departure from previous empirical approaches to study the recruitment problem in its ability to address higher frequency “within-year” variability.

Whereas previous empirical attempts have been defeated by the necessity to combine shorter scale variations, having various causes, into single annual composites, SARP offered the possibility of resolving different causes and effects on the time scales on which they actually act to determine net reproductive success.

Accordingly, a number of regional field-going SARP components (direct investigations) were initiated to test the several recruitment hypotheses (starvation, predation, advection) (Bakun et al. 1991): a US SARP in the California Current on anchovy, an Iberian SARP on anchovy and sardine in a joint Spanish-Portuguese-US project (López-Jamar and García 1992), a SW Atlantic SARP on anchovy and sardine in a co-operation by Brazil, Uruguay, Argentina, Germany and Sweden (Alheit et al. 1991) and a EURO-SARP project on anchovy, sardine and sprat in European waters run by scientists from Germany, Spain, Portugal and the
UK (Valenzuela et al. 1991, Alheit and Bakun 1991). A major aspect of SARP’s scientific rationale was the application of the comparative method of science whereby the multiple expressions of the problem afforded by various species groups inhabiting different regional ecosystems were considered as “proxy replicates” of similar processes, gaining additional explanatory power (degrees of freedom), to sort out the complex interacting mechanisms involved in recruitment variability. The Comparative Scientific Method (Bakun 1996) is particularly appropriate to problem areas where experimental controls are unavailable. This is one of the reasons why a co-ordinated international scientific SARP effort was thought to offer large potential benefits. Whereas all these SARP initiatives provided a wealth of new important information on the life history of small pelagics, it has to be admitted that no breakthrough was made in understanding and predicting recruitment. The main constraint was that no regional initiative had sufficient funding to carry out the complete SARP programme. On the other hand, the increase in temporal resolution for the study of larval demography was insufficient by itself to explain differential larval mortality without a comparable increase in resolution in the observation of the potentially causally related oceanographic variables. A serious blow was delivered to the SARP initiative when the most promising US SARP project was stopped by sudden federal budget restrictions.

Progress was made using inferential methods as suggested by the Guiding Group of Experts. Scientists from the Peruvian-German aid project PROCOPA teamed up in 1981 with an international group to rescue, assemble and analyze on a monthly basis long-term time series from the period 1953 – 1982 of all measured variables likely to have affected the Peruvian anchovy and its ecosystem. This resulted in an extremely rich data archive captured in two books (Pauly and Tsukayama 1987, Pauly et al. 1989) which have served as an important source in later studies on the impact of climate variability on the Humboldt Current and its small pelagic fish resources (e.g. Alheit and Bernal 1993, Alheit and Niquen 2004).
A meeting which proved to be a milestone in small pelagics research was the “Expert Consultation to examine changes in Abundance and Species Composition of Neritic Fish Resources” organized by G. Sharp and J. Csirke of FAO in 1983 in San José, Costa Rica (FAO 1983). This meeting gathered most of the information on ecology and fisheries of the large stocks of small pelagics relevant then for SARP and later for SPACC, a regional project of the GLOBEC programme, particularly from developing countries, and still serves as a rich source of information. A key paper which was an enormous stimulus for climate variability research within SPACC even 20 years thereafter was given by T. Kawasaki (1983) on synchronous large-scale fluctuations of the three sardine stocks in the Pacific.

The CEOS project (Durand et al. 1998) was an international collaborative study of potential effects of global climate change on the living resources of the highly productive eastern ocean upwelling ecosystems and on the ecological and economic issues directly associated with such effects. CEOS involved a variety of research institutions, notably NOAA/NMFS, ORSTOM and ICLARM, and was devoted to a study of the potential effects of global change on the resources of upwelling systems through identification of global and local effects impacting on these systems. A major focus of the study were the clupeoid fishes (such as anchovy and sardine). The main objectives were: (1) to assemble, summarize and analyze the data record of the four decades since 1960 regarding the four eastern boundary upwelling ecosystems and other upwelling areas, (2) to apply the comparative method to identify key physical processes and ecosystem responses and (3) to resolve underlying global-scale trends that in each individual regional system may be obscured by local interannual and interdecadal variability. Major ideas emanating from the CEOS project are (i) the “Ocean Triad Concept” of Bakun (1996) which suggests that an optimal combination of three physical processes
(enrichment, concentration, retention) provides an optimal situation for successful fish recruitment and (ii) the “Optimal Environmental Window” hypothesis (Cury and Roy 1989) which is a dome-shaped response curve of population growth to increasing intensity of wind stress-associated mixing and transport. The CEOS project paved the way for SPACC, as it started to look not only at recruitment, but also at climatic effects on the dynamics of small pelagics.

SARP had established itself in the international science community so much that it opened access to national funding to carry out recruitment research. Although the large international funding hoped for in the mid-1980s never materialized, several SARP projects were established successfully using national funding. However, due to its complexity the recruitment problem could not be solved by SARP. It became clear in the early 1990s that (i) recruitment studies must be conducted from an ecosystem point of view and that (ii) climatic effects play a major role in population fluctuations of small pelagics leading to so-called regimes (Lluch-Belda et al. 1992).

Consequently, SARP and CEOS researchers widened the scope of their investigations accordingly and created in 1994 jointly the SPACC (Small Pelagic Fishes and Climate Change) project which became one of the four core projects of GLOBEC (Global Ocean Ecosystem Dynamics) of the IGBP (International Geosphere Biosphere) Programme. Science (Hunter and Alheit 1995) and Implementation (Hunter and Alheit 1997) plans of SPACC were developed at three international meetings in La Paz, Mexico, (1994), Swakopmund, Namibia, (1995) and Mexico City (1996). SPACC’s objective is to clarify the effect of climate variability on the population dynamics of pelagic fish by comparing the ecosystems that support such populations (Hunter and Alheit 1995). The goals are (i) to describe the
characteristics and variability of the physical environment and of zooplankton population dynamics and their impact on small pelagic fish populations in each key ecosystem and (ii) to improve understanding of the nature and causes of long-term changes in these ecosystems.

SPACC uses two general approaches to meet these goals:

1. Retrospective studies, wherein ecosystem histories are reconstructed by means of fishery data and zooplankton and other time series and paleoecological data. This initiative was started in 1994 when SPACC researchers analysed long-term data from ecosystems rich in small pelagics together with SCOR Working Group 98 on “World-wide Large-scale fluctuations of Sardine and Anchovy Populations” (Schwartzlose et al. 1999).

2. Process studies in which cause-and-effect linkages between zooplankton, fish population dynamics and ocean forcing are inferred from comparisons of standard measurements made in different ecosystems.

The long-range goal is to develop predictive scenarios for the fate of small pelagic fish populations. Results of the SPACC project are presented in the following chapters.

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