Proposal for a SCOR working group on

Coupled climate-to-fish-to-fishers models for understanding mechanisms underlying low-frequency fluctuations in small pelagic fish

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Abstract. The low-frequency variability of small pelagic fish abundance is one of the most emblematic and best-documented cases of fish population fluctuations not explained wholly by fishing effort. Over the last 25 years, diverse observations have been integrated into several hypotheses; however, due to limited-duration time series, hypothesis testing has proven extremely difficult with the available statistical and empirical tools. As a result, the mechanistic basis for how the physics, biogeochemistry, and biology interact to result in the various patterns of synchronous variability across widely separated systems remains unknown. Identification of these mechanisms is necessary in order to explore projections and to build scenarios of the amplitude and timing of stock fluctuations, and their responses to human interactions (fisheries) and climate change. The proposed working group (WG) aims to implement and integrate state-of-the-art modeling tools and expertise to tackle this important scientific and environmental problem. We will use spatially and temporally explicit models that mechanistically represent the feedbacks among the various components of the climate-to-fishers system. We propose to take advantage of the unique opportunity of the present existence of several nationally funded projects to study - via modeling approaches - the causes of low-frequency variability of small pelagic fish. The establishment by SCOR of this WG will enable the coordination and integration of these ongoing modeling efforts into a global view of the synchrony/asynchrony phenomenon. At the same time, the WG proposes to gather, update and enhance available datasets, historical information and knowledge from the different oceanic systems (e.g., Eastern and Western North Pacific, Southeast Pacific and Southeast Atlantic). These datasets will be used to force the models as well as evaluate the model results against observations. The WG requests three years of support, complementing nationally funded projects, the recent SPACC and GLOBEC synthesis efforts, and other related activities, to facilitate a needed international effort in this area. The support will be used to hold annual meetings, produce two scientific reports and at least one paper in a primary literature journal. Furthermore, we are committed to continue searching for complementary financial support to broaden our capacities and outreach. The results of this WG will contribute to the understanding and managing of small pelagic fish stocks, which are of significant economic and ecological value, in the context of low-frequency fluctuations due to climate change, fishing, and other factors.

Scientific rationale and relevance. Climate-scale variability and its impact on fish resources have only recently become widely accepted (e.g., Cushing 1992; Lehodey et al. 2006; Fréon et al. 2009). They were first detected by Ljungman in the 1880s who published an analysis of the Baltic herring catch fluctuations showing a 55-year cycle due to natural conditions, apparently forcing the schools to change their spawning and feeding places (Parrish et al., 2000). The most compelling example of climate-driven fish stock changes is probably the fluctuations of sardines and anchovies described since the early 1980s, the so-called Regime Problem (Lluch-Belda et al., 1989, 1992; Schwartzlose et al., 1999). Landings of sardines show synchronous variations off Japan, California, Peru, and Chile, with populations flourishing for 20 to 30 years and then practically disappearing for similar periods. Periods of low sardine abundance have coincided with increases in anchovy populations. Benguela Current sardine and anchovies, in the Atlantic Ocean, appear to be in synchrony with Pacific stocks, but in opposite phase (i.e., Benguela sardine stocks flourishing during periods of high anchovy in the Pacific, and vice versa). As demonstrated through paleo-reconstructions based on sardine and anchovy scales (Baumgartner et al., 1992), and because synchrony takes place even when different fishery management schemes exist among systems (Schwartzlose et al., 1999), fluctuations appear to be at least partially fishery-independent. Further, because of the large spatial and coherent temporal scales involved, a single global driver linked to large-scale atmospheric or oceanic forcing has been proposed to explain the variations in the different systems. The Regime Indicator Series (RIS; Lluch-Cota et al., 1997), synthesized from the catch series of the four mentioned systems, has been related to the low-frequency component of different climate series, including the Pacific Decadal Oscillation and the North Atlantic Oscillation (Chavez et al., 2003) and the low-frequency signature in global ocean temperature (Tourre et al., 2007), but no mechanism linking the physics to the biology and synchronously operating in widely separated systems has been demonstrated. What remains elusive is a mechanistic basis for how the physics, biogeochemistry, and biology interact to result in the various patterns of synchronous variability across widely separated systems. **Understanding these mechanisms is necessary to explore projections and build scenarios of the natural-driven amplitude and timing of stock fluctuations, and their responses to human interactions (fisheries) and climate change.**

Background and proposal. It has been more than 25 years since the paper by Kawasaki (1983) first called attention to the synchrony among catch series of the three main sardine fisheries in the Pacific basin (Japan, California and Humboldt), and more than 20 years since SCOR WG 98 on Worldwide Large-scale Fluctuations of Sardine and Anchovy Populations was formed to explore the then-called Regime Problem. Other significant efforts were the development of the GLOBEC SPACC program (SPACC, 2008) and the IRI workshop in Honolulu in 2001 (Bakun and Broad, 2001). The early reports were highly successful in documenting the fluctuations, alternation and synchrony, and in pooling existing hypotheses to explain them; however, testing was out of their reach, mainly because *a)* retrospective studies are limited at best, to less than a century of catch series, to a few decades of physical oceanography and climate time series, and to even fewer long-term ecosystem observations; and *b)* the development of reliable modeling tools that allow adequate exploration of this problem has only taken place during the last few years.

The primary question for our proposed WG is *which model scenarios can generate low-frequency variations in the abundance of small pelagic fish (periods of increasing, high, decreasing, and low abundance), and do they correspond to prevailing conditions observed during the different regimes in the different systems.*

We will approach this question by testing and contrasting the three main groups of synthetic hypotheses of the Regime Problem today:

1) Environmental conditions control the low-frequency variability in the fish populations through: a) the link of reproduction success to alternating strong and weak modes of boundary current flow, and the resulting conditions of distinct nearshore and offshore habitats (MacCall 2001), b) temperature control of the populations expansion and contraction via adult spawning behavior and effects on early life stages (Lluch-Belda et al. 1991; Takasuka and Aoki 2006), and c) the food availability and composition (enrichment) determining population success (Van der Lingen et al. 2001).
2) Fishing pressure can reshape, and even suppress the low-frequency synchrony signal by impacting the population dynamics: *a)* affecting longevity and the capacity of the populations to survive adverse environmental periods, *b)* changing the populations reproduction and migratory capacities by altering the size classes (fecundity, swimming), and *c)* because population productivity might depend on migratory behavior that recruits learn from older fish, fishing could affect the chain of transmission, potentially causing instability and collapse (Petitgas et al. 2006).
3) Rapidly evolving adaptive response mechanisms being the cause of low-frequency biomass and distribution changes, including individuals' affinities, ethological inertia (school trap), and strong selection pressure (fishing or predation; Bakun, 2001).

To contrast these hypotheses, and building and integrating findings of the projects outlined below, the WG will compare existing data, analyses, and models of the oceanography, ecology and fisheries of several small pelagic systems, including the California Current and the Gulf of California, the Benguela Current, off Japan, and the Humboldt Current system. We will consider models that represent the physical-to-biogeochemical-to-fish linkages both in individual- and concentration-based frameworks. Among these are the physical circulation model (ROMS) already implemented in some of the systems (Curchitser et al., 2005); a Nitrogen-Phytoplankton-Zooplankton-Detritus model (NEMURO; Kishi et al. 2006), and its extension in NEMURO.SAN (Rose et al., 2006) which is an individual-based model (including bioenergetics) for the small pelagic fish populations (sardine and anchovies) and their predators including fishing pressure; ATLANTIS, an Ecosystem Box-Model with detailed coupling between physical and biological processes (Fulton et al., 2004); and OSMOSE, an Individual Based Model based on predation rules and trophic interactions (Shin et al., 2004). These models have their own strengths and weaknesses, so comparing the results of different models will allow exploration of the fishery systems from different perspectives as well as the construction of ensembles of solutions allowing for consideration of likelihoods and uncertainties in relation to the proposed scenarios. The models we propose to use are fully coupled, spatially explicit physical/biological models. The physical models are general circulation models (GCMs) capable of describing the time evolution of the three-dimensional ocean circulation, including changes in currents, temperature and salinity. They can be driven by historical reanalysis or by future projections as given by the IPCC class of models. The biological models (including models for top-predation—fishers) vary in design but all can mechanistically respond to the environmental conditions supplied by the physical GCM.

We will contribute to the solution of the Regime Problem by studying the particular case of low-frequency fluctuations of sardine and anchovy abundance within a particular system, or by contrasting different systems during the same time period. Sardine and anchovy were selected as target fish species because they are a well-studied pair of small pelagics that co-occur in multiple ecosystems that demonstrate low-frequency alternations in abundance within ecosystems and basin-scale synchronies among ecosystems. We propose to carry out this study through the combination of historical data and by the use of emerging modeling tools.

Justification of the group. Our proposal is timely because state-of-the-art information on the topic is to be delivered by 2010 by GLOBEC and SPACC as part of their syntheses, and the simultaneous existence of several model-based projects that the WG members already lead.

Regarding modeling and data synthesis, there are two particularly relevant workshops programmed for the upcoming GLOBEC Open Science Meeting in June 2009, one on “Modelling ecosystems and ocean processes: the GLOBEC perspective of the past, present and future”, and another on “Worldwide large-scale fluctuations of sardine and anchovy”, both chaired by proposed members of this WG. We can also capitalize on the recently established inter-disciplinarity between physical oceanographers, modelers, and fisheries scientists owing in part to international initiatives. Of particular relevance is that, during the last few years, some of the proposed WG members, fisheries and physical oceanography scientists, have already collaborated in workshops organized by PICES, GLOBEC, APN and CAPaBLE projects (Werner et al. 2005, 2007; Kishi et al., 2006), to discuss strategies and possibilities to deal with the Regime Problem with a completely fresh approach and a brand new toolbox of models and analysis techniques.

Regarding related modeling studies underway, several projects relevant to our proposed WG efforts have been funded to deal with the model implementation and data analysis. The WG will build on these as we coordinate our approaches to enable a more integrated and global treatment:

- *US CAMEO program (Comparative Analysis of Marine Ecosystems):* jointly funded by the US NSF and NOAA (Curchitser, Rose, Megrey, MacCall, Checkley and Werner with in-kind collaborative efforts from Mexico, Canada and Japan) to develop physics-to-fish-to-fishers models for the California Current and for the Oyashio/Kuroshio Current System. In this 2-year effort, short-term (one year) and long-term (decadal) simulations of sardine dynamics will be performed for the two systems to demonstrate the utility of physics to fish to fishers modeling and the power of the comparative approach for understanding how bottom-up (climate and physics) and top-down (predation and harvest) factors can affect small pelagic fish abundances.
- *UK QUEST.FISH* (Barange, Blanchard): which has as objectives to estimate primary (phytoplankton) and secondary (zooplankton) production in key coastal-ocean fisheries around the world under climate change scenarios; link primary production to fish production and fisheries catches and to develop climate-forced models of fish biomass and production; investigate the socio-economic consequences of climate-driven changes in fish production for global fish-based commodities, such as fishmeal; and develop improved ways of assessing vulnerability of fisheries to future climate change, in the context of other drivers of change: supply-demand changes, governance scenarios, macro-economic change.
- *Japan SUPRFISH project (Studies on Prediction and Application of Fish Species Alternation):* Ito has been funded by the Ministry of Agriculture, Forest and Fisheries to elucidate mechanism of the fish species alternation and develop mathematical models representing fish species alternation. *Japan DoCoFis project (Dynamics of Commercial Fish Stocks):* Ito and Kishi have been funded by Fisheries Agency to investigate climate change effects on commercial fish stocks. *Japan CREST program (Core Research for Evolution Science and Technology):* Yamanaka has been funded to develop next generation mechanistic models for marine ecosystems.

Ultimately, our proposal is opportune because small pelagic fish remain the most important large fishery and source of marine protein (about one-third of total marine catch), as well as one of the most unpredictable in terms of population levels and, thus, are difficult to manage. These difficulties are occurring in times when fisheries management paradigms are changing rapidly, when yearly technological advances result in new levels of observational and analysis capabilities, and most importantly, when nations are fully committed to reduce extreme poverty and hunger in less than a decade (UN Millennium Development Goal).

Terms of reference. To accomplish our goals we propose meeting once a year for a three-year period, with participation of Full, Associate (collaborators with already secured SCOR independent funding) and Corresponding members (when possible and based on other funding sources). The WG will:

- Gather and update available datasets, historical information and knowledge from the different sardine-anchovy systems (e.g., Eastern and Western North Pacific, Southeast Pacific and Southeast Atlantic).
- Carry out a detailed review of the existing hypotheses on the Regime Problem, supporting facts and contradictions, to identify the specific questions to be asked to the data and models in order to test the different components of the synthetic hypotheses described above, based on the outcomes of the GLOBEC Open Science Meeting, and the upcoming GLOBEC and SPACC synthesis books.
- Analyze and compare modeling approaches and strategies for their applicability for dealing with the three core hypotheses of drivers of low-frequency cycles: environmental variation, fishing pressure, and adaptive mechanisms. Each of the modeling approaches has strengths and weaknesses; taken together, most of the ingredients for a comprehensive or optimally-scaled model likely exist. Assembly of the

models together with the hypotheses and data, all within a working group framework, will enable efficient evaluation of the modeling approaches, development of a set of specific strategies for developing new models and improving the existing models, and rapid exchange of people's experiences about what approaches show promise and noted weaknesses in these approaches. Identify what aspects of the modeling exist and what components either need enhancement or simplification or need to be added. Produce reports the on current understanding of the regime problem in small pelagic fish, including a description of the existing hypotheses and fundamental questions, a report on the state-of-the-art approaches and strategies for extending existing models and developing new models to deal with bottom-up (environmental) and top-down (fishing) effects, and a report that summarizes and synthesises the modeling results to date related to the studied systems. The workshops will provide the forum for furthering model development.

Timetable:

- Meeting 1 (2010)—Update methods, data and contacts, establish experimentation, data-gathering and modeling strategies, and generate a technical report on the topic's state of the art.
- Meeting 2 (2011)—Discuss preliminary modeling results, make systems comparisons, deal with modeling milestones, and generate a second report on the modeling tools.
- Meeting 3 (2012)—Integration, discussion and writing of the final report, which will be a scientific paper reporting our results. We will further transmit our results through diverse scientific presentations at congresses and symposia, and in particular by bridging to as many related programs and groups as possible (PICES-FUTURE, ICES, IMBER, CLIOTOP, SCOR WG 125 on Global Comparisons of Zooplankton Time Series and other SCOR WGs, etc.).

The chairs will be responsible for 1) implementing and maintaining a website for the working group, for members to share information, data and tools, and for other scientists and general public interested in the topic; 2) delivering the annual reports and the scientific paper; and 3) dissemination of progress and main achievements through specialized newsletters, maintaining an updated calendar of events, providing documents and material to all members willing to present at congresses or seminars, and interacting with other groups.

Deliverables

- Yearly reports to SCOR during the duration of the WG
- Contributed papers and presentations in scientific meetings
- One paper (final report) in a primary literature journal
- Publicly available data and modeling tools
- A web site for the group

Additional products may be possible as we secure additional funding (e.g., from START and APN) and incorporate more experts.

Membership. Designed to cover knowledge in the fields of physical, ecological, fisheries and socioeconomics sciences, on the four main small pelagic systems (California Current System, Japan, Humboldt, and Benguela), and on each of the models and tools to be used. Additional details on each of the proposed members is available in the temporary website http://www.pescamexico.org/scor/

Name	Country	System	Expertise
Full members			
Akinori Takasuka	Japan	NW Pacific	Fisheries/ Plankton
Beth Fulton	Australia	SW Pacific	Ecosystem modeling, ATLANTIS
Carl van der Lingen	South Africa	SE Atlantic	Fisheries Ecology
Enrique Curchitser	USA	All systems	Physical oceanography, ROMS (***Co-Chair***)
Julia Blanchard	UK	All systems	Socioeconomic modeling, QUEST_Fish
Kenneth Rose	USA	All systems	Bioenergetics modeling, NEMURO.SAN
Luis Cubillos	Chile	SE Pacific	Fisheries Sciences
Salvador Lluch-Cota	Mexico	NE Pacific	Fisheries Ecology (***Co-Chair***)
Shin-ichi Ito	Japan	NW Pacific	Physical oceanography, NEMURO
Yunne Shin	France	All systems	Ecosystem modeling, OSMOSE
Associate members *(This is a preliminary list of participants fully involved in the activities, but not financed by SCOR. The number will depend on our ability to obtain funds from other sources)*.			
Alejandro Pares	Mexico	NE Pacific	Mexican Pacific ROMS
Bernard Megrey	USA	NE Pacific	Fisheries, ecosystem modeling NEMURO.SAN
David Checkley	USA	NE Pacific	Plankton expert, SCOR WG 125
Francisco Werner	USA	All systems	Physical modeling, coupling NEMURO
Manuel Barange	UK	All systems	Ecological and socioeconomic models
Michio Kishi	Japan	NW Pacific	Physical-biological modeling, NEMURO
Miguel Bernal	Spain	All systems	Fisheries scientist, statistical models
Morgane Travers	France	All systems	Ecosystem indicators, end-to-end models
Ryan Rykaczewski	USA	All systems	General Circulation Models
Samuel Hormozabal	Chile	SE Pacific	Physical oceanography, links to biology
Yasuhiro Yamanaka	Japan	All systems	Climate change, Earth System Modeling
Corresponding members *(These are scientists with long experience in the Regime problem. All were members of SCOR WG98 that we will invite into the discussions, at least through email/video links)*.			
Alec MacCall	USA	NE Pacific	SCOR WG98
Andrew Bakun	USA	All systems	SCOR WG98
Daniel Lluch-Belda	Mexico	NE Pacific	SCOR WG98
Jurgen Alheit	Germany	SE Pacific	SCOR WG98, SPACC
Tuyoshio Kawasaki	Japan	NW Pacific	SCOR WG98

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