- Making a Difference –

Scientific Capacity Building & Enhancement for Sustainable Development in Developing Countries

Toward Quantitative Understanding of Natural Fluctuations of Marine Coastal Fisheries of Sardines and Anchovies and their Impact on Fishing-Dependent Human Communities

Final Report for APN CAPaBLE Project:
2004-CB08NSY-Kishi
Project Leader: Michio J. Kishi

Toward Quantitative Understanding of Natural Fluctuations of Marine Coastal Fisheries of Sardines and Anchovies and their Impact on Fishing-Dependent Human Communities

2004-CB08NSY-Kishi

Final Report submitted to APN

Overview of project work and outcomes

Non-technical summary

Together with long-term ecosystem-specific oceanographic and fisheries data sets, our aim is to understand the effect of climate change effects on marine ecosystems, quantify its effects on fish growth and production in distinct geographic regions that support sardine and anchovy populations. We also aim to provide explanations for the sardine and anchovy abundance trends, and explore how to best integrate these results into the decision making process by fisheries/resource managers and policy makers.

Objectives

The objectives are to extend a marine food-web and fisheries bioenergetics modelling approach developed under APN funding (to study Pacific Herring) for the study of sardines and anchovies. Together with long-term area-specific oceanographic and fisheries data sets, we aim to understand the propagation of climate change effects up the marine food-web, quantify its effects on energy cycling and fish growth and production in distinct geographic regions in upwelling regions that support important exploited marine fish populations. A workshop in the Fall of 2005 (in Japan) was held to integrate the work which included attendees from Latin America, Europe and Africa as well as Asia.

Amount received and number years supported

The Grant awarded to this project was:

- US$ 10,000 for 2005/2006

Work undertaken and Results

At the workshop held in Tokyo, Japan (14-17 November 2005) we reviewed recent data and modeling approaches that could help explain the annual and inter-decadal variability of sardine and anchovy populations. We also outlined a common multi-species, spatially-explicit modeling approach, which is an extension to the NEMURO.FISH model. The work-plan for the group in the coming months will focus on addressing the question "How much can bottom-up food-web dynamics explain sardine and anchovy growth and relative abundance between warm and cold regimes in the different ecosystems?" Specific tasks and objectives include:

- Initiate a review paper (as an update to the 1989 symposium) on the processes that affect sardine and anchovy populations, including comparisons among ecosystems where possible.
- Develop bioenergetics growth models for sardine and anchovy with sufficient detail to capture important differences in the feeding behavior and energetics between species.
- Apply the NEMURO.FISH((North Pacific Ecosystem Model for Understanding Regional Oceanography. For Including Saury and Herring)) model, updated

for sardines and anchovies, as a box (point) model using predicted prey from an uncoupled spatially-explicit NEMURO lower trophic model.

- Extend NEMURO.FISH to a 2-dimensional model that simulates sardine and anchovy population dynamics, with potential application to a variety of geographic locations with contrasting lower trophic level and fish dynamics.
- Analyze existing field data from different locations to quantify and compare the contraction and expansion response of sardine and anchovy populations to environmental and biomass conditions.
- Consider the need to incorporate parameters or/and outputs of bio-economic models in future developments regarding NEMURO.FISH to capture the impact of top-down (human) approaches in generating or enhancing the cyclic behavior of pelagic fish populations.

Relevance to the APN CAPaBLE Programme and its Objectives

The present project has brought together scientists from India, Bangladesh, the Philippines, and the P.R. of China with colleagues from Japan, US, Mexico, the UK, South Africa, Chile and France (all of the latter were funded from separate sources). Sardines and anchovies are of importance globally and their fluctuations are significant economically, societally as well as scientifically. The workshop provided the opportunity to define a framework for developing a systematic approach to study the global environmental factors affecting the populations of these species and the incorporation of this understanding in management strategies.

Self evaluation

We believe that our work is progressing at an appropriate pace at this point. The next meeting in Hawaii this April 2006 (of a sub-group of the research team) will provide a next check in our progress. At that time we hope to have additional key data made available and the extensions to the modeling approaches to include more than one fish species. The presentations at the October 2006 PICES Annual Conference in Yokohama will provide a forum for the project's results. The sub-group meetings in Hawaii and Yokohama will be at no cost to this project.

Publications

A report of the Tokyo workshop will be published in the PICES Newsletter (2006, pending). Two primary journal articles are planned, one on the extension of the available data sets since 1989 and the other on the modeling formulation that include the multi-species approach. Both are targeted for submission by the end of 2007.

Acknowledgments

We wish to thank the Japanese Fisheries Research Agency (FRA, http://ss.myg.affrc.go.jp/), PICES (http://www.pices.int), the Global Ocean Ecosystem Dynamics Program (GLOBEC, http://www.globec.org), and the Inter-American Institute for Global Change research (IAI, http://www.iai.int/) for providing additional support to make the workshop possible.

Technical Report

Abstract

At the workshop held in Tokyo, Japan (14-17 November 2005) we reviewed recent data and modeling approaches that could help explain the annual and inter-decadal variability of sardine and anchovy populations. We also outlined a common multi-species, spatially-explicit modeling approach, which is an extension to the NEMURO.FISH model.

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1. Introduction

We propose to build on ongoing APN award to F. Werner and B. Megrey (Number 2004-10-NSY, US$45,000) entitled *"Climate Interactions and Marine Ecosystems: Effects of Climate on the Structure and Function of Marine Food-Webs and Implications for Marine Fish Production in the North Pacific Ocean and Marginal Seas"*. In particular, and in the short-term, we propose to extend the above project to include the study of *sardines and anchovies,* their fluctuations and the implications to management. In the longer-term, this work is viewed to investigate the natural causes of inter-annual and inter-decadal variability of marine ecosystems in key coastal regions, their impacts to fishing-dependent coastal communities, and in turn the consequences to these marine ecosystems by the responses of these human communities.

2. Workshop Outputs

A workshop on *"Global comparison of sardine, anchovy and other small pelagics: building towards a multi-species model"* was held in Tokyo, Japan, from 14-17 November 2005. Core support for the workshop was provided by APN-CAPaBLE with additional funding from the Japanese Fisheries Research Agency (FRA), North Pacific marine Science Organization (PICES), Global Ocean Ecosystem Dynamics (GLOBEC), the and the Inter American Institute for Global Change research (IAI), enabling participation by 22 attendees from Chile, China, India, France, Japan, Mexico, Pakistan, the Philippines, South Africa, the UK, and the USA. The goals of the workshop were to explore ways to extend an existing marine food-web and fisheries model to ecosystems containing sardine and anchovy. Together with long-term ecosystem-specific oceanographic and fisheries data sets, our aim was to understand the propagation of climate change effects up the marine food-web, quantify its effects on energy cycling and fish growth and production in distinct geographic regions that support important sardine and anchovy populations, to explain synchronous and asynchronous patterns of abundance trends, and explore how to best integrate these results into the decision making process by fisheries/resource managers and policy makers. Over the past century, global fluctuations in the populations of sardines and anchovies have been documented (Fig. 1).

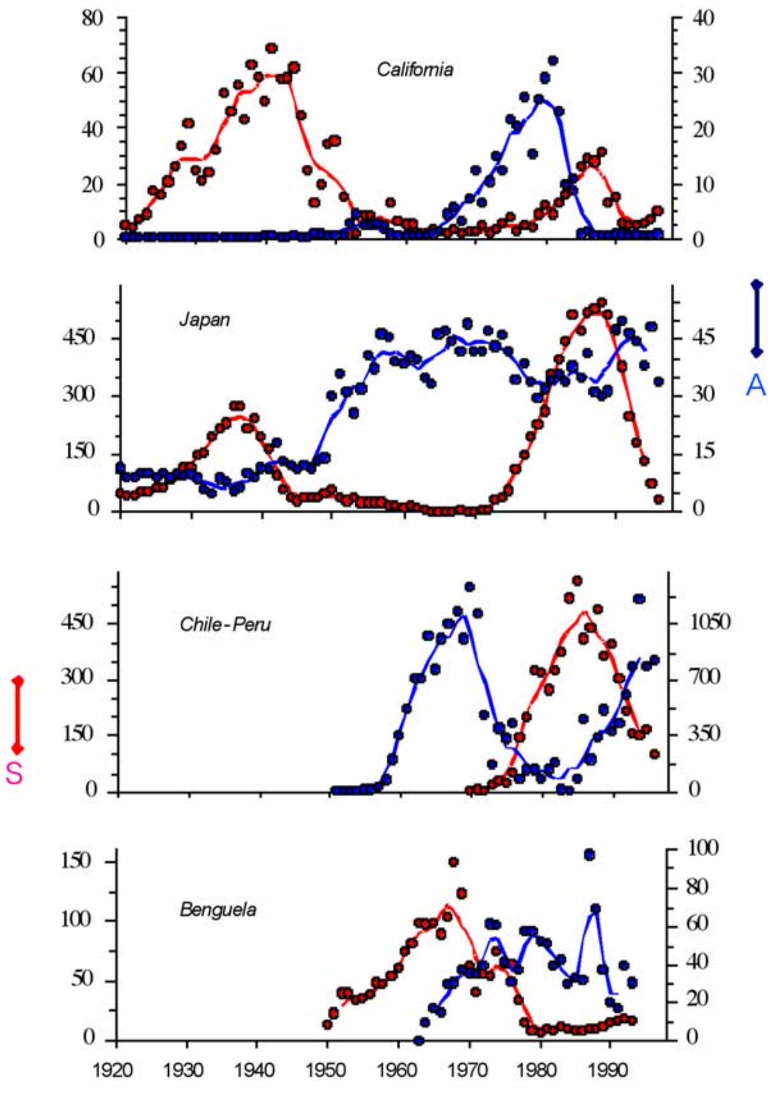

Fig. 1. Sardine and anchovy catch at three sites in the Pacific and in the Benguela region from 1920 to 1996 (courtesy of S. Lluch-Cota, one of the participants of workshop).

The amplitude of fluctuations can be high, and inter-annual and longer-term fluctuations contribute significantly to the total variability of the world's fish harvest. Additionally, the fluctuations appear to be at times asynchronous across species within specific regions, as well as synchronous within species at larger (basin) scales. For example, sardine populations exhibit synchrony over a large part of the Pacific (Humboldt Current, California Current, and Kuroshio Current areas). On the other hand, sardines do not show any apparent systematic synchrony between the Pacific and Atlantic Oceans. The local out-of-phase asynchrony between sardine and anchovy may result from differences in species life-histories, as well as from bottom-up processes driven by climate shifts. The in-phase synchrony of sardine populations within the Pacific basin also suggests a bottom-up, climate-driven component. The possibility of climate-induced variability in sardine and anchovy population fluctuations was previously discussed at the symposium entitled "Long-term variability of pelagic fish populations and their environment" that was held in Nemuro, Hokkaido, Japan in 1989. Since the 1989 symposium, our ability to model marine ecosystems and their response to physical forcing has evolved rapidly. For example, the PICES CCCC (Carrying Capacity and Climate Change) MODEL Task Team has built a community ecosystem model called the "North Pacific Ecosystem Model for Understanding Regional Oceanography (NEMURO)" (Kishi et al. 2006) and coupled the NEMURO model to a bioenergetics-based population dynamics model of fish. The coupled model, called NEMURO.FISH (Fig. 2; Megrey et al. 2006), has been used to examine the responses of Pacific herring (*Clupea pallasii*) and Pacific saury (*Cololabis saira*) to decadal variations in climatic conditions focusing on the 1950-2000 time period.

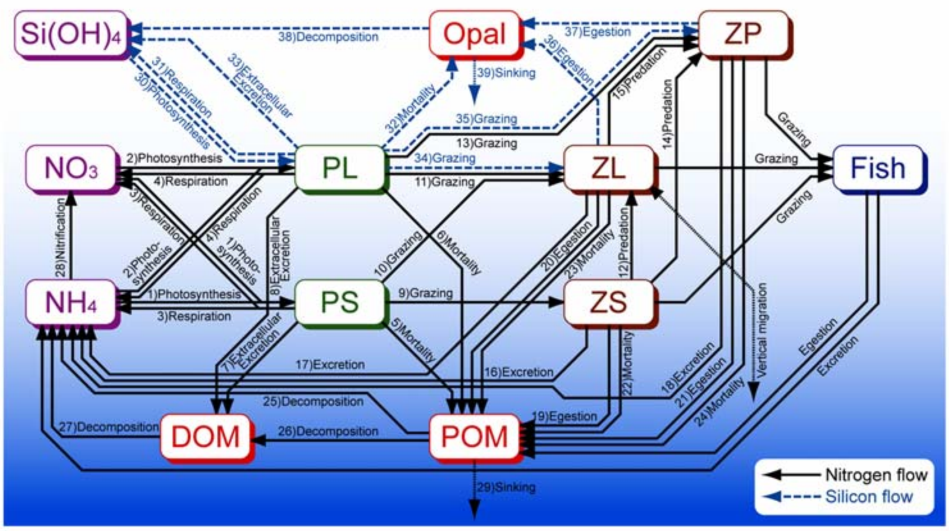

Fig.2 Flow chart of "NEMURO.FISH", ecosystem model for northern Pacific Ocean.

At the November 2005 workshop in Tokyo, we reviewed recent data and modeling approaches that could help explain the annual and inter-decadal variability of sardine and anchovy populations. We also outlined a common multi-species, spatially-explicit modeling approach, which is an extension to the NEMURO.FISH model, to study the synchrony and asynchrony of sardine and anchovy populations. Workshop attendees outlined a comparative approach designed to study the effects of the climate change on sardine and anchovy population dynamics by focusing on the populations located in the key geographic areas accompanied by supporting data for model comparison, calibration and validation. A smaller group of the investigators met on 18-19 April 2006 in Hawaii before the PICES CCCC Synthesis Symposium to review the advances since the Tokyo workshop and plan the next steps. Some of the results from these efforts will be presented at the PICES Annual Meeting in October, 2006 (Yokohama, Japan; http://www.pices.int/meetings/annual/PICES15/background.aspx), at the S6 session on *"Modeling and historical data analysis of pelagic fish, with special focus on sardine and anchovy"* co-chaired by S. Ito, M. Kishi, B. Megrey and F. Werner. The output of above session will be published by the end of 2007.

Sardine and anchovy dynamics

(a) Growth.-- Daily growth in body weight of sardines and anchovy are simulated using bioenergetics equations. The Bioenergetics Task Team organized at the workshop will configure bioenergetics models for the two species. Any information on preferred (or optimal) water temperatures for growth, and information on the extreme warm and cold water temperatures tolerated for growth, is helpful. Coarse diet information aids in specifying the vulnerabilities of fish to the different prey types that are used in the functional response relationship. Temperature preferences and tolerances, and diets, should be specified by age or life stage. Differences between the feeding behavior and the energetics (energy budgets) of sardine and anchovy will be helpful to the Bioenergetics Task Team. Calibration of anchovy and sardine growth is achieved by comparison of predicted and observed weights-at-age. Weights-at-age is usually reported as mean weight at age-1, age-2, etc. We need to be careful in how we define ages to ensure a match between observed data and model output. We need to be clear on how we define birthdays (e.g., January 1 for all fish versus from beginning of spawning season). Using the number of months for age can help clarify what is meant by an age-1, age-2, etc. fish. We can also use lengths-at-age instead of weights-at-age; we would convert model output of weight into length using a length-weight relationship. Fish condition indices (i.e., fish are fat or skinny Early life stage dynamics involves tracking the numbers of eggs, yolk-sac larvae, and larvae each day as they develop and die, until reaching the defined recruitment. The early life stage option would involve knowing development durations (in days) of eggs, yolk-sac larvae, and larvae as functions of water temperature, and the daily mortality rates that occur during each life stage. Often we include density-dependence in the first year of life; in what stage and how density-dependent mortality operates will need to be guessed at by the experts.

(b) Mortality.-- Natural and fishing mortality rates are specified by life stage or age, and perhaps can differ by habitat region.

(c) Recruitment.-- In order to close the life cycle, we must take spawning biomass or total egg production each year and predict the number of recruits, which then become the newest (youngest) members of the population each year. Recruitment can be defined in a number of ways, but we usually use something like numbers of individuals reaching 6 months of age or reaching the juvenile life stage. There are two options for predicting recruitment each year: early life stage dynamics or spawner-recruit relationship.

The spawner-recruit approach, which has been used with herring in NEMURO.FISH, involves computing spawning biomass and using a Beverton-Holt or Ricker equation to predict recruits from spawning biomass (Megrey et al., in review). Sometimes environmental variables (e.g., sea surface temperature) are included in the spawner-recruit relationship. These environmental variables may or may not be the same as those used in the NPZ and fish growth aspects of NEMURO.SAN. Thus, we may have a water temperature for the NPZ and bioenergetics, but an independently estimated sea surface temperature for recruitment.

For both approaches, we need information on aspects of spawning in order to compute total egg production (for the early life stage approach) and spawning biomass (for the spawner-recruit approach). Data are needed on the fraction of females mature by age or size, the male to female sex ratio, and fecundity of females by age or size. Information on when sardine and anchovy spawn (say by month or between two water temperatures), and the number of batches from each female and the frequency of releasing batches during the spawning season, is also helpful

(d) Movement.-- Moving fish between the habitat regions and among model cells within each habitat region will be achieved using fixed rules and an approach like the ideal free distribution. Fixed rules are appropriate with movements that are migration-based, such as movement from the feeding habitat to the spawning habitat when temperatures are appropriate for spawning. The Ideal Free Distribution approach is useful to predict the contraction and expansion of fish within habitat regions in response to sparse or crowded conditions. Information on the migration timing and routes, and how anchovy and sardine contract and expand under different conditions is needed in order to confirm the movement simulated in NEMURO.SAN.

Table 1. Summary of the information needed for configuring NEMURO.SAN to be representative of a specific location.

Category	Sub-Category	Information Needed
Spatial scales	Spatial scales (1.b)	Number, spatial arrangement, and dimensions of habitat regions
Lower trophic level dynamics	Driving or forcing variables (2.a)	Water temperature, incident solar radiation, and mixed layer depth by month or season, and if possible by habitat region
	Calibration (2.b)	Monthly or seasonal concentrations of nutrients, small and large phytoplankton or total chlorophyll, and small, large, and predatory zooplankton for the whole system or if possible by habitat region
Sardine and anchovy dynamics	Bioenergetics (3.a)	Temperature preferences and tolerances related to growth, and diet information, by age or life stage
	Calibration of growth (3.a)	Mean weights-at-age, lengths-at-age, condition factors Mean weight by month for a year-class
	Mortality (3.b)	Natural and fish mortality rates by age or size, and if appropriate by habitat region
	Recruitment (3.c)	Egg, yolk-sac larval, and larval stage durations as a function of temperature, and daily mortality rates by stage Spawner-recruit data for fitting Beverton-Holt or Ricker functions to, or already fitted spawner-recruit curves, which may include environmental variables separate or shared with the NPZ and bioenergetics models Male to female sex ratio, frequency of spawning bouts, maturity and fecundity of females by age or size, and environmental cues that define the beginning and end of the spawning season
	Movement (3.d)	Fixed rules for seasonal migrations among habitat regions Interannual patterns of population contraction and expansion within habitat regions based on population abundances or environmental conditions

3. APN-Funded Participants

The APN-Fund was used as travel expenses for the following participants:

(1) Wei Hao (China) :Physical Oceanographer/Modeler
Professor,
Key Lab. Of Physical Oceanography
Ocean University of China
5 Yushan Roard, Quindao, China

(2) Pratap Kumar Mohanty (India) :Fisheries Oceanographer
Reader
Department of Marine Sciences
Meteorology and Physical Oceanography Laboratory
Berhampur University
Bhanjabihar - 760 007
Orissa, INDIA

(3) Md.Kawser Ahmed(Bangladesh) :Fisheries Oceanographer
Nationality: Bangladeshi
Mailing Address: Lab. Of Ecology, Environment & Climate Change
Department of Fisheries, University of Dhaka

(4) Rohelano M.Biones(Phillipnes) :Natural Resource Economist
Unit 33A, 8 Wack-Wack Road Condominium,
Wack-Wack Road 1550,
Mandaluyong City, Metro Manila, Philippines

The other participants to the workshop are listed in the appendix.

5. References

Kishi, M. J., M. Kashiwai, D. M. Ware, B. A. Megrey, D. L. Eslinger, F. E. Werner, M. Aita-Noguchi, T. Azumaya, M. Fujii, S. Hashimoto, H. Iizumi, Y. Ishida, S. Kang, G. A. Kantakov, H. Kim, K. Komatsu, V. V. Navrotsky, L. S. Smith, K. Tdokoro, A. Tsuda, O. Yamamura, Y. Yamanaka, K. Yokouchi, N. Yoshie, J. Zhang, Y. I. Zuenko and V. I. Zvalinsky (2006): NEMURO - A lower trophic level model for the North Pacific marine ecosystem. *Ecological Modelling*, (accepted).

Megrey, M., Rose, K.A., Ito, S., Hay, D.E., Werner, F.E., Yamanaka, Y., Maki Noguchi-Aita, M., (2006): North Pacific basin-scale differences in lower and higher trophic level marine ecosystem responses to climate impacts using a nutrient-phytoplankton-zooplankton model coupled to a fish bioenergetics mode. *Ecological Modelling*, (accepted).

6. Appendix

6.1 Agenda for the FRA / APN / IAI / GLOBEC / PICES workshop

"Global comparison of sardine, anchovy and other small pelagics ? building towards a multi-species model"

Date: 14-17 Nov. 2005
Venue: "Kiku no Ma" (Chrysanthemum room)
2F, Hotel BlueWave Inn Asakusa
2-33-7, Asakusa, Taito, Tokyo, Japan
Conveners: S. Ito, M. Kishi, C. Werner, B. Megrey and K. Rose
Organized by: Fisheries Research Agency (FRA) Japan
Sponsored by: Asia-Pacific Network for Global Change Research (APN)
Inter-American Institute for Global Change Research (IAI)
Global Ocean Ecosystem Dynamics (GLOBEC)
North Pacific Marine Science Organization (PICES)

Monday, November 14th

Opening Session (08:30-09:00)

08:30-09:00 Overview of the workshop objectives Shin-ichi Ito

Reviews of sardine and anchovy response to the climate variability (09:00-12:00)

California Current and Gulf of California

09:00-09:20 Opportunities and problems in linking sardine and anchovy populations to environmental variability Larry Jacobson
09:20-09:40 The California Current Ecosystem: a brief overview with a focus on California Sardine Vera Agostini
09:40-10:00 Some Comments on the Gulf of California environment and modeling of sardine system Gulf of California Salvador Lluch-Cota

Benguela Current

10:00-10:20 Review of variability in biomass, growth, and other characteristics of anchovy Engraulis encrasicolus and sardine Sardinops sagax in the Benguela current upwelling ecosystem Carl van der Lingen
(Coffee)
10:30-10:50 Density-dependent and density-independent strategies of space occupation by anchovy and sardine in the southern Benguela Manuel Barange

Humbolt Current

10:50-11:10 #Humbolt Current Lucho Cubicles

Yellow Sea

11:10-11:30 #Yellow Sea Wei Hao

Indian Ocean

11:30-11:50 An overview of sardine and anchovies fishery along the Indian coasts
Paratap Mohanty
(Lunch)

Continue (13:00-13:40)

13:00-13:20 #Indian Ocean Kawser Ahmed

Intercomparison

13:20-13:40 #Intercomparison Francisco Chavez

Reviews of NEMURO and NEMURO.FISH (13:40-15:40)

13:40-14:40 NEMURO overview: Michio Kishi
(20 minutes presentation + 40 minutes discussion)
14:40-15:40 NEMURO.FISH overview: Bernard Megrey
(20 minutes presentation + 40 minutes discussion)
(Coffee)

Reviews of sardine and anchovy modeling approaches (15:50-17:30)

15:50-16:10 Ecosystem change in the western north Pacific associated with global warming obtained by the 3-D NEMURO. Taketo Hashioka

16:10-16:30 Cross-comparing models: Evaluating the ecosystem effects of fishing, and testing the behaviour of indicators Yunne Shin

16:30-16:50 Bioenergetics-base modeling of climate effects on the population dynamics of Northern anchovy Kenneth Rose

16:50-17:10 Japanese sardine growth model using NEMURO.FISH Shin-ichi Ito

17:10-17:30 #Economic models Roehl Briones

Tuesday, November 15th

09:00-12:00 Discussion on the hypothesis of sardine and anchovy variability Cisco Werner

13:30-17:30 Brain storming discussion on How far do we need modify and extend the models to test the hypothesis Michio Kishi

17:30-18:00 Additional review of sardine and anchovy response to the climate variability

Oyashio/Kuroshio

Potential temperature-based mechanisms for anchovy and sardine see-sawing.

Akinori Takasuka

Wednesday, November 16th and Thursday, November 17th

Model coding and parameters setting working group

Wednesday, November 16th

08:30-11:30 Group discussion on modeling sardine and anchovy based on NEMURO families.

- group 1. Sardine and Anchovy growth model parameterization including life histories.
- group 2. Population dynamics modeling of sardine and anchovy especially including recruitments to close the life cycles.

11:30-12:00 Report from group discussion

13:30-16:30 Group discussion on modeling sardine and anchovy based on NEMURO families.

- group 1. Sardine and Anchovy growth comparison using a model driven by outputs from the NEMURO embedded in an OGCM
- group 2. Coupling the population dynamics modeling with sardine and anchovy growth model.

16:30-18:00 Report from group discussion

Thursday, November 17th

08:30-12:00 Discussion on building multi-species modeling.

13:30-17:00 Discussion on future plan

6.2 Participants list

Count	Funding Source	Name	Country	Discipline	Region
1	APN	Wei Hao	China	Physical Oceanography/Modeler	Yellow Sea
2	APN	Pavakar Mishva	India	Fisherer ies Oceanography	Indian Ocean
3	APN	Kawser Ahmed	Bangladesh	Fisherer ies Oceanography	Indian Ocean
4	APN	Rohelano Briones	Phillipines	Natural Resouce Economist	Asia
5	FRA	C Werner	USA, NC	Physical Oceanographer/Modeler	Calif Current
6	FRA	B Megrey	USA, Seattle	Fisheries/Ecosystem Modeling	Calif Current
7	FRA	K Rose	USA, LA	Ecosystem Modeling	Calif Current
8	FRA	L Jacobson	USA, Mass.	Fisheries Biology/Stock Assessment	Calif Current
9	FRA	Carl Van der Lingen	Cape Town, SA	Fisheries Biology/Stock Assessment	Benguela
10	FRA	Vera Agostini	USA, Seattle	Stock Assessment	Calif Current & Medit.
11	FRA	Yunne Shin	Montpielle, France	Fisheries/Ecosystem Modeling	Benguela
12	GLOBEC	Andres Uriarte	Spain	Anchovy/Sardine Stock Assesment	Bay of Biscay
13	GLOBEC	Manuel Barange	UK	surveys and assessment	Benguela
14	PICES	Salvador Luch-Cota	La Paz, Mexico	Fisheries Oceanography/Ecology	Calif Current
	PICES	**?**			
15	IAI	Lucho Cubillos	Chile	Stock assessment of sardines	Humbolt
16	IAI	Miguel Ñiquen	Peru	Fisheries Biology	Humbolt
17	own support	Fei Chai			
18	own support	Chai student			
19	own support	Francisco Chavez (?)	USA	Biological Oceanography	Calif Current Humboldt
20	Japanese	M. Kishi	Japan	Physical Oceanographer/Modeler	Oyashio/Kuroshio
21	Japanese	S. Ito	Japan	Fisheries Oceanography	Oyashio/Kuroshio
22	Japanese	Y. Yamanaka	Japan	Physical Oceanographer/Modeler	Oyashio/Kuroshio
23	Japanese	A Noguchi	Japan	Physical Oceanographer/Modeler	Oyashio/Kuroshio
24	Japanese	Akihiko Yatsu	Japan	Japanese Sardine/Anchovy Fisheries Biologist	Oyashio/Kuroshio
25	Japanese	Onizuka	Japan		Oyashio/Kuroshio
26	Japanese	Kishi-sans student	Japan		Oyashio/Kuroshio
27	Japanese	Yamanaka-san student	Japan		Oyashio/Kuroshio
28	Japanese	Takasuka		Jap sarsine and anchovy	Oyashio/Kuroshio
29	Japanese	Noto		Japanses sardine	Oyashio/Kuroshio
30	Japanese	Suda		operational model	Oyashio/Kuroshio