MoES - NOAA Technical Cooperation

Report of the workshop on

Development of Predictive Capabilities on Marine Fisheries and Harmful Algal Blooms in Indian Seas

Hyderabad, India
February 11-14, 2013

1. Background

India is the world's second most populous country and its coastal populations rely on fisheries for food. Sustainable fisheries management through science-based assessments is important for India's food security. Two phenomena are of particular concern: (1) the sardine fishery in the Arabian Sea is showing fluctuation in catches, for reasons not well understood; and (2) the increasing frequency and extent of harmful algal blooms (HABs) in the coastal and oceanic areas of the Indian Exclusive Economic Zone (EEZ) may be altering biogeochemical cycles and possibly enhancing the spread of the oxygen minimum zone. There is also interest in developing the capacity to produce operational products related to fishing zone advisories as well as in developing an understanding of the biology and dynamics of HABs with a view to developing species-specific models of HAB events.

The US National Oceanic and Atmospheric Administration (NOAA) and India's Ministry of Earth Sciences (MoES) have an active Memorandum of Understanding (MoU) for bilateral science cooperation. Although the MoU has mainly focused on climate and weather science, both countries are interested in expanding cooperation on living marine resource (LMR) and ecosystem science. The science of predicting fluctuations in the abundance and distribution of small pelagic fishes in upwelling systems, as well as the understanding and forecasting of HABs, are of interest to both MoES and NOAA. Both organizations have active research programs on small pelagic fishes and HABs, as well as similar eastern boundary current upwelling systems. For these reasons, increased collaboration would be beneficial.

2. Objectives and Goals

This workshop was designed as an initial step for scientists from INCOIS*, NMFS-NOAA, CMLRE, CMFRI, NIO and other institutions to provide briefings on each other's scientific and institutional expertise, and to discuss research opportunities. The main objective of the workshop

was to begin to explore the types of research needed for implementation of the following long term goals: (1) short-term prediction of sardine, mackerel and anchovies of the southeast Arabian Sea, and (2) a HAB monitoring and forecasting system for the Indian EEZ. To support these goals, another objective was to formulate detailed plans for a series of technical workshops to be held in 2013-2015.

*Glossary of acronyms is given in Appendix1.

3. Workshop Execution

The workshop on "Development of Predictive Capabilities on Marine Fisheries and Harmful Algal Blooms in Indian Seas" was organized by Indian National Centre for Ocean Information Services (INCOIS) at Hyderabad, India. The workshop began with the opening remarks by Dr. S.S.C. Shenoi, Director, INCOIS, Dr. Ned Cyr, NOAA and Dr. Usha Varanasi, University of Washington.

In his opening remarks, Dr. Shenoi noted that there are currently eight Implementing Arrangements (IA) between NOAA and MoES but none address marine living resources (MLRs). He remarked that 55% of the fishery yield comes from CPS fishes, that INCOIS is providing the fishery zone advisories, and that from this collaboration they are looking to improve the advisories. These advisories are provided to the fishermen so they know where it is more likely to find fish. Dr. Shenoi also noted that the west coast of India is not a typical eastern boundary system. It is influenced by drivers outside of the system; not just driven by the local winds.

Dr. Varanasi reviewed the history of the interactions between NMFS/NOAA and INCOIS, CMLRE and other MoES entities. NOAA is involved in partnership with MoES and has signed a MoU in 2008. There is a wide range of interests encompassed by the agreement. Meetings to establish collaborations between NMFS and MoES began in Jan 2009: Dr. Varanasi, who was then the director of NWFSC and a member of NOAA's team working with MoES, met with INCOIS to explore mutual interests in fisheries and HAB science and monitoring. In October 2009 Dr. Cyr attended the First Joint Executive Meeting between MoES and NOAA in New Delhi, India to explore broader collaboration on fisheries issues. In Dec 2010 Varanasi held talks with INCOIS about improving HAB forecasting. In 2012 with support from NMFS OST and enthusiastic participation of CMLRE and INCOIS, collaborative projects were proposed on Development of Predictive Capabilities on Marine Fisheries and Harmful Algal Blooms in Indian Seas. The MoU between MoES and NOAA supports the application of scientific information for constituents and

resource managers. Varanasi emphasized that agency science needs to focus on issues of relevance to living marine resouce management, and to provide information in a timely manner. Moreover, there is a need for integrated data management with an eye toward effective management of fisheries – for sustainable fisheries, healthy ecosystems, economic opportunities and human health implications. She noted the need for ecosystem based management and that the science must be highly credible and independent, but needs to work closely and in sync with management needs. To accomplish the broad goal, the proposed bilateral partnership must eventually grow and expand beyond CPS and HABs to establish a long-term program that includes other mutual research interests such as those (i.e., food-chain modeling and marine mammal surveys) described in the proposed Implementing agreement (IA) between NMFS/NOAA and MoES. There was discussion that good forecasting and prediction may lead to greater use of resources. Thus, it was recognized that there is also a need to make sure that proper resource management controls are in place.

The opening remarks were followed by introduction of the participants (List of Attendees is given in Appendix 2). Subsequently, Directors of Indian and U.S. agencies presented their institutional activities. This was followed by the technical presentations and one breakout session was conducted in parallel on HABs and Fisheries. The detailed agenda of the workshop is enclosed as Appendix 2.

4. Presentation Summary

4.1. Institutional Activities

4.1.1. Dr. S.S.C. Shenoi, INCOIS

INCOIS is an autonomous organization under MoES. The Director reports to, and is advised by a INCOIS Society Governing Council, Research Advisory Committee, and Finance Committee. Has an umbrella of 5-year plan to guide activities. INCOIS was established in 1999. Its mission is to provide ocean information and advisory services to society, industry, government and scientist community through observations and constantly improved through systematic and focused research. Further activities of INCOIS are organized under various groups such as modeling and ocean observation, advisory services and satellite oceanography, information services and ocean sciences, data and information management, computation and web, international training center for operational oceanography and executive support services. The advisories from INCOIS are disseminated in 10 languages spoken in the coastal areas of India. Further, the advisories are generated in a form that can be interpreted by the fishermen. Recently INCOIS has

started to provide advisories for tuna fisheries. In addition INCOIS has started to provide advisories on sea state, and validation is done using wave rider buoys; eight such buoys are deployed. Also, INCOIS operates a tsunami warning system, Argo floats, RAMA buoys in collaboration with NOAA's Pacific Marine Environmental Laboratory, with India supplying 60 days at sea annually on its research vessels to service the RAMA buoys. INCOIS produces an atlas of coastal variability – storm surges, tsunamis, etc. which developers can use to determine types of construction activities along the coast. Data are disseminated through a variety of methods – email, fax, SMS, radio, local papers, kiosks, etc., including fisher-friendly mobile apps.

India has an open access fishery with no regulations except a fishing ban during monsoon season. Most fisheries are below maximum sustainable yield (MSY). Monitoring and enforcement of regulations are very difficult. Most local fishermen are involved in low technology subsistence fishing; the larger vessels in the open-ocean are more of a concern.

4.1.2. Dr. V. N. Sanjeevan, CMLRE

CMLRE was established in 1989 and is part of MoES. CMLRE operates a research vessel, the *Sagar Sampada*, which has conducted 312 cruises and can berth up to 25 scientists. The vessel has made a couple of cruises to the Southern Ocean. The research vessel has a Simrad EK 60, as well as a CTD, ADCP, core sampler, bottom trawling capacity, plankton net, seven labs, and an integrated trawl system. Due to the long length of India's coastline, it is difficult to conduct routine/regular surveys at all locations. CMLRE has initiated an integrated taxonomic information system (IndOBIS) and a microbial oceanography program starting this year. CMLRE also conducts monitoring and modeling of marine ecosystems, including HABs. Deep sea research includes myctophid research: There is an estimate of high biomass of myctophids exceeding 100 million metric ton in the central Arabian Sea.

4.1.3. Dr. Ned Cyr, NMFS OST

Dr. Cyr provided a high level overview of NMFS and the role of science in the agency. Fisheries contribute US$79 billion and 1.5 million jobs to the U.S. economy. NMFS' budget is approximately US$900, of which US$400 million devoted to science. Sustainable fisheries are governed by Magnuson- Stevens Act, which stipulates that the U.S. cannot allow overfishing. The U.S. also has regulations to protect LMRs through the

Endangered Species Act (ESA) and the Marine Mammal Protection Act (MMPA). NMFS high priority science activities include living marine resource surveys, science to support ecosystem approaches to management, and advanced sampling technologies to improve survey capability and fishery-dependent data collection.

4.1.4. Dr. John Stein, NWFSC

The NWFSC has responsibility for the science to address endangered Pacific salmon, surveys for commercial groundfish species and identifying overfished species, and research to support recovery of southern resident killer whales. In the Pacific Northwest NMFS manages over 150,000 square miles of ocean and freshwater habitat when the range of Pacific salmon and marine fish are both included. The NWFSC conducts an acoustic trawl survey for hake on NOAA's Fishery Research Vessel and also includes physical oceanography, HAB sampling, and plankton sampling during this fishery-independent survey. In addition the Center conducts a groundfish bottom travel survey, which is done using contract fishing vessels. Dr. Stein highlighted the Center's science on seafood safety and responding to environmental emergencies as well as the research leading to the identification of a HAB 'window of opportunity', which is when environmental and oceanographic conditions increase the likelihood for a HAB event to occur.

4.1.5. Dr. Cisco Werner, SWFSC

Dr. Werner reviewed activities of the SWFSC's Divisions noting the environmental data serving and processing services of the Pacific Research Division as well as the coastal pelagic species (CPS)-relevant survey capabilities and advanced technology groups of the Fisheries Resources Division. He described the new Technology Test Tank in the La Jolla Laboratory (http://swfsc.noaa.gov/textblock.aspx?id=16022&ParentMenuId=630), and offered Indian colleagues access to the Tank. The test tank will support ecosystem-based fisheries management through new or innovative uses of technologies, including novel platforms for deploying optical and acoustic sensors, such as inexpensive instrumented buoys and small craft, remotely operated vehicles (ROV) and autonomous underwater vehicles (AUV), gliders, untethered profilers, drifters and floats. There were several questions on how the SW Center is using AUVs, the causes of the sardine fluctuations and degree to which fishing pressure versus environmental factors contributed to such a changes.

4.1.6. Dr. Sundarmoorthy, ICMAM

Monitoring locations around the Indian coast include 25 parameters and PAH analysis. The parameters being measured include water quality, metals, sediment, biological characteristics (chlorophyll-a, phaeophytin, phytoplankton, zooplankton), benthos, and microbiology. There is a moderate nitrogen increase in monitored coastal waters and pathogenic bacteria are high due to sewage. In addition, pesticide levels, and increases in nutrients and bacteria are of concern. Coastal health is classified as sectors: SWI – V. SW-I includes allowable shellfishing. ICMAM conducts lab bioassays according to USEPA protocols. They are also conducting oil spill modeling to determine trajectory of oil after a spill as well as the assessment of beach erosion and tsunami mapping.

4.1.7. Dr. A. C. Anil, NIO-Goa

The institute was formed in 1966 after a comprehensive series of cruises to characterize the ocean around and beyond India. NIO's mission is to improve understanding of the sea and translate knowledge to the benefit of all. Ocean Finder is a project that brings biological, physical and chemical oceanography together. Research is conducted to isolate, culture and identify phytoplankton species. Ballast-water transport of HABs and pathogenic organisms are studied. Mesocosm experiments have been conducted and additional mesocosm studies are being planned using multiple bags at each site.

Research is driven internally at NIO and not by a Division structure. One project is focused on the impact of deoxygenation (hypoxia), eutrophication and acidification on the marine ecosystem. NIO scientists are moving from expeditions to experimental mode for understanding how to forecast LMR status. One approach will be to pick an organism to understand the relationship between ocean conditions and populations dynamics.

NIO will be acquiring a new 80 m research vessel. NIO has collaborations with scientists in several countries, with the highest number of collaboration with USA scientists/agencies. HABs and bioinvasions (invasive species) are topics of special interest of the speaker.

4.1.8. Dr. Sunil Mohammed, CMFRI

Located in Cochin, CMFRI was started in 1947 with the independence of India, and conducts stock assessments, mariculture research, etc. There are 3 regional centers and 9

research centers in CMFRI. Fisheries as distributed across species are as follows: 4% mollusks, 10% crustacean, 20% demersal (benthic), 52% pelagic fisheries. Ecosystem modeling is using ECOPATH in three areas. He noted that clam beds have degraded over time. Mariculture is based mostly on shrimp and crab although there is some lobster culture. Mussel and oyster farming technology has been developed by CMFRI and transferred to industry. Early years' efforts by CMFRI helped to develop shrimp aquaculture as well as mussel and seaweed culture. Some work has also been carried out on pearl culture technology and culture of grouper and ornamental fish among other projects.

4.2. **Technical presentations**

4.2.1. Dr. V.N. Sanjeevan, CMLRE - forecasting sardine

Cruises over 10-15 years have identified 4-5 major different ecosystems. June-Sept is monsoon season (upwelling season) but in October the winds slacken (transition and deepening of mixed layer depth) and this is the most productive time of the year). He noted the need for a proper strategy for fishery survey transects. Some transect lines are 100km apart. There is no systematic (annual) data collection in each region. Proper data for development of models are needed and again this is linked to the design of a good survey plan.

CMLRE is working with physicists to describe the upwelling process on the west coast, which is driven by currents moving from south to north and then coupled with Rossby waves propagating offshore. Dr. Sanjeevan expressed some dissatisfaction with the structure of their icthyoplankton surveys, and feels that transects are too far apart and seems to be determined by the location of towns. Finally, he laid out a plan to get better abundance estimation for sardine.

4.2.2. Dr. T. Srinivasa Kumar, INCOIS - Operational Services

Their services are very dependent on utilizing satellite data. Fishing zone advisories are developed from SST, ocean colour (chlorophyll), and winds. Although this is a correlation-based advisory, it may be adequate since it is only an advisory. They have also developed a tuna advisory, which is a correlative product that correlates satellite parameters and tuna catch. Tunas are also being tagged to collect information on migrations and dive behavior.

On the NW coast, large *Noctiluca* blooms are found, a phenomenon that is correlated with low oxygen zones. There are interactions between the algal blooms and fishery yield, thus more focus is on ecosystem functioning than on seafood quality and human health/export.

INCOIS also has immediate plans to start a services for "Detection and Monitoring of HABs" in Indian waters

4.2.3. Dr. Anil Kumar Vijayam, CMLRE

CMLRE focuses mostly on biogeochemical aspects of nutrient cycling, distribution of other organisms, and climate change. There is no major focus on toxic HABs. A total of 2030 stations have been surveyed for microalgae – 86 bloom forming species, and 45 potentially toxic species. Fish mortality associated with *Cochlodinium polydrikoides*, *Karenia brevis*, *Karenia mikimotoi*, *Noctilica scintillans*, *Trichodesmium erythraeu*, and *Chattonella marina*. A green *Noctiluca* bloom in winter time and a red *Noctiluca* bloom during the summer have been linked to the monsoon.

CMLRE's open ocean monitoring program has been underway since 1998 and has identified 452 species - 83 species form blooms and about 45 are potentially toxic. Good data are available on species composition and distribution of algal species.

4.2.4. Dr. William Peterson, NWFSC

Dr. Peterson reviewed the NWFSC's ocean monitoring to project salmon recruitment. He highlighted the May, June, September sampling of juvenile salmon off the coast and bi-weekly sampling of hydrography and nutrients along the Newport (Oregon, USA) line. Dr. Peterson presented a food-chain approach to projecting fish recruitment/abundance. He recommended that at least a bottom-up driven hypothesis should be part of the set of hypotheses to be considered. Last couple of years the PDO has been very negative, but there was very weak upwelling, so it seems PDO and upwelling are becoming uncoupled, but the reasons are unclear.

Dr. Peterson also listed several questions that one would need to consider if his approach was to be adopted in the Arabian Sea, including: Where do the fish live – do they migrate between feeding and spawning areas? When and where do they spawn? How do the fish react to the two monsoons? Are the habitat parameters known? What is the relative

importance of continental shelf waters vs. more offshore oceanic waters? What are the generation times? What do they eat as larvae, juveniles and adults? Dr. Peterson noted that his approach has a spatial variability component (May/June/September cruises) and a temporal variability component (biweekly sampling of the Newport line), and that both are very important.

The NWFSC team also noted the potential value of taking a chemical ecology approach as well to understanding the distribution and inter-annual variability of condition and how that relates to ocean conditions. Dr. Shenoi noted that in India they do not see much variation in SST. Dr. Mohamed noted that the sardines are called oil sardines and inter-annual variation was looked at 50-60 years ago but has not been looked at recently.

4.2.5. Dr. Francisco Werner, SWFSC

Dr. Werner focused on predictive capabilities, including observations and modeling. His group at the SWFSC has developed a statistical model based on SST, Chlorophyll, and SSH based on current knowledge of distribution and habitat use. This model has only been tested for sardine in CA current and not yet for other CPS.

Another formulation was presented that included a climate-to-fish-to-fishers Earth System Model. It is suggested that it could be valuable to export the approach to west coast to India.

(Note: Dr. Enrique Curchitser, from Rutgers University, will be at INCOIS for one month in August 2013 and will lead a workshop on this topic.)

EBUS (Eastern Boundary Upwelling Systems) – coupled modeling research. Cisco presented an approach and preliminary results that could be applied to the EBUS on the west coast of India. A key component is the addition of the forcing of the local/regional scale on the larger climate scale. All are run as global models. Two-way coupling allows some explanation of processes such as teleconnections. Using Individual Based Models (IBMs), also known as agent-based models, one can simulate fishing fleets as particles.

4.2.6. Dr. Vera Trainer, NWFSC – Forecasting HABs in the U.S.

Dr. Trainer presented case studies of research to develop operational forecasts/outlooks for HABs in the U.S. from Florida to the Great Lakes to the Pacific Northwest of the U.S. (PNW). A main conclusion of the research is that remote sensing cannot be used universally to forecast HAB events. Ranges from good success with cyanobacteria, which develops blooms of high cell concentration, to the PNW where remote sensing is used to characterize

mesoscale features off the State of Washington's west coast; but in the PNW at the highest concentration of HABs, they only make up 10% of the total cell concentration.

4.2.7. Dr. Mark Wells, University of Maine – Shifting paradigms in "What is a HAB"

Dr. Wells presented a talk on general conceptual models of HABs based on light and nutrients, and used this approach in identifying key aspects of the workshop we are working to develop. In defining a HAB, it is a societal term and at one end of the spectrum there are high biomass events and at the other end there are the low biomass, toxic events, such as *Chattonella* or *Cochlodinium* blooms that can lead to very high mortality in fish net pens. Blooms of nutritionally inadequate species can lead to phytoplankton communities with inadequate supplies of essential compounds, such as essential fatty acids (EPA and DHA). Remote sensing is useful for high biomass events but so far of no use for the latter two events. Dr. Wells presented a conceptual model of low to high nutrients on one axis and stable to turbulent mixing on the other and 3 to 4 zones. The 4th zone is a void, no growth, due to low nutrients and high turbulence.

4.2.8. Dr. A.C. Anil - HABs in Indian waters

NIO has been conducting a cyst mapping survey as part of a National Ballast Water Program. They have cyst maps on both coasts, and have taken sediment cores down to about 120 cm. They have a good data set on species in coastal waters. Dr. Anil also noted that there have been 101 cases of HABs with 39 species responsible for bloom occurrence. Most blooms are naturally driven due to physical forcing, such as monsoonal influence, river discharge, and seasonal upwelling. Most blooms occur on the west coast of India. NIO is tasked with creating cyst maps along all the major ports of India. Ships of opportunity have been used to collect surface water samples and have measured daily variation in phytoplankton at Dona Paula Bay. Research has shown that cysts of 10 potential HAB species (*Alexandrium* spp.) have been found on the west coast. Cysts on the southeast coast of India were less abundant. Cyst sampling suggests that autotrophic cysts have been present (blooming) for some time (found at 60 cm depth). Core dating indicates that *C. polykrikoides* cysts have been blooming since 1926, and *Alexandrium* cysts have been blooming since the1980s.

4.2.9 Dr. Anil Kumar Vijayam, CMLRE - Overview of Indian Marine Fisheries

An overview was provided of fish species, vessel type, fishing type and fishery value. He noted that mechanized fishing is now predominant. Gross value of the fishery is $2.8 billion,

with a $1.6 billion export value. The oil sardine fishery is significant, as are fisheries for whitebaits and mackerel. Mechanized fishing (trawling) is the major type. Dramatic increases in fishing effort and decrease in catch rates are observed. Restrictions are documented but rarely enforced.

There has been a sudden influx of pufferfish with damage to nets. Pufferfish biomass increased very dramatically and appears to be due to a collapse of predators, such as catfish, cobia and sharks. CMFRI does fishing fleet and gear assessments every 10 years, and single species stock assessments. Oil sardine is an omnivore (feeds on phytoplankton and zooplankton). There are 5 major gear types and more than 25 craft/gear combinations. And there are more than 1000 species that are exploited. The Ministry of Agriculture (MoAg) within which CMFRI is located, is the lead agency. There is also a Fishery Survey Institute, and the MoAg works with maritime state agencies. Fishery regulation is divested to the states.

Territorial waters are based on a 12 mile territorial sea zone, but the states also have jurisdiction out to the end of the EEZ, a major difference compared to USA. The only fishery closure is for mechanized sector and is 45 days during the monsoon season. The traditional sector is the motorized sector.

India has 31 Marine Protected areas (MPAs) that represent about 6% of the coastal area. There is no real enforcement of fish size limits. There is an Indian Wildlife Protection Act of 1972. The Act does not work well to stop catch but is enforced at the level of trade. Sea cucumbers are at risk of overfishing but harvest is still occurring; the market is China.
There is a feeling that single species stock assessments are not adequate. He presented a chart towards the end of the talk that indicated that fishing effort was pretty high for oil sardine and mackerels. Highest density of oil sardine is seasonally off Cape Comorin and then larvae/juveniles move north. Anchovies also appear to spawn off the cape, and he noted that catch of anchovy is low due to a drop in market. Mackerels also appear to spawn off the cape, while oil sardine spawn north of the cape along the west coast. They do have studies of the relationship between ocean conditions and biomass for oil sardines.

5. Breakout Group Discussion Summary

Fisheries Group	HAB Group
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5.1. Fisheries Group

Much of the discussion of implementation of a fisheries survey and forecasting program centered around the necessity of establishing a regular systematic monitoring program. Relevant aspects of the CalCOFI and Newport ocean observation programs on the U.S. west coast could be adopted as plans are developed for surveys of small pelagic fishes along the west coast of India. In order to adopt an ecosystem approach, the fish surveys should be accompanied by hydrographic measurements (temperature, salinity and oxygen profiles), water column sampling of chlorophyll (size fractioned), zooplankton sampling (using the WP-2 standard was suggested – 0.57 m diameter mouth with 200 micron mesh) and krill and icthyoplankton sampling using a bongo net (60 cm mouth and 333 mesh). Lengthy discussions focused on the use of the CUFES (Continuous Underway Fish Egg Sampler) as a means of charting the distribution of eggs of small pelagic fishes, especially sardines. The use of high frequency acoustics as a means of estimating biomass of sardines was discussed. The participants learned that there was a plan by CMLRE to initiate monthly surveys, beginning in May 2013 and to aid in the sampling design, it was agreed that Indian scientists would consider adopting the sampling design presently used by U.S. Scientists on the west coast to survey sardine and hake stocks (referred to as the SaKe

program) in the California Current. It is clear that there is the potential to look at distribution of sardine eggs in the context of mesoscale oceanographic features through use of both underway SST measurements as well as through use of remotely-sensed satellite data (so long as clouds were not a problem). It was recognized by all that there would be value in establishing a research program that focuses on lipid content of key organisms within the food web through directed sampling of phytoplankton (use size fractionation into the < 2 and < 20 micrometer size fractions), zooplankton (either through bulk analysis of all copepods or through analysis of the dominant species) and the juvenile and adult sardines. Finally, it was agreed that an exchange of scientists would have great value to both Indian and U.S. scientists and the participants agreed to strive to reach this goal as soon as possible. Training of Indian scientists in the use of CUFES, high frequency acoustics and lipid analysis will be useful. The goal is to provide a prediction to fisherman on expected catch of sardines, mackerel and anchovies.

To do so, there is the need to get advice on appropriate survey design that could be implemented by CMLRE surveys as soon as possible. There are at least a couple of months to finalize because it is desired that the sampling start in April. The goal is to develop a systematic survey design that includes the key parameters to be measured. There exists a considerable amount of data to inform the survey design. While very useful, the existing surveys in India have not been conducted in a systematic manner. For example, for 3 years they have conducted aerial survey in conjunction with ships. Schools are up to 15 – 20 nautical miles offshore. There is also a common challenge of estimating fish in waters shallower than 30 meters. CMLRE will work on a sampling plan and NMFS will review and provide a list of critical parameters to measure.

India has not applied the Daily Egg Production Method (DEPM) to their stocks. To do so will require acoustic and at sea sampling, and then further analysis in the lab. Indian participants also inquired about purchasing the CUFES or providing them with the design. NMFS noted that one can keep this method less expensive by visually assessing egg numbers and subsampling for further analysis. Or, a flow-cam can be used for more automated egg enumeration. April to October is the anticipated time frame for surveys to sample monthly at stations spaced approximately 10 miles apart. The plan is to sampling out to 200 nmiles from shore, on a monthly basis. There appear to be 6–7 cohorts and the spawning moves north with time. In July there are no satellite images available due to high

cloud cover. There is a concern about Kelvin and Rossby waves and the influence on upwelling near Cape Cormorin.

Discussions revealed that there will be a summer school from 5 -14 August, 2013 at INCOIS on ecosystem modeling, conducted in conjunction with the International Centre for Theoretical Physics. There is a concern that there is both remote and local forcing affecting the habitat of coastal pelagic species and that getting a better understanding of the influence of oceanography on retention and advection of coastal pelagic species eggs is needed. Instructors are bringing the ROMS (Regional Ocean Models) and MOM (Molecular Ocean Models) models to this workshop. Thus, there may be an opportunity to use these models to inform sampling either in a forecast or hindcast mode. The model of how the ocean works off of South Africa looks to be very similar to the conditions off of India. Suggestion is to conduct the survey and use the biological data to inform the modeling work to be initiated this August. Thus, the goal is have the data as part of the upcoming workshop in August.

NMFS agreed to try to locate an extra CUFES to send to CMLRE. If not possible, NMFS will send specifications and contact from where CMLRE can purchase a CUFES. Discussion also followed that NMFS will assist in installation and training for CUFES. Discussion on lipid analysis generated interest and the need to get information on sampling and analysis methods. A proposal was made to exchange samples to initially characterize the kind of lipids in zooplankton (copepods) that would be food for sardine. This year consider collecting a few samples throughout the sampling period then use them for a scoping study of lipid profile/amount over time. Over 80% of plankton is copepods and data on size fractions is available, but there is a need to further classify the copepod to species.

5.2. **HAB Group**

The discussion in the HAB session centered initially on two known problems in Indian coastal waters, namely high biomass events that can lead to oxygen deprivation in subsurface waters, and toxic blooms that can cause direct human impacts through the consumption of seafood. The presentation on HABs in Indian waters set the stage for much of the discussion. In addition, the concept of nutritionally inadequate blooms was considered in terms of marine ecosystems in general and fisheries productivity in particular.

A portion of the time was devoted to considering what was known about the physical oceanographic conditions in Indian coastal waters, and the different sampling programs currently performed among the agencies. A consensus developed on the necessity of combining in-situ observational, satellite, and modeling data into a single database that would lead to better understanding and characterization of HAB outbreaks in Indian waters, and ultimately provide the foundation for forecasting these events.

Although high phytoplankton biomass events and the presence of toxin producing phytoplankton are both well recognized as HABs, there is much less awareness about the emerging understanding of HABs and the phytoplankton production of essential fatty acids that support productive ecosystems. This nutritional issue is of particular concern when dealing with large, mono-specific phytoplankton blooms because no one species of phytoplankton produces all the essential fatty acids in the required ratios. Extended mono-specific blooms can then end up generating nutrient deficiencies within the food web. The group discussed approaches for quantifying these potential impacts using the analysis of essential fatty acids in both phytoplankton and fish. What emerged from the breakout discussion is a list of key information and training goals that would help develop a cohesive plan for measuring the effects of HABs on the food supply and ecosystem health.

Discussion of what is a HAB:

1. High biomass events
    a. There are 10+ years of data now available on a variety of relevant in-situ and remote sensing data – look to integrate these using time series analysis.
    b. The workshop should include collaboration/training in time series analysis methods using a subset of these available data.
    c. Data types needed: Satellite, in-situ chlorophyll together with other data types to provide early warning of HAB events (satellite data, radiometry, CDOM, surface chlorophyll, water transparency, DO, winds, currents, nutrients (N, P, Si), weather models, fish landing data — will need to consider what the basal parameters are for modeling.
    d. Study sites (2000 stations from 1998-2012) – determine 3 focus areas as a demonstration sites for example – 1 NW, 1 central, 1 southwest. Start with one site if staff and resources are limited.
    e. Discussed the issue of restrictions on data exchange – will need to be covered.

f. Goal is to include potential regime shifts, entry of new phytoplankton species, increase frequency of certain (green *Noctiluca*) blooms, dynamics of bloom events (initiation, development, decline), and understanding key parameters triggering these stages

g. Will need to include transport models – entry of biological data into ROMS

2. Toxin production events

a. Focus on neurotoxins in phytoplankton (combined with sampling for time series) and shellfish (e.g., Paralytic Shellfish Poisoning) or fish (e.g., *Ciguatera* poisoning)

b. Training will be in the use of new, simplified ELISA (enzyme linked immunosorbent assay).

c. Focus on hands-on training for those actually responsible for running these analyses.

d. Include analysis of fish stomach content for biotoxin-domoic acid- analysis

3. Nutritionally inadequate bloom events

a. Where phytoplankton community composition (or community succession) leads to inadequate supplies of essential molecules (e.g., essential fatty acids EPA, DHA) in the food web.

b. measure composition and abundance of essential fatty acids (e.g. EPA, DHA), the lipid content of phytoplankton and fish to give an integrated measure of essential fatty acid supply.

6. Action Items / Recommendations

Tasks	Description	Responsibility	Time limit
HAB: Leads - Vera Trainer and Srinivas Kumar			
ROMS modeling	Simulation of physico-chemical process studies and subsequently Coupling of physical model with biological model	INCOIS (Srinivas), CMLRE, SWFSC (Cisco)	August 2013
Times series measurement	Initiate studies on plankton distribution abundance and Fishery data	MLR HAB working group, (led by CMLRE), SATCORE (INCOIS)	August 2013
Preparation of meta data	Collating in situ from possible sources	CMLRE (Anil Kumar), INCOIS (Aneesh)	April 2013
Integration of times series analysis training		Training to be held at Cochin and to be conducted by CMLRE (~ Jan2014).	~ Oct/Nov, 2013? Or combined with

		Training to be provided by NMFS.	fishery (NMFS preference Jan 2014)workshop
Toxin detection – ELISA test		MLR HAB group Anil Kumar, CMLRE)Jan2014	~ Oct/Nov, 2013? Or combined with fishery workshop
Fatty acid profiling workshop		NIO, Goa, NIOT, Chennai? NWFSC	Future plan (UV)
Field data collection		CMLRE-MLR Programme INCOIS-SATCORE programme	(Peterson and Trainer) to advise on taking of samples during CMLRE survey for lipid analysis
Fisheries: Leads- VN Sanjeevan, Cisco Werner, Bill Peterson			
US survey design for SaKe to be supplied to CMLRE	Adopt a similar plan to suit SEAS survey	NMFS/CMLRE	Documents provided at the initial Feb 2013 Workshop
Survey design for southwest coast of India developed	Coast (<30m) survey on hired boats and >30m onboard FORV SS.	CMLRE/CMFRI/NMFS	20th April, 2013
Participation of Indian scientists in US survey / online training		CMLRE, SWFSC	Mid June
Consolidation of available data and information		CMLRE/CMFRI, INCOIS	May 2013
Modeling of SW monsoon upwelling	Incorporating Ekman pumping and remote forcings.	CMLRE/INCOIS/NMFS	December, 2013
CUFES acquisition and training	During dry dock repair of FORV at Kochi	NMFS	April/May, 2013, Training-TBD
US survey design for SaKe to be supplied to CMLRE	Adopt a similar plan to suit SEAS survey	NMFS	Documents provided at the initial Feb 2013 Workshop
Survey design for southwest coast of India developed	Coast (<30m) survey on hired boats and >30m onboard FORV SS.	CMLRE/CMFRI/NMFS	20th April, 2013
Participation of		CMLRE, SWFSC	Mid June

Indian scientists in US survey / online training			
Consolidaton of available data and information		CMLRE/CMFRI, INCOIS	May 2013
Modelling of SW monsoon upwelling	Incorporating Ekman pumping and remote forcings.	CMLRE/INCOIS/NMFS	December, 2013
Monthly surveys - May-October 2013 including acoustics surveys	EK-60 Echosounder & SM90 SONAR onboard FORV	CMLRE/CMFRI	May, 2013
Daily Egg Production Model (DEPM) trials	Oil-sardine, Indian mackerel and anchovies of SEAS	CMLRE/CMFRI	November, 2013
STEP-SAM workshop		MoES/NOAA	January 2014?

Appendix 1

Glossary of Acronyms

Organizations:

NOAA - National Oceanic and Atmospheric Administration

NMFS - National Marine Fisheries Service (NOAA)

OST - Office of Science and Technology (NMFS/NOAA)

NWFSC - Northwest Fisheries Science Center (NMFS/NOAA)

SWFSC - Southwest Fisheries Science Center (NMFS/NOAA

MoES - Ministry of Earth Sciences

MoAg – Ministry of Agriculture

INCOIS - Indian National Center for Ocean Information Service (MoES)

CMLRE - Center for Marine Living Resources and Ecosystems (MoES)

ICMAM - Integrated Coastal and Marine Area Management (MoES)

NIOT - National Institute for Ocean Technology (MoES)

CMFRI - Central Marine Fisheries Research Institute (Minstryi of Agriculture, India)

NIO - National Institute of Oceanography (Council for Scientific and Industrial Research)

Other terms

MOU - Memorandum of Understanding

SATCORE - SATellite Coastal and Oceanographic REsearch

LMR - Living Marine Resources

EEZ - Exclusive Economic Zone

HAB - Harmful Algal Bloom

HABWOO – HAB Window of Opportunity

CUFES - Continuous Underway Fish Egg Sampler

DPEM – Daily Egg Production Method

ROM - Regional Ocean Model

EK-60 – SIMRAD echosounder

CTD - conductivity (salinity), temperature and depth (pressure)

ADCP - acoustic doppler current profiler

AUV - autonomous underwater vehicle

MSY - Maximum Sustainable Yield

PAH - Polynuclear Aromatic Hydrocarbon

EFA - Essential Fatty Acids

EPA - Eicosa pentaenoic acid

DHA - Docosa hexaenoic acid

PDO - Pacific Decadal Oscillation

CPS - Coastal Pelagic Species

Appendix 2: Workshop Agenda

Development of Predictive capabilities of Marine Fisheries and Harmful Algal Blooms in Indian Seas

Date: February 11 - 14, 2013

Venue: Indian National Centre for Ocean Information Services (INCOIS), Hyderabad

Earth System Sciences Organizations (ESSO), Ministry of Earth Sciences (MoES)

Sl.	Participants	Affiliation	Country
1	Dr. S. S. C. Shenoi (shenoi@incois.gov.in)	Indian National Centre for Ocean Information Services (INCOIS), Hyderabad	INDIA
2	Dr. T. Srinivasa Kumar (srinivas@incois.gov.in)		
3	Dr. Aneesh Lotliker (aneesh@incois.gov.in)		
4	Mr. M. Nagaraja Kumar (raja@incois.gov.in)		
5	Nimit Kumar, INCOIS (nimitkumar.j@incois.gov.in)		
6	Sourav Maity, INCOIS (souravm@incois.gov.in)		
7	Dr. V. N. Sanjeevan (sanjeevanmoes@gmail.com)	Centre for Marine Living Resources and Ecology (CMLRE), Kochi	
8	Dr. R. M. Dwivedi (rashmindwivedi@gmail.com)		
9	Dr. Anil Kumar Vijayan (anilkumarv@cmlre.gov.in)		
10	Dr. V. Kripa (vasantkripa@gmail.com)	Central Marine Fisheries Research Institute (CMFRI)	
11	Dr. Sunilkumar Mohamed (ksmohamed@vsnl.com)		
12	Dr. A. C. Anil (acanil@nio.org)	National Institute of Oceanography (NIO)	
13	Dr. Sundarmoorthy (sundar@icmam.gov.in)	Integrated Coastal and Marine Area Management (ICMAM)	

14	Dr. Ned Cyr NMFS/OST (ned.cyr@noaa.gov)	NMFS Office of Science and Technology	USA
15	Dr. Bill Peterson NWFSC (bill.peterson@noaa.gov)	Northwest Fisheries Science Center	
16	Dr. John E. Stein NWFSC (john.e.stein@noaa.gov)		
17	Dr. Vera L. Trainer NWFSC (vera.l.trainer@noaa.gov)		
18	Dr. Mark L. Wells (mlwells@maine.edu)	University of Maine	
19	Dr. Cisco Werner (cisco.werner@noaa.gov)	Southwest Fisheries Science Center	
20	Dr. Usha Varanasi (ushav@uw.edu)	University of Washington	

Time Table

Date	09:30 - 10:30	10:30 - 11:00	11:00 - 12:00 15 min each	12:00 - 13:00	13:00 - 14:30	14:30 - 15:30 30 min each 4 speakers	15:30 - 16:00	16:00 - 17:00
11 Feb	Welcome, Introductions, Opening Remarks, Status of IA & Work Plan and goals for this workshop (i.e., a report and specifics on the next steps?	Tea / Coffee break	Talks on activities at INCOIS, CMLRE, CMFRI, NIO, ICMAM NMFS/OST, NWFSC, SWFSC	Cont...	Lunch Break	Technical presentations by PIs (INCOIS, CMLRE and NMFS) about their research and briefly work proposed in the work plan Cont...	Tea / Coffee Break	Cont…
12 Feb	Parallel Sessions on Fisheries and HABs including presentations from Experts		Cont...	Cont...		Cont…		Visit to INCOIS
13 Feb	Presentations from HAB and Fisheries groups – determination of linkages between groups		Parallel Sessions on Fisheries and HABs: Design of workshops	Cont...		City Visit followed by Dinner		
14 Feb	Project presentation Working Group on Fisheries		Project presentation Working Group on HABs	Finalization of the Work Plan & Conclusion		Free time		

Detailed Agenda (draft 1/6/13)

11 February 2013

Welcome and Goals

9:30-9:40 Welcome (S.S.C. Shenoi)
9:40-9:50 Introductions (all participants)
9:50-10:30 Opening Remarks, Status of IA and workplan, Goals for this Workshop (Usha Varanasi)

10:30-11:00 Coffee, tea break

Talks by Directors regarding institutional activities

11:00 -11:15 INCOIS (S.S.C. Shenoi)
11:15 -11:30 CMLRE (V. N. Sanjeevan)
11:30 -11:45 NMFS/OST (Ned Cyr)
11:45 -12:00 NWFSC (John Stein)
12:00 -12:15 SWFSC (Cisco Werner)
12:15 -12:30 ICMAM (Representative)
12:30 -12:34 NIO (A. C. Anil, NIO)
12:45 -13:00 CMFRI (Representative)

13:00 – 14:30 Lunch Break

Technical presentations by PIs about their research and briefly work proposed in the workplan

14:30-15:00 Operational Services of INCOIS related to Fisheries & HABs (Srinivasa Kumar)
15:00-15:30 CMLRE (V. N. Sanjeevan)
16:00-16:30 Pacific Northwest HAB bulletin: a synthesis of research and monitoring (Vera Trainer)
16:30- 16:45 Outlooks and outcomes for fisheries: Part A (Cisco Werner)
16:45 -17:00 Outlooks and outcomes for fisheries: Part B (Bill Peterson)

12 February 2013

Parallel Sessions on Fisheries and HABs including presentations from Experts

HABs

09:30-10:00 Details on HABs in India (Dr. Ashok Kumar)
10:00-10:30 Strategies for monitoring HABs: Seafood safety assurance (Mark Wells)

10:30-11:00 Tea, coffee break

11:00-13:00 Workshop with discussion of key questions
Key Questions

1. Exactly what kinds of data are available on hydrography, nutrients and plankton for surveys. Are there data on primary production? Are there data on phytoplankton or zooplankton species? Is the frequency of data collection sufficient to resolve seasonal cycles of upwelling, hydrography, nutrients, and plankton species?
2. What is known about the extent and magnitude of HAB problems in Indian waters vs. what is not known?
3. What is the balance between the goals of protection of human health vs. fisheries yields?
4. What is the existing expertise and capacity for phytoplankton monitoring vs. toxin detection?
5. What are the main environmental pressures likely contributing to HABs, e.g., anthropogenic vs. natural sources of nutrients?
6. What is the primary source of these blooms, coastal vs. oceanic?
7. What are the existing monitoring programs, and are they shore-based monitoring vs. remote detection (moorings)?
8. Can we improve operational detection of Blooms using Remote Sensing & in-situ Data?
9. Have different bloom causing organisms in sea water been optically characterized to enable remote detection?
10. What is the status of bloom prediction? Are physical and/or biogeochemical models being used for understanding bloom initiation, growth, decay & transport?
11. How large blooms impact biogeochemistry of the seas?

12. What coastal regions are at greatest risk from HABs? What segments of the population are at greatest risk? Are there strong community-based organizations who might wish to be involved in HAB detection?
13. How are data related to harmful algal blooms and related environmental factors stored and integrated?

13:00 – 14:30 Lunch break

14:30-17:00
Continued discussion

<u>Fisheries</u>

09:30 -10:00 Opening remarks on Fisheries in India (Dr. K. Sunil Kumar Mohamed, CMFRI)

10:00 -1030 Strategies for monitoring fisheries. Werner (sardines and anchovies) and Peterson (Pacific salmon)

10:30 -11:00 Tea and coffee

11:00 -13:00 Discussion of key questions:

1. Exactly what kinds of data are available on hydrography, nutrients and plankton for surveys. Are there data on primary production? Are there data on phytoplankton or zooplankton species? Is the frequency of data collection sufficient to resolve seasonal cycles of upwelling, hydrography, nutrients, and plankton species?
2. Planning documents which were sent to us mentioned that sardines are found quite near the coast but that the *FORV Sagar Sampada* can only sample in waters deeper than 30 m. How much of the population lives in waters < 30 m in depth? Is it feasible to establish a nearshore sampling program along the SW coast for hydrography, phytoplankton and zooplankton at least during the May-October period, using small research vessels or fishing vessels?
3. Are the habitat parameters known for sardines, mackerels and anchovy, in terms of water mass characteristics, ocean color and plankton where these fish live? Do we know where these fish live year-round and do we know their migration patterns? Remote sensing data (SST, color, SSH) could be very useful here.
4. Do we know sardine diets during larval, juvenile and adult stages? It would be desirable to monitor those species that dominate the diets so understand better how food supply might control recruitment. The same question needs to be asked w.r.t. mackerels and anchovies.

5. Do we know if the fecundity of the small pelagics is affected by food concentration or other aspects of ocean conditions?
6. Planning documents mentioned the need for measurements of secondary production. How much work has been done to date to measure primary production?
7. How to begin to explore methods for forecasting. What parameters do we want to forecast: recruitment, growth, adult biomass, fishery yield? What can we do now with data available from buoys and satellites; what kinds of products must wait the collection of new data?
8. What is the potential for developing coupled physical-biological models that can be used in forecast mode?

14:30-17:00

Continued discussion

There was some discussion of the use of acoustics to estimate the biomass of sardines during the small pelagic fish surveys along the west coast of India, either through use of the Acoustic Doppler Current Profiler, or through use of a dedicated instrument such as a Simrad EK60. Both the Northwest and Southwest Science Centers have expertise in the use of this instrument and use of the backscatter signal in their surveys of the biomass of hake (whiting) and sardines. Discussion continued about the possibility of the SWFSC and NWFSC lending their expertise). There was further discussion of the potential to use the high frequency acoustics signals operating at 120 and 200 kHz to estimate the biomass of coastal pelagic fishes. Again, expertise resides in both the Northwest and Southwest Centers. Even though Peterson has an active sampling program for krill as part of his ocean observations program at Newport, that work is based on samples from Bongo nets, not high frequency acoustics. Considerable work on use of acoustics to estimate biomass of krill is being done in the California Current, thus methodologies exist as to how to do such surveys and how to process the data. Three key results are that they are very patchy, they usually most concentrated at the continental shelf break and that large numbers are often associated with submarine canyons; we hope to be able to add high frequency acoustics as part of the Ocean Observations Initiative(OOI) funded by the National Science Foundation that will be established off Newport in a few years from now. The OOI system will include many instruments such as current meters and CTD profilers moored along the Newport Hydrographic Line with each instrument attached to a fiber optics cable that has electrical power which will allow the transmission of all data in real time for many years.

13 February 2013

Parallel Sessions on Fisheries and HABs including presentations from Experts: Determine linkages between groups

09:30 - 10:00 Summary of previous day's findings: HAB Working Group
10:00 - 10:30 Summary of previous day's findings: Fisheries Working Group

10:30 – 11:00 Tea, coffee break

11:00 - 13:00 Detailed development of a workshop and strategy for collaboration

13:00 - 14:30 Lunch

14:30 Social Visit followed by Dinner

14 February 2013

Finalize Workplan

09:30 – 10:30 Project Presentation Fisheries Working group

10:30 – 11:00 Tea, coffee break

11:00 – 12:00 Project Presentation HAB Working group

12:00 - 12:30 Finalization of work plan and final questions.

12:30 - 13:00 Valedictory