PFRP

Pelagic Fisheries Research Program
university of hawai‘i at mānoa

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Western and Central Pacific Fisheries Commission Cuts More Bait

John Sibert

The third regular session of the Western and Central Pacific Fisheries Commission (WCPFC) was held 11–15 December 2006 in Apia, Samoa. Conservation and management of bigeye and yellowfin tuna featured prominently on the agenda.

The commission considered study results from its Scientific Committee (SC). The SC study clearly showed that 25% and 10% reductions in fishing mortality (from the 2001–2004 reference period), respectively, on bigeye and yellowfin tuna are required to eliminate overfishing and to maintain species populations at sizes capable of producing maximum sustainable yield.[1]

The commission also considered a paper prepared by the WCPFC Secretariat on the application of time-area closures to achieve the required mortality reduction. The commission decided to reject all time-areas closures. Instead, the WCPFC chose to extend the ineffective Conservation and Management Measures adopted in 2005.

The 2006 measures continue to impose catch limits and reporting requirements on small-scale fisheries but fail to reduce yellowfin and bigeye mortality or bycatch in the purse seine fishery. The 2001–2004 reference period continues to be the basis for regulation. Exemptions for WCPFC members who caught less than 2000 metric tons in 2004 also remain.

While this regular session made no advances in bigeye and yellowfin conservation, it did make some progress in other areas. Agreement was reached about the specifications of a Vessel Monitoring System to include: vessel reporting; automatic location communicator failure; cost recovery; and obligations and roles of fishing vessels, commission members, non-members, participating territories, the Pacific Islands Forum Fisheries Agency Secretariat, and the WCPFC Secretariat.

Additional agreements on the observer program, catch documentation, boarding and inspection, and vessel registry remain necessary. Should more rigorous conservation measures be enacted in the future, WCPFC will have need of these additional monitoring, control, and surveillance capabilities for enforcement.

[1] *PFRP Newsletter* 11 (4), October 2006

Tuna in a purse seiner's net (Photo courtesy of NOAA Photo Library).

The final report of the third regular session is currently under revision. When completed, the report will be posted on the WCPFC website http://www.wcpfc.int/.

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CONTENTS

CLIOTOP/PFRP Workshop: The Role of Squid in Pelagic Marine Ecosystems

Robert J. Olson and Jock W. Young

Squid play a central role in marine pelagic food webs by linking the massive biomass of the micronekton, particularly myctophid fishes, to many oceanic top predators, particularly tunas and billfishes (Figure 1). Characterized by short life spans and fast growth rates, squid may respond more readily to environmental change than perhaps any other mid-trophic-level organism in the open ocean.

The international research program Global Ocean Ecosystem Dynamics (GLOBEC, http://www.globec.org/) implemented, in 2004, a multi-regional program called Climate Impacts on Oceanic Top Predators (CLIOTOP[1]). As part of the broader CLIOTOP initiative aimed at "identifying the impact of both climatic variability and fishing on the structure and function of open ocean ecosystems," five working groups were established (see Maury and Lehodey 2005 for a full description).

Working Group 3, "Trophic Pathways in Open Ocean Ecosystems," developed a number of objectives to better understand the "trophic pathways that underlie the production of tunas and other oceanic top predators." As squid are the central link in many, if not most, pelagic ecosystems, a concerted research effort on squid is critical to advancing our understanding of what may be occurring in changing oceanographic conditions.

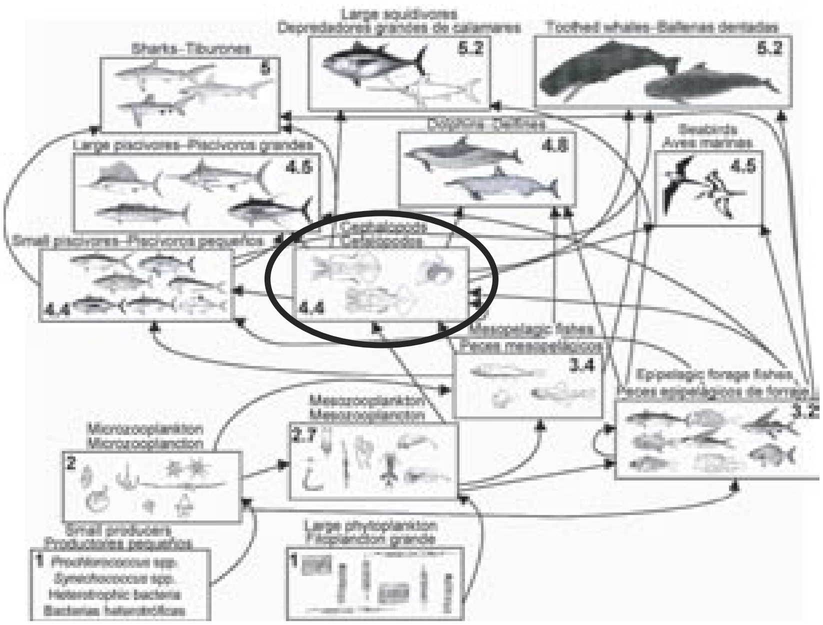


Figure 1. Simplified food-web diagram of the pelagic ecosystem in the tropical eastern Pacific Ocean, with cephalopods highlighted (after Olson and Watters 2003). The numbers inside the boxes indicate the approximate trophic level of each group.

Of all the components of the pelagic ecosystem leading to top predators such as the tunas, squid are perhaps the least understood. In part, this is because of their ability to largely avoid capture by conventional marine sampling techniques. Other factors, such as their complex taxonomy compounded by their relatively fast digestion in predator stomachs, have meant that detailed information on their role in many ocean ecosystems is lacking.

Nevertheless, new technologies, including those able to track squid movements (e.g., archival and satellite tags) and new biochemical techniques capable of identifying squid presence in the tissues of their predators (e.g., stable isotope and fatty acid analysis), are helping to resolve some of the questions surrounding squids.

With encouragement and sponsorship from CLIOTOP and the Pelagic Fisheries Research Program (PFRP), a workshop was held at the Hawai‘i Imin International Conference Center at Jefferson Hall of the East-West Center at the University of Hawai‘i immediately following the 2006 PFRP Principal Investigators' Meeting. This workshop brought together squid ecologists working in diverse ecosystems and oceanographic regions from the Pacific, Atlantic, and Indian Oceans. It aimed to summarize relevant information on key pelagic squid species—addressing how changing oceanographic conditions may affect squid's role as prey and, in some cases, as predator. Workshop topics included:

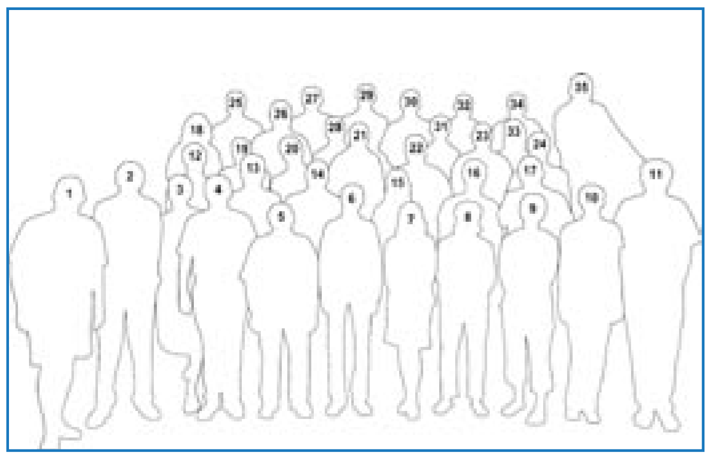
- consideration of the role of squid in pelagic ecosystems supporting tunas and other upper-level predators;
- consideration of how climate change might impact squid populations and the ecosystem;
- consideration of the recent range expansions of *Dosidicus gigas* in the Pacific Ocean, especially in terms of the effects of such expansions on the various Pacific ecosystems;
- identification of the research needs addressing pelagic squid required to meet the goals of GLOBEC-CLIOTOP and the identification of potential research proposals.

The workshop hosted twenty-one oral and five poster presentations by researchers from numerous countries including: Australia, Canada, Chile, France, Great Britain (including the Falkland Islands), Japan, Mexico, Portugal, and the USA (both east and west coasts) (Figure 2).

[1] In 2004, the international research program GLOBEC (Global Ocean Ecosystem Dynamics) (http://www.globec.org/) implemented a regional program called CLIOTOP (Climate Impacts on Oceanic Top Predators). CLIOTOP aims to identify, characterize, and model the key processes involved in the dynamics of oceanic pelagic ecosystems in a context of both climate variability and change and intensive fishing of top predators. The goal is to improve knowledge and to develop a reliable predictive capacity for single species and ecosystem dynamics at short-, medium-, and long-term scales.

Figure 2a. (left) Group photo of workshop participants. (Photo courtesy of Alexander Arkhipkin)

Figure 2b. (below) Workshop participants: 1, Frances Juanes; 2, George Jackson; 3, Rui Rosa; 4, Ron O'Dor; 5, Robert Olson; 6, Reka Domokos; 7, Susana Camarillo-Coop; 8, Brittany Graham; 9, Bridget Ferriss; 10, Inna Senina; 11, John Sibert; 12, Taro Ichii; 13, William Walsh; 14, William Boecklen; 15, Mary Hunsicker; 16, Anders Nielsen; 17, Felipe Galván-Magaña; 18, Heidi Dewar; 19, Richard Young; 20, Brian Popp; 21, Enzo Acuña; 22, César Salinas-Zavala; 23, Pierre Klieber; 24, Eric Hochberg; 25, Unai Markaida; 26, Enrique Morales-Bojórquez; 27, Patrick Lehodey; 28, Hugo Arancibia; 29, Jock Young; 30, Kenneth Baltz; 31, Molly Lutcavage; 32, Matthew Parry; 33, Valerie Allain; 34, Graham Pierce; 35, William Gilly. (not photographed: Yasunori Sakurai and Alexander Arkhipkin)



Theme Summaries

The workshop featured four main themes: biology and ecology, trophic links, climate impacts, and modeling. A final session, led by the moderators from each theme, reviewed the outcomes from each theme and highlighted potential future research. A detailed report on this workshop, including extended abstracts from each presenter and summaries of the discussions and conclusions, is being prepared by the conveners. The report will be published as part of the *GLOBEC Report* series later this year. Brief preliminary summaries of the workshop themes follow.

Biology and Ecology—The biology and ecology theme highlighted the unique life histories of oceanic squids. Many of the presentations concentrated on the jumbo or Humboldt squid, *Dosidicus gigas*, an ommastrephid species. In the eastern Pacific Ocean this species has undergone a massive biomass and range expansion in recent years. It is the target of the world's largest cephalopod fishery, yet relatively little is known of its natural behaviors.

Discussion centered on the potential reasons for the range expansion. Possibly in response to a warming trend in the Pacific Ocean, the apparent wide tolerance of this species to temperature variations, changes in the oxygen minimum layer and CO_2 concentration, its migratory capacity, and its generalist feeding habits have enabled this species to expand its range. Data was presented on the vertical and horizontal distribution of adults and the distribution of paralarvae, as well as on unique aspects of this squid's physiology, morphology, and reproductive biology. The importance of nektonic squid as biological pumps, transporting substantial amounts of resources between ecosystems, and the susceptibility of these processes to alteration by climate change was discussed.

Trophic Links—Pelagic squids function as both key prey and as key predators in ocean ecosystems. Cephalopod prey are important components of the diet of large pelagic fishes in the central North Atlantic, the eastern Pacific, and elsewhere (although data for the Indian Ocean were not presented at the workshop).

Squid are also voracious predators. The ecosystem effects of the range expansion of *D. gigas* were illustrated by predation data for commercially-important pelagic fishes in Chile and groundfishes in the California Current. Vertically-migrating myctophid fishes and a galatheid crustacean, *Pleuroncodes planipes*, dominate the diet of *D. gigas* in the Gulf of California and adjacent waters (Figure 3). Biochemical techniques such as fatty acid and stable isotope analyses have become popular for identifying squid in the diets of large fishes, such as swordfish, and for exploring their role in the ecosystem.

Climate Impacts—By the end of the next century global mean sea surface temperatures (SSTs) are expected to rise substantially.

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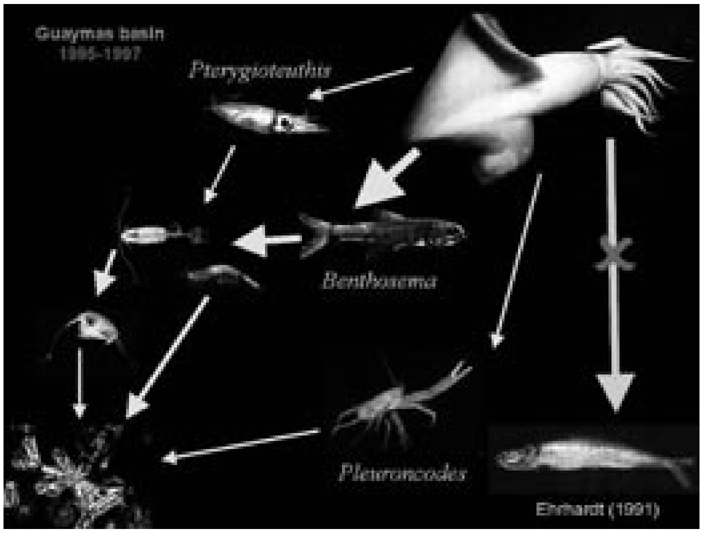

Figure 3. Food habits of jumbo squid *Dosidicus gigas* in the Guaymas basin of the Gulf of California, Mexico (Markaida and Sosa-Nishizaki 2003). Predation on fishery resources such as sardines, anchovies, and shrimp is very limited (note deleted path to sardines, largely postulated by Ehrhardt 1991). (Courtesy of Unai Markaida)

Climate change may impact ecosystems via complex effects on squid populations. Studies of loliginid squid have provided evidence that increasing temperatures could result in complex interacting effects on egg development time, hatchling size, growth rate, life span, feeding rate, survival, and movements.

Changes in physical parameters, such as wind stress, air temperature, SST, and mixed-layer depth, can explain trends in stock size and distribution of *Todarodes pacificus* in the western Pacific Ocean. The neon flying squid, *Ommastrephes bartramii*, was found to respond quickly to environmental and ecosystem changes caused by climate change and fishery effects. The responses of the neon flying squid to these changes may have affected ecologically-related species.

The El Niño-Southern Oscillation is thought to influence the abundance and population structure of *Dosidicus gigas* in the Gulf of California. Increasing CO_2 in the atmosphere and the resultant acidification of ocean waters can have sublethal effects on respiration physiology and reduce the scope for activity of *D. gigas*. This could affect the animals' ability to catch prey and escape predators.

Modeling—Not only are cephalopods important components of pelagic ecosystems, their economic importance, as evidenced by fisheries landings, has increased rapidly over the past thirty years. A modeling study of seventeen large marine ecosystems estimated that approximately 10 to 30% of the fishery landings and market values may pass through the cephalopod biomass pool.

Because generations are essentially non-overlapping, modeling of squid population dynamics (and coincident impacts on ecosystems) reduces to predicting recruitment success. Environmental signals are expected to have strong effects on spawning and hatching success and on growth and survival of early life stages. A review of approaches to modeling spatiotemporal patterns in squid life history, distribution, abundance, and fisheries and to identify relevant research questions in relation to *D. gigas* was presented. An Ecopath with Ecosim model for central Chile was used to estimate the potential impact of predation by *D. gigas* on pelagic and demersal fishes in that region. Increased predation by *D. gigas*, following from their greater abundance in Chile between 2000 and 2005, could have had a moderate-to-strong impact on hake. No similar impact was noted on either the common sardine or the anchovy.

Perspectives—There was informal consensus at the workshop that an international research effort was needed to better understand the jumbo squid and its role in structuring the pelagic and mesopelagic ecosystems within its range. An understanding of the reasons for rapid, massive, range expansions by cephalopods is lacking. The opportunity to study this phenomenon in *D. gigas* may lead to a better understanding of other oceanic ommastrephids, such as *Ommastrephes bartramii* and *Sthenotheuthis oualaniensis*, in the Pacific and other oceans.

The ability of these squid species to respond rapidly to variations in environments and to changing oceanographic conditions and their plasticity in biological parameters implies that pelagic cephalopods might serve as useful ecological indicators of ecosystem change.

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Papua New Guinea Tuna-Tagging Project

David G. Itano

Tuna landings from the western and central Pacific Ocean (WCPO) region in 2005 were estimated to exceed 2.14 million metric tons, representing a new record for fisheries that have seen their total catch of skipjack, yellowfin, albacore, and bigeye tuna hover at close to 2 million mt/yr since 2001 (Williams and Reid 2006).

Effort by the fishery sector utilizing live-bait for pole-and-line operations has decreased. At the same time total tuna landings have increased, driven primarily by increases in large-scale purse seine effort across the region. Purse seine vessels have become increasingly efficient through a combination of technological advances and accumulated experience. One significant factor in their increasing efficiency has been their increasing use of fish aggregation devices (FADs).

Addressing the Issues

To address these issues the Oceanic Fisheries Programme of the Secretariat of the Pacific Community (SPC), in collaboration with the National Fisheries Authority (NFA) of Papua New Guinea (PNG), is conducting a medium-scale tuna tagging and assessment project. The objectives of this project are to obtain information on:

- the medium and large-scale movements of tuna within and from the PNG exclusive economic zone (EEZ);
- the current exploitation rates of tuna within the PNG EEZ by all fisheries;

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UPCOMING EVENTS

The Challenge of Change: Managing for Sustainability of Oceanic Top Predator Species

GLOBEC-CLIOTOP Working Group 5 (Socioeconomic Aspects and Management Strategies), a National Science Foundation-Community Building Workshop

April 12–14, 2007; Marine Science Institute; University of California, Santa Barbara; Santa Barbara, California

Contact: Kathleen Miller <kathleen@ucar.edu>

58th Tuna Conference

May 21–24, 2007, Lake Arrowhead, California

Contacts: Daniel Margulies, Jeanne Wexler, and Maria Santiago
Inter-American Tropical Tuna Commission, 8604 La Jolla Shores Drive, La Jolla, California 92037-1508
Tel: 858.546.7120; Fax: 858.546.7133
http://www.tunaconference.org/

Scientific Committee, Western and Central Pacific Fisheries Commission, Third Regular Session

August 13–24, 2007, Honolulu, Hawai‘i

http://www.wcpfc.int/

Second International Symposium on Tagging and Tracking Marine Fish with Electronic Devices

October 8–11, 2007, Donostia-San Sebastian, Spain

http://unh.edu/taggingsymposium/

PFRP Principal Investigators Workshop

November 13–15, 2007, Honolulu, Hawai‘i

Contact: John Sibert <sibert@hawaii.edu>
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GLOBEC-CLIOTOP, 1st CLIOTOP Symposium

December 3–7, 2007, La Paz, Mexico

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https://www.confmanager.com/main.cfm?cid=722

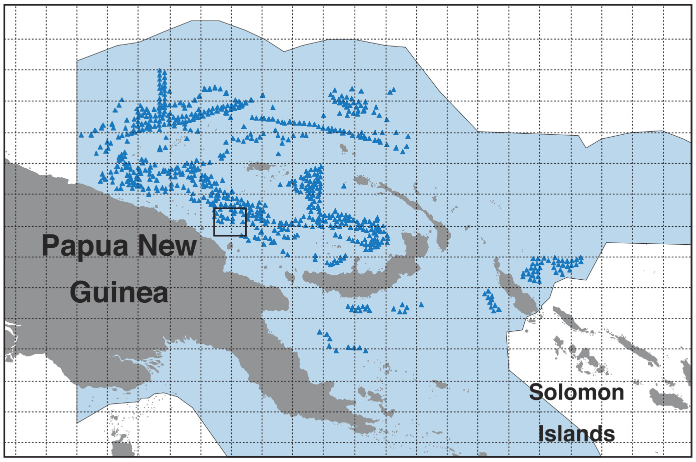

Figure 1. Some of the anchored FAD positions used to support purse seine operations in the Papua New Guinea EEZ (in shaded area) (Figure courtesy of SPC).

Figure 2. The *Soltai 6*, chartered to conduct tagging and research activities, seen circling an anchored FAD in PNG waters (Photo courtesy of D. Itano).

- the trophic status of tuna from free-swimming tuna schools and tuna found in association with FADs, natural floating objects, and seamounts;
- the variability and extent of bycatch from PNG purse seine fleets;
- the behavior and spatial dynamics of tunas associated with anchored FADs.

These objectives are being addressed through a short-term but intensive tagging effort that will produce data useful for regional stock assessments of the principal target species. The project is funded by domestic and international sources including the PNG NFA, the New Zealand Agency for International Development, the Australian Centre for International Agricultural Research, the European Commission, the Global Environment Facility, and the Pelagic Fisheries Research Program (PFRP). The PFRP contribution will assist in funding the project component related to the spatial dynamics and behavior of tuna associated with anchored FADs.

The study site is particularly suited to an examination of medium-scale movement and FAD-related issues as it is based within the archipelagic waters of PNG encompassing the highly productive Bismarck and Solomon Seas. These waters have been developed, primarily through the use of anchored FADs, for large-scale tuna harvesting by PNG domestic and domestically-based foreign purse seine fleets. Estimates of FAD numbers vary widely but close to 1000 anchored FADs are believed to be in use (Figure 1). A total of 1000 anchored FADs are permitted for deployment by PNG domestic fishing companies under conditions of the NFA National FAD Management Policy.

Tuna landings from the study site have increased rapidly and have remained above 100,000 mt/yr since 2003 (Kumoru and Koren 2006). Tuna landings by PNG domestic and licensed foreign purse seiners in the outer areas of the PNG EEZ have been close to 200,000 mt/yr during the same period. Obviously the impact of the FADs and FAD fishery, both domestically and on bordering areas, is a critical concern to the region and the Western and Central Pacific Fisheries Commission (WCPFC).

Project Objectives

The project objectives are being addressed by six months of vessel charter divided between two three-month tagging cruises in 2006–07. The SPC has chartered the pole-and-line vessel *Soltai 6* (Figure 2), owned and operated by Soltai Fishing and Processing, Ltd., a Solomon Islands-based company.

Unlike previous large-scale SPC tagging programs, the PNG project is using a combination of conventional, sonic, internal archival, and popup satellite transmitting tags to address different aspects of tuna movement and behavior. Tissue and stomach samples are also being taken from retained catch to support trophic studies on tuna condition in relation to FADs and seamounts and for comparisons with other regions.

Results

Concluding in November 2006, Cruise 1 was highly successful. It produced 22,430 conventional, 73 archival, and 47 sonic tag releases in total for all three tuna tropical tuna species: skipjack, yellowfin, and bigeye. The majority of tag releases were made on schools found associated with anchored FADs. The remainder of tag releases was divided between those schools found in association with drifting logs, seamounts, and current lines and unassociated (free-swimming) schools.

The species composition of conventional tag releases-62% skipjack, 35% yellowfin, and 3% bigeye-came very close to the project target release ratio of 60:30:10. Releases of bigeye fell short of the project target as this species proved difficult to capture in quantity with pole-and-line gear. However the overall tag release numbers were almost 50% above the 15,000 target level set for the first cruise. This success was largely generated by the use of an efficient vessel and an excellent working relationship between the SPC staff, their PNG-national counterparts onboard, and the hardworking Solomon Island crew.

Information on the vertical behavior of yellowfin and bigeye tuna is of great interest to the WCPFC, particularly as this behavior relates to FAD-related vulnerability to purse seine gear. This information is needed to refine habitat-based fishery models as well as to evaluate options to improve targeting of larger tuna while reducing the take of juvenile or undersize tuna by purse seine gear.

Figure 3. An acoustic receiver (arrow) suspended below an anchored FAD float (Photo courtesy of D. Itano).

The PFRP portion of the overall project funded the participation of University of Hawai'i-based researchers. These researchers will address issues related to the residence times, movement rates, and vertical behavior of tropical tuna in relation to large-scale anchored FAD arrays. In Hawai'i anchored FADs have been used as acoustic listening stations to monitor the movement and behavior patterns of tuna implanted with sonic transmitter tags (Dagorn et al. 2006). These techniques were successfully adapted during Cruise 1 of the project by attaching sonic receivers to PNG FAD floats. This allowed easy deployment and retrieval of the receivers (Figure 3), facilitating the downloading of sonic data. The medium-size bigeye and yellowfin suitable for sonic and archival tagging were captured primarily during night handline operations close the FADs.

Cruise 2 will begin in February 2007 and will initially concentrate on the Solomon Sea and eastern Bismarck Archipelago areas. Following on the good numbers of conventional tag releases already achieved, this second cruise will increase its focus on archival and sonic tagging and the collection of biological samples to support related trophic studies.

As all aspects of the project will continue to be carried out in a balanced manner, conventional tagging will still occupy the majority of daylight hours. However SPC and contracted personnel will be looking to place additional emphasis on increasing the numbers of bigeye tag releases. They will also continue to work at developing ever more efficient procedures to tag and release all three tuna species with conventional and electronic tags during normal pole-and-line operations.

Past and Future

Historically the SPC has conducted large-scale tuna tagging programs roughly every ten years as a means to assess stock size and exploitation rates in the WCPO region. These past projects defined movement and exploitation rates of WCPO tuna stocks before and during the rapid development of large-scale regional fisheries but prior to the widespread use of FADs. These findings will provide historical references significantly benefiting the analysis of the new data resulting from the current effort in PNG.

Additional funding support will be sought to allow a follow-on Phase 2 project in areas of the WCPO beyond PNG. This concept was strongly supported by the delegates attending the recent regular session of the WCPFC held in Apia, Samoa.

For further information or to report a recaptured tag please visit the SPC Oceanic Fisheries Programme tagging website at: http://www.spc.int/OceanFish/Html/TAG/index.htm.

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Erratum

Page 3 of the October–December 2006 *PFRP Newsletter,* 11 (4), contains a significant mistake in the second paragraph in the sentence addressing the relationship between current biomass and biomass at maximum sustainable yield (MSY). The correct statement is "Similarly, if B/B_{msy} is less than one the stock is in an overfished state." Thanks to an alert reader for pointing out the error.

Pelagic Fisheries Science in the Pacific, 2005 and Beyond—PIFSC and PFRP

Samuel G. Pooley

The following is based on a presentation at the September 2005 meeting of PFRP Principal Investigators. It remains relevant today.

It is timely to be taking a good look at what kinds of research will best benefit pelagic fisheries in the twenty-first century. Much of what we have accomplished regarding the study of pelagic fisheries over the past ten years has been the product of the close working relationship between the Pacific Islands Fisheries Science Center (PIFSC) of the U.S. National Oceanic and Atmospheric Administration (NOAA), the Pelagic Fisheries Research Program (PFRP), and the efforts of independent PFRP scientists.

Since 1992 PIFSC scientists have been Principal Investigators (PIs) or co-PIs on thirty-five PFRP projects covering a wide range of topics and disciplines. These projects have been critical to generating essential basic knowledge, helping to identify policy applications, building professional relationships, and supporting graduate students.

But where are we today? We face a number of big-picture changes affecting our research environment. While domestic events have significantly defined our past ten years, even larger international changes loom on the horizon. These include:

- Changes in national and commercial forces impacting Pacific tuna
- Over-fishing of albacore, bigeye, and yellowfin tunas
- Significance of protected-species interactions
- Institutionalization of science

Key Issues

Providing research-based scientific advice for today's international management of pelagic fisheries is without a doubt the key issue in developing sound conservation and management strategies. Scientists from PIFSC and PFRP are actively involved in stock assessment supporting Regional Fishery Management Organizations (RFMOs) including the Western and Central Pacific Fisheries Commission and the Inter-American Tropical Tuna Commission. This research also helps inform the work of scientific bodies such as the International Scientific Committee on Tuna and Tuna-like Species in the North Pacific Ocean (ISC).

We must also address how best to deal with the new international structures formalizing scientific advice. Many perceive these international structures as being more "institutionalized" than similar organizations affecting our domestic fishery management. Such an institutionalization of international science forces pelagic fisheries researchers to consider the strategic imperatives of their work along with their quest for basic scientific knowledge.

Adding to the challenges posed by this perceived institutionalization of international science, recent U.S. domestic legislation has raised serious issues regarding the participation of U.S. researchers in RFMOs and in our ability to collaborate with scientists from other countries and international bodies. Some of these issues include:

- U.S. domestic longline fishery closures
- U.S. shark-finning bans
- U.S. by-catch and fishing-capacity plans of action and similar plans of the Fisheries Department of the Food and Agriculture Organization of the United Nations
- U.S. quotas on the catch of bigeye tuna in waters east of 150° W longitude

These matters affect U.S. scientists by putting our research efforts into a highly politicized and, to a certain extent, competitive world view. And the international scientific enterprise is increasingly "institutionalized" by these RFMOs, offering fewer avenues for scientist-to-scientist collaboration and exchange.

The stakes remain high. The temporary closure of the Hawai'i swordfish fishery from 2000 to mid-2004 caused a loss of $22 million in ex-vessel revenue and a $55 million overall economic impact (based on Leung and Pooley 2002). The closure also had severe social impacts on Vietnamese-American and other fishermen, their families, and the entire fishing community (Allen et al. 2005).

The Hawai'i swordfish fishery reopened in mid-2004 under constraints (using transferable certificates) on the number of days fishing and a "hard cap" on the number of loggerhead and leatherback sea turtles permitted to be caught incidentally each year.

In 2005 the swordfish fishery operated throughout the year and $8 million worth of swordfish was landed without the fishery reaching predetermined limits on turtle interactions. However the 2006 swordfish season was truncated in March when the limit on turtle interactions was reached—with only $5 million (by preliminary estimates) worth of swordfish landed. Substantial logistical problems were caused for both the swordfish vessels and crews and the shore-side businesses handling their product.

Increasing Understanding

PFRP research can make contributions to these issues—everywhere from providing a better understanding of the pelagic environment affecting both swordfish and turtles to generating a better understanding of the motivations of fishermen.

Coincident with NOAA's increasing international responsibilities in the central Pacific, NOAA has been moving toward an ecosystem approach to fisheries management. While it remains a difficult concept operationally and it is being implemented in a difficult budgetary environment, NOAA is taking ecosystem science and research seriously. We have conducted ecosystem research for many years and we are increasing our efforts in both pelagic and insular marine environments.

NOAA's ecosystem goal is to "Protect, restore, and manage the use of coastal and ocean resources through an ecosystem approach to management." Successful outcomes in moving toward and meeting this goal include healthy and productive coastal and marine ecosystems benefiting society and a well-informed public attentively acting as steward of these ecosystems.

The list of research priorities is long and the challenge of turning research into timely, high-quality applications is daunting.

Ecosystem approaches to management of natural resource systems involve an increased focus on several strategic research components:

- Integrated monitoring systems
- Coordinated science
- Habitat characterization
- Food web, foraging, trophic dynamics, and movement
- By-catch and incidental catch
- Aquaculture
- Seafood safety

Pelagic Fishery Projects

Pelagic fishery science remains the largest single focus within PIFSC: twenty-five of the fifty-eight PIFSC research milestones involve pelagic subjects. All PIFSC research divisions, except the coral reef ecosystem division, are involved in pelagics research including:

- Stock assessments
- Fishery biology
- Ecosystems and oceanography
- By-catch mitigation
- Monitoring and data integration
- Socioeconomics
- Protected species

New PIFSC research efforts in pelagic studies, which may also prove beneficial to PFRP projects, include:

- Acoustics and other advanced technology
- Cetaceans
- Ecosystem indicators
- Short-turn-around applications and outreach

The Public Environment

Even as we discuss our science we must be alert to important changes in our public environment. These changes will continue to raise questions about how we as scientists and as scientific organizations relate to the public and the media. Questions which are not easily answered but which must be addressed include:

- Whether or how to respond to shifts in public and media perceptions?
- Do we need to apply new types of science or shift our methods?
- Do we need to monitor the public's choices and uses of marine resources more closely to better understand their perceptions, what they value, and why?

The Future

PFRP has been very successful in identifying and involving scientific talent from around the world and building collaborative relationships. But there is much more to be done.

Too many of our researchers spend too many hours coercing raw data into the forms required for analysis. While it is obviously *critical* for researchers to acquire and know their data, we need to pay more attention to generating greater efficiency in data management.

Looking forward we see ever more opportunities for international collaboration. The PICES (the North Pacific Marine Ecosystem Organization) and its Ecosystems Impact workshop with GLOBEC, which convened in Honolulu in April 2006, was one very fruitful example of such collaboration. As we move deeper into ecosystem research the need for greater coordination with other researchers will only increase.

In terms of identifying specific opportunities, I would include:

- Intellectual capacity building—Development of a U.H. School of Fisheries
- Improving efficiency, as noted above, of data accessibility to support researchers
- Linking to other organizations—e.g., PICES and ISC
- Cooperative research with industry
- Coordinated applications of science
- Increasing public outreach (including media)
- Securing long-term funding

PFRP is in excellent position to move ahead. We at PIFSC look forward to continuing our partnership and advancing our common goals.

PFRP

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Climatic Oscillations and Tuna Catch Rates in the Indian Ocean[1]

Frédéric Ménard, Francis Marsac, Edwige Bellier, and Bernard Cazelles

Introduction

Fish stocks are known to fluctuate extensively over a large range of spatial and temporal scales. Several ecological processes may induce such fluctuations. Climatic oscillations, anomalies, or changes clearly affect population dynamics in marine ecosystems. Variations in marine population abundance are very often associated with large-scale climate indices such as the North Atlantic Oscillation or the Southern Oscillation Index (Stenseth et al. 2004).

These global climate indices represent dominant climate patterns in the world's oceans and they can be good predictors of ecological processes (Hallett et al. 2004). Therefore, analyses of long-term time series are crucial to explore the association between climate variability and population fluctuations. Such studies can reveal a substantial amount of information on the temporal and spatial coherence between physical and biological properties and thus on the dynamics of the ecosystems with important fishery and ecological management implications.

Tunas are intensively exploited by industrial fisheries, using both surface (mainly purse seine) and deepwater (longline) gears. Here we studied the links between climate variability and tuna fisheries in the oceanic ecosystem of the equatorial Indian Ocean. We carried out wavelet analyses to quantify the pattern of variability in the time series and non-stationary associations between tuna and climatic signals.

The Time Series

We used two data sets (Figures 1 and 2) to identify patterns of variability in the fishery data and their links with climate oscillations: catch rates of bigeye *Thunnus obesus* (catch per unit of effort [CPUE] in number of fish/1000 hooks) from the Japanese longline fishery for the period 1955–2002 and catch rates of yellowfin *Thunnus albacares* (CPUE in mt/fishing day) from the industrial purse seine fishery for the period 1984–2003. Both time series were computed on a monthly basis within the boxes of Figure 1.

We used the Indian Oscillation Index (IOI, Marsac and Le Blanc 1998) as a proxy of climate variability in the Indian Ocean. The IOI is based on the variability in surface pressure anomalies between Mahe (Seychelles) and Darwin (Australia). Values < 1 indicate warm events (increase of sea surface temperature and strengthening of easterly winds in the equator). Values > 1 indicate cold events.

Wavelet Analysis

Wavelet analysis (Box 1) performs a time-frequency analysis of the signal, which permits the estimation of the spectral characteristics of the signal as a function of time and then the identification of different periodic components and their time evolution all along the time series. In other words, transient dynamics or gradual changes of the periodic components of the signal can be detected. Furthermore, cross-wavelets generalise these possibilities to the analyses of dependencies between two signals.

Box 1. Wavelets derive from a mother wavelet $\psi(t)$, expressed as a function of the time position τ and the scale of the wavelets a. A wavelet transform of a time series $x(t)$ is defined as a convolution product:

$$W_x(a,\tau) = \frac{1}{\sqrt{a}} \int_{-\infty}^{+\infty} x(t)\psi^*\left(\frac{t-\tau}{a}\right)dt$$

The wavelet power spectrum (*WPS*) estimates the distribution of variance between $f(f{\approx}1/a)$ and τ.

$$WPS_x(f,\tau) = |W_x(f,\tau)|^2$$

The global wavelet spectrum is computed as time-average of *WPS* for each frequency:

$$\overline{WPS}_x(f) = \frac{\sigma_x^2}{T}\int_0^T |W_x(f,\tau)|^2 d\tau$$

The wavelet cross spectrum *WCS* between $x(t)$ and $y(t)$ provides local information on the covariance at particular frequencies:

$$WCS_{x,y}(f,\tau) = W_x(f,\tau)W_y^*(f,\tau)$$

To quantify the statistical significance of the patterns we performed a resampling method based on a Markov process (Cazelles and Stones 2003).

Results and Discussion

Our results (Figures 3 and 4) indicated that tuna catch rates and IOI climate index were closely associated to each other and that these associations appeared transient in time. First, periodic modes of 4- and 5-year duration were found in tuna and IOI series. Second, we identified time intervals, from 1970 to 1990 for bigeye and from 1984 to 1991 and then from 1993 to 2001 for yellowfin, when tuna and IOI time series co-varied at 4- and 5-year modes. Third, oscillating components demonstrated that the link between IOI and bigeye catch rates in the 1970–1990 time interval was constantly out of phase. For yellowfin the difference in synchrony evidenced by the oscillating components revealed more complex dynamics of the association between tuna and IOI series: a two-step change with an out-of-phase relation before 1991, and an in-phase relation after 1995, especially during the 1997–1998 time period, which corresponded to one of the strongest warm events occurring in the Indian Ocean during the last decades.

The equatorial area of the Indian Ocean is known to exhibit a clear response to the El Niño-Southern Oscillation (ENSO). White

[1] "Climatic Oscillations and Tuna Catch Rates in the Indian Ocean" is adapted from an article that originally appeared in *Fisheries Oceanography,* 16 (1): 95–104, 2007.

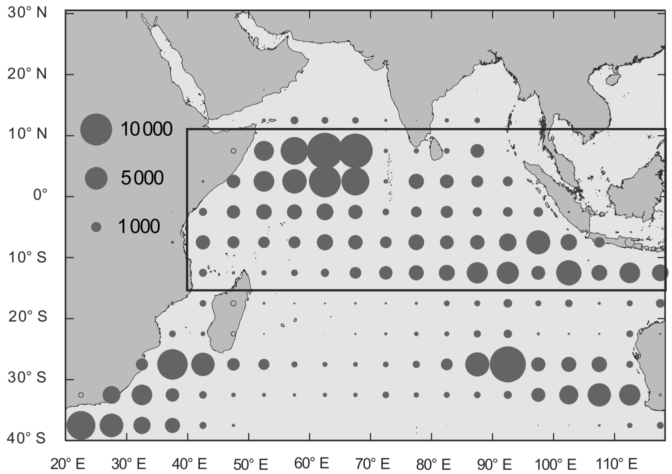

Figure 1a. Bigeye catch in numbers by 5° square (average 1970–2002).

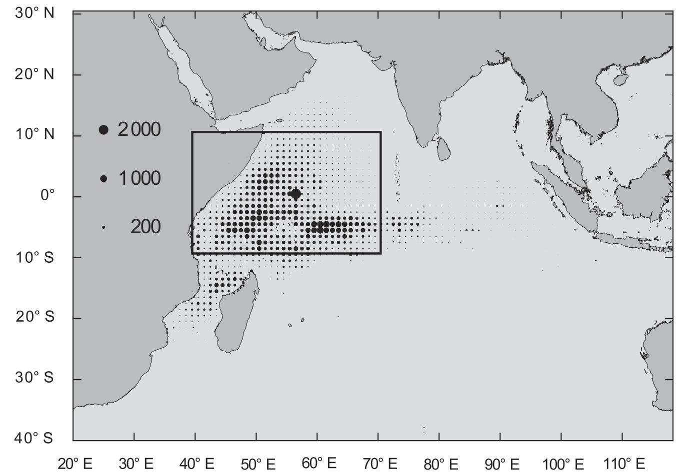

Figure 1b. Yellowfin catch in weight by 1° square (average 1984–2003).

and Cayan (2000) showed that this area is the favorable place of the ENSO signal propagation with periods from 3 to 5 years, i.e. the periodic band revealed by the wavelet analyses. Climate variability can affect species distribution in space and time, resource accessibility to fishing gears, and species abundance through biological processes such as recruitment, growth, and mortality.

The synchronies between IOI and tuna catch rates (out-of-phase or in-phase relations) argued for a non-lagged effect of the warm events on the catchability of tuna rather than for complex changes in the production regime that could affect the survival of tuna larvae in the different spawning grounds. We thus support the catchability hypothesis for explaining the changes in tuna catch rates.

An increase of longline CPUEs of bigeye matched the warm events characterized by low IOI values in 1972–73, 1977–78, and 1982–83. Warm episodes induced a decrease in the overall production of surface layers, which may extend to tuna forage production. Indeed, when prey are scarce, tuna are not satiated and more readily bite at the longline baits, increasing their catchability (Bertrand et al. 2002).

The warm events affected the purse seine catchability in a more complex way. During the early stages of warm episodes, the thermocline (i.e., the depth of the mixed layer) deepens in the west. The extension of these temperature anomalies is variable in time and space, does not always occur with the same amplitude, and generates complex local effects. As long as Indian Ocean warm episodes remained moderate, such as in 1987–88, 1991–92, and 1994–95, yellowfin habitat (which is the surface layer) was not strongly affected by temperature anomalies.

We propose the following hypothesis to interpret the out-of-phase relation between IOI and yellowfin signals before 1991: a decrease in the food availability due to warm episodes may intensify the schooling behavior of yellowfin for maximizing prey search

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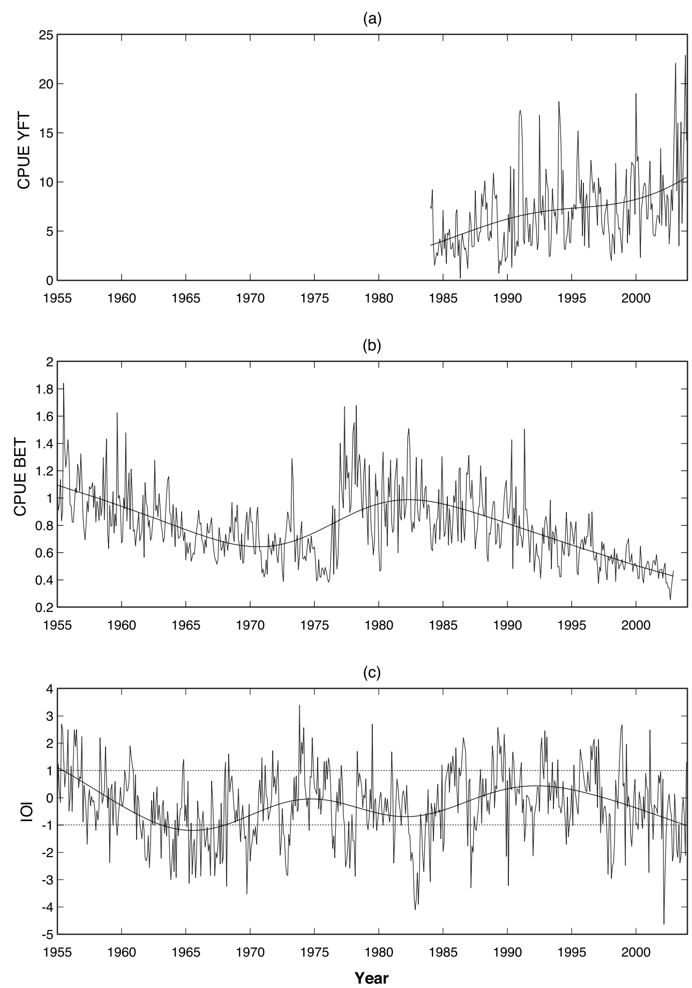

Figure 2. Monthly time series. (a) CPUE of yellowfin tuna. (b) CPUE of bigeye tuna. (c) Indian Oscillation Index. The black lines represent the trend of the series.

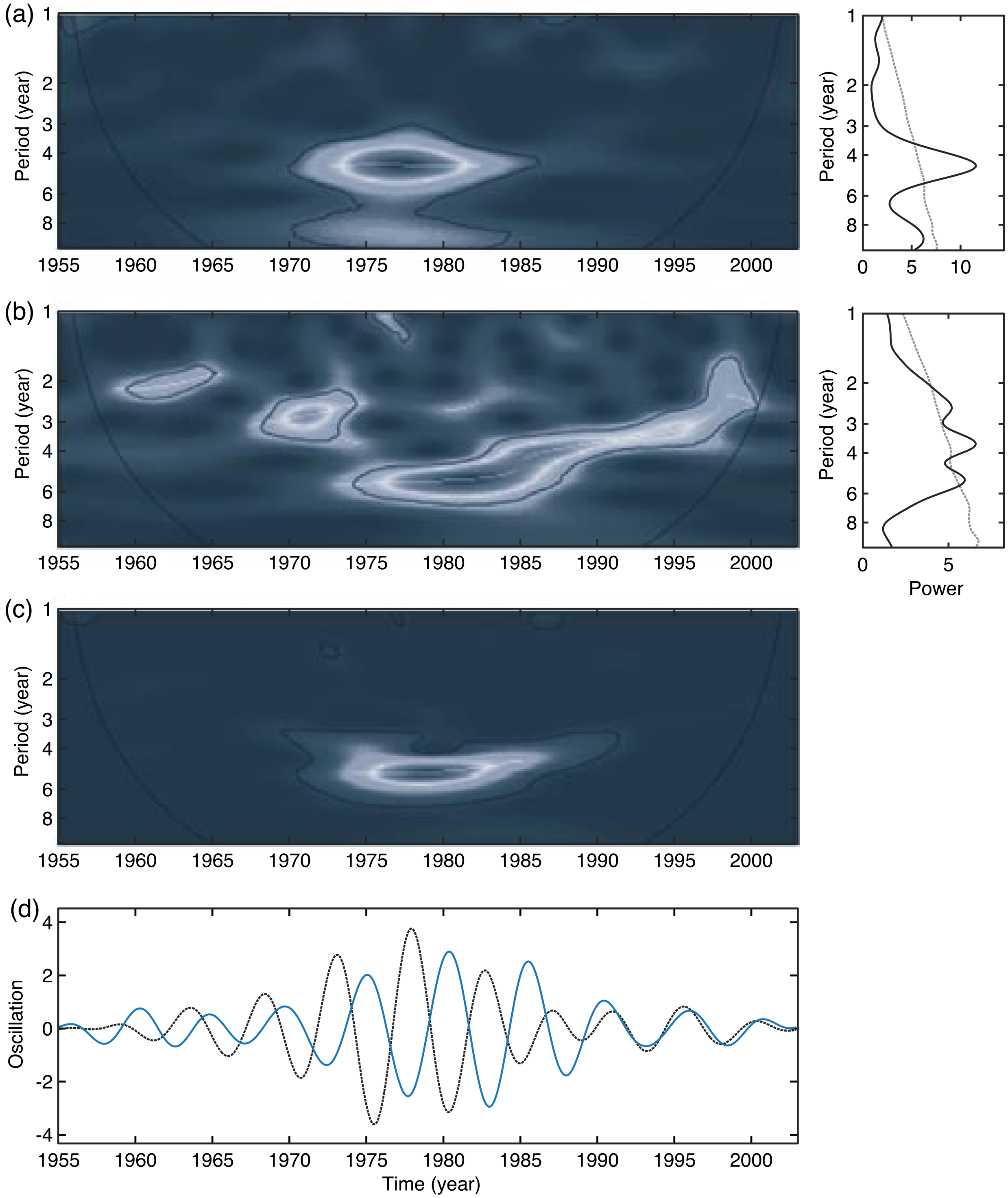

Figure 3. Wavelet analysis of bigeye CPUE and IOI series. (a) Left: wavelet power spectrum (WPS) of the tuna series. It gives a measure of the variance distribution according to time and for each period. Low power values in light blue and high values in darker blue. White lines indicate oscillation crests. Black lines show the cone of influence, the region where edge effects are present (below the cone, values should be interpreted cautiously, Torrence and Campo 1998). Black dashed lines show the 5% significance level based on 500 bootstrapped series. (a) Right: Global WPS of the tuna series as a function of period. (b) Left: WPS of the IOI series. (b) Right: Global WPS of the IOI series. (c): wavelet cross spectrum (WCS) between bigeye and IOI series. It identifies period bands and time intervals within which the two series co-vary. (d): Oscillating components (arbitrary units) for bigeye (black line) and IOI (blue line) computed with the wavelet transform in the 5-year period band.

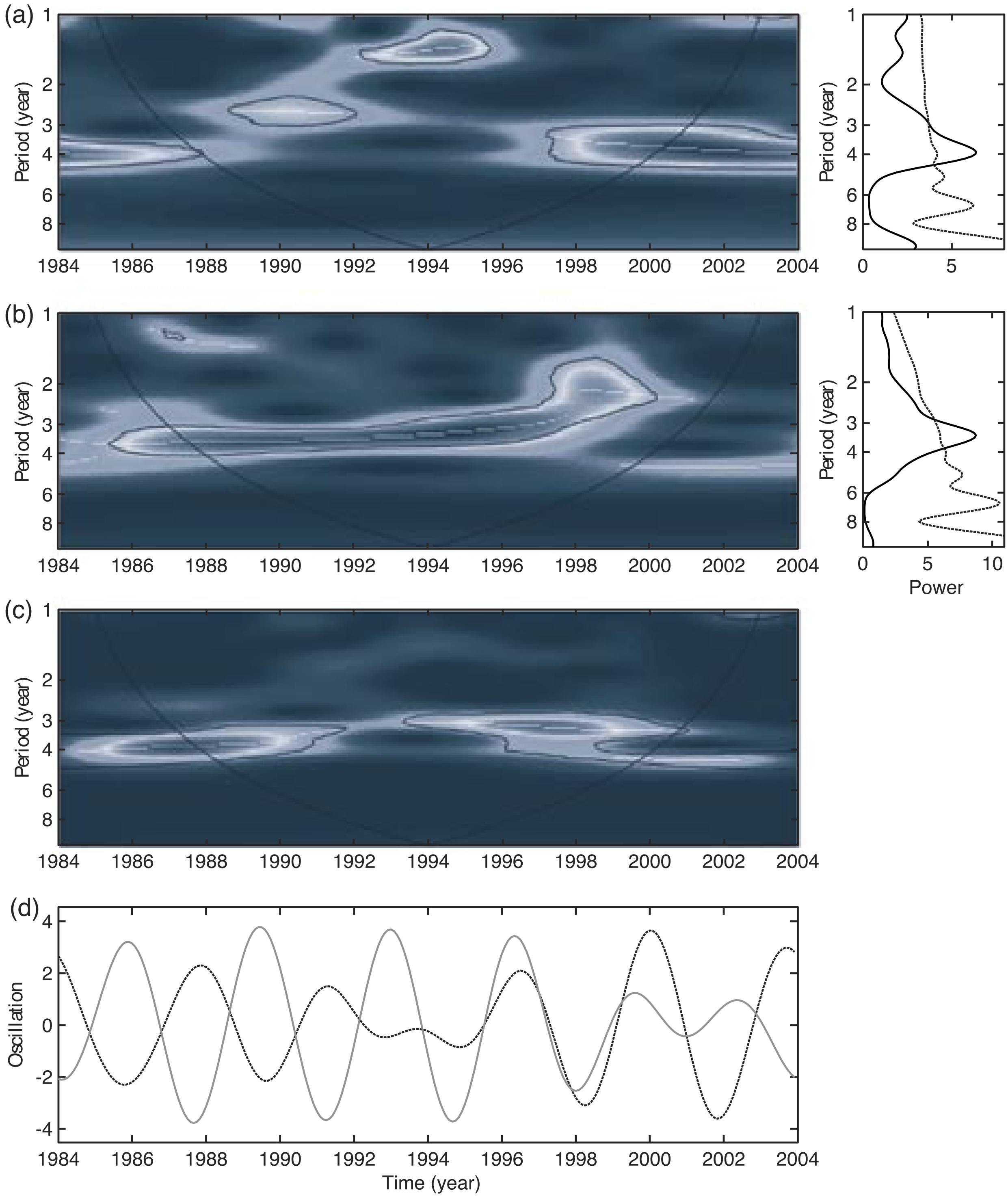

Figure 4. Wavelet analysis of yellowfin CPUE and IOI series. All values and symbols are as in Figure 3. (a) Left: WPS of the tuna series. (a) Right: Global WPS of the tuna series as a function of period. (b) Left: WPS of the IOI series. (b) Right: Global WPS of the IOI series. (c): WCS between yellowfin and IOI series. (d): Oscillating components (arbitrary units) for yellowfin (black line) and IOI (gray line) computed with the wavelet transform in the 4-year period band.

(continued on page 14)

Climatic Oscillations (continued from page 13)

(Pitcher and Parrish 1993) and therefore may increase their vulnerability to purse seine gear. In the case of the very strong warm event of 1997–98, the thermocline deepened dramatically in the west, the traditional purse seine fishery zone, and became shallower in the east. Therefore there may have been a deeper vertical distribution of tunas due to the warm surface temperature, and yellowfin became much less vulnerable to the purse seine in the west and more vulnerable in the east (in Figure 1b: the significant purse seine catch in the east occurred during the 1997 warm episode only).

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Mapping the Seasonal Distribution of Bluefin Tuna in the Gulf of Maine and the Gulf Stream Area Using Pop-up Satellite Tags

Francois Royer and Molly Lutcavage

Introduction

Atlantic bluefin tuna (*Thunnus thynnus*) are currently undergoing heavy exploitation by over twenty-one national fisheries. While the exact status and structure of the stock of this species remain uncertain, many indicators point to strongly depleted biomasses (Fromentin and Powers 2005). Research-based scientific advice has been to significantly reduce catches in order to rebuild the population. However, complicating the current bluefin management crisis, there are signs of considerable variability in regional distributions, migration patterns, condition factors, and landing statistics (Sibert et al. 2006, Golet et al. in press).

New insights from ecological research now allow us to formulate several hypotheses to explain how fishing pressure and environmental variability interact for bluefin tuna. This allows us to re-examine tagging data to refine and re-sort these data. New methods have been developed to filter, standardize, and combine complex datasets (Sibert et al. 2003, Nielsen et al. 2005). These new tools provide a more detailed description of bluefin tuna migratory patterns and their timelines. This provides more insight into probable causes for the observed spatial and ecological shifts.

We apply here a state-space filter to geolocation data generated by Pop-up Satellite Archival Tags (PSATs) deployed in the Gulf of Maine in summer and fall of 2002 and 2003. An improved dataset has been built using bathymetry and sea surface temperature (SST) data as constraints. This allows us to better depict the seasonal distribution and movements of spawning-size bluefin tuna in the Gulf of Maine and the Gulf Stream areas.

Tagging Data

One hundred thirty-five PSATs of the same model (PTT-100, Microwave Telemetry, Inc., Columbia, MD 21045, USA) were deployed over two consecutive years in the Gulf of Maine. Both the commercial purse seine fishing boat *White Dove Too* and the sport fishing vessel *Cookie Too* were used for tagging operations. When possible, individuals from the same school were tagged (Wilson et al. 2005). Sixty-eight and sixty-seven tags were deployed in 2002 and 2003, respectively, between early June and early October. Deployment and reporting positions are shown in Figure 1.

Estimated sunset and sunrise times and a compressed series of pressure and temperature values were transmitted, after pop-off, by the PSATs to the Argos instruments aboard National Oceanic and Atmospheric Administration Polar-orbiting Operational Environmental Satellites.

Hourly depth data are originally coded into 5.38 meter bins, while hourly temperature measurements have a resolution of ± 0.07°C. Daily light-based positions were computed by Microwave Telemetry. Temperature and depth records were screened to remove

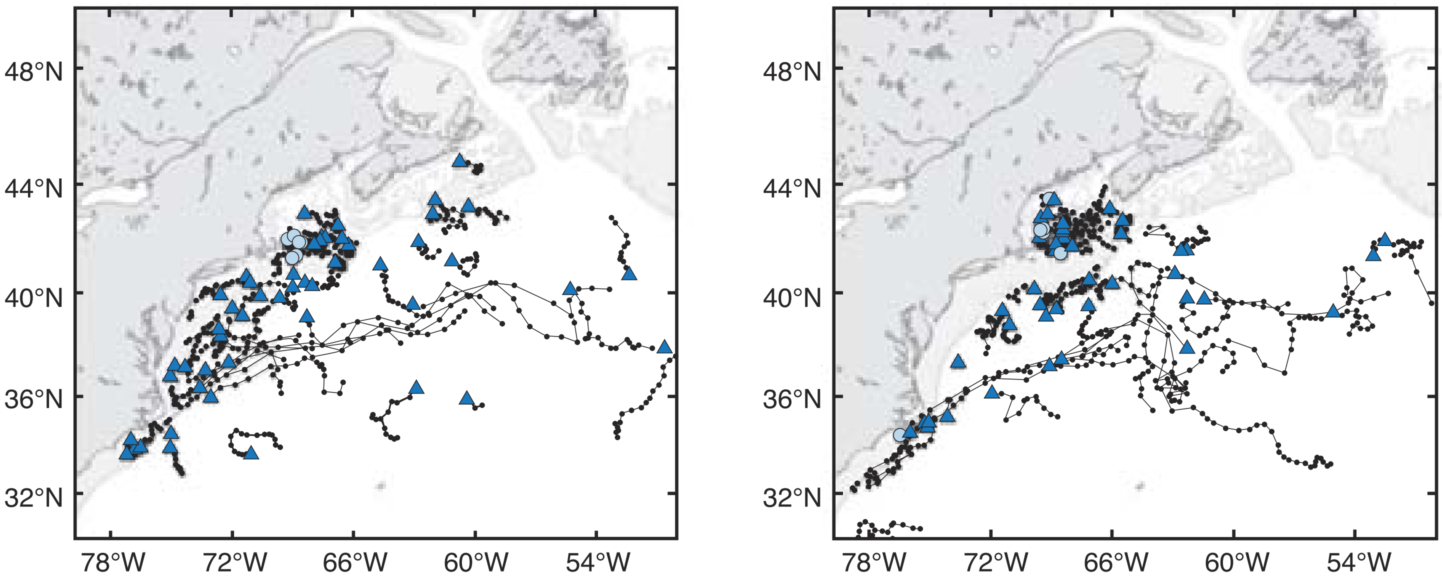

Figure 1. a) Tagging (circles) and pop-off (triangles) positions for the 2002 bluefin tuna releases b) 2003 releases. The black trajectories identify the drifting/transmission phase of each tag.

possible compression artifacts (i.e., to locate and discard the maximum detectable changes in depth, +86.07 and -80.69 m.h^{-1}, Howey, pers. comm.).

Filtering Method

We used an Ensemble Kalman Filter (EnKF, Evensen 2003) to filter the light-based geolocations: the state of each fish at a given time being its position (distance from a reference time, Sibert et al. 2003) and a measure of the daily SST (The maximum value of ambient temperature shown in the surface-to-5m depth layer was used as a proxy for true SST.).

During the prediction step of the EnKF (Figure 2) an estimate of the local bathymetry would be constructed and re-sampled according to the maximum depth of the fish. Using these updated samples the spatial covariance of SST was estimated from remote-sensing fields (here 8-day composites of Advanced Very High Resolution Radiometer SSTs with a 9-km ground resolution). The corresponding ensemble mean and covariance were then inserted into the classic Kalman equations to give a filtered estimate (Sibert et al. 2003).

The final estimate was given by running a second filter backwards instead of using a fixed-lag smoother. This prevented the use of outdated covariance matrices in the case of data gaps. A position was predicted or updated each day, thus giving comparable trajectories with their associated uncertainty. A simple random walk with no movement bias was assumed. As a seasonal (north-south) migration was expected, this may not support a unique value for the movement bias.

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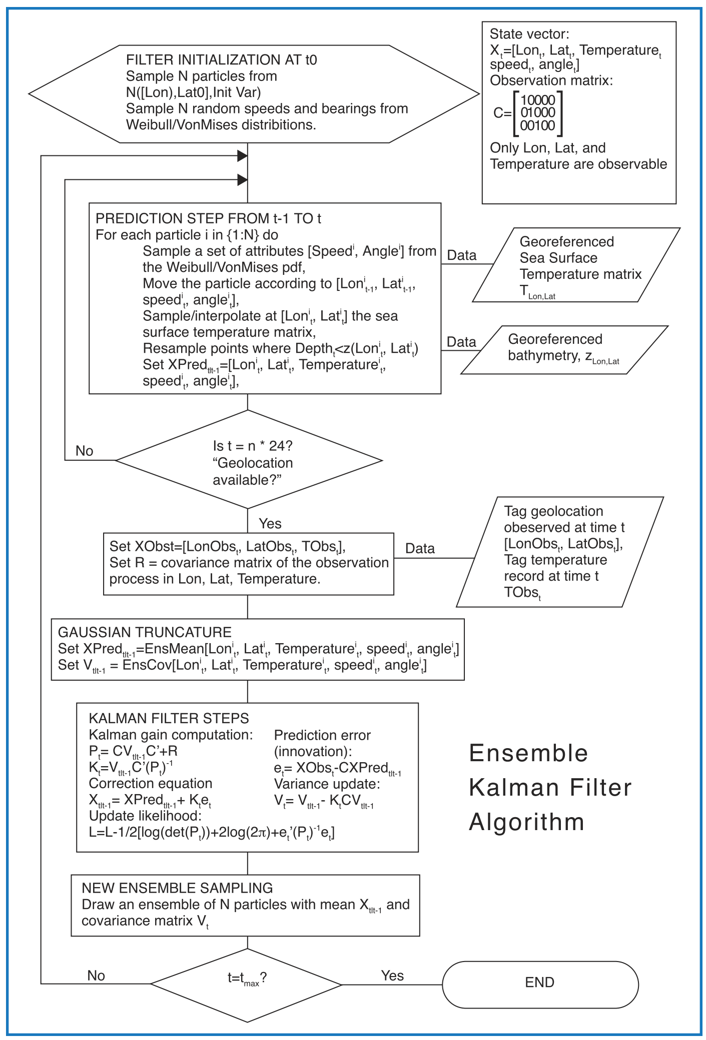

(right) Figure 2. Algorithm chart for an Ensemble Kalman Filter assimilating geographical position and SST with bathymetry as a constraint.

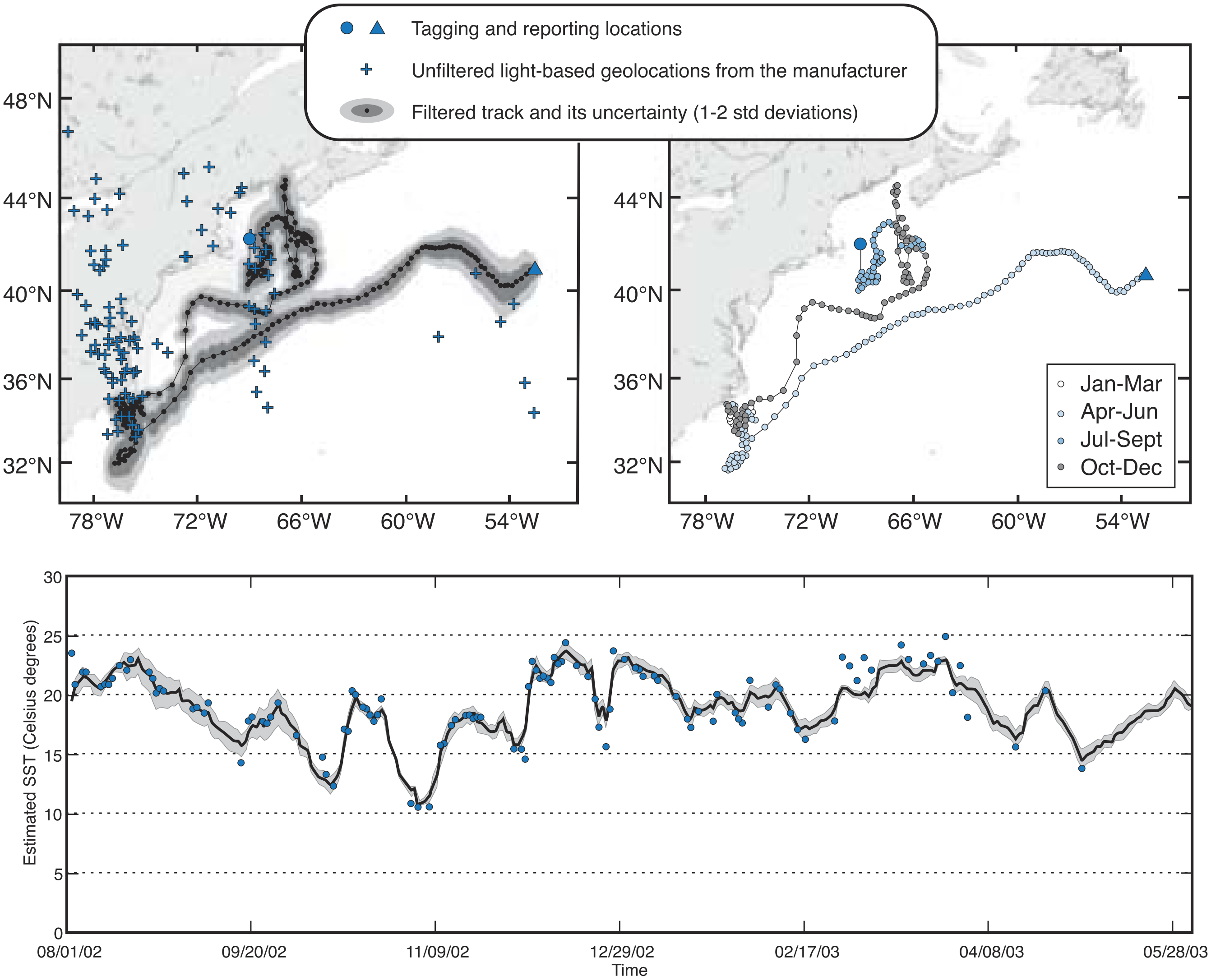

Figure 3. Example of fit for tag# 37008 (2002), a) in the geographical space (trajectory), b) with a color-coding by month, c) for the SST variable (blue: observations generated by the tag, black line: EnKF fit using AVHRR SST composites).

Improved Views of Seasonal Distribution and Movement Patterns

The filtering/smoothing process greatly enhanced the quality of our data sets and provided tracks interpolated to a common (daily) time grid. Strong thermal gradients and well-delineated features obviously helped constrain the final estimates (e.g., the Gulf Stream wall, the continental shelf-break, and the Gulf of Maine channels). In particular, stationary behavior (high residency in localized areas) became clearly separated from extensive/migratory movements (Figure 3). This yields a more accurate timeline of bluefin migratory behavior; improves our confidence in estimates of residency times, departure, and return dates for each individual fish; and helps define interannual shifts in dispersal and behavioral patterns (Figures 3 and 4).

The performance of the filtering method is currently limited by the accuracy and resolution of the temperature fields. Figure 3.b shows the fitted SST and the large gradients experienced over a few days: this information is crucial in separating actual movement from artifacts of the light-based geolocation. As an example, in Figure 4 a north-south movement in the Gulf of Maine prior to departure displays a coherent signature in SSTs (between October 1 and 30, 2002). Whether this is realistic or due to a cold water mass “missed” by the composite imagery remains to be investigated.

Another important application of optimized datasets is to provide a better oceanographic context for interpretation of the vertical habitat of bluefin tuna. In our example (Figure 5), a behavioral switch between shallow and deep depth patterns and, presumably, target prey is clearly visible. For example, shallow depth patterns from December to March correspond to the winter feeding grounds off coastal North Carolina, where bluefin usually forage on menhaden. The deep descents during and after April correspond to the well-mixed waters of the Gulf Stream, where bluefin probably target squids (Matthews et al. 1977).

Using these new analytic tools we are now able to interpret fish movements in relation to meso-scale features. This was not previously feasible when using data from pop-up tags, which do not provide the data density and geolocation resolution of classic archival tags .

The filter's capacity to provide daily interpolations also improved assessment of the habitat utilization distribution of tagged animals. E.g., merging the posterior distribution of each position from each fish allowed us to construct habitat utilization distribution surfaces for each year. Initially the annual dispersal patterns of tagged bluefin tuna (Figure 1) appear similar but closer inspection reveals a shift to the south of the Gulf of Maine and the northern wall of the Gulf Stream for fish released in 2003 (Figure 6).

A unique feature of our dataset is that some tag deployments were conducted from a purse seine fishing boat. This enabled concurrent release of fish tagged from the same school. As most tagging operations took place in the southern Gulf of Maine, we can now test the hypothesis that fish of comparable size and school affiliation will exhibit similar migration behavior.

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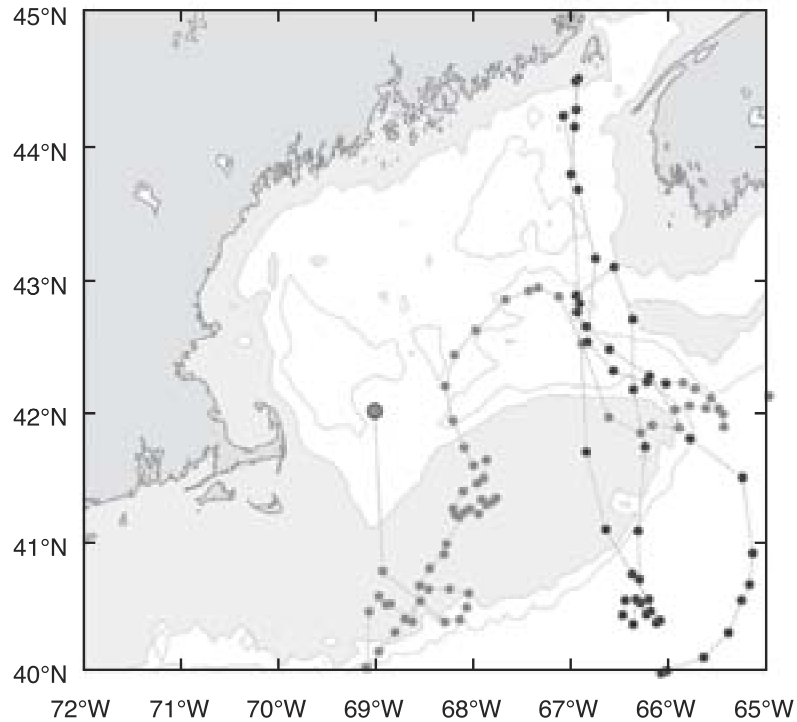
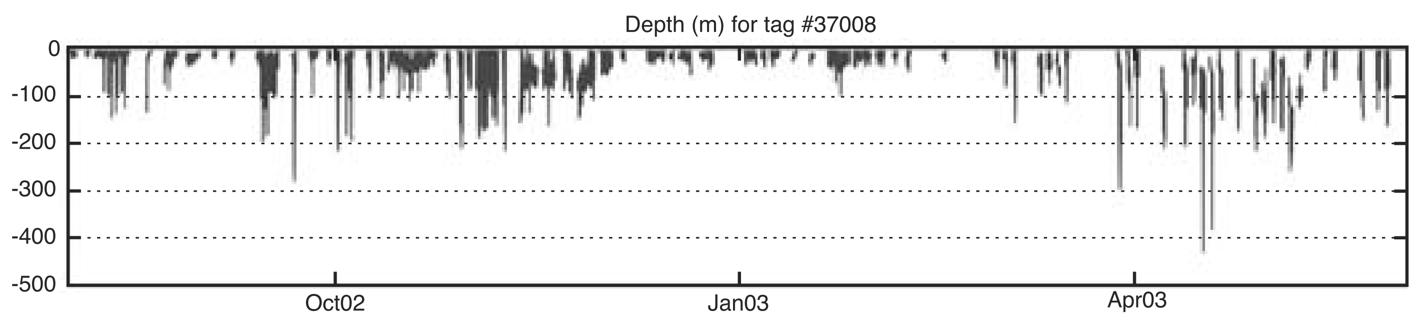


Figure 4. Detail of bluefin tuna tag #37008 near the Gulf of the Maine. A north-south movement (1-30 October 2002) can be seen before the fish leaves the Gulf heading towards the Gulf Stream edge. The signature of these movements can also be seen in the SST measurements.



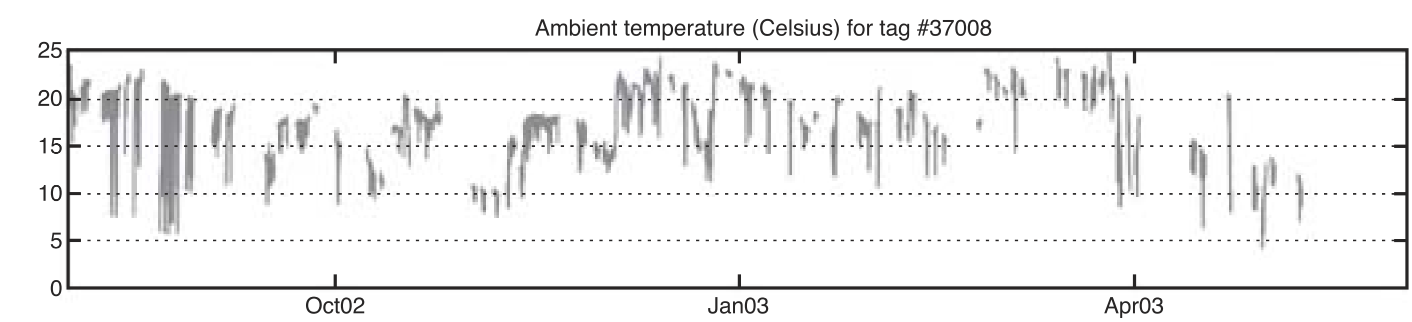


Figure 5. Depth and temperature records for bluefin tuna tag# 37008. Gaps are due to transmission interruptions or lost messages. Each time series has a 1-hour resolution.

Mapping (continued from page 17)

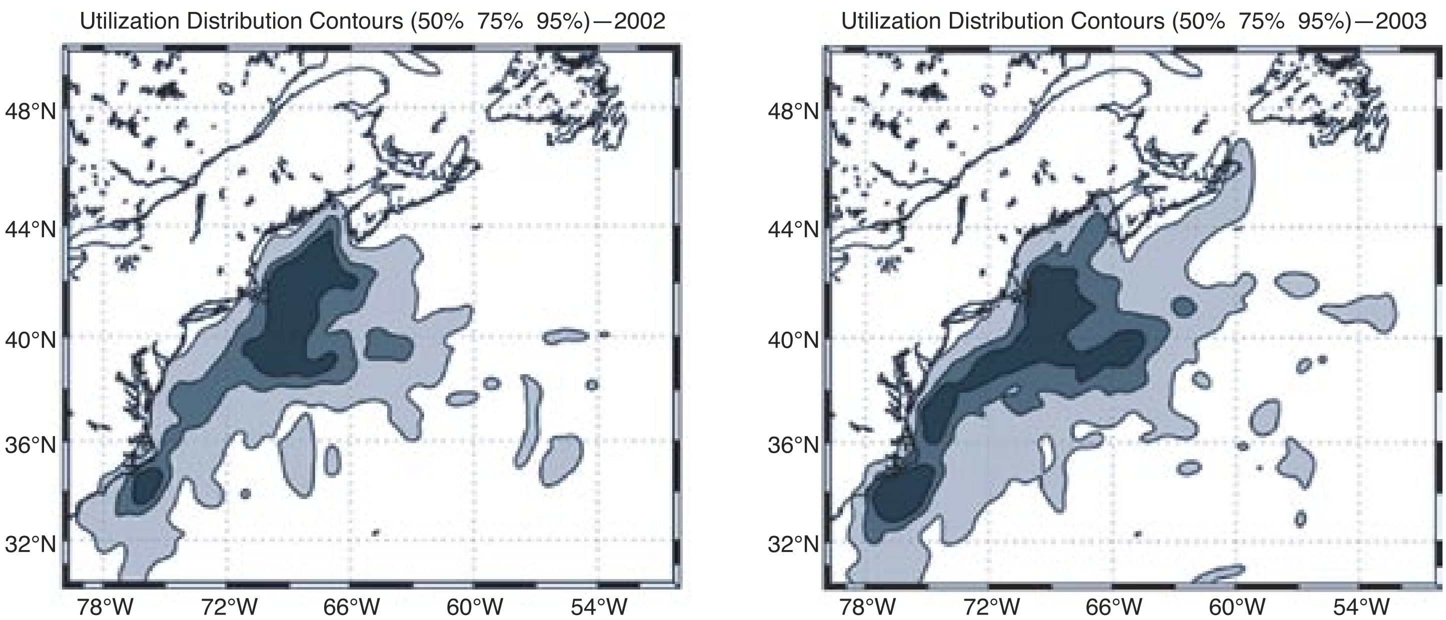


Figure 6. Annual bluefin tuna Utilization Distribution contours (50%, 75% and 95%) built by aggregating the posterior distribution of each daily position from each fish.

Can We Envision the Future of Popup Satellite Tags?

Based on improvements currently being realized in popup satellite tag performance and data analysis, we can now obtain more reliable information on the movements of large pelagic species and their interaction with ocean features. Progress in this field justifies greater confidence in the fishery-independent data returned by these tags and their ability to portray movements on a smaller spatial and temporal scale than was previously thought possible.

Future developments—including tag miniaturization, enhanced data storage and transmission capacity, and addition of physiological sensors—will open the door to further progress in ecological applications. These advances will allow tracking of non-pelagic species and juveniles and will generate a better understanding of their habitat.

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From Physics to Fish: An Example of the Madden-Julian Oscillation

Raghu Murtugudde

Madden-Julian Oscillations (MJOs) are the most typical form of tropical atmospheric intraseasonal variability. These oscillations represent somewhat repeatable, low-frequency phenomena connecting weather and climate. The interactions of MJOs with other weather/climate processes from cyclones and hurricanes, onsets and/or breaks in monsoons, and El Niño have been extensively documented.

In recent years there has been a growing interest in using MJOs to serve as a bridge between weather and climate predictions. In large part this is because MJOs exhibit useful predictability with lead times of two-to-three weeks. MJOs are characterized by large-scale eastward-propagating disturbances in winds, precipitation, cloudiness, and radiation. They leave clear and identifiable signatures in the upper-ocean temperatures and currents. Not surprisingly, the effects of MJOs significantly affect marine ecosystems.

Analysis of satellite data on ocean color and rainfall shows that MJOs produce systematic and significant variations in ocean surface chlorophyll (Chl) in a number of regions across the tropical Indian and Pacific Oceans.

During boreal summer the northern Indian Ocean, a large part of the northern tropical Pacific Ocean, and parts of the far eastern Pacific display an MJO-response in Chl. MJO-induced variations in Chl during boreal winter are strongest in the northwest Indian Ocean, broad areas of western and central Pacific Ocean, and coastal Mexico (See figure on page 20).

Effects on Commercial Fisheries

All of these regions are rich in commercial fisheries. Variations in surface Chl and in the primary production of organic matter by basic photosynthesizers have the potential for affecting associated fisheries forage. Such a response can produce effects cascading all the way up to the top predators.

State of the art fisheries models, such as the "Apex Predators ECOsystem Model" and the "Spatial Environmental Population Dynamics Model," rely on fisheries forage estimates derived from bio/geochemical models that predict primary production given predicted surface forcings-the latter of which can include MJO-related variations.

Further research must examine historical fish-catch data to determine if the influence of MJOs on Chl extends to an impact on fish abundance and if empirical relations can be derived to use two-to-three week MJO-predictions to make operational predictions for fisheries.

Mechanistic descriptions intended to explain the observed MJO-Chl relationship are already being developed using bio-physical ocean models driven by both observed and simulated MJOs. These bio-physical models are also being used for nowcasting and forecasting anoxic or hypoxic conditions, harmful algal blooms, and pathogens of significance to human health.

The consequences of anoxia/hypoxia, harmful algal blooms, and pathogens for fisheries must also be investigated. Such investigations are needed to explore the potential for predicting fish-catch as well as for predicting the abundance and habitat/quality of fisheries. Studies working from the most basic bio-physical events to extended prediction of significant real-world phenomena have thus far been focused on climate, agroeconomics, and human health. The extension of such studies to fisheries is not only logical but essential.

Bio-physical ocean models are global in their representations. Thus the concepts of ecosystem forecasting are functional not only in the context of MJOs and the tropics-such forecasting may easily be extended to higher latitudes. Locally forced features such as the subtropical fronts and remotely forced regions such as the Benguela dome are significant and predictable not only for the physical environment but also generate significant and predictable effects on fisheries variability.

Longer time-scale events include the east-west migration of tuna in the western Pacific warm pool region during El Niño events, Rossby wave signatures in the Kuroshio region of the North Pacific on decadal time-scales, and the spinning up and down of the subtropical gyres in the Atlantic and Pacific Oceans at decadal or multidecadal time-scales. The latter suggest similarities with the so-called sardine and anchovy regimes and the decadal variability of salmon in the Northwest U.S. While theoretical predictability for these longer time-scales may be seductive, the scale of data changes in relevant environmental fields, such as those for sea surface temperatures, tend to be quite small-often well-below the magnitude of the annual cycle.

Conclusion

The relatively more frequent occurrence of MJO events thus offers predictable phenomena with more readily quantifiable, larger scale, data. Further study of MJOs could well provide the potential for near-term improvements in fisheries forecasting. Such near-term improvements in fisheries forecasting should be recognized as easily accessible "low-hanging fruit" and effort should be focused upon these studies so that the potential benefits may be "plucked" as soon as possible.

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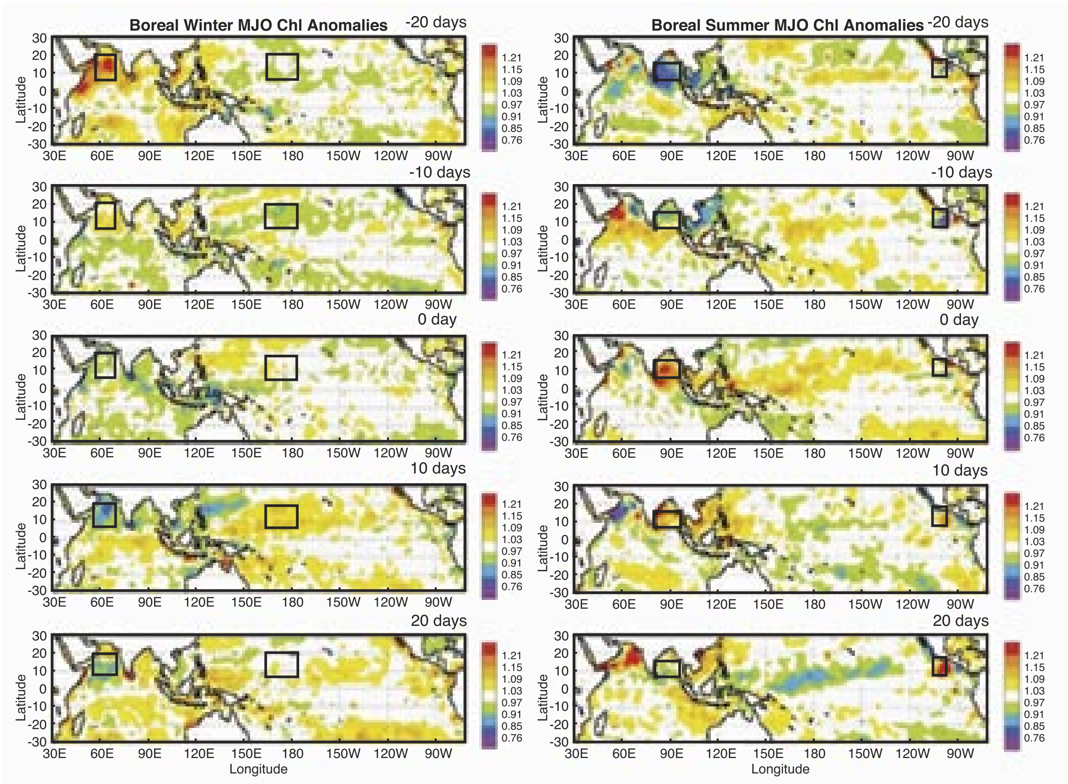

Sea-surface chlorophyll readings from the Sea-viewing Wide-Field of View Sensor, a NASA satellite measuring ocean color. Chlorophyll has been filtered to capture the boreal summer (right) and winter (left). MJO-forced Chl anomalies are shown for a composite 50-day period (-20, -10, 0, 10, and 20 days) representing the life cycle of the MJO. The rectangular boxes highlight a few of the regions where there are significant MJO-induced surface chlorophyll responses. These lead to corresponding primary production responses which are expected to lead to anomalies in forage and potentially in fisheries. (from Murtugudde, p. 19)

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