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MAY 2012

**THE SWFSC DIRECTOR'S
2012 REPORT ON RESEARCH
REGARDING HIGHLY MIGRATORY
SPECIES AND THEIR FISHERIES
IN THE NORTH PACIFIC OCEAN**

by

The Southwest Fisheries
Science Center

ADMINISTRATIVE REPORT LJ-12-04

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INTRODUCTION

In *The SWFSC Director's 2012 Report on Research Regarding Highly Migratory Species and Their Fisheries in the North Pacific Ocean* you will find details of Southwest Fisheries Science Center research during the past year (May 1, 2011, to April 30, 2012) relating to tunas, albacore, billfishes, oceanic sharks, and protected species associated with their fisheries. The Center's biological, economic, and oceanographic research was focused on supporting the information needs of international scientific working groups and committees, the Pacific Fishery Management Council, and the National Marine Fisheries Service. Major tuna-related activities included stock assessments, socio-economic research, research on interactions between fisheries and protected species, population dynamics studies including spatial and temporal modeling of fish movements, and life history studies. The data collection and analyses were aimed at supporting healthy U.S. and Pacific fisheries, protected marine species, and fish habitat, and providing the best available science to help promote effective fisheries management. Significant accomplishments from the past year include: completion of a north Pacific albacore stock assessment conducted under the ISC and lead by Center scientists that included a new age and growth model developed in part with samples provided by our industry partners; tagging and tracking the elusive basking shark in the eastern Pacific Ocean; validation of band-pair deposition periodicity in vertebrae of juvenile shortfin mako sharks; and conducting alternative gear trials to target swordfish below turtle habitat during the day.

Cisco Werner, Ph.D.
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I. SUPPORTING U.S. OBLIGATIONS OF INTERNATIONAL AGREEMENTS

The United States is party to a number of international agreements for the conservation of highly migratory species (HMS) in the Pacific Ocean. As such, it is obligated to collect fishery statistics from U.S. HMS fisheries and to participate in advancing fishery science for species of interest. Scientists at the Southwest Fisheries Science Center (SWFSC) have been tasked to fulfill this obligation. In this section, brief descriptions of some of the contributions and activities during the past year, May 2011–April 2012, are described.

Monitoring the Purse Seine Fishery in the Western-Central Pacific Ocean – The National Marine Fisheries Service (NMFS) collects and manages data from the U.S. purse seine fishery for tropical tunas in the western-central Pacific Ocean as part of U.S. obligations under the South Pacific Tuna Treaty. Information from U.S. vessels licensed to fish under the treaty is collected by the NMFS Pacific Islands Region (PIR) field office in American Samoa and transmitted to the SWFSC in La Jolla, California, where information from logbooks, landings and biological data from port sampling are processed.

The size of the U.S. purse seine fleet decreased in 2010 to 37 vessels from 39 vessels in 2009. Preliminary estimates of the 2010 catch are 246,133 metric tons (t), a decrease of 13% from the 282,848 t caught in 2009. Skipjack tuna (*Katsuwonus pelamis*) dominated the catch (88%), followed by yellowfin tuna (*Thunnus albacares*) (10%), and bigeye tuna (*T. obesus*) (2%). Data for 2011 are still being compiled.

Contributing to the Work of the ISC – The United States is a member of the International Scientific Committee for Tuna and Tuna-like Species in the North Pacific Ocean (ISC), along with Canada, China, Chinese Taipei, Japan, Korea, the North Pacific Marine Science Organization, the Secretariat of the Pacific Community, and the Food and Agriculture Organization. The purpose of the ISC is to enhance scientific research and cooperation for conservation and rational utilization of species of tuna and tuna-like fishes which inhabit the North Pacific Ocean, and to establish the scientific groundwork for the conservation and rational utilization of these species in the region through a multilateral regime. The ISC is organized into five Working Groups—statistics, Pacific bluefin tuna, albacore, billfish and sharks—that meet intercessionally and report to a Plenary body. The overall chairman of the ISC is Gerard DiNardo of the NMFS Pacific Islands Fisheries Science Center (PIFSC). Results of the ISC are made available to participating members and to HMS regional fisheries management organizations of the Pacific Ocean.

The 11th ISC Plenary, held in San Francisco 20-25 July 2011, was attended by members from Canada, Chinese Taipei, Japan, Korea, Mexico, and the United States. A member of the Western and Central Pacific Fisheries Commission (WCPFC) Secretariat attended as an observer. PIFSC Director Sam Pooley led the U.S. delegation at this meeting.

Key Results of the 11th Meeting – The Plenary reviewed results and conclusions, which were based on new data and updated analyses, of the albacore tuna, billfish, and Pacific bluefin tuna working groups. The Plenary endorsed the findings that the albacore stock was not experiencing overfishing and that the stock is likely not in an overfished condition. It further recommended

that the fishing mortality rate on albacore (*Thunnus alalunga*) tuna not be increased. Regarding Pacific bluefin tuna (*T. orientalis*), striped marlin (*Tetrapterus audax*), and North Pacific stocks of swordfish (*Xiphias gladius*), the Plenary maintained the conservation advice of ISC10 with minor changes for clarification. The Plenary endorsed the work plan of the shark working group and the prioritized list of ISC shark species of interest, blue (*Prionace glauca*) and shortfin mako (*Isurus oxyrinchus*) sharks, was ranked high priority. A special seminar on Best Available Scientific Information was held – concepts from which ISC will incorporate into its Operations Manual. The ISC work plan for 2011-2012 includes completing a new stock assessment for striped marlin and Pacific bluefin tuna by ISC12, continuing preparation for a Pacific blue marlin (*Makaira nigricans*) stock assessment in 2012, preparations for an updated blue shark stock assessment in 2012/2013, implementing improved database and website management, and conducting a peer review of its structure. After three years serving as vice chairman of ISC, Michel Dreyfus stepped down. The Plenary elected Chi-Lu Sun to serve as vice chairman for 2011-2014. The next Plenary will be held in Japan in July 2012.

Albacore Stock Assessment and Research – The commercial surface albacore fishery is the most important fishery for HMS on the U.S. West Coast. In June 2011, SWFSC researchers led an assessment of the status and trends in the North Pacific albacore stock, as members of the ISC Albacore Working Group (ALBWG), at a meeting in Shimizu, Japan. The assessment was conducted using fishery data through 2009 and a seasonal, length-based, age-structured Stock Synthesis (SS3) model. Based on this assessment, the North Pacific albacore stock is considered not to be overfished and overfishing is not occurring.

The assessment model used quarterly catch and size composition data, with 16 defined fisheries, eight abundance indices, and conditional age-at-length (otolith aging) data. One of the most important changes with respect to previous assessments is a change in the growth curve for the stock. A fixed growth curve from Yabuta and Yukinawa (1963) was used in previous assessments. However, a recent study by SWFSC scientists in collaboration with Japanese scientists from the National Research Institute of Far Seas Fisheries (Wells et al., 2011) showed that the Yabuta and Yukinawa (1963) growth curve was not representative of the North Pacific albacore stock. Otolith aging data from Wells et al. (2011) was employed for this assessment, and the growth curve was estimated within the assessment model, which resulted in a more representative growth curve and improved fits to the length composition data. Most importantly, the L_{∞} was estimated to be 118 cm rather than the 146.6 cm from Yabuta and Yukinawa (1963).

The base-case model estimates that spawning stock biomass (SSB) has likely fluctuated between 300,000 and 500,000 t between 1966 and 2009, and that recruitment has averaged approximately 48 million fish annually during this period. Fishing mortality (F-at-age) increases to its highest level on 3-year-old juvenile albacore and then declines to a much lower and stable level in mature fish. Current fishing mortality ($F_{2006-2008}$) is lower than $F_{2002-2004}$ (current F from the 2006 assessment) and is about 71% of $F_{SSB-ATHL}$, which means F is below the fishing mortality that would lead SSB to fall below the average of the ten historically lowest estimated SSBs (SSB-ATHL) threshold. Estimates of $F_{2006-2008}$ expressed as a ratio relative to several potential F-based reference points (F_{MAX} , $F_{0.1}$, F_{MED} , $F_{20-50\%}$) are also less than 1.0. It is based on these findings that the ALBWG concluded that overfishing is not occurring and the stock is not in an overfished condition.

In addition to the stock assessment, SWFSC scientists are also involved in several studies that will improve our understanding of the population dynamics and biology of North Pacific albacore. Importantly, SWFSC scientists recently published a paper (Childers et al., 2011) in the journal *Fisheries Oceanography* on the “Migration and behavior of juvenile North Pacific albacore (*Thunnus alalunga*),” which describes the results of our long-term, electronic tagging experiment. SWFSC scientists, in collaboration with PIFSC and Canada’s Department of Fisheries and Oceans (DFO) scientists, have also recently received funding from NOAA’s Fisheries and the Environment (FATE) program, to study the “Influence of the North Pacific Current on the spatial distribution and availability of North Pacific albacore in the northeast Pacific Ocean.” We expect to develop (1) an environmental time series that indicates albacore availability to U.S. surface fisheries and (2) integrate the time series into future stock assessment models.

Bluefin Tuna Stock Assessment and Research – Pacific bluefin tuna was historically an important commercial fishery for HMS on the U.S. West Coast. In recent years, however, the primary U.S. fishery targeting this species has been the U.S. sport fishery operating out of San Diego, California. There remains an important commercial fishery for Pacific bluefin tuna in Mexican waters.

As members of the ISC Pacific Bluefin Working Group (PBFWG), SWFSC researchers are preparing for a full stock assessment of Pacific bluefin tuna scheduled for June 2012. The PBFWG currently uses a length-based, age-structured Stock Synthesis model for stock assessments. In January 2012, SWFSC scientists met with fellow members of the PBFWG in La Jolla to discuss data inputs and model specifications for the upcoming assessment. At a previous PBFWG meeting, SWFSC researchers demonstrated the detrimental effects of assessment model misfits to eastern Pacific Ocean (EPO) time-series. The PBFWG therefore decided to not fit the assessment model to EPO abundance indices in the upcoming assessment. In addition, SWFSC researchers also developed a SS3-VPA hybrid model and a SS3 model incorporating trans-Pacific movements as research tools to help improve future assessment models. A manuscript on the SS3-VPA model entitled “A hybrid Stock Synthesis-Virtual Population Analysis model of Pacific bluefin tuna” is currently under review.

II. SUPPORTING PACIFIC FISHERY MANAGEMENT COUNCIL ACTIVITIES –

Center scientists Stephen Stohs and Suzanne Kohin continued serving on the Highly Migratory Species Management Team (HMSMT) of the Pacific Fishery Management Council (PFMC) over the past year. Stohs served as HMSMT chair from April 2009 through 2012. The chairmanship was passed to a team member from Washington Department of Fish and Wildlife in January 2012, but Stohs still plays a leadership role with respect to Federal input to the team. The team met several times in 2011 and early 2012 to review fishery information, complete assignments from the Council and evaluate provisions of the Fishery Management Plan for U.S. West Coast Fisheries for Highly Migratory Species.

The main HMS issues facing the team and the Council over the past year have been (1) assisting the Council with providing recommendations on international HMS fishery management issues

to the U.S. delegations of the WCPFC and Inter-American Tropical Tuna Commission (IATTC); (2) participating in and reporting to the Council on activities relevant to west coast swordfish fisheries, including a two-day informational meeting held with stakeholders in San Diego during May 2011; (3) providing updates to the Council and its advisory bodies on the status of North Pacific albacore following completion of the 2011 assessment and helping to develop an albacore management framework for West Coast fishers; (4) working with state, PacFIN, and RecFIN representatives to tackle ongoing data management discrepancies; and (5) preparing the 2011 Stock Assessment and Fishery Evaluation (SAFE) Report and planning for the 2012 SAFE Report.

III. HIGHLY MIGRATORY SPECIES DATA COORDINATION - The PIFSC, PIR, Southwest Region (SWR), and SWFSC share reporting obligations for HMS fisheries in the Pacific. Staff from each office collaborate to meet the international reporting obligations to Regional Fisheries Management Organizations (RFMOs), Councils and other customers and provide HMS data summaries required by these reporting obligations. Staff from each office routinely exchange information needed for various reports, data submissions, and other reporting purposes such as informal data requests. Formal annual meetings of the staff members have not occurred since 2005, though ad hoc meetings and correspondence continue.

HMS staff participate in the Fisheries Information System (FIS) based at NMFS headquarters. A representative from SWFSC, SWR, PIFSC, and PIR is on the FIS Program Management Team, which directs FIS-sponsored projects and activities. FIS funds numerous projects that contribute toward improving fisheries-dependent data that are collected and maintained by the agency and partner organizations. Staff members from SWFSC, SWR, PIFSC, and PIR are leading several of these projects to improve data collection and management systems in their respective regions.

HMS information technology specialists at the SWFSC are also improving data collection methods. Current and past electronic data collection and monitoring projects include data monitoring systems for regional observer programs, electronic calipers and handheld computers used to collect length measurements, and electronic logbook software applications. These monitoring and collection methods increase the data quality and timeliness of reporting while reducing operational costs and easing reporting burdens on fishermen. In addition, web-based reporting systems continue to be developed by SWFSC staff, improving the quality and availability of information collected in remote locations.

IV. ADVANCING RESEARCH ON TUNAS, BILLFISH, AND OPAH

The SWFSC research on tunas and billfishes in the Pacific Ocean has largely been focused on improving our understanding of the biology and ecology of the animals to support needs for assessing the effects of fishing and environment on the population or stock. Described below are studies that have been recently completed or are ongoing by Center staff. These studies are carried out largely in cooperation with stakeholders and in collaboration with colleagues both in the U.S. and abroad.

Monitoring the U.S. Albacore Troll and Pole-and-Line Fishery – U.S. troll and pole-and-line vessels have fished for North Pacific albacore since the early 1900s and for South Pacific

albacore since 1986. North Pacific albacore fishing areas range from Vancouver Island to the coast of Baja California and from the U.S. West Coast to approximately 160°E. The fishing season begins in late April and can last into mid-November. The size of the troll fleet for a season ranges from 500 vessels to more than 1,000 vessels. Approximately 632 U.S. troll and pole-and-line vessels fished for North Pacific albacore in 2010. The total albacore catch in 2010 was 12,661 t, a slight decrease from the 12,793 t caught by vessels in 2009. Data for the 2011 season are currently being compiled.

Fishing areas for South Pacific albacore extend eastward from the east coast of New Zealand to approximately 110°W and between 30°S to 45°S, overlapping the jurisdictional areas of two RFMOs. This fishery begins in late December and continues until early April of the following year. The international troll fleet in the South Pacific consists of 5 to more than 50 vessels. Factors such as increased fuel costs, lower ex-vessel prices and reduced availability of fish have contributed to a decrease in participation in the South Pacific troll fishery in recent years. Only 6 U.S. troll vessels fished for albacore in the South Pacific during the 2009-2010 season; they caught 237 t of albacore, an increase from 150 t caught the previous season by 4 vessels. Bycatch species are sometimes reported in vessel logbooks and include yellowtail, dolphinfish (*Coryphaena hippurus*), and skipjack, as well as yellowfin, bigeye, and bluefin tunas.

Cooperative Research with the U.S. Surface Albacore Fishery – SWFSC scientists are working with the American Fishermen’s Research Foundation (AFRF) and the American Albacore Fishing Association on monitoring programs and other research efforts to improve knowledge of the biology and migration of North Pacific albacore in the waters off the U.S. Pacific coast. The cooperative research is described below.

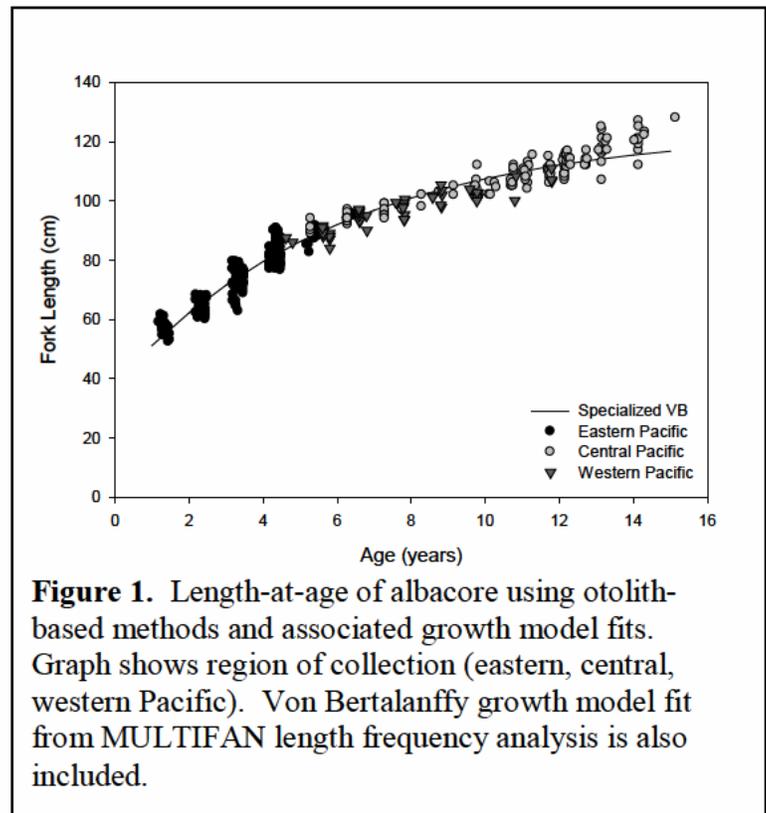
North Pacific Albacore Biological Data Sampling Program – Since 1961, a biological data collection program, or port sampling program, has been in place for collecting size data from albacore landings made by the U.S. and Canadian troll fleets at ports along the U.S. Pacific coast. State fishery personnel collect the biological data by following sampling and data processing instructions provided by the SWFSC, where the database is maintained. In recent years, with AFRF support, fishermen have also collected biological data during selected fishing trips. These data are collected to augment data collected through the port sampling program. Following procedures established by SWFSC scientists, fishermen on 5 vessels measured 1,010 albacore during the 2010 season. During 2011, 2 vessels measured 1,939 fish. The sample information provided by the fishermen helped to fill in gaps missed by the port sampling program. Overall, the sizes were found to be generally similar to those collected through the port sampling program.

North Pacific Albacore Archival Tagging Project – The SWFSC and AFRF initiated an archival tagging program in 2001 to study the migration patterns and stock structure of juvenile albacore in the North Pacific. Since 2001, a total of 720 archival tags and 43 dummy tags have been deployed. Two tagging trips were conducted during 2011, both off northern Oregon aboard the chartered F/V *Royal Dawn*: 1-6 August, during which 39 tags were deployed and 5-9 October with an additional 51 tags deployed. This is the greatest tagging effort since 2006, and plans are being made to similarly deploy over 100 tags during the 2012 season. During 2011, no additional tag recaptures were reported.

Because of the broad range of movement patterns and behaviors recorded by the first 22 recoveries, a greater number of tag returns from fish that have been at liberty for several years will be needed in order to fully understand the dynamics and structure of the North Pacific albacore stock. In addition, information on the distribution and migrations of adults is needed. In 2010, the SWFSC purchased 4 mini pop-off satellite archival (mini-PSAT) tags to launch a pilot project to deploy tags on adult albacore that are caught near Hawaii in an artisanal handline fishery. The study is designed to determine whether there are distinct spawning populations of albacore in the central and western Pacific, and to study the movements of adult albacore. PSAT tag retention on albacore has been poor in past studies, but the new generation mini-PSAT is 40% smaller and two attachment methods have been designed to test. If either attachment provides long-term records, then a larger study will be initiated to obtain information on adult albacore migrations, spawning areas, and stock structure. During August 2011, a SWFSC scientist traveled to Hawaii to deploy these experimental tags on adult albacore typically caught in the handline fishery at that time of year. Unfortunately, the handline fishery has seen sporadic low catches of adult albacore for the past two years, and no fish were caught during the trip. Plans have been made to continue the effort during the 2012 season.

Otolith Collections to Support Stock Assessments – Given the uncertainty surrounding current growth models and stock structure of North Pacific albacore, scientists at the SWFSC have continued expanding on the biological sampling program along the U.S. West Coast and have also acquired samples from both the central and western Pacific. This and other ongoing studies support the ISC’s recent proposal for a North Pacific-wide sampling program to address the uncertainties with current growth models and stock structure for albacore in the EPO. Two objectives of the sampling program that relate most directly to stock assessments are age and growth, and population structure using otolith-based methods.

Age and Growth – Age and growth of North Pacific albacore was assessed by examining annual growth increments in sagittal otoliths from 486 fish collected throughout the North Pacific Ocean. A wide size range of albacore (52-128 cm fork length, FL) was collected in the western, central, and eastern Pacific Ocean in attempt to incorporate size-at-age information over juvenile, sub-adult, and adult life history stages. Overall, ages ranged from 1 to 15 years with the majority of fish between 2 to 4 years of age. Growth models fit otolith-based size-at-age well and the specialized von



Bertalanffy (VB) model provided the best fit (Fig. 1). Biological parameters of the specialized VB model included $L_{\infty}=124.1$, $K=0.164$, and $t_0=-2.239$. Daily ages of several age-1 fish (55-61 cm FL) were also determined and confirmed correct annual age class assignments, with daily ages ranging from 378 to 505 days. In addition to otolith-based techniques, dorsal fin spines and length frequency (LF) analysis were used to generate estimates of size-at-age. Fin spine ages generally matched otolith-derived ages (85% of samples), though samples were only available and analyzed for young fish. Results of the VB growth model generated from LF analysis provided similar size-at-age for the first five age classes but estimated smaller sizes for fish ages 6 to 9, which may be a product of the limited size distribution from fishery-dependent data. Results suggest North Pacific albacore are a relatively long-lived tuna species and provide updated biological parameters useful for future stock assessment models incorporating age-specific life history information.

Population Structure – Population structure of North Pacific albacore appears to be more complex than the current single stock hypothesis given the apparent regional differences in growth rates and movement patterns in the EPO. Accurately characterizing population structure and stock mixing is critical to effective management. Otolith chemistry is one approach to investigate population structure of tunas and other fish. The principal assumption is that the otolith acts as a natural tag because the chemical composition of the otolith is related to the physicochemical conditions of the water mass inhabited. As such, the purpose of this study is to examine otolith stable isotopes of carbon ($\delta^{13}\text{C}$) and oxygen ($\delta^{18}\text{O}$) in addition to several trace elements in whole otoliths of albacore collected in the northern region (offshore Oregon and Washington, $> 40^{\circ}\text{N}$) and southern region (offshore Southern California and northern Baja California, Mexico, $< 40^{\circ}\text{N}$). Samples from three age classes (ages 2-4) were collected from each region through recreational and commercial fisheries from during the 2010 and 2011 seasons. Significant differences existed in otolith chemistry from fish collected between the two regions ($P < 0.05$) and overall cross-validated classification success was 100%, with age-specific comparisons exceeding 90% success. Otolith $\delta^{18}\text{O}$ was significantly enriched in the southern region relative to the northern region, similar to reported seawater $\delta^{18}\text{O}$ differences. In addition, significantly higher concentrations of sodium and magnesium, combined with lower phosphorus in otoliths from fish collected in the southern region, is consistent with regional physicochemical conditions (i.e., salinity, temperature, phosphate). Our findings support previous studies that have shown limited regional mixing of albacore in the EPO and provide life history information useful for management of North Pacific albacore.

Biological Sampling of Tunas in the Eastern Pacific Ocean – Tunas in the EPO, including the waters off the U.S. and Mexico, support substantial commercial and recreational fisheries and are also important components of the local food web. To better understand their basic biology and ecological role in the EPO, the SWFSC and the Sportfishing Association of California initiated a biological sampling program in 2007 to collect data on tuna and other HMS. While initially the program was focused in the Southern California Bight (SCB), in 2009 the program was expanded to the northeast Pacific Ocean working with commercial fishermen to collect samples from albacore off Oregon and Washington (see above). Utilizing the commercial passenger fishing vessels (CPFV), commercial albacore troll/baitboat fleet, and recreational anglers based out of San Diego and SWFSC research cruises, we have collected samples from albacore, bluefin, yellowfin, skipjack, opah (*Lampris guttatus*), and dorado (*Coryphaena sp.*) (Table 1). In

2010 the program was expanded to include Monterey Bay and San Francisco, areas where albacore are commonly encountered from August through December. Research efforts using biological samples have focused on a range of questions. Initial efforts centered on characterizing diets using stomach contents and investigating interannual and interspecific differences. In the past few years, the research program has expanded to include (1) stable isotope analysis of muscle tissue to provide an integrated picture of foraging and (2) using otoliths both to better characterize age and growth of albacore and to examine stock structure using microchemistry (see above section).

Table 1. Summary of all fish sampled by the biological sampling program for tuna and related species.

Species	2007	2008	2009	2010	2011
Albacore	116	35	66	309	85
Yellowfin	15	45	95	71	128
Bluefin	0	75	78	54	189
Skipjack	0	5	9	8	15
Opah	0	0	1	11	16
Dorado	0	43	39	0	40

Tuna Foraging Ecology – With the reauthorization of the Magnuson-Stevens Fishery Conservation and Management Act in 2006, there is a move towards ecosystem-based management. Understanding temporal and spatial patterns in who is eating who is critical to this approach. To determine the trophic relationships of highly migratory species in the California Current, the SWFSC has been investigating the foraging ecology of a range of species since 1999.

Analyses of stomach contents conducted to date reveal a number of interesting patterns across species and years. Preliminary analysis of stomach contents shows that tuna forage almost exclusively on juvenile fish and squid. For albacore, the average standard length of fish prey was 5.3 cm, and for the squid, lower rostral length was 0.34 cm. A comparison across years for albacore reveals some interesting differences. In 2007, small epipelagic teleosts comprised the dominant prey category by frequency of occurrence (89%), followed by cephalopods (18%) and crustaceans (16%). In 2008, a shift in prey composition occurred with cephalopods [*Abraliopsis felis*], California market squid (*Loligo opalescens*), and jumbo squid (*Dosidicus gigas*)] playing a more important role by frequency of occurrence (86%), followed by teleosts (84%) and crustaceans (56%). The composition of the teleosts also shifted between years. In 2007, 80% of the stomachs contained northern anchovies (*Engraulis mordax*), whereas in 2008 this dropped to only 2%. Juvenile *Sebastes* spp., myctophids, and jack mackerel (*Trachurus symmetricus*) made up the majority of teleost prey in 2008. Further analysis is needed to determine the potential reasons for the shift in prey between years. Preliminary results from 2009 appear to be similar to 2008, with much of the diet comprising crustaceans, teleost, and cephalopod typically associated with the deep scattering layer (DSL). Samples collected during 2010 and 2011 are currently being analyzed. Overall, analysis shows that prey composition can vary dramatically and will likely be linked to oceanographic conditions.

Stable isotope analyses of muscle tissues are currently being used to help characterize trophic relationships between prey and predators in the SCB. The California Current is known as a highly productive eastern boundary current, and researchers have suggested that these are wasp-waist systems with low diversity at mid-trophic levels. This low diversity of prey for top predators had been linked to dramatic bottom-up effects associated with variability in mid-level prey species. Estimates of trophic level are being used to evaluate links between prey and predators in regards to wasp-waist dynamics. Preliminary results suggest predator-prey relationships in the SCB are more complex than would be predicted in a wasp-waist system, with a high degree of diversity and omnivory in predator diets. Consequently, predators in the SCB should be more resilient to prey variability than would be suggested under a wasp-waist model.

In addition to studying the HMS themselves, the predators can be used as biological samplers and provide a snapshot of the forage base. Linking changes to environmental factors that influence the recruitment, distribution, and resulting availability of forage prey types may reveal insight about habitat quality and migration patterns of HMS in the California Current. By sampling over multiple years we are gaining insight into the impacts of climate variability on local prey and predators which will help us to predict the impacts of climate change on the California Current ecosystem.

Cooperative Research with Billfish Anglers – The SWFSC and billfish angling community have been working together since 1963 to study various aspects of billfish biology and to obtain an index of angler success in the Pacific Ocean. This collaboration has resulted in one of the longest time-series available for recreational billfishing, charting trends in catch-per-unit-effort (CPUE) for key species. The research has also included recreational and commercial fishery monitoring, stock assessments efforts, biological research into the life history and ecology of specific billfish species, and determining the economic importance of billfish resources. Two major components of the cooperative research that were the focus in 2011 were the International Billfish Angler Survey and the Billfish Tagging Program.

International Billfish Angler Survey – In 2011, SWFSC researchers summarized the results from the 2010 Billfish Angler Survey. Initiated in 1969, the survey now provides a 42-year time series of billfish angling effort and catch in the Pacific Ocean. The time series of angler success provides a measure of relative abundance and is the only fisheries-independent survey in the Pacific. CPUE, measured in number of billfish caught per angler fishing day across all reporting areas in the Pacific, was 0.44 in 2010. This CPUE is slightly lower than that reported in 2009 (0.46) and well below the most recent 5-year average (2005-2009; 0.66). CPUE time series were examined individually for the main species caught [Pacific blue marlin, striped marlin, Pacific sailfish (*Istiophorus platypterus*), and black marlin (*Makaira indica*)] in the main fishing areas (Tahiti; Hawaii; Baja California, Mexico; Southern California; Guatemala; Costa Rica; Panama; and Australia; Fig. 2). The CPUE for several species was lower in locations where they are commonly targeted. Blue marlin CPUE off Hawaii was 0.22, which was above average but a decrease from the previous two years. Blue marlin CPUE off Baja California, Mexico, was 0.07 in 2010, which is the median catch rate for this area. Striped marlin CPUE off Southern California was the lowest on record (0.03). Despite an increase in reported catch throughout Mexico, a drop in striped marlin CPUE was also reported from Baja California. La Niña conditions brought cold waters to these areas from July through October and may have

contributed to this drop in CPUE. Sailfish CPUE reported throughout Mexico was 0.18, the lowest number in more than a decade.

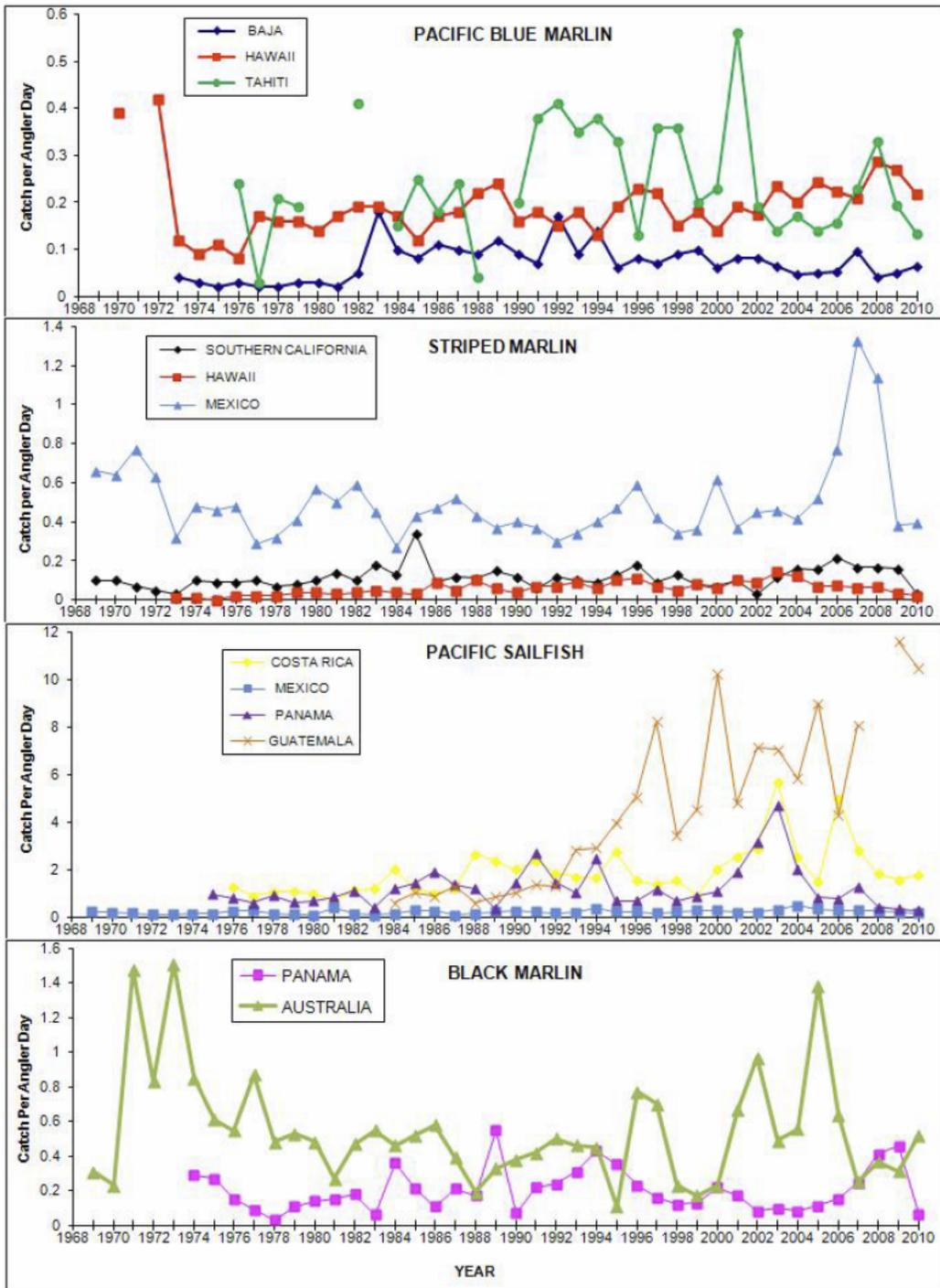


Figure 2. CPUE as catch-per-angler-day is shown from 1969 through 2010 for Pacific blue marlin, striped marlin, Pacific sailfish, and black marlin.

Recreational Billfish Tagging Program – The SWFSC’s Billfish Tagging Program has provided tagging supplies to recreational billfish anglers for 49 consecutive years. Tag release and

recapture data are used to determine movement and migration patterns, species distribution, and age and growth patterns. This volunteer tagging program depends on the participation and cooperation of recreational anglers, sportfishing organizations, and commercial fishers. Since its inception, more than 62,000 fish of 75 different species have been tagged and released.

Emphasis continues to be on the skillful tag and release of billfish. A total of 416 tags were released on billfish in 2010 through the efforts of over 300 anglers and 95 captains.

Unfortunately, the 2010 tag release total is down from recent years and may reflect a decrease in fishing effort by our constituents. Indeed, 2010 had the highest percentage of anglers reporting “no fishing” in the International Billfish Angler Survey. Fortunately, preliminary reports indicate the tagging effort increased substantially in 2011. Table 2 shows the tagging effort for 2010 and tag recoveries throughout the program’s history. The data include releases made by SWFSC scientists during research cruises.

Swordfish Research and SLUTH – Since 2006, NMFS has been studying swordfish in the SCB to examine migratory patterns, foraging ecology, and local stock structure. In 2008, researchers in the SWFSC’s Fisheries Resources Division (FRD) teamed up with the Protected Resources Division (PRD) and the SWR to launch a new initiative, Swordfish and Leatherback Use of Temperate Habitat (SLUTH). The overarching objective of SLUTH is to integrate studies of swordfish and leatherback sea turtles to inform management and conservation efforts. The endangered leatherback is taken incidentally in swordfish fisheries, and concerns about leatherback populations are currently shaping the management of swordfish fisheries along the U.S. West Coast. The first step in this process was a stakeholder workshop that was conducted in May 2008. A report detailing the content and discussions of the workshop was published as an Administrative Report in 2009 (Benson et al., 2009; LJ-09-06). While a large organized initiative has yet to be established, FRD and PRD have a number of ongoing research projects to characterize the habitat of swordfish and leatherback sea turtles to identify where habitat separation is maximized in time and space. Information on habitat separation can be used to increase the selectivity of fisheries and to reduce bycatch.

Characterizing Target Catch and Non-target Species Catch and the Behavior of Fishermen – Part of the SLUTH initiative is to explore creative methods to reduce the bycatch of non-target species in the California drift gillnet fishery (CADGN). One approach is to use the fisheries data to better understand the environmental factors that affect the distribution of leatherbacks, swordfish, and the fishers themselves. Working together, researchers from the PRD and FRD are using novel statistical approaches including boosted regression trees and random forests to model the relationships between the distribution and abundance of the focal species, fishing effort, and a range of factors. The first approach has been to characterize the impact of environment on catch rates. Results indicate that catch rates respond to both biotic (primary production, zooplankton abundance) and abiotic (sea surface temperature or SST, currents, depth) factors. If combined with data on location (i.e., latitude/longitude) and time of year (i.e., month), these factors can be used to predict swordfish catch rates with impressive accuracy (e.g., cross validated R^2 of ~ 0.7). A manuscript covering this research is in preparation for the ICES Journal of Marine Science. A second approach is to use the fisheries data to better understand the factors that affect the distribution of fishing effort. Patterns in bycatch may be more directly linked to fishing effort rather than target species. Many factors other than target species distribution can influence where fishers fish, for example vessel size, distance from shore, and

home port. Our results suggest that it is possible to accurately predict fishing effort using a modest set of readily available predictor variables. Thus, with information on bycatch species distributions we could forecast where the probability of bycatch is high and make adjustments in advance. A manuscript on this research is ready for submission to the journal Conservation Biology.

Table 2. Summary of fish tagged through the Billfish Tagging Program in 2010 with releases and recoveries for 1963–2010, including SWFSC’s ongoing research tagging.

SPECIES NAME	RELEASE 2010	RELEASE TOTAL	RETURN TOTAL	RETURN RATE (%)
Striped Marlin	43	22934	345	1.50
Pacific Blue Marlin	307	10765	90	0.84
Sailfish	22	9201	49	0.53
Billfish, unidentified	9	4386	6	0.14
Black Marlin	2	3387	69	2.04
Shortfin Mako Shark	56	2303	217	9.42
Shortbill Spearfish	33	2145	2	0.09
Blue Shark	196	1226	126	10.28
Common Thresher Shark	274	1330	78	5.86
Broadbill Swordfish	0	521	17	3.26
Yellowfin Tuna	0	349	25	7.16
Skipjack Tuna	0	100	2	2.00
Albacore Tuna	33	749	29	3.87
Bigeye Tuna	0	79	0	0.00
Bluefin Tuna	0	58	2	3.45
Bronze Whaler Shark	0	51	3	5.88
Hammerhead Shark	0	55	2	3.92
Leopard Shark	0	45	8	17.78
Whitetip Shark	0	44	1	2.33
Soupfin Shark	0	33	1	3.03
Atlantic Blue Marlin	0	43	0	0.00
Salmon Shark	0	33	3	9.09
Silky Shark	0	21	0	0.00
White Marlin	0	13	1	7.69
Basking Shark	0	7	0	0.00
Longbill Spearfish	0	3	0	0.00
Other Tunas	0	21	1	4.76
All Others	3	2538	114	4.49
TOTAL	978	62440	1191	1.92

Improving Location Estimates from Electronic Tags – In addition to characterizing swordfish habitat using catch data, electronic tags are also being used. While the traditional pop-up satellite tags provide valuable information on vertical behavior, obtaining an accurate assessment of location is made challenging by the diel vertical migrations of swordfish. We are currently working with a researcher at CSIRO (Commonwealth Scientific and Industrial Research Organisation) in Australia on software to improve light-based geolocation estimates. The novel

approach treats the data as sequentially independent decisions instead of constructing a track. This allows us to concentrate on the analysis of covariates describing the movement instead of estimating a model describing the full path of the animal. This approach will be used to characterize the impacts of environment on both large-scale and vertical movements. In addition, the code will be further developed for use with other tag types. This type of approach will improve our ability to understand and predict movements and consequently overlap with protected species.

Opah Research in the Eastern Pacific Ocean – The opah is a large, mid-water pelagic fish that occurs seasonally in the SCB. While they are not targeted, they are taken incidentally in both local recreational fisheries for tuna and the CADGN fishery targeting swordfish. In recent years opah has become increasingly popular in seafood markets. Despite their value to commercial and recreational fishermen, little research on the basic biology and ecology of opah has been conducted, especially in the SCB. For example, there is little data on foraging ecology, size composition in fisheries, essential habitat, and stock structure. To begin to fill some of the data gaps, in 2009 the SWFSC began collecting biological samples from opah caught and initiated an electronic tagging program in 2011.

Incidental Take of Opah in the Southern California Bight – Based on a preliminary analysis of the CADGN observer database, covering the years from 1990 to 2005, catch rates were relatively consistent across years, averaging 0.53 opah per set. Peak catch rates were observed in 1997 (1.2 opah per set) during El Niño oceanographic conditions. This is similar to a reported increase in opah landings during the 1982-83 El Niño and suggests that the SCB may be towards the northern extent of the core of the opah's range. After 2005 there appears to have been an increase in catch rates, with the average from 2006-2010 at 1.6 opah per set. For comparison, the catch rate for swordfish from 1990-2010 was 2.1 per set. If recent trends persist, opah could become a more important component of the fishery. Further evaluation of observer and logbook data from the CADGN needs to be conducted to determine whether the variability is related to abundance, availability, fishing practices, or environmental conditions.

Opah Foraging Ecology – Over the past three years, stomachs have been collected from 28 opah. Preliminary analysis of 10 stomachs revealed a total of 19 species, including hake, barracudinas, and Octopodoteuthis, with cephalopods making up 5 of the 7 most important prey species. Based on the data collected to date, opah appear to feed primarily on species associated with the DSL. This is consistent with their diel migrations that are similar to those of swordfish that also feed on the DSL. A previous study in the central North Pacific also found that mesopelagic prey species dominated opah diet composition. A comparison with diets of tunas and swordfish from the SCB suggests greater niche overlap with swordfish than with tunas. Considering that opah are often caught in association with tunas, the differences in their diets could reflect habitat partitioning.

Electronic Tagging – To help characterize the vertical and horizontal movements of opah in the SCB, two Wildlife Computers PSAT-Mk10 tags were deployed on opah in October 2011 during a research longline cruise conducted by the SWFSC. This is the first time an opah has been tagged in the EPO. The PAT tags were programmed to collect light, depth, and temperature data for 240 days and then to release from the fish. One tag reported back to the Argos satellite

prematurely. For the first 21 days of the record, behaviors were similar to those reported off Hawaii. While the opah remained below the mixed layer, they exhibited a deep diel migration (Fig. 3). At 21 days it appears that the opah was ingested by an endothermic predator. The tag was ultimately expelled and came to the surface where logged data were transmitted to satellite. The second tag is still at liberty. Additional tags will be deployed in 2012 to further examine their habitat use and migratory patterns in the EPO.

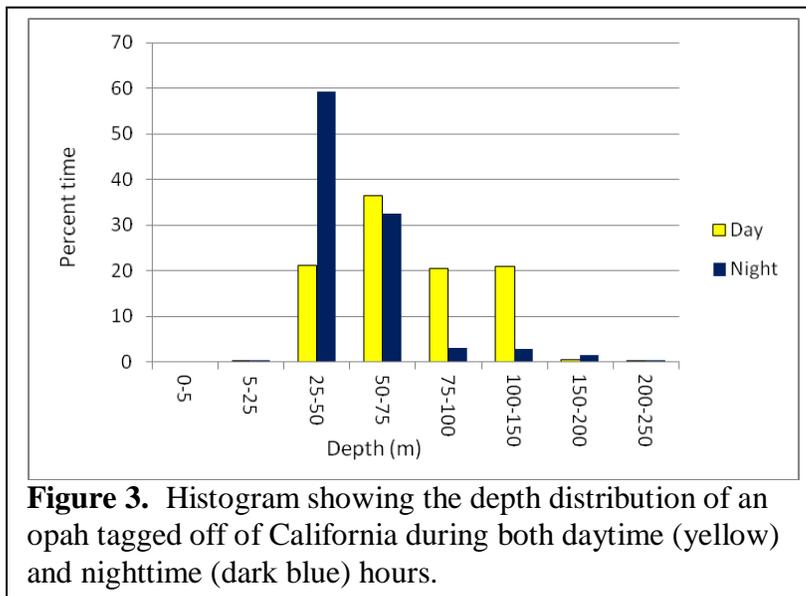


Figure 3. Histogram showing the depth distribution of an opah tagged off of California during both daytime (yellow) and nighttime (dark blue) hours.

Gill Morphology – In 2011, three sets of opah gills were preserved in 10% formalin and transported to the SWFSC for examination and comparison to other pelagic fishes. Determination of gill surface area and associated dimensions allows for insights into both the metabolic requirements and dissolved oxygen concentrations experienced by this species. In addition to a number of morphometric similarities with other pelagic fishes, opah gills show extensive fusion of the gill filaments, a characteristic previously documented only in high-performance teleosts (tunas of the genus *Thunnus*, the wahoo, *Acanthocybium solandri*, and billfishes). The occurrence of filament fusions in opah suggests a role other than that proposed for the high-performance fishes, which use gill fusions to maintain optimal gill orientation and reduce branchial flow rates during ram ventilation. Opah are not thought to be obligate ram ventilators, but like tunas are active predators.

V. ADVANCING PELAGIC SHARK RESEARCH

The SWFSC’s shark research program focuses on pelagic sharks that occur along the U.S. Pacific coast, including shortfin mako, blue sharks, basking sharks (*Cetorhinus maximus*), and three species of thresher sharks: common thresher (*Alopias vulpinus*), bigeye thresher (*A. superciliosus*), and pelagic thresher (*A. pelagicus*). Center scientists are studying the sharks’ biology, distribution, movements, stock structure, population status, and potential vulnerability to fishing pressure. This information is provided to international, national, and regional fisheries conservation and management bodies having stewardship for sharks. Some of the recently completed and ongoing shark research activities being carried out at the SWFSC are discussed below.

Abundance Surveys – The blue, shortfin mako, and thresher sharks are all taken in regional commercial and recreational fisheries. Common thresher and mako sharks have the greatest commercial value and are also specifically targeted by sport fishers, especially off Southern California. Although the blue shark is targeted in Mexico, it has little market importance in the U.S. but is a leading bycatch species in the CADGN and high-seas longline fisheries. Although

catches of adult blue, thresher, and shortfin mako sharks do occur, the commercial and sport catch of these species off Southern California consists largely of juvenile sharks.

To track trends in the abundance of juvenile and subadult blue and shortfin mako sharks and neonate common thresher sharks, surveys are carried out in the SCB each summer. Efforts to determine abundance trends from commercial fishery data have been complicated by changes in regulations, targeted areas, and fishing methods over time. These changes have resulted in inconsistent capture rates and catch distributions that are difficult to interpret. Therefore, fishery-independent sampling was initiated, with slightly different survey strategies required depending upon the species.

Offshore longline surveys from relatively large research vessels have proved most effective for sampling and estimating abundance trends of the more oceanic shortfin mako and blue sharks. For mako sharks, the surveys have enabled the SWFSC to obtain a valuable abundance index, which can be linked to a historical time series of logbook and landings data from a former experimental shortfin mako longline fishery in the SCB that occurred during 1988-1991. Abundance trend information is also obtained for the blue shark, which is compared to that obtained by observers of the CADGN and U.S. and Japanese high-seas longline fisheries.

Surveys for neonate thresher sharks are conducted using a small commercial longline vessel. Initial studies demonstrated that neonate threshers are rarely encountered in waters deeper than about 90 m. Therefore, surveys are conducted in the shallower nearshore waters between Point Conception, California, to the north and the U.S.-Mexico border to the south. The primary purpose of the surveys is to produce a relative abundance index for the West Coast population by periodically sampling 0-year pups (neonates) in their nursery grounds off Southern California. Representative areas were initially identified and are now sampled annually. The resulting neonate index of abundance should mirror adult abundance because adult population and recruitment should be tightly linked in K-selected species such as sharks. This study complements the fishery-dependent data available through the nearshore small mesh net fisheries and offshore CADGN fishery to provide measures of relative abundance of common thresher sharks for stock assessment models.

Juvenile Mako and Blue Shark Survey – In 2011, the SWFSC conducted its eighteenth juvenile shark survey for mako and blue sharks since 1994. The annual abundance survey was completed between 24 June and 13 July 2011. Working aboard F/V *Ventura II*, a team of scientists and volunteers fished a total of 5,493 hooks during 27 daytime sets inside seven focal areas within the SCB. Survey catch totaled 61 shortfin makos, 49 blue sharks, 5 pelagic rays (*Pteroplatytrygon violacea*), 4 opah, and 1 common mola (*Mola mola*). The preliminary data indicate that the nominal survey catch rate was 0.28 per 100 hook-hours for shortfin mako and 0.22 per 100 hook-hours for blue sharks. The nominal CPUE for both blue and shortfin mako sharks were slightly higher than for the previous year. However, while more detailed analyses are needed, there is a declining trend in nominal CPUE for both species over the time series of the survey (Fig. 4).

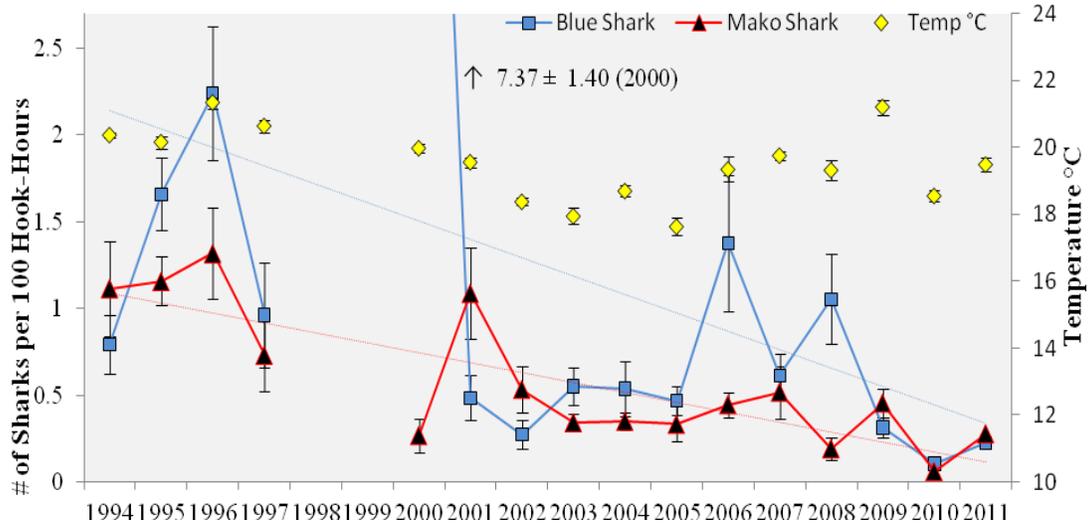


Figure 4. Average (\pm standard error) catch and temperature per survey set for shortfin mako and blue sharks, 1994 – 2011. No data were collected in 1998 and 1999. Blue shark catch per 100 hook-hours was 7.37 in 2000.

Additional research projects were also conducted after the shark survey was completed. The ship re-deployed 21–30 October 2011. The first goal of the final leg was to develop and test the potential for setting a longline deep during the day in order to catch and tag swordfish to study their fine-scale habitat-use patterns. The second goal was to troll for small tunas to deploy archival tags and collect biological samples. Eleven deep longline sets and many hours of trolling were conducted in an area west of Point Conception and offshore up to Central California. All fish caught were documented and released with or without tags or retained for biological sampling. Three swordfish were caught and one was tagged with a satellite tag. Two opah were also tagged. The three species that comprised the majority of the catch were blue sharks ($n=105$), albacore ($n=25$, 23 of which were caught while trolling), and opah ($n=10$). A total of 97 blue sharks were tagged with conventional tags. A number of rare deepwater species, such as the king-of-the-salmon (*Trachipterus altivelis*), were also caught.

During the combined summer and fall HMS cruise, 48 longline sets and over 30 hours of trolling were completed. A total of 474 fish were caught. Ancillary sampling, including trolling, resulted in 353 captures, which was nearly 75% of the total catch. Many of the captures outside of survey blocks were juvenile blue sharks caught near the Mexican border ($\sim 32^{\circ}\text{N}$, 118.2°W). In 2011, 14 opah were caught, in comparison to 16 in 2010 and 8 in 2009. Prior to 2009, only one other opah had been recorded during a longline survey cruise, in June of 2000. A total of 366 conventional spaghetti tags were released on sharks for movement and stock structure data. A total of 452 DNA samples were collected, including samples from 315 blue sharks, 68 shortfin makos, 25 albacore, 12 opah, 9 skipjack, 7 bluefin tuna, 4 Pacific pomfret (*Brama japonica*), 4 lancetfish, 3 king-of-the-salmon, 3 pelagic rays, 3 swordfish, and 1 common thresher.

In a cooperative effort with TOPP (Tagging of Pacific Pelagics), a total of 7 electronic tags were deployed on sharks to examine the habitat-use patterns in the California Current System. Two shortfin mako sharks (182 and 235 cm FL) and four blue sharks (161, 164, 169, 171, and 226 cm FL) were released with radio position transmitting (SPOT) tags (see below).

Neonate Common Thresher Shark Survey – In 2011, the SWFSC team conducted the survey aboard the F/V *Outer Banks*. Forty-seven longline sets were made in relatively shallow, nearshore waters and a total of 4,800 hooks were fished during the 18-day cruise. A total of 556 fish including a range of species were sampled during the survey. Three hundred and ninety-one (391) common thresher sharks were tagged with conventional tags for movement and stock structure data and 409 DNA samples were collected.

The preliminary survey data indicate that the average nominal catch rate by set was 5.57 per 100 hook-hours for common thresher sharks. This is the highest catch rate since the inception of the sampling program. The distribution of common threshers is very patchy and areas of high abundance are not consistent across years. In all years, a large percentage of the catch has been neonates, which were found in all areas surveyed. In addition to providing important information on abundance and distributions, the thresher shark pre-recruit survey enhances other ongoing research at SWFSC, including age and growth, feeding, and habitat utilization studies.

Electronic Tagging Studies – Since 1999, NOAA (National Oceanic and Atmospheric Administration) has been using satellite technology to study the movements and behaviors primarily of blue, shortfin mako, and common thresher sharks, while other species are tagged opportunistically. In recent years, shark tag deployments have been carried out in collaboration with Mexican colleagues at CICESE (Centro de Investigación Científica y de Educación Superior de Ensenada), and Canadian colleagues at the DFO Pacific Biological Station in Nanaimo, British Columbia, and the TOPP program (www.topp.org). The goals of the projects are to document and compare the movements and behaviors of these species in the California Current and to link these data to physical and biological oceanography. This approach will allow us to characterize the essential habitats of sharks and subsequently to better understand how populations might shift in response to changes in environmental conditions on short or long time scales.

In 2011, 2 shortfin mako sharks, 5 blue sharks, and 2 basking sharks were tagged with either SPOT tags or towed GPS tags. Since 1999, a total of 97 makos, 90 blue sharks, 28 common threshers, 2 hammerheads, and 3 basking sharks have been satellite tagged through collaborative projects.

SPOT tags continue to provide excellent information on the movements of blue and mako sharks, and we now have a decade worth of data for both species. Of the 5 tags deployed on blue sharks, those deployed on smaller sharks (~165 cm FL) lasted for an average of 62 days whereas the tag deployed on a large male (226 cm FL) lasted for almost 6 months. With the large amount of data obtained from SPOT tags, we can begin to look at large-scale patterns and whether there is habitat separation based on sex or size as is seen in the central Pacific. Figure 5 shows the tracks from male and female blue sharks. Both sexes spend considerable time in the California Current, with the females possibly extending farther to the north and south. When offshore, generally, the females move south into the subtropical convergence zone whereas the males make more westerly migrations. There is some suggestion in two of the longer tracks that the males may return to the California Current in subsequent years. Both habitat separation by sex and site fidelity have implications for the management of blue shark populations. For example,

fidelity to specific areas is increasingly recognized in fish from swordfish to salmon sharks (*Lamna ditropis*) and increases the potential for regional local depletion where fisheries exist.

For mako sharks, 5 tags were still transmitting in early 2012. Two of these were deployed in 2009, 1 was deployed in 2010 and the remaining 2 tags were deployed in 2011. The SPOT tags continue to be an excellent tool for studying the movements of mako sharks and the multiyear records provide an incredible opportunity to examine seasonal movement patterns and regional fidelity. For the two tags deployed in 2009, both returned for the third year in a row to the same destination. The large female (205 cm FL at tagging) traveled southeast of Hawaii and the 174 cm FL male traveled into the Sea of Cortez (Fig. 6.). Additional analyses are needed to determine (1) how patterns link to sex and size, (2) what triggers the onset of migration, and (3) what characterizes the ultimate destinations. As with blue sharks, this type of regional site fidelity has important implications for management.

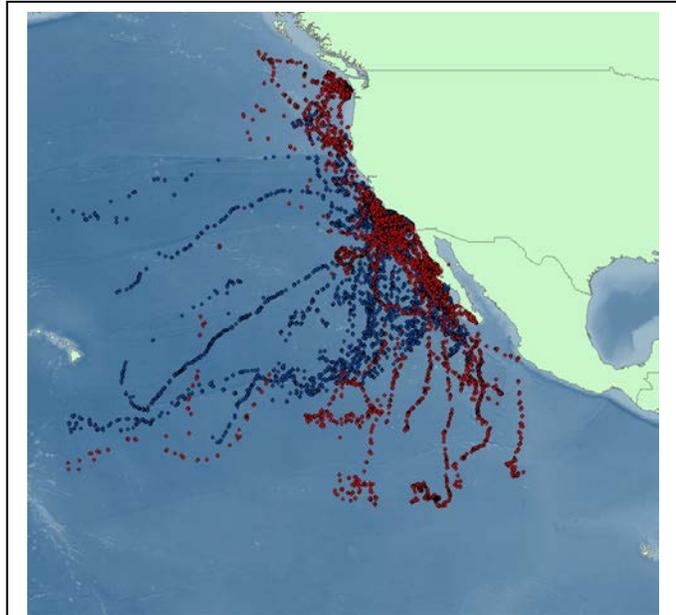


Figure 5. Comparison of the tracks of blue sharks for males (blue) and females (red) over the course of the study.

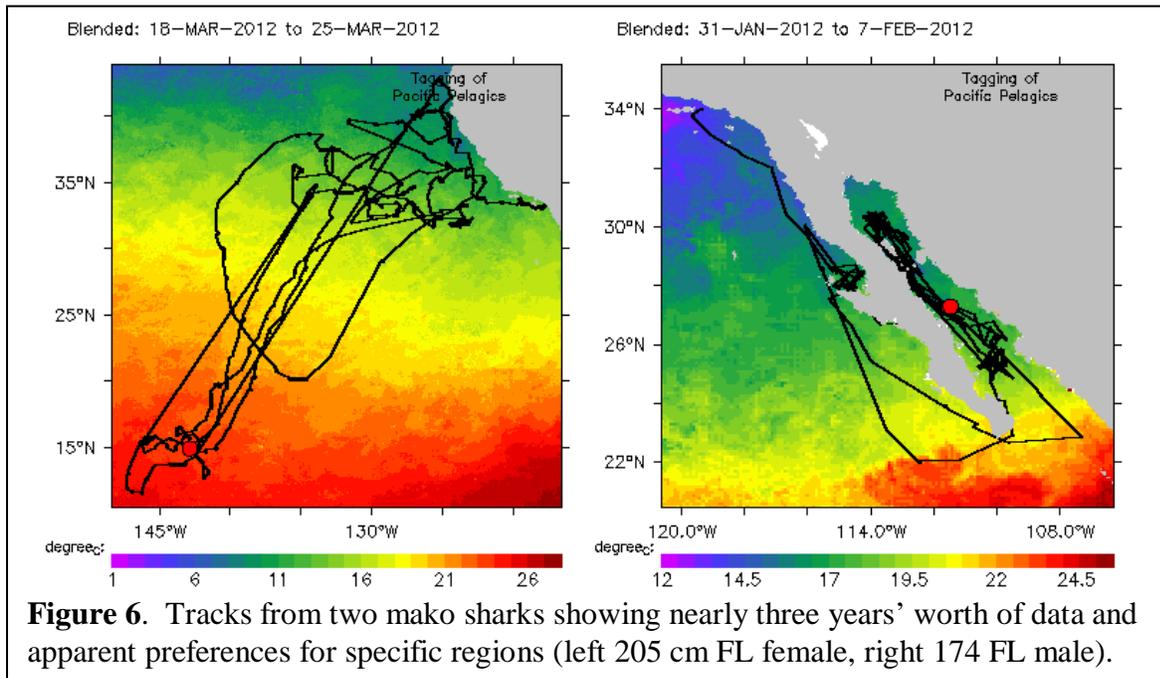


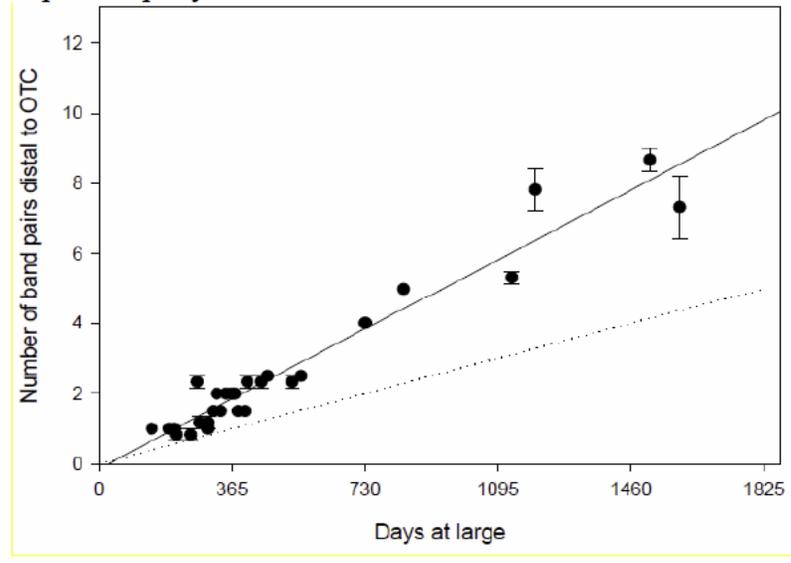
Figure 6. Tracks from two mako sharks showing nearly three years' worth of data and apparent preferences for specific regions (left 205 cm FL female, right 174 FL male).

Age Validation Studies – Age and growth of mako, common thresher, and blue sharks are being estimated from band formation in vertebrae. In addition to being important for studying basic biology, accurate age and growth curves are needed in stock assessments. SWFSC scientists are validating aging methods for these three species based on band deposition periodicity determined using oxytetracycline (OTC). Our annual research surveys provide an opportunity to tag animals with OTC. When the shark is recaptured and the vertebrae recovered, the number of bands laid down since the known date of OTC injection can be used to determine band deposition periodicity. Since the beginning of the program in 1997, 2,463 OTC-marked individuals have been released during juvenile shark surveys. Sharks tagged include 987 shortfin mako, 918 common thresher, 539 blue, 16 silky (*Carcharhinus falciformis*), and 3 pelagic thresher sharks.

Oxytetracycline Age Validation of Juvenile Shortfin Makos – The purpose of this study was to validate vertebral band counts for ageing juvenile shortfin mako and to resolve the discrepancy between the fast observed growth rates and the much slower growth predicted by age-at-length models that assume that only one band pair is deposited per year. OTC-labeled vertebrae of 29 juvenile shortfin mako were obtained from tag-recapture activities. Time at liberty for the 29 sharks ranged from 4 months to 4.4 years (mean=1.3 years). Growth information was also

obtained from length frequency modal analyses (MULTIFAN and MIXDIST) using a 29-year dataset of commercial and research catch data, in addition to tag-recapture growth models (GROTAG) using lengths and time-at-liberty. For samples used for age validation, shark size at time of release ranged from 79 to 142 cm FL and from 98 to 200 cm FL at recapture. Results from band counts of vertebrae distal to OTC marks indicate two band pairs (2 translucent and 2 opaque) are formed per year for shortfin mako of the size range examined (Fig. 7). In addition, total band pair counts at length compared well with results of a similar study in this region, suggesting vertebral readings were similar, and only assumptions about deposition rate differed. Growth rates calculated from length frequency modal analyses estimate 26.5 to 35.5 cm per year for the first age class mode (85 cm FL), and 22.4 to 28.6 cm per year for the second age class mode (130 cm FL). In addition, the GROTAG model also resulted in a rapid growth rate during time at liberty for tagged fish of the two youngest age classes with estimates of 28.7 and 19.6 cm FL per year at 85 and 130 cm FL, respectively. Collectively, these methods suggest rapid growth of juvenile shortfin mako in the

Figure 7. Number of band pairs between OTC mark and outer edge of shortfin mako shark vertebrae relative to the number of days at large. Average readings are based on three independent readers (± 1 standard error). Solid line shows the expected number of band pairs if two band pairs are deposited per year versus the dotted line for one band pair deposited per year.



SCB and suggest biannual deposition in vertebrae. An analysis of juvenile mako shark band deposition patterns is now complete and a manuscript has been drafted.

Foraging Ecology of Shortfin Mako, Blue and Common Thresher Sharks – The California Current is a productive eastern boundary current that is an important nursery and foraging ground for a number of highly migratory shark species. As mentioned above, three of the most abundant juvenile sharks in the California Current are the shortfin mako, blue and common thresher sharks. To better understand niche separation and the ecological role of these overlapping species, stomach content analyses have been ongoing at the SWFSC since 1999. Stomachs are obtained primarily from the CADGN observer program.

A synthesis comparing the foraging ecology of shortfin mako, blue and common thresher sharks was recently published in the journal *Environmental Biology of Fishes* (Preti et al., 2012). In this study, stomach contents of sharks collected from 2002 to 2008 were identified to the lowest taxonomic level and analyzed using univariate and multivariate methods. Of 330 mako sharks sampled, 238 stomachs contained 42 prey taxa, with jumbo squid, and Pacific saury (*Cololabis saira*) representing the most important prey based on the geometric index of importance (GII). Of the 158 blue sharks sampled, 114 stomachs contained 38 prey taxa, with jumbo and *Gonatus* spp. squids representing the most important prey. Lastly, 225 thresher sharks were sampled and 157 stomachs contained 18 prey taxa with northern anchovy and Pacific sardine (*Sardinops sagax*) identified as the most important prey. Overall, mako sharks had the most diverse diet, feeding on many species of teleosts and cephalopods, followed by blue sharks, which consumed a wide range of prey (primarily cephalopods), while thresher sharks were most specialized, feeding primarily on coastal pelagic teleosts. Despite similarities in habitat, the diets of these three common shark species are distinct in the California Current, indicating niche separation.

The data on shark foraging ecology were also used to develop a new approach for characterizing habitat use and improving our understanding of ecological interactions. We introduce a resampling method to indirectly estimate foraging habitat based on diet data and knowledge of prey habitat use. The method is unique in that (1) it is based on resampling by bootstrapping; and (2) it does not require quantitative prey distribution information. For this study, we combined diet data with qualitative prey distribution information for six different habitats segregated by depth and distance from shore. The combined data were organized into various matrices and resampled by bootstrapping to create an estimate of predator distribution based on prey habitat occupancy. Our method indicates a significant difference in foraging habitat. Generally, blue sharks foraged more frequently in offshore habitats, thresher sharks foraged mostly in nearshore epipelagic habitats, and makos foraged both near- and offshore in epi- and mesopelagic habitats. The flexibility of the new method should allow for wide application, adding to the suite of possible indirect techniques available to infer foraging habitat use. The results of this research are being prepared for publication.

In addition to foraging ecology, we have started to investigate algal toxins (domoic acid) in thresher shark in the SCB. Thresher sharks forage near shore and feed on small schooling fish such as sardine and anchovy, making them prime candidates for exposure to domoic acid. Domoic acid was detected in stomach contents and blood samples collected from thresher sharks along the Southern California coast during September 2011. For stomach contents, 6 of 8

samples were positive, with values ranging from 4.5 to 44.6 ng/g. Stomach contents of sharks positive for domoic acid included market squid, Pacific mackerel, and Pacific sardine – species well known to harbor domoic acid. Blood samples were positive in 3 of 6 cases, with values ranging from 0.9 to 47.9 ng/g. The value of 47.9 ng/g is one of the highest reported concentrations of domoic acid measured in blood from a field-collected fish or animal. These levels are, however, far below what would be considered toxic to humans. The regulatory limit for domoic acid in shellfish is 20,000 ng/g. Our findings confirm that thresher sharks are exposed to domoic acid, and measurable levels of this toxin can occur in their blood stream. Further studies are needed to document domoic acid in muscle and the potential implications of measured concentrations for shark and human health.

Survival after Capture and Release – Common thresher, shortfin mako, and blue sharks are captured in both commercial and recreational fisheries in the California Current. The CADGN fishery is the commercial fishery which catches the greatest number of each of these species. While thresher and mako sharks are landed, almost all blue sharks are discarded. For thresher and mako sharks, regional recreational fisheries are growing in popularity. Recreational fishers are often only interested in the challenge of the fight and will frequently release their catch. The survival rate of sharks released both from the CADGN fishery and by recreational anglers is unknown. Reliable estimates of removals (i.e., mortality) are necessary in order to adequately assess the status of the stocks and determine the effects of the fisheries on their abundance.

Blue Sharks Released from the California Drift Gillnet Fishery – The CADGN fishery targets swordfish in the California Current. With the exception of ocean sunfish, blue sharks are caught in greater numbers than any other finfish species taken in this fishery. Nearly all blue shark are discarded at sea due to lack of market value. A 2009 analysis of the 1990-2008 observer data reveals that 32% of blue sharks captured were released alive, and an additional 5% were discarded with their disposition unknown. The remaining 63% were discarded dead.

In 2007, the SWFSC and the SWR began deploying PSAT tags on sharks released from the CADGN fishery to assess survivorship. The tags were programmed to pop off after 30 days. The goal was to tag sharks such that the sex ratio, range of sizes, and condition at release were comparable to those released from the fishery. As a part of the study, a set of criteria was developed to document the condition of all blue sharks released: good, fair or poor.

Since initiating the study in 2007, 12 blue sharks (100 to 200 cm FL, median 149 cm) have been tagged by fishery observers. Nine of these animals were male, one was female, and the sex of 2 animals was unknown. Three of the 12 sharks were released in “good” condition while the remaining 9 were released in “fair” condition. Satellite tag records suggest that all animals survived the acute effects of capture in the CADGN fishery. Temperature, depth, and movement data demonstrated behavior of blue sharks that was similar to that reported in other studies. One tag appeared to have been ingested by a predator after 17 days and regurgitated 3 days later.

To meet the goal of matching the general composition of the catch, additional tag deployments are necessary. In the fishery the sex ratio is roughly 60% male and 40% female, and from 2007 to 2010, 29% of blue sharks were released in poor condition. Of the sharks tagged to date, none have been in poor condition, the average size is larger than that observed in the fishery, and few

females have been tagged. Thus, tagging efforts during the 2010-2011 and 2011-2012 seasons were focused on smaller sharks, females, and animals released in poor condition. Tags were distributed among observers as widely as possible in an attempt to ensure deployment. However, due to the decreased effort and observer coverage, and the small numbers of blue sharks caught overall, particularly of the desired size, sex, and conditions, only one blue shark was tagged for this study during the 2011-2012 CADGN season. This shark was in fair condition and survived after release. The objectives for the 2012-2013 season will be to deploy more tags. Results to date suggest a 100% survival rate for male blue sharks released in fair or better condition.

Thresher Sharks Released from the Recreational Fishery – The SWFSC, SWR, and Pflieger Institute of Environmental Research are conducting a study to assess the post-release survival of thresher sharks caught by recreational anglers. During the first phase of the study, sharks were released after tail hooking, and results demonstrated that survivorship is low for sharks greater than 185 cm FL or enduring fight times exceeding 85 minutes. Those results were published in the journal Fisheries Research in 2010 (Heberer et al., 2010). The goal of the second phase of the study is to determine whether sharks that are released with trailing fishing gear survive.

Survivorship is being determined using PSATs deployed on sub-adult and adult common thresher sharks. To date, PSATs have been deployed on 8 common thresher sharks (132 to 175 cm FL, median 141 cm) captured using fishery standard techniques and released with trailing gear. Of the 8 sharks, 5 died within 24 hours, 2 sharks survived with the trailing gear, and one of the PSATs did not report. The remaining tags will be deployed during spring 2012.

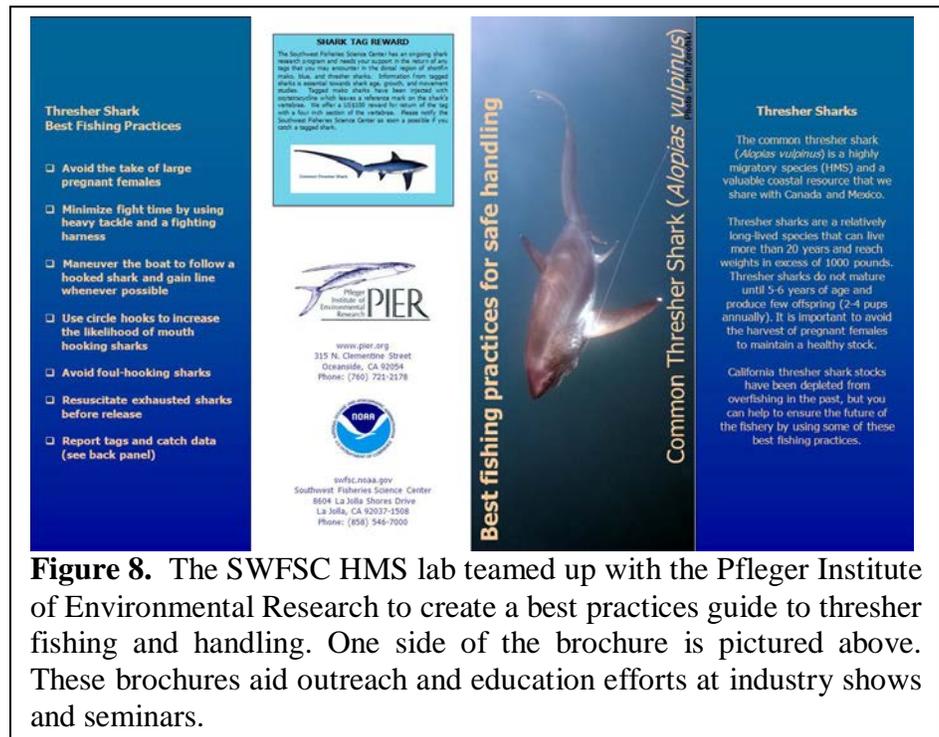


Figure 8. The SWFSC HMS lab teamed up with the Pflieger Institute of Environmental Research to create a best practices guide to thresher fishing and handling. One side of the brochure is pictured above. These brochures aid outreach and education efforts at industry shows and seminars.

In addition to the studies of survival, concurrent investigations on the effectiveness of degradable links and alternative fishing techniques to reduce tail hooking and trailing gear were also being performed to reduce overall post-release mortality in the recreational fishery. The results from all phases of this study will be used to estimate the survival rates and reduce the mortality of recreationally caught thresher sharks. A major component of this project is education and outreach to the recreational fishing community in order to promote fishing practices that enhance thresher shark catch and release survival (Fig. 8.).

Shark Stock Assessments – The SWSFC contributes to working groups of the PFMC and ISC. Starting in 2010, we began working with member nations of the ISC as well as scientific partners in Mexico and of the IATTC to conduct the first formal assessments of common thresher, blue and mako sharks in the North Pacific and EPO. These sharks are both fishing targets and incidental bycatch in numerous transboundary fisheries and their status requires long-term monitoring.

The first stock assessment is being conducted on thresher sharks. Thresher sharks occur along the coast of the U.S. and Mexico and are important to local commercial and recreational fisheries. While preliminary analyses suggest that the population is rebounding after declines in the early 1980s, no official stock assessment has been conducted and analyses to date have only included data from the U.S. A stock assessment will better reflect population level trends if data from the entire range are included. Preliminary analyses confirm previous indications that the stock biomass is increasing.

Basking Shark Research Program – The eastern North Pacific basking shark population appears to have declined dramatically in the last 50 years with no evidence of recovery. Where hundreds to thousands of individuals were observed off the U.S. West Coast in the early to mid-1900s, sighting even a few individuals is now rare. The apparent reduced abundance in the eastern North Pacific is likely linked to targeted fisheries off California in the first half of the 1900s and the eradication program established off Canada to keep basking sharks from destroying salmon nets. Due to concern about basking shark populations along the west coast of North America, the basking shark was listed as endangered in Canada and as a Species of Concern in the U.S. in 2010. Unfortunately, efforts to understand trends are hampered by the lack of basic data on movements, the influence of environment on abundance and distribution, information on the full geographic range of the eastern North Pacific stock, and basic life-history information. Given the severe data gaps for this population, the SWFSC initiated a basking shark research program in 2010 with SOC funding to (1) mine existing data for additional biological information, (2) conduct an electronic tagging study, (3) improve international data collection, and (4) improve national sightings information by developing a sightings website and an education and outreach program centered around Monterey Bay, California. Monterey is a historic basking shark hotspot where the California basking shark fishery in the early 1900s was based.

This research program has progressed at a number of different levels. A dedicated website (<http://swfsc.noaa.gov/baskingshark/>), email (basking.shark@noaa.gov), and hotline (858-334-2884) have been established as a part of a sightings network. Information on sightings will help with documenting patterns of occurrence and tagging efforts. We also developed a trilateral team with colleagues in Canada and Mexico to coordinate research efforts. The second meeting of the trilateral team took place in May 2011. In addition, we deployed two satellite tags on basking sharks off San Diego in the summer of 2011.

The use of satellite tags is critical for examining large-scale movement patterns and habitat use, which are essential for understanding patterns and trends in abundance. The first tag deployed in 2011 released early after 8 days and floated to a beach where the tag was recovered. No track was estimated for this tag given the short deployment duration. The second tag remained on the

shark for 8 months and popped up northeast of Hawaii. Using both the light-based and GPS locations, an estimated track between tag and release was obtained (Fig. 9). It appears that the second shark moved northwest from San Diego, shortly after being tagged, towards the Channel Islands then northward around Point Conception toward Morro Bay. This is the same area visited by a single shark tagged in 2010. In mid-August the shark moved offshore, ultimately finding an area off Hawaii where it remained for approximately three months before the tag popped off in February 2012.

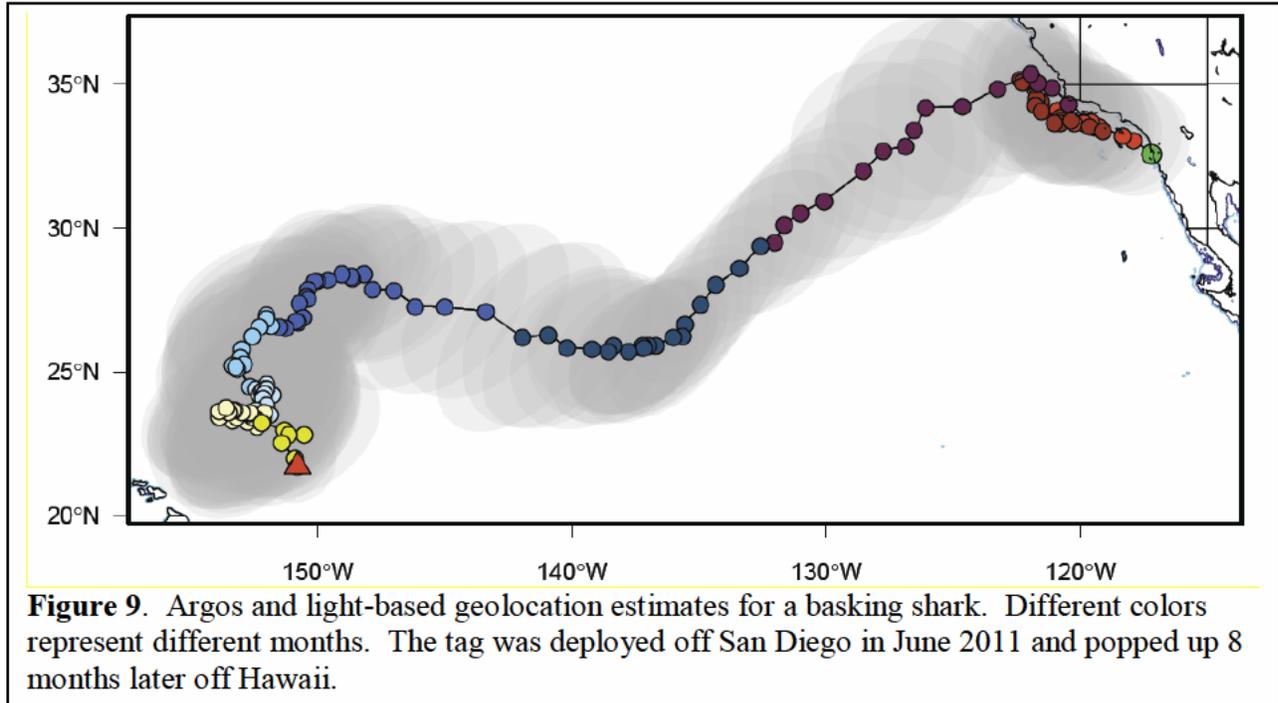


Figure 9. Argos and light-based geolocation estimates for a basking shark. Different colors represent different months. The tag was deployed off San Diego in June 2011 and popped up 8 months later off Hawaii.

The tagged basking sharks have shown distinct onshore-offshore patterns in vertical habitat use. Nearshore behaviors are characterized by high variability in vertical habitat use. At some times sharks remain in near surface waters while at other times they are deep in the water column. Diel patterns are also apparent during some periods but not others. This is in sharp contrast to their offshore behavior where vertical habitat use is quite consistent. Offshore they remain exclusively below the mixed layer and exhibit a deep vertical migration. For example, off Hawaii the daytime depths were about 500 m whereas nighttime depths were about 200 m. These depths are consistent with the diel migrations of the deep scattering layer in this area. The diversity of prey in the DSL raises the potential that, if their vertical behavior reflects foraging on the DSL, then offshore their diet may be more variable than near shore where they seem to target calanoid copepods. Basking sharks have shown impressive plasticity in vertical behaviors in this study as well as in the Atlantic. Dramatic shifts in behavior make estimating abundance based on aerial surveys and predicting overlap with fisheries challenging. Additional information on the patterns in vertical and horizontal movements is needed.

Genetic Analysis of Highly Migratory Species –

Shortfin Mako Shark – The shortfin mako is a commonly encountered shark in temperate marine fisheries but little is known about regional connectivity. Amber Michaud’s recent

master's thesis completed in collaboration with the University of San Diego and SWFSC provided evidence of regional stock structure within the Pacific. Her study, using mitochondrial haplotype data, showed a strong subdivision between northern and southern hemisphere populations, with additional subdivision between southeast and southwest Pacific populations; however, no subdivision was found in the North Pacific using this marker. The results of this study have been updated with additional samples collected in the western Pacific and are being prepared for publication. As part of his Ph.D. work at University of California Davis and San Diego State University in collaboration with the SWFSC, Dovi Kacev has been developing a suite of nuclear microsatellite markers to further refine the spatial and temporal resolution of shortfin mako stocks within the Pacific. In addition to studies of stock structure, these markers will be used to develop estimates of effective population size within the California Current region. Currently data generation and analyses are underway for the Pacific studies. These markers have also been shared with international collaborators and are currently being applied to global studies of shortfin makos.

Common Thresher Shark – Common threshers are commonly encountered in temperate coastal marine fisheries but little is known about regional connectivity. In recent years they have become part of an increasingly important recreational fishery in Southern California in addition to being an important component of local gillnet fisheries. In order to better understand population connectivity, Dovi Kacev has been developing nuclear microsatellite markers for this species as well. Application of these markers has begun and data collection is just beginning.

Opah – The opah or moonfish is found worldwide in tropical and subtropical waters. Though caught mainly as bycatch in pelagic tuna fisheries, opah command a high price in the market and thus few are discarded. Despite being known to science for over 230 years, the existence of two morphotypes in the North Pacific was only recently discovered by PIFSC port samplers in Honolulu. The most conspicuous difference between these morphotypes is the relative size of the eye, leading to the labeling of the morphotypes as “big-eye” and “small-eye” opah. Genetic analyses performed at the SWFSC confirm that the two morphotypes are genetically distinct and in fact represent separate species. In an effort to understand the distribution of these two species, additional samples have been acquired from museums and observer programs worldwide. Examination of these samples has provided evidence for additional cryptic species and suggests there are at least five species within the opah species complex. Genetic analyses, species descriptions, and distribution maps are being prepared for publication.

Outreach – In an effort to increase international collaboration and capacity building, a genetic species identification course was taught at the III Taller Interregional de Tiburones en el Océano Pacífico Oriental in Manta, Ecuador, 6-9 July 2010. This course involved hands-on experience using locally collected shark fins. The goals were to both genetically identify species groups that are commonly misidentified such as the hammerhead and thresher sharks, as well as species common in this region. Some of the techniques are now being applied to studies of shark landings in Columbia and the initial results and methods have been published in the journal *Molecular Ecology Resources* (Caballero et al., 2012).

VI. IDCPA RESEARCH

The SWFSC research conducted under the International Dolphin Conservation Program Act

(IDCPA) during 2011 was focused on evaluating line transect methodology and the potential roles of the fishery and ecosystem in the apparent lack of recovery of depleted dolphin stocks in the eastern tropical Pacific Ocean (ETP). This lack of recovery follows a period of significant reductions in observed dolphin mortality in the ETP tuna purse seine fishery. Research activities included (1) analysis of data collected during the 2007 survey designed to collect fine-scale ecosystem data and assess standard methods for collecting dolphin sighting data, and (2) other data analyses, processing, and publications.

Analysis of *Stenella* Abundance Research-Line Transect and Ecosystem Survey Data – In 2007, SWFSC conducted a *Stenella* Abundance Research-Line Transect and Ecosystem (STAR-LITE) cruise to survey marine mammals and their habitat in the ETP. The primary objective of the STAR-LITE cruise was to investigate line transect methods used on surveys in the ETP and to explore fine-scale spatial and temporal variability in the ecosystem using a multidisciplinary approach.

Two different cetacean survey methodologies (“passing mode” and “closing mode”) were compared using both empirical data and simulation models, and a manuscript has been published in the *Journal of Cetacean Research and Management* (Schwarz et al., 2010). Passing survey mode—when the survey ship does not make any changes in course to approach a cetacean sighting—was compared with closing survey mode—when such course changes are made to further investigate the sighting. The results of the analysis indicated that observers are able to identify animals to species less often and that estimates of dolphin group size are lower when surveys are conducted in passing mode (no course changes are made). However, conducting surveys in closing mode results in lower encounter rates due to the stop-start nature of the survey method. Continuing to explore potential sources of bias in our methods and explicitly accounting for these in our models is critical to refining our models and ultimately improving our approaches to estimating abundance of ETP dolphins and other cetaceans.

Ecosystem data collected on this same cruise (STAR-LITE 2007) have been analyzed. As expected, environmental variability within days and day-to-day was relatively small. However, the passage of tropical storm Kiko through the study area caused persistent changes in the entire ecosystem. Wind mixing decreased surface temperature and reduced fine-scale variability. The thermocline shoaled and stratification decreased. Chlorophyll in the surface layer increased, apparently due to both mixing of phytoplankton from depth and to enhanced production. Macrozooplankton biomass increased slowly, perhaps in response to the increased phytoplankton production. These environmental changes had a variety of effects on mid-trophic and apex predator components of the ecosystem. Changes in flying fish abundance and diet, and in the abundance and community composition of both seabirds and cetaceans are being investigated. A paper describing these results is in preparation.

This is the eleventh year of similar investigations conducted during the past 20 years, with previous cruises in 1986-1990, 1998-2000, 2003, and 2006. Using an ecosystem approach, we conducted research on physical and biological oceanography (dolphin habitat); mid-trophic-level fishes and squids (dolphin prey); and seabirds, marine turtles, and other cetaceans (dolphin commensals, competitors, and predators). Data and analyses resulting from STAR surveys form the basis for many international measures adopted to conserve dolphin stocks and manage the

tuna purse seine fishery in the ETP. The next full STAR survey, scheduled to occur in the fall of 2009, was postponed by one year due to ship time constraints. On 6 April 2010, STAR 2010 was again postponed due to the same constraints. And in January 2010, plans for conducting STAR in the fall of 2011 were canceled indefinitely. At this time, the future of these cetacean and ecosystem assessment cruises is uncertain.

Data Analyses, Processing, and Publication – The SWFSC’s investigations of dolphin stocks historically depleted by the ETP tuna purse seine fishery (spinner, *Stenella longirostris*, and pantropical spotted, *S. attenuata*, dolphins) are conducted with an ecosystem approach. In addition to investigating the status and trends of these dolphin stocks, auxiliary projects are conducted to improve our understanding of their surrounding environment. Data analyses, processing, and publications included (1) investigations of cetacean biodiversity hotspots; (2) identifying critical habitat for large whales; (3) ecosystem modeling; (4) assessment of relative fishery exposure for ETP dolphins; (5) variation and predictors of vessel response behaviors in ETP dolphins; (6) dolphin swimming kinematics research; (7) investigations of dolphin reproductive biology; (8) ETP dolphin population genetic structure; (9) investigations of the ETP ecosystem and its change over time; (10) metrics of ecosystem impact of the ETP purse seine fishery; and (11) cephalopods as indicators of spatial variation in biochemical properties between marine systems.

Investigations of Cetacean Biodiversity Hotspots – A paper was published (Kaschner et al., 2011) with Gerrodette as a co-author. This paper uses a model to predict cetacean species richness patterns, and validates the model with empirical data, including data collected in the ETP.

Ballance, Redfern, and Pitman are finalizing a manuscript investigating species richness hotspots for 28 species of cetaceans in the ETP (ca. 20 million km²) based on data collected using line transect methods aboard NOAA research vessels, August–November, in each of 10 years during a 21-year period (1986-2006). Density was calculated using species- and area-specific published values of $g(0)$ and $f(0)$, and interpolated throughout a 1° x 1° grid of the study area using two smoothing algorithms and two resolutions. Density was converted to presence/absence on a species-specific basis, and species richness (number of species recorded in a particular grid cell) was mapped for all years combined. Richness hotspots were defined as any grid cell that contained greater than 40% of the total species pool (≥ 11 species) and were clearly evident in three distinct regions: the Equatorial Front, the Costa Rica Dome, and waters to the southwest of the Baja California peninsula. Although these hotspots encompassed areas of highest density for a few species, the correlation between richness and density for any given species was generally low (mean 0.25, range 0.03 to 0.44), as was the proportion of cells where a particular species was present and encompassed by a hotspot (mean 20%, range 4% to 56%). These results were robust to smoothing algorithm and spatial resolution.

Identifying Critical Habitat for Large Whales – Many species of baleen whales migrate long distances between breeding and feeding areas. These species are exposed to anthropogenic threats in their feeding and breeding areas and along their migration routes; threats include entanglement in fishing gear, ship strikes, ocean noise, contaminants, and climate change. Mitigating these threats requires a transboundary, systematic planning approach. We are using

three species of baleen whales in the ETP to explore several components of the planning process. The ETP is seasonally occupied by migratory blue and humpback whales from both northern and southern hemispheres; it also hosts important numbers of resident Bryde's whales. We will use 10 years of large-scale survey effort in offshore waters to compare two methods for predicting species density: habitat models (using sea surface temperature, salinity, and chlorophyll, mixed layer depth, and sea floor depth as predictor variables) and inverse distance weighted interpolation of daily density estimates. Generalized additive models will be used to relate habitat variables to an effort-corrected estimate of the number of whales. Both methods will be used to derive a synoptic grid of density for blue, humpback, and Bryde's whales. For humpback whales, we will also predict the location of breeding areas using an envelope model of mother-calf sightings in coastal surveys off Mexico, Costa Rica, Panama, and Ecuador. Different metrics for delineating critical habitat (e.g., protecting a percentage of a population, protecting areas of known occurrence, or protecting known breeding or feeding areas) will be applied to the density grids for each species.

Ecosystem Modeling – Development of an ecosystem model to explore patterns of cetacean distribution, migration, feeding, and breeding has begun. Data fields used by Patrick Lehody (France) to drive a spatial ecosystem and population dynamics model (SEAPODYM) for tuna were obtained (temperature, salinity, currents, chlorophyll, primary productivity, and mid-trophic level biomass). Comparisons of SEAPODYM model data to data collected on SWFSC cetacean and ecosystem assessment surveys have been completed for the California Current and will be done for the ETP. The next step is to test whether the inclusion of mid-trophic level biomass improves cetacean habitat models. In the future, we will use these ecosystem variables to drive a population- or individual-based model of cetacean species to explain current ecological patterns and predict future changes.

Assessment of Relative Fishery Exposure for ETP Dolphins – For the past half century, the purse seine fishery for yellowfin tuna has been a significant factor in the lives of dolphins in the ETP. However, little is known about how frequently an individual dolphin is exposed to the fishery, and no methods are available for accurately assessing the prior exposure of dolphins encountered at sea. Archer et al. (2010) developed a method to estimate an index of exposure based on a model of dolphin movement derived from data collected from multiple tracking studies. Based on this movement model, the method weights purse seine sets given their distance from a particular school of dolphins sighted at sea and how long ago they occurred. The method also takes into account the species composition and school size in the set. In their paper, as a demonstration, the authors use the method to examine the spatial and temporal distribution of this index over an 11-year period for which we have detailed data on purse seine sets. While the method was designed for examining exposure to the ETP purse seine fishery, it is also applicable to studies of other anthropogenic effects where there is concern about exposure rates, such as underwater sound, pollution, or ship strikes. Planned studies for this index include examining its relationship to evasive behavior, calf production as assessed from aerial photographs, and reproductive rates as measured from skin biopsies.

Variation and Predictors of Vessel Response Behaviors in ETP Dolphins – Dolphins exhibit a range of vessel response behaviors, from those that readily approach and bow ride to others that are indifferent or actively evasive. However, the factors responsible for this variation have not

been examined. Archer et al. (2010) used a tree-based modeling method to investigate the influence of geography, time of day, species composition, and fishery exposure on the responses of five species of dolphins in the ETP, comprising 10 management stocks. Data were collected for 2,667 sightings during four research cruises between 1998 and 2003. The relative frequency of five responses (approaching the vessel, bow riding, running, school splitting, and low swimming) showed significant ($p < 0.0005$) variability among species, as well as stocks within the same species. Striped (*Stenella coeruleoalba*), whitebelly spinner (*S. longirostris*), and western-southern pantropical spotted dolphins (*S. attenuata attenuata*) tended to be evasive, while coastal spotted (*S. attenuata graffmani*) and common bottlenose dolphins (*Tursiops truncatus*) tended to be attracted to the vessel. There was a strong tendency of dolphins sighted offshore to be significantly more evasive than those less than about 100 nmi from the coast. The degree of evasiveness in stocks that are frequently targeted by the tuna purse seine fishery (northeastern spotted, *S. attenuata*; eastern spinner, *S. longirostris orientalis*; and short-beaked common, *Delphinus delphis*) was greater with more purse seine activity in the vicinity, while no significant relationship was found for those stocks that are rarely set on. For each stock, vessel response had a relatively unique suite of predictors, indicating an interplay of intrinsic, natural extrinsic and anthropogenic factors.

Dolphin Swimming Kinematics Research – In September 2011, the final paper was published in the series of studies investigating swimming kinematics of mother and calf dolphins. These studies are part of an effort to determine whether chase and encirclement of dolphin mother-calf pairs by tuna purse seiners in the ETP may be contributing to lack of population recovery. This paper (Noren et al., 2011) presents the first empirical analysis of the hydrodynamic effects of late pregnancy on swimming kinematics of female dolphins. Study results show that morphological changes during late pregnancy, particularly the large increase in frontal cross section as well as the decreased amplitude of propulsive movements by the flukes, lead to significant decreases in swim performance during this period. Results from this series of studies will contribute to development of a hydrodynamics-based energetics model investigating the potential for dolphin mother-calf separation and subsequent calf mortality due to tuna purse seine chase in the ETP.

Investigations of Dolphin Reproductive Biology – A doctoral dissertation (Kellar et al., 2008) was completed examining the pregnancy patterns of spotted dolphins in the ETP. This work has been revised and submitted to Marine Ecology Progress Series for review. It states that one hypothesis for the lack of recovery of the spotted dolphin population in the ETP is that continued chase and encirclement by the tuna fishery negatively affects reproduction.

Insufficient life history sampling in this region over the last decade makes traditional estimation of population reproductive rates impossible. The current reproductive patterns of these dolphins were examined using a molecular method to assess pregnancy state from blubber progesterone concentrations in biopsy samples. Blubber progesterone was quantified in 212 biopsies from female offshore spotted dolphins sampled between 1998 and 2003 in the northeastern tropical Pacific. These concentrations were found to be sharply bimodal with no value observed between 49 ng/g and 87 ng/g, a finding consistent with the concentration gap between known pregnant and non-pregnant dolphins. Given that high blubber progesterone (≥ 87 ng/g) indicates pregnancy, we found that 11.8% of the biopsied females were pregnant. This is substantially lower than an estimate of the proportion pregnant found in the fishery kill over the same region

(22.3%) between 1973 and 1992. To try to ascertain the potential cause of this discrepancy, the relationship between pregnancy and fishery exposure was analyzed, and we found that pregnant females were exposed to significantly less fishery activity than non-pregnant ones ($P < 0.046$), suggesting that the fishery has an inhibitive effect on pregnancy. However, there are several caveats to this finding, and how this relationship might explain the discrepancy between these data sets is unclear. We also examined and modeled spatial patterns of reproduction and found that pregnancy was more aggregated than random ($P = 0.020$), with the highest proportion pregnant in the mouth of the Gulf of California, an area with relatively low reported fishery activity.

In 2009, work began quantifying the levels of progesterone in spinner dolphins to replicate this study in another fishery-impacted species. To date, 189 animals have been processed; hormones have been measured and pregnancy determination is complete. The next step is to analyze and add a spinner dolphin-specific fishery exposure index to these data and assess the relationship between reproduction and exposure.

ETP Dolphin Population Genetic Structure – Research is underway to determine population genetic structure for spotted and spinner dolphins in the ETP. Cranial and external morphology, as well as reproductive strategies, differ across the range of these animals; thus, genetic differences are expected. Population structure information is needed to develop accurate stock abundance estimates for population-specific dolphin bycatch limits.

In 2011, work began quantifying the levels of genetic structure in spinner and spotted dolphin populations in the ETP. Matthew Leslie (Ph.D. student at Scripps Institution of Oceanography) has collected DNA sequence data for a subset of biopsy samples ($n=250$) using high-throughput DNA sequencing. These data include 80 nuclear loci (84Kbp) and entire mitochondrial genomes (16Kbp). The mitogenomic data are currently being analyzed using an integrated phylogenetic and population genetic framework to characterize variability and structure. Additional samples are being sequenced from throughout the spinner dolphin distribution in order to place these populations within a global phylogeographic context. Nuclear DNA data have been used to develop single nucleotide polymorphism (SNP) assays that will be employed in genotyping additional modern and historical specimens.

The next step is to analyze the mitogenomic data and collect additional nuclear SNP genotypes using the assays developed. Additional sampling of museum specimens may be required.

Investigations of the ETP Ecosystem and Its Change over Time – An analysis of variations in thermocline depth and stratification in the eastern tropical and North Pacific has been accepted for publication, pending revision, in the *Journal of Climate* (Fiedler et al., 2012). Time series from 1958-2008 were decomposed into seasonal, interannual cycle, and long-term trend components using state-space techniques. On shorter time scales, interannual variations related to the El Niño-Southern Oscillation (ENSO) are seen. Long-term regional variability is observed, either a monotonic trend or with one or more change points resembling climate regime shifts. Such changes in upper-ocean structure and associated ecosystem effects are well known in well-monitored regions such as the California Current. In the eastern equatorial Pacific, the pycnocline has shoaled but become less stratified, while in the ETP warm pool, pycnocline depth

and stratification has varied up and down with little overall change. The thermocline influences nutrient input to surface waters, which limits primary productivity throughout this region. Potential ecosystem effects of the observed long-term trends are discussed. Further analysis will quantify the extent to which interannual cyclic variability observed at higher latitudes, for example in the California Current, is related to ENSO.

Vilchis and Ballance completed a retrospective study analyzing trophic level of seabirds in the eastern Pacific warm pool during the past 50 years. They set out to gauge effects of the 1976-77 regime shift of the Pacific Ocean in a tropical and pelagic community of seabirds. Using study skins of historical specimens from museum collections, they retrospectively (1960-2006) measured stable carbon ($\delta^{13}\text{C}$) and nitrogen ($\delta^{15}\text{N}$) isotopes for a suite of ecologically and phylogenetically diverse seabirds from the eastern Pacific warm pool. In this region, seabirds generally forage by depending on subsurface predators to drive prey to the surface or by associating with oceanographic features that increase productivity or aggregate prey in space or time. They did not find community-wide changes in response to the 1976-77 regime shift. Instead, they found evidence suggesting a trophic shift and or change in foraging area for sooty terns (*Onychoprion fuscatus*) and a long-term decrease in feather $\delta^{13}\text{C}$ for the eastern Pacific warm pool seabird community. This long-term decrease in feather $\delta^{13}\text{C}$ can be accounted for by the Suess effect and not a decline in primary productivity of the system. Vilchis and Ballance hypothesize that a deepening trend in thermocline depth in the eastern Pacific warm pool is affecting sooty terns more so than other species in the subsurface predator-dependent guild which depend less on smaller subsurface predators like skipjack tuna. The manuscript of this study is currently in revision.

Metrics of Ecosystem Impact of the ETP Purse Seine Fishery – A manuscript was recently published (Gerrodette et al., 2012) that summarizes the ecological effects of the ETP purse seine tuna fishery by measuring the total removals (target catch and bycatch) using a variety of metrics. It was found that floating-object sets removed 2-3 times as much biomass per set as dolphin or unassociated sets. However, the three types of purse seine fishing differed in the composition and amount of both target catch and bycatch. Metrics of ecosystem removal which measured diversity, trophic level, and replacement time were more informative than metrics of biomass or numbers of individuals.

Cephalopods as Indicators of Spatial Variation in Biochemical Properties between Marine Systems – Ruiz-Cooley et al. (2010) and Ruiz-Cooley and Gerrodette (in review) quantified two biochemical tracers ($\delta^{13}\text{C}$ and $\delta^{15}\text{N}$) from epi-mesopelagic squid tissues, the jumbo squid and purple back squid (*Stenoteuthis oualaniensis*), to investigate ontogenetic shifts in diet, habitat use and differentiate distinct groups or subpopulations based on the unique biochemical properties of their habitat along the eastern Pacific. These two squid species are key components in food webs from the ETP and potential prey of tuna and dolphins as well as other pelagic fish and odontocetes. For the first time, Ruiz-Cooley and Gerrodette revealed that $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ measured from tissues of these squid species can serve to track large-scale latitudinal, longitudinal, and geographic variability in the biochemical distribution of carbon and nitrogen along the eastern Pacific. Furthermore, the results from this study can serve for future studies using stable isotope analysis investigating pelagic food web dynamics, which are not well known.

Challenge against the U.S. Dolphin-Safe Labeling Standard for Tuna – In October 2008, Mexico filed a request for World Trade Organization (WTO) dispute settlement consultations with the United States. Mexico made several claims that U.S. dolphin-safe measures are inconsistent with various aspects of the Agreement on Technical Barrier to Trade and the General Agreement on Tariffs and Trade. Specifically, Mexico argued the U.S. measures:

- create a competitive disadvantage for Mexican tuna products;
- are more trade restrictive than necessary to achieve their objectives – specifically, to inform consumers and ensure the U.S. market is not used to encourage fishing practices that adversely affect dolphins; and
- could be replaced by a less trade restrictive alternative labeling standard that allows tuna that is caught by chasing and encircling dolphins to be labeled as dolphin-safe as long as no dolphins are observed killed or seriously injured, and that still meets the U.S. objectives.

In support of these arguments, Mexico claimed that (1) ETP dolphin stocks are recovering, (2) there is no evidence that the fishery is impacting dolphins beyond observed kills, (3) there is an inconsistency between the standards that apply to tuna inside and outside the ETP, assuming that dolphin bycatch and intentional chase and encirclement of dolphins occurs in tuna fisheries outside the ETP, (4) catching tuna in association with dolphins is better for tuna stocks and the ecosystem because it results in primarily mature yellowfin with less bycatch of non-target species than other tuna fishing methods, and (5) U.S. consumers are actually unclear on the current dolphin-safe definition, so the U.S. measures fail to meet the objective of not misleading tuna consumers.

In briefs and oral arguments the United States cited the fundamental difference in tuna-dolphin associations inside and outside the ETP as a basis for its labeling scheme and relied heavily on results from its IDCPA research program and decades of prior SWFSC research and monitoring in the ETP to refute Mexico's claims. Specifically, the United States cited several published papers that indicate when using ecologically meaningful metrics fishing on dolphins is not obviously better than other methods of catching tuna and that indicate ETP dolphin stocks are not increasing at a rate consistent with recovery and that there is substantial evidence to support the hypothesis that unobserved impacts of intentional chase and encirclement (e.g., mother-calf separation and lower calf production in areas of greater purse seine fishing effort) are impeding recovery.

A panel was established to consider Mexico's claims. A panel report was made public on 15 September 2011, rejecting most of Mexico's claims. The panel found that the objectives of the U.S. measures are legitimate, that the measures do not treat Mexico's tuna products any less favorably than tuna products from the United States or other WTO members, and that any adverse effects felt by Mexican tuna producers from the U.S. labeling requirements are the result of choices made by Mexico's own fishing fleet and canners. However, the panel also found the U.S. measures to be more trade restrictive than necessary to achieve the objectives of the measures.

Following issuance of the panel's report, both Mexico and the United States appealed the WTO

panel's findings to a WTO Appellate Body. Decisions on those appeals are expected in 2012.

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