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# THE SWFSC DIRECTOR'S 2013 REPORT ON RESEARCH REGARDING HIGHLY MIGRATORY SPECIES (HMS) AND THEIR FISHERIES IN THE NORTH PACIFIC OCEAN

by

The Southwest Fisheries
Science Center

ADMINISTRATIVE REPORT LJ-14-03

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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. This section includes brief descriptions of some of the contributions and activities during the past year, May 2012–April 2013.

**Monitoring U.S. HMS Fisheries –** SWFSC scientists monitor eight U.S. HMS fisheries in the Pacific, providing information from these fisheries to HMS researchers and fisheries managers in support of the conservation and management of HMS stocks in the Pacific. Information on vessels, gears, effort, catch, bycatch, protected species interactions, landings, biological sampling, and observer data are compiled and managed by the fisheries monitoring group under the Fisheries Resources Division (FRD). This information is routinely summarized and data products are provided to researchers and fisheries management organizations as well as other customers. Fisheries monitoring staff collaborate with staff from other National Marine Fisheries Service (NMFS) regional science centers, regional offices, headquarters, fisheries councils, commissions, and others to collect and share information from HMS fisheries in the Pacific.

The purse-seine fishery, operating in the western-central Pacific Ocean (WCPO), is the largest of these eight monitored HMS fisheries. The fishery harvests over 200,000 metric tons (t) of tropical tunas each year, generating millions of dollars in ex-vessel revenue. SWFSC staff manage the data from the WCPO purse-seine fleet as part of U.S. obligations under the South Pacific Tuna Treaty (SPTT). The purse-seine fishery in the eastern Pacific Ocean (EPO), which was historically a large-vessel fleet fishing throughout the tropics, has dwindled to a few smaller coastal purse-seine vessels that occasionally target albacore (*Thunnus alalunga*) and bluefin tuna (*Thunnus orientalis)* in southern California waters. The north Pacific albacore surface (troll/pole and line) fishery is the largest HMS fishery based on the West Coast. This fishery began in the 1940s and has expanded and contracted over the decades from southern California and Baja waters to the international dateline, to the southern Pacific Ocean in the austral summer months (creating an entirely new fishery in 1986) and most recently back to the coastal waters off Washington and Oregon. The large-mesh drift gillnet fishery off of California targets swordfish and thresher sharks. The California harpoon fishery targets swordfish. The longline fishery that targets swordfish and tunas used to be based out of California, but most vessels have since relocated to Hawaii. The recreational fisheries that target HMS are composed of private and commercial passenger vessels that target albacore off of Washington and Oregon, and albacore, bluefin, and yellowfin tunas in southern California waters. The 2012 total landed catch for the HMS fisheries that the SWFSC FRD staff monitors is shown in Table 1 below.

**Table 1**: Landed catch in the U.S. HMS fisheries. Catches cannot be reported for fisheries for which fewer than 3 vessels participated.

| FISHERY | 2012 CATCH IN METRIC TONS | NUMBER OF VESSELS |
|---|---|---|
| Central Western Pacific Ocean (WCPO) Purse Seine | 259,760 | 39 |
| North Pacific Albacore Troll and Pole-and-line | 14,137 | 816 |
| South Pacific Albacore Troll | 198 | 7 |
| Eastern Tropical Pacific (ETP) Purse seine | | < 3 |
| California Large-mesh Drift Gillnet | 97 | 17 |
| California Harpoon | 21 | 9 |
| Longline (California-based) | | < 3 |

***North Pacific Albacore Troll and Pole-and-line–*** Total annual catch of the North Pacific albacore troll and pole-and-line fishery (a.k.a. albacore surface fishery) in 2012 totaled 14,137 t, an increase of 28% from 11,037 t in 2011. The number of vessels also increased from 641 vessels in 2011 to 816 vessels in 2012. The average weight of retained albacore in 2012 is 15.4 pounds compared to 16.3 pounds average weight in 2011. Logbook data from this and other HMS fisheries are required to be submitted to SWFSC under the HMS Fisheries Management Plan enacted by the Pacific Fishery Management Council in 2005. An electronic logbook computer application was made available to fishermen in this fishery in 2006. Each year between five and ten vessels utilize this electronic logbook program and submit their logbook data electronically. Efforts to update and improve this reporting option have been in progress for several years.

***South Pacific Albacore Troll–*** Participation in the South Pacific albacore troll fishery has decreased substantially in recent years relative to the 1980s and early 1990s, when greater than 50 vessels typically participated annually. Seven vessels participated in the 2012 fishery, compared to six vessels in 2011. Total catch in 2012 was 198 t, a decrease of 51% from the 402 t landed in 2011. No size sampling has been done in this fishery since 2007. In recent years, vessels from this fishery have sold their catches in French Polynesia and Canada.

***Purse-seine Fisheries (EPO and WCPO)–*** The U.S. has purse-seine vessels fishing in the EPO and WCPO. In the EPO, the purse-seine fishery has two components. Smaller coastal purse-seine vessels based out of southern California ports normally target mackerel, sardines, anchovies, and other coastal pelagic species and occasionally target albacore or bluefin tuna when schools are available during summer months. In recent years less than three of these vessels have fished for tuna. Larger purse-seine vessels based out of American Samoa target tropical tunas and fish mostly in the WCPO, but occasionally fish in the EPO. In 2012, 39 vessels caught 259,760 t of all species combined (yellowfin, bigeye (*Thunnus obesus)*, and skipjack (*Katsuwonus pelamis*) tunas) in the WCPO purse-seine fishery. In recent years very few of these vessels fished in the

EPO.

***California Large-mesh Drift Gillnet –*** The California large-mesh drift gillnet (CADGN) fleet decreased from 23 vessels in 2011 to 17 vessels in 2012. These vessels landed 121 t of swordfish caught in 2011 compared to 97 t of swordfish in 2012. FRD staff manage the gillnet logbook database (including set net and small-mesh drift gillnet) on behalf of California Department of Fish and Wildlife (CDFW). Data editing and data entry are done by staff from both offices. The NOAA Southwest Regional office (SWR) runs a fishery observer program to monitor ~20% of the fishery effort and conducts on-board size sampling.

***California Harpoon–*** The California harpoon fishery decreased from 17 vessels in 2011 to 9 vessels in 2012. These vessels caught 21 t in 2011 of swordfish compared to 5 t in 2012. No size sampling information is collected from this fishery. The logbook data from this fishery are also managed by SWFSC staff in cooperation with CDFW.

***Longline (California-based)–*** In recent years less than three longline vessels have operated out of Southern California. Most longline vessels targeting tunas and swordfish are based out of Hawaii. Logbook data from the west coast are submitted to the SWR and maintained at SWFSC. Data from this fishery are combined by the Pacific Islands Fisheries Science Center (PIFSC) for reporting.

***Recreational HMS Fisheries–*** The recreational catch of albacore by vessels that target albacore off the west coast increased from 415 t in 2011 to 902 t in 2012. Estimates for recreational catches of bluefin tuna are not available yet for 2012, but estimates for 2011 are 499 t.

***Miscellaneous Fisheries***– HMS caught incidentally in other fisheries are summarized from the PacFIN database where state landings data from marine fisheries are maintained. The major customers that require detailed information on U.S. HMS fisheries in the Pacific Ocean are three regional fisheries management organizations (RFMOs): the Western and Central Pacific Fisheries Commission (WCPFC), the Inter-American Tropical Tuna Commission (IATTC), and the International Scientific Committee for Tuna and Tuna-like Species in the North Pacific Ocean (ISC). SWFSC staff compile and summarize a wide variety of fisheries statistics and group these summaries by various time and space resolutions for submission to these RFMOs in order to fulfill the U.S. membership obligations. Statistics range from annual catch and bycatch estimates to size composition of the catches and estimations of fishing effort.

**Contributing to the Work of the ISC (Sarah Shoffler)** –The United States is a member of the ISC. Other members include 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 PIFSC. Results of the ISC are made available to participating

members and to RFMOs of the Pacific Ocean.

**Albacore Stock Assessment and Research** –The commercial surface albacore fishery is the most important fishery for HMS on the U.S. West Coast. In preparation for the upcoming stock assessment due in April 2014, SWFSC researchers attended an intercessional workshop of the ISC Albacore Working Group (ALBWG) in Shanghai, China, from 19-26 March 2013. The goals of this workshop were: (1) to review results of high priority research and develop proposals for incorporation into stock assessment process/model; (2) to discuss information and advice on biological reference points requested by the Northern Committee of the Western and Central Pacific Fisheries Commission (Northern Committee, 2012) and develop work plans and assignments to prepare WG responses for ISC Plenary review in July 2013; and (3) to discuss Chinese fishery data for north Pacific albacore with Chinese scientists. Matters related to the future work plans for the WG and the next stock assessment cycle, beginning in the fall of 2013, were also included on the agenda for this workshop. During the workshop, SWFSC researchers presented their work on understanding the influences on the observed population scaling of the previous north Pacific albacore stock assessment model.

**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. Nevertheless, there remains an important commercial fishery for Pacific bluefin tuna in Mexican waters. In November 2012, SWFSC researchers participated in the stock assessment of Pacific bluefin tuna as members of the ISC Pacific Bluefin Tuna Working Group (PBFWG).The assessment was conducted using fishery data through 2011 and a seasonal, length-based, age-structured Stock Synthesis (SS3) model. Based on this assessment, the Pacific bluefin tuna stock is considered to be overfished and overfishing continues to occur.

A total of 14 fisheries were defined for use in the stock assessment model based on country/gear stratification. Quarterly observations of catch and size composition (when available) were input into the model to describe the removal processes. Annual estimates of standardized catch per unit effort (CPUE) from the Japanese distant water and coastal longline, Taiwanese longline, and Japanese troll fleets were used as measures of the population's relative abundance. Life history parameters included a length-at-age relationship from otolith-derived ages and natural mortality estimates from a tag-recapture study. The assessment model was fit to the input data in a likelihood-based statistical framework.

The working group recognized uncertainties in the standardized CPUE series, weighting of data, and the methods used to estimate selectivity patterns. The influences of these uncertainties on stock dynamics were considered using alternative models and characterized by 20 trial runs. Extensive model runs were conducted using alternative data weightings and structural assumptions. While no single model provided a good fit to all sources of data that were considered reliable, the key model results from each model generally agreed. All plausible models depicted large long-term fluctuations in spawning stock biomass (SSB) and an overexploited stock that has been declining for over a decade. Model estimates of current biomass are at or near the lowest level; however, there is no evidence of reduced recruitment. The WG agreed to use a representative run (Run 2) to determine stock status and provide

management advice, acknowledging that while it represents the general conclusions above, the model was unable to reconcile all key data sources.

The representative run indicated that the 2010 levels (most current) of stock biomass (age 0+) as well as SSB were 53,216 mt and 22,606 mt, respectively. The recent 5-year average level of recruitment (calendar years 2006-2010) was 15.6 million fish. Estimated age-specific fishing mortalities on the stock in the recent period (2007-2009) relative to 2002-2004 (the base period for the current WCPFC conservation and management measure 2010-04) show 4%,17%, 8%, 41% and 10% increases for ages 0, 1, 2, 3 and 4+, respectively. Although no target or limit reference points have been established for the Pacific bluefin tuna stock under the auspices of the WCPFC and IATTC, the current F (average 2007-2009) is above all reasonable target and limit biological reference points (BRPs), indicating overfishing of the population.

**Shark Stock Assessments**– SWSFC staff provide scientific advice on the stock status of pelagic sharks to domestic and international (RFMOs) fishery management organizations. Collaborative stock assessment work on pelagic sharks is organized through the Shark Working Group (SHARKWG) of the ISC (chaired by Dr. Suzanne Kohin – SWFSC), and through other multinational efforts. In 2010, the SHARKWG, in collaboration with scientists in member nations of the ISC, the IATTC, Mexico, and the Secretariat of the Pacific Community (SPC), began the first formal assessments of common thresher, blue, and shortfin mako sharks in the eastern Pacific and north Pacific basins. These sharks are both targeted and caught incidentally as bycatch in numerous fisheries throughout their range and their status requires long-term monitoring.

In order to promote data collection in Mexico, the SWFSC and SWR began a multiyear effort with collaborators at Centro de Investigación Científica y de Educación Superior de Ensenada (CICESE), led by Dr. Oscar Sosa-Nishizaki, to coordinate artisanal fish camp monitoring and sampling in Baja California, Mexico, and help advance cooperative stock assessment efforts with Mexico, U.S., and IATTC scientists. CICESE scientists are conducting data collection for common thresher, blue, and shortfin mako sharks at fish camps throughout Baja California. The 2012 sampling effort was completed in early 2013.The 2012 sampling was extensive and now supplements a time series begun as part of an earlier collaboration with investigators at Scripps Institution of Oceanography (SIO) and CICESE. As a result of the new sampling program, fishery data for pelagic sharks now includes some size and sex sampling as well as several years of species-specific catch information. The data collected thus far have already been used to develop historic and recent time series catch information for common thresher, blue, and shortfin mako sharks.

In 2012, shark assessment effort was focused on conducting the first ISC SHARKWG stock assessment of north Pacific blue shark. The assessment is on track to be completed in time for review by the ISC Plenary in July. The assessment is being conducted with a Bayesian Surplus Production model using compiled estimated catch data for most North Pacific nations including Canada, China, Chinese Taipei, Japan, Korea, Mexico, and the U.S., as well as some estimated catch contributed by IATTC for purse-seine vessels operating in the IATTC Convention area, and non-ISC member longline catch in the WCPFC Convention area contributed by SPC. Preliminary modeling with an age-structured model will also be conducted. For Mexico catch,

the species composition data collected through the sampling program described above contributed to an analysis of estimated blue shark catch for use in the assessment (Sosa-Nishizaki, 2013).

## II. SUPPORTING PACIFIC FISHERY MANAGEMENT COUNCIL ACTIVITIES

SWFSC 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 continued to serve as vice chair after having served as chair of the HMSMT from April 2009 through January 2012. Center scientist Tim Sippel is scheduled to replace Kohin on the HMSMT beginning with the June 2013 Council meeting.

The team met several times in 2012 and early 2013 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 developing recommendations on international HMS fishery management issues to the U.S. delegations of the WCPFC and IATTC, including Council recommendations to the WCPFC Northern Committee (NC) delegation on the adoption of biological reference points under the proposed management framework for North Pacific albacore tuna; (2) presenting a proposal to the Highly Migratory Species Advisory Subpanel (HMSAS) to develop a decision template for managing the U.S. west coast commercial albacore fishery in case a future international RFMO management measure requires a domestic management response; (3) reporting at the March 2013 Council meeting on potential changes to the closure dates for, and/or the southern boundary of, the Pacific Leatherback Conservation Area (PLCA) and the next steps for establishing hard take caps for Endangered Species Act-listed sea turtles in the large-mesh drift gillnet fishery to mitigate bycatch impacts; and (4) preparing the 2012 Stock Assessment and Fishery Evaluation (SAFE) Report and planning for the 2013 SAFE Report.

## III. ADVANCING RESEARCH ON TUNAS, BILLFISH, AND OPAH

SWFSC scientists have focused on improving the biological and ecological understanding of tunas and billfishes in the Pacific Ocean to better assess the effects of fishing and the environment on their populations or stocks. Described here 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.

**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 (AAFA) 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.

***North Pacific Albacore Size Data Sampling Program –*** Since 1961, size data have been collected from albacore landings made by the U.S. and Canadian troll fleets at ports along the U.S. Pacific coast. SWFSC staff work with state fishery personnel to collect the biological data

from albacore fishing vessels when they unload their catches in coastal ports. In recent years, with AFRF support, fishermen onboard two to five vessels have also collected biological data during selected fishing trips, which augment the size data collected through the port sampling program. These data are all sent to SWFSC for processing.

***North Pacific Albacore Archival Tagging Project*** – Staff from 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 801 archival tags and 43 dummy tags were deployed. Two tagging trips were conducted during 2012 aboard the chartered F/V *Royal Dawn*. The first trip occurred off Oregon, 5-12 October, during which 56 tags were deployed, and the second was off central California, 1-7 November, when an additional 25 tags were deployed. Plans are being made to similarly deploy over 100 tags during the 2013 season.

During 2012, one recapture was reported by an angler on a recreational trip out of Astoria, Oregon. The recaptured fish was at liberty just over one year. All the detailed tag data were recovered. The juvenile albacore was tagged in August 2011 off Oregon. Over the following year, the fish migrated out into the central-north Pacific transition zone reaching roughly 180° in late April before turning back toward the North America coast. The movement pattern and timing were similar to several other recovered juvenile albacore tagged on the U.S. commercial troll fishing grounds off Oregon. This is one of 5 migration patterns described so far from 23 albacore tagged and recaptured in the eastern Pacific waters off the U.S and Mexico.

Because of the broad range of movement patterns and behaviors recorded by the first 23 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. Information on the distribution and migrations of adults is also needed. In 2010, the SWFSC purchased four 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 group is collaborating with researchers from the SPC who have contributed two mini-PSATs in order to help test the use of the new attachment anchors on albacore for potential use on south Pacific albacore. Albacore are some of the smaller tunas and their flesh and skin is soft relative to other tuna species that have carried these types of tags for up to one year.

During August 2012, a cooperating fisherman deployed three of the mini-PSATs on handline-caught albacore ranging from 102 to 114 cm FL. They were all rigged with a standard dart anchor, and two of the tags popped off prematurely after only two weeks. The third tag has not yet reported, but was programmed for 350 days. Plans have been made to continue the effort during the 2013 season in hopes of getting longer deployments with a newly designed loop type of attachment.

***Collection and Analysis of Biological Samples to Support Stock Assessments*** –Given the uncertainty surrounding current growth models, stock structure, and ecosystem interactions of several tuna and tuna-like species in the North Pacific, scientists at the SWFSC have been collecting biological samples of otoliths, muscle, liver DNA fin biopsies, and stomachs through a cooperative biological sampling program along the U.S. West Coast. In addition, otoliths have been acquired from the central and western Pacific, in collaboration with Japanese scientists.

Sample collection is ongoing and supports the ISC's recent proposal for a North Pacific-wide sampling program to address the uncertainties regarding biological information, notably growth models, maturity schedules, and stock structure of several tuna and tuna-like species.

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), the program was expanded in 2009 to the northeast Pacific Ocean where commercial fishermen collected samples from albacore off Oregon and Washington. In 2010, the program was expanded to central California (Monterey Bay and San Francisco) where albacore are commonly encountered from August through November in the California Current (CC). In 2012, samples from albacore, Pacific bluefin tuna, yellowfin tuna (*Thunnus albacares*), skipjack (*Katsuwonus pelamis*), yellowtail (*Seriola lalandi*), opah (*Lampris guttatas*) and dorado (*Coryphaena hippurus*) were collected (Table 2) from collaborative efforts with the commercial passenger fishing vessels (CPFV), the commercial albacore troll and pole-and-line fleet, recreational anglers based out of San Diego, along with SWFSC research cruises.

**Table 2**. Summary of all fish sampled by the biological sampling program for tuna and related species.

| Species | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 |
|---|---|---|---|---|---|---|---|
| Pacific Bluefin | 0 | 75 | 78 | 54 | 189 | 294 | 171 |
| Albacore: Washington/ Oregon | 0 | 0 | 42 | 191 | 49 | 60 | 60 |
| Albacore: Central California | 0 | 0 | 0 | 0 | 27 | 31 | 43 |
| Albacore: Southern California | 116 | 35 | 93 | 118 | 7 | 62 | 3 |
| Yellowfin | 15 | 45 | 95 | 71 | 128 | 132 | 112 |
| Skipjack | 0 | 5 | 9 | 8 | 15 | 16 | 25 |
| Yellowtail | 0 | 0 | 7 | 30 | 190 | 186 | 90 |
| Opah | 0 | 0 | 1 | 11 | 16 | 64 | 30 |
| Dorado | 0 | 43 | 39 | 0 | 40 | 18 | 0 |

These biological samples are used to understand an array of questions. Initial efforts centered on characterizing diets of tunas in the SCB using stomach contents and investigating inter-annual and interspecific differences. In the past few years, the research program expanded to include (1) stable isotope analysis of muscle tissue to provide an integrated picture of foraging and migration patterns of tunas in the CC, (2) using otoliths to better characterize age and growth of albacore, (3) radioanalysis of radiocesium found in the muscle tissue of Pacific bluefin tuna exposed to waters containing radionuclides discharged from the failed Fukushima nuclear power plant in Japan, (4) using otolith microchemistry to determine the dynamics and stock structure of albacore and bluefin in the North Pacific, (5) characterizing the genetic diversity of California yellowtail in preparation for commercial aquaculture production off southern California, (6) comparing inshore- versus offshore-caught California yellowtail with respect to ontogeny and migration patterns using stable isotope analysis and lab derived trophic discrimination factors, and (7) characterizing the diet of opah and other mesopelagic predators.

***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 whom is critical to this approach. To determine the trophic relationships of highly migratory species in the California Current, SWFSC scientists have 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 tunas 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 the percentage of stomachs in which prey are found. 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. During the period fish were sampled, anecdotal data from the commercial fishery for California market squid corroborates that squid availability has been increasing since 2008. Results from 2009 appear to be similar to 2008, with much of the diet comprised by crustaceans, teleosts, and cephalopod typically associated with the deep scattering layer (DSL). In 2010, epipelagic teleosts dominated the diet of albacore in the SCB with Pacific mackerel and saury making up 50% of the diet by frequency of occurrence. Samples collected during 2011 and 2012 are currently being analyzed. Overall, analysis shows that prey composition can vary dramatically and will likely be linked to oceanographic conditions.

Regional diet differences between albacore caught off Washington, Oregon, and southern California are also being explored. Crustaceans and cephalopods comprise a larger portion of the diet for albacore caught in Washington and Oregon. Results will be used to explore differences in migration patterns and growth rates between the two different regions to assist with stock structure analysis and management. Diet analysis of Pacific bluefin and yellowfin is currently under way and will be compared to albacore. Preliminary results suggest tunas in the SCB exhibit different foraging strategies with yellowfin and albacore foraging on epipelagic prey in larger numbers than bluefin.

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 has 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. 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 highly migratory large pelagic fish 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. The result of sampling over multiple years gives scientists insight into the impacts of climate variability on local prey and predators, which will help predict the impacts of climate change in the California Current ecosystem.

***Albacore Age and Growth*** –During 2012, a manuscript was finalized describing the results of ageing 486 albacore of a wide size range collected throughout the North Pacific Ocean. The growth model is considered an improvement over models previously published and used in stock assessments of north Pacific albacore. Simulations demonstrated that use of the otolith data and the fitted revised growth curve had a dramatic result on the 2011 stock assessment. Of particular importance is the $L_\infty$ parameter, which can be thought of as representing the average size of the oldest fish in the population. The growth model used in previous stock assessments had a significantly larger $L_\infty$, which implied that fish of a larger size should be present in the population. Since these large fish were not present in the catch, the assessment results showed that the stock experienced high fishing mortality such that the fish did not survive long enough to reach these large sizes.

One of the other findings of the albacore age and growth study was that albacore of the same age had slightly different lengths depending upon where they were collected, suggesting that there may be regional differences in growth. The next phase of the collaborative work is to try to further examine this pattern in addition to studying the difference in growth rates between sexes. Collaboration under the ISC will continue during a winter 2013/2014 ISC-sponsored albacore and bluefin tuna ageing workshop.

***Radioanalysis of Radiocesium Found in the Muscle Tissue of Pacific Bluefin Tuna –*** The detection of Fukushima-derived radionuclides in Pacific bluefin tuna (PBF) that crossed the Pacific Ocean to the California Current Large Marine Ecosystem (CCLME) in 2011 presented the potential to use radiocesium as a tracer in highly migratory species. This tracer requires that all western Pacific Ocean emigrants acquire the Cs134 signal, a radioisotope undetectable in Pacific biota prior to the Fukushima accident in 2011. Working collaboratively with scientists at Stanford University and Stony Brook University, FRD scientists tested the efficacy of the radiocesium tracer by measuring Cs134 and Cs137 in Pacific bluefin tuna (n = 50) caught in the CCLME in 2012, more than a year after the Fukushima accident. All small Pacific bluefin tuna (n = 28; recent migrants from Japan) had Cs134 ($0.7 \pm 0.2$ Bq $kg^{-1}$) and elevated Cs137 ($2.0 \pm 0.5$ Bq $kg^{-1}$) in their white muscle tissue. Most larger, older fish, presumed to have remained in the CCLME since the prior summer (n = 22), had no Cs134 and only background levels of Cs137, showing that one year in the CCLME is sufficient for Cs134 and Cs137 values in Pacific bluefin tuna to reach pre-Fukushima levels. Radiocesium concentrations in 2012 Pacific bluefin

tuna were less than half those from 2011, with levels during both years well below safety thresholds for public health. Detection of Cs134 in all recent migrant Pacific bluefin tuna supports the use of radiocesium as a tracer in migratory animals in 2012.

***Microchemistry Analysis of Bluefin and Albacore Otoliths–*** Otolith chemistry is one approach used 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 ambient water. For Pacific bluefin, the purpose of the study is to examine stable isotope composition in whole otoliths collected in the WCPO and EPO over several age classes of fish. Comparison of young of the year, juvenile, and adult bluefin otoliths will be used to characterize the water chemistry for different collection regions and known spawning grounds. Results will help determine how many Pacific bluefin migrate to the California Current and to characterize the dynamics of movement in the Pacific Ocean, data which is critical to effective management. In 2012, researchers began collecting young of the year bluefin from spawning area waters near Japan.

For albacore, the purpose of the study is to determine whether there are two substocks of albacore that utilize the waters of the California Current Large Marine Ecosystem. Based on differences in growth rates and movement patterns, it is hypothesized that albacore caught in southern California and Mexico waters comprise a separate substock from those caught on the commercial fishing grounds of Oregon and Washington with relatively little mixing during their sub-adult years. This study began in 2011 and is ongoing. Preliminary analyses show that significant differences exist in otolith chemistry from ages 2-4 fish collected between the two regions and overall cross-validated classification success was 100%, with age-specific comparisons exceeding 90% success. Otolith delta18O was significantly enriched in the southern region relative to the northern region, similar to reported seawater delta18O 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). These 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.

***Albacore Distribution and Environmental Effects***– SWFSC scientists, in collaboration with Canada's Department of Fisheries and Oceans (DFO) scientists, received funding last year 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". Some preliminary results were recently presented at the ISC Albacore Working Group meeting in Shanghai (19-25 March 2013) and published in a working paper titled "Environmental influences on albacore tuna (*Thunnus alalunga*) distribution in the coastal and open oceans of the Northeast Pacific: preliminary results from boosted regression trees models". Boosted regression trees models were used to examine the link between albacore distribution and a range of environmental variables, such as temperature, sea surface heights, chlorophyll-*a*, etc. Once the study is more comprehensive, the analyses may be integrated into population dynamics models to help improve albacore management in the face of environmental changes.

**Cooperative Research with Billfish Anglers** – SWFSC researchers have been working with the billfish angling community 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 CPUE time-series available for the recreational fishing of billfishes. The research has also included recreational and commercial fishery monitoring, stock assessment 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 for 2012 were the International Billfish Angler Survey and the Billfish Tagging Program.

***International Billfish Angler Survey***– In 2012, SWFSC researchers summarized the results from the 2011 Billfish Angler Survey. Initiated in 1969, the survey now provides a 43-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 covering the entire Pacific. The CPUE, measured in number of billfish caught per angler fishing day, was 0.44 across all reporting areas, in 2011. This was slightly lower than that reported in 2010 (0.46) and well below the most recent 5-year average (2007-2011; 0.58 CPUE). The CPUEs reported from most individual locations did not fluctuate much from the previous year; however, an increase was reported from off the coasts of both Hawaii and Baja California, Mexico. Conversely, the billfish CPUE reported off Southern California decreased and remains at a historic low.

The 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 (Hawaii; Baja California, Mexico; Southern California; Costa Rica; Panama; Tahiti; and Australia; Figure 1). Blue marlin CPUE off Hawaii was 0.28, which was above the annual average, however off Baja California, Mexico, it dropped to 0.03, the lowest reported value since 1981. Striped marlin CPUE off Southern California was the lowest on record (0.02). Striped marlin CPUE did, however, increase in all areas reported throughout Mexico. Not shown was an increase in striped marlin CPUE off Baja California from 0.45 in 2010 to 0.54 in 2011. Despite this increase, 0.54 is slightly below the annual average reported from this area (0.59). Sailfish CPUE reported throughout Mexico was 0.18, the second lowest value in more than a decade.

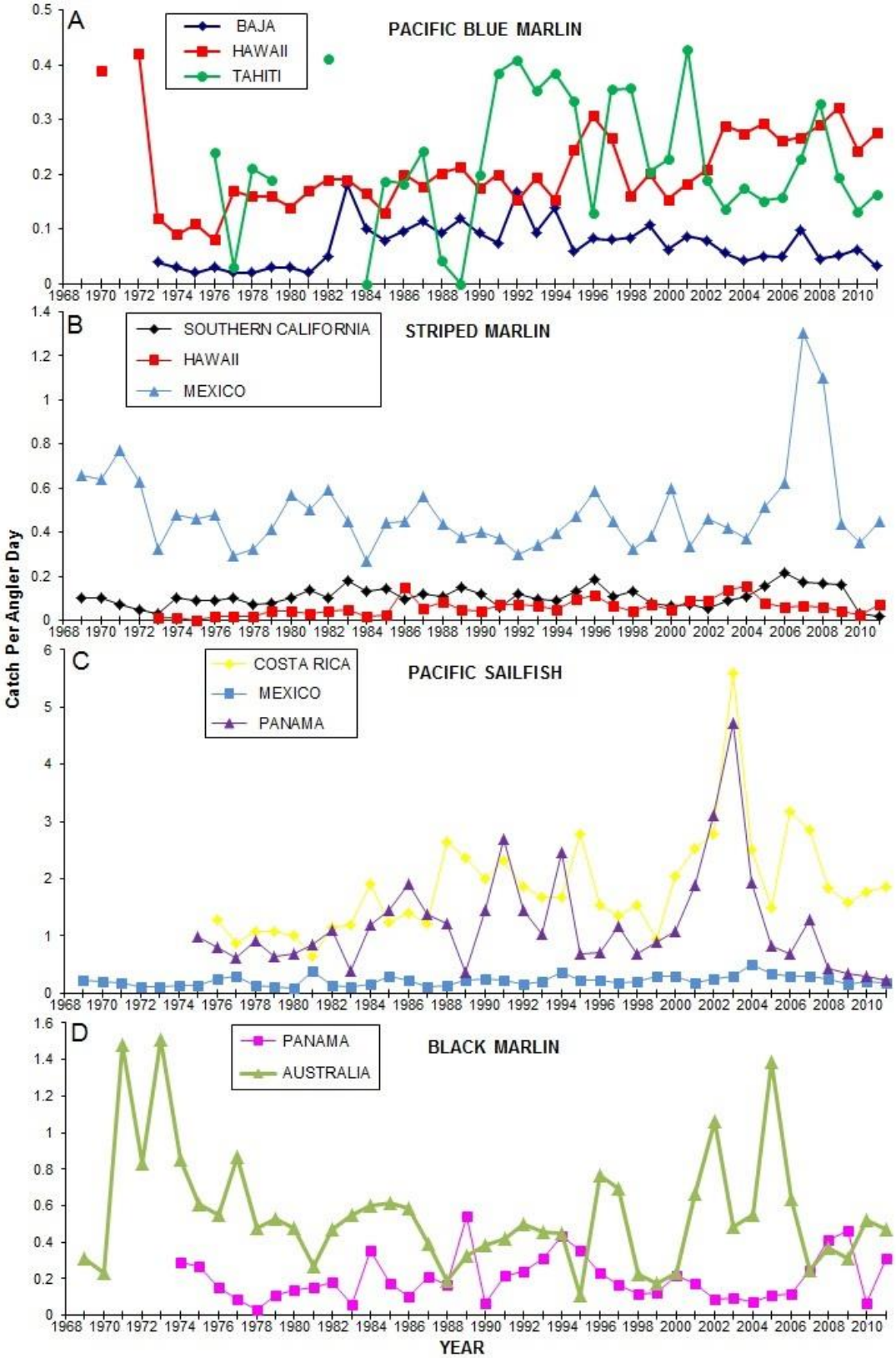


**Figure 1.** CPUE as catch-per-angler-day is shown from 1969 through 2011 for Pacific blue marlin, striped marlin, Pacific sailfish, and black marlin.

***Recreational Billfish Tagging Program***–2012 marks the 50th year that the SWFSC's Billfish Tagging Program has provided tagging supplies to recreational billfish anglers. 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. In collaboration with CDFW, over 76,000 fish have been tagged and released since the inception of the tagging program. Emphasis continues to be on the skillful tag and release of billfish. A total of 902 tags were released on billfish in 2011 through the efforts of a combination of over 700 anglers and 127 captains. This was an increase of over 100% in the number of tags released in 2010. A total of 846 tags were deployed on billfish off Hawaii, representing over 90% of the total tagging effort. The majority of these tags (596) were released on blue marlin. Nearly all billfish species were tagged in greater percentages compared to the previous year. The most substantial difference was a 300% increase in the number of striped marlin tagged. Table 3 shows the tagging effort for 2011 and tag recoveries throughout the program's history. The data include releases made by SWFSC scientists during research cruises.

**Table 3.**Summary of fish tagged through the Billfish Tagging Program in 2011 with releases and recoveries for 1963–2011, including SWFSC's ongoing research tagging.

| SPECIES NAME | RELEASE 2011 | RELEASE TOTAL | RETURN TOTAL | RETURN RATE (%) |
|---|---|---|---|---|
| Striped Marlin | 178 | 23112 | 347 | 1.50 |
| Pacific Blue Marlin | 608 | 11382 | 93 | 0.82 |
| Sailfish | 21 | 9222 | 49 | 0.53 |
| Billfish, unidentified | 0 | 4386 | 6 | 0.14 |
| Black Marlin | 3 | 3390 | 69 | 2.04 |
| Shortfin Mako Shark | 64 | 5486 | 313 | 5.71 |
| Shortbill Spearfish | 91 | 2236 | 2 | 0.09 |
| Common Thresher Shark | 407 | 1872 | 90 | 4.81 |
| Blue Shark | 301 | 9609 | 171 | 1.78 |
| Albacore Tuna | 90 | 849 | 29 | 3.42 |
| Broadbill Swordfish | 1 | 522 | 17 | 3.26 |
| Yellowfin Tuna | 0 | 349 | 25 | 7.16 |
| Skipjack Tuna | 0 | 100 | 2 | 2.00 |
| Bigeye Tuna | 0 | 79 | 2 | 2.53 |
| Bluefin Tuna | 0 | 58 | 8 | 13.79 |
| Hammerhead Shark | 0 | 62 | 2 | 3.23 |
| Bronze Whaler Shark | 0 | 52 | 3 | 5.77 |
| Leopard Shark | 1 | 224 | 12 | 5.36 |
| Whitetip Shark | 0 | 44 | 1 | 2.27 |
| Atlantic Blue Marlin | 0 | 43 | 0 | 0.00 |
| Soupfin Shark | 0 | 40 | 1 | 2.50 |
| Salmon Shark | 0 | 36 | 3 | 8.33 |
| Silky Shark | 0 | 24 | 1 | 4.17 |
| White Marlin | 0 | 13 | 1 | 7.69 |
| Basking Shark | 0 | 65 | 0 | 0.00 |
| Longbill Spearfish | 0 | 3 | 0 | 0.00 |
| Other Tunas | 0 | 21 | 1 | 4.76 |
| All Others | 4 | 2832 | 124 | 4.38 |
| **TOTAL** | **1,769** | **76,111** | **1372** | **1.80** |

**Swordfish Research and SLUTH** –Since 2006, SWFSC researchers have been studying swordfish in the SCB to examine migratory patterns, foraging ecology, and local stock structure. In 2008, FRD teamed up with the Protected Resources Division (PRD) and the NOAA 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 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). 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.

***Modeling Leatherback Turtle Temporal and Spatial Use of the PLCA* –** To investigate the possibility of predicting occurrence and behavior of leatherback turtles in the PLCA using satellite telemetry data, SWFSC scientists have been modeling the assumed behavior and occurrence of the tagged turtles in the PLCA using a suite of oceanographic and environmental variables. Satellite telemetry data of leatherback turtles in the PLCA were compiled from 41 individuals. Daily locations of these turtles were estimated using a statistical movement model. The movement model also provided the probability of foraging/transit behavior for each estimated location. Based on the results of a previous study, seven environmental variables were selected to model turtles' behavior using the statistical method of random forests and boosted regression trees. The variables in the model are sea-surface temperature, chlorophyll concentrations, latitude, longitude, day-of-the-year, eddy kinetic energy, and depth. Boosted regression trees and random forests are non-parametric regression/categorization analytical tools that use multiple predictor variables to build mathematical prediction models for a response variable.

A preliminary analysis indicated that all seven variables were useful in predicting the probability of foraging and that more than 70% of the variability in the dependent variable (probability of possible foraging) can be explained by the models. Seasonality of their behavior was indicated by the importance of the day-of-the-year variable in the prediction model. The output of the models will be used to develop probability surfaces of turtles' behavior for given environmental conditions and to identify the temporal and spatial use of the PLCA by leatherback turtles. This information can be used to identify the sites of greatest leatherback bycatch vulnerability.

***Deep-set Longline Survey to Investigate Swordfish-Sea Turtle Habitat Separation* –** In the fall of 2011 and 2012, using NOAA cooperative research funds and funds awarded by Collaborative Fisheries Research (CFR) West, SWFSC scientists conducted 10-day and 16-day deep-set pelagic longline cruises off Central and Southern California. The 2012 research cruise was conducted between 23 October and 7 November, 2012. The objectives of the cruises were 1) to experiment with targeting swordfish deep during the day below the epipelagic waters where sea turtles live, and 2) to deploy electronic tags on swordfish to examine their fine scale behavior in an area where they overlap with turtles .In collaboration with the fishermen aboard the F/V *Ventura II*, the team worked on methods for setting gear deep during the day. A total of 28 sets were made during the two cruises. For each set, approximately 12 miles of monofilament mainline was set with an average of 288 branchlines, 36 feet in length. 18/0 C style hooks were baited with whole mackerel or sardine. Time-depth recorders were used to document hook depth across all sets and hook numbers. Fishing depth was determined by the maximum depth recorded per deployment. In 2012, fishing depths ranged from 107 m to 460 m. The average minimum depth per set was 139 m (± 19 m SD); average max depth per set was 350 m (± 55 m).

A range of marketable species were caught including swordfish, tunas and opah, and satellite tags were deployed on swordfish and opah. One common mola (*Mola mola*) and a number of blue sharks were also caught, nearly all of which were released alive. Unfortunately, in 2011, weather restricted most effort to more southern waters, south of Point Conception. In 2012, waters shifted to winter conditions earlier than usual and overall fishing was very poor at that time for the drift gillnet fleet and the experiment. Some funding has been received to continue the experiments during 2013 with the goals of 1) further developing the deep-set fishing approach, 2) better characterizing the potential catch composition, 3) characterizing catch in relation to depth and oceanography including the deep scattering layer, 4) deploying electronic tags on swordfish and other potential target species, and 5) assessing the economic value of the catch. Based on the results to date, the fishing technique shows promise for catching swordfish and other marketable species at depths below the turtle habitat.

***Swordfish Deep-Set Buoy Gear Research –*** The SWR and Pfleger Institute of Environmental Research (PIER) are conducting research using a deep-set vertical line configuration to target swordfish within the California exclusive economic zone. To minimize interactions with species of concern, the deep-set gear was designed to fish below the thermocline (270 to 350m) during daylight hours. Gear specifications include the use of ten individual sets of deep-set gear which consist of two-8m gangions with 18/0 circle hooks. All ten sets are soaked for four consecutive hours and baited with both mackerel and squid. Gear trials were conducted during the 2011 and 2012 swordfish seasons off the coast of southern California using both research and cooperative fisher vessels. A total of 54 sets were completed resulting in the capture of 15 swordfish. No interactions with species of concern were recorded across all 4,320 hook-hours. Additional non-target catch included: bigeye thresher sharks, *Alopias superciliosus* (7), opah (2), blue sharks (2), and common thresher shark, *Alopias vulpinus* (1).These data suggest that deep-set buoy gear can selectively be used to target swordfish in deep waters during the day off southern California. Additional trials that investigate alternative configurations (i.e., gear modification, bait presentation) and reduce the probability of lost gear are currently underway.

***Foraging Ecology of Swordfish in the SCB –***In support of ecosystem based studies, the foraging ecology of swordfish is being studied to examine predator-prey interactions and niche overlap with other pelagic predators. Over the past year, 53 swordfish stomachs from the 2011 and 2012 seasons were analyzed. The stomachs were predominantly provided through the CADGN observer program. The results of these analyzed stomachs show that the most frequently encountered prey species (F=Frequency of prey occurrence) were: *Gonatopsis borealis* squid (F=32), market squid (F=27), duckbill barracudina (*Magnisudis atlantica*) (F=27), and Pacific hake (*Merluccius productus*) (F=24). These very preliminary results show a possible shift in feeding trends. In past seasons, jumbo squid was frequently found in the stomachs of swordfish, while current data indicates a decrease in the importance of jumbo squid.

**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, SWFSC scientists began collecting biological samples from opah caught in 2009 and initiated an electronic tagging program in 2011.

***Incidental Catch of Opah during Juvenile Shark Abundance Surveys Conducted by the SWFSC–*** From 2009 to 2012 a total of 67 opah were caught during the cruises associated with the SWFSC's annual Juvenile Shark Abundance Survey. In contrast, only one opah was caught in the 19 years of the survey prior to 2009. Thirty-nine opah were caught during the 2012 cruise, 14 opah were caught in 2011, 16 in 2010, and 8 in 2009. Prior to 2009, only one other opah had been recorded during a longline survey cruise, in June 2000. The apparent increase in opah availability provided an opportunity to begin collecting biological samples and data for a species which little is known about. This apparent increase is likely influenced by many factors including fishing methods and environmental variability. The research vessel historically used to conduct the survey, the 171-foot-long NOAA ship *David Starr Jordan* (DSJ), was no longer available after 2007. To continue the shark survey, in the absence of the DSJ, the SWFSC began chartering smaller commercial longline fishing vessels in 2008 which may have impacted catch rates. Further analyses of the variability in survey catch as well as examining opah catch using logbooks from the CADGN and recreational sport fishing efforts are underway. Additional efforts will focus on the impacts of environmental variability, and how opah catch rates are influenced by El-Niño Southern Oscillation (ENSO) events.

***Opah Foraging Ecology–*** To characterize the foraging ecology of opah in the California Current SWFSC researchers began collecting opah stomachs in 2009. A total of 68 stomachs have been collected to date. Sampled fish ranged from 72 cm to 126 cm FL with a mean of 98 cm FL. Stomach contents included species of squid and fish typically associated with mesopelagic waters. Thirteen species of cephalopods were identified with three (*L. opalescens, Gonatus* spp., *D. giga*s) making up the most important prey items based on the IRI (index of relative importance). Squid ranged from 30 mm (*Gonatus* spp.) to over 266 mm mantle length (*D. giga*s). In addition, a few stomachs were dominated by epipelagic fish including Pacific saury (*Cololabis saira*). Interestingly, 30% of stomachs contained either small pieces of kelp or plastic. Regional diet differences comparing central and southern California are also being examined. 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. A comparison of diets between opah, tunas and swordfish from the SCB suggests greater niche overlap between opah and swordfish than between opah and tunas. Considering opah are often caught in association with tunas, differences in their diets could reflect habitat partitioning.

***Opah Electronic Tagging –*** To help characterize the vertical and horizontal movements of opah in the California Current, eight Wildlife Computers PSAT-Mk10 tags were deployed on opah in the SCB (n=4) and off central California (n=4). All tags were deployed during research longline cruises conducted by SWFSC scientists. The PAT tags were programed to collect light level, depth, and temperature data for 240 days. Four tags popped off prematurely. Preliminary analysis suggests opah in the California Current exhibit similar behavior as those observed near Hawaii, with diel patterns moving between depths of ~ 250 m during the day to ~50 m at night. Unlike

most diel vertical migrators, opah appear to remain below the mixed layer. Light level and temperature data recorded from one tag indicated it was possibly predated upon by an endothermic shark. The four fish with full 240-day deployments traveled distances ranging from 589 to 1,404 nautical miles. Of these, three fish released off southern California popped up in March off Mexico. One tag deployed off central California in late October 2011 popped up northeast of Hawaii in June.

***Gill Morphology and Regional Heterothermy*** – 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.

A number of opah were collected on the 2012 shark cruise and deep-set long line cruise for determination of blood properties, gill structure, and the assessment of the ability to retain internal body heat. Because opah live in a relatively deep habitat where both low temperatures and low dissolved oxygen concentrations can limit physiological processes, understanding opah adaptations to withstand these conditions can provide insight into their thermal and dissolved oxygen tolerances. Unlike most pelagic fish, the opah uses its pectoral fins for continuous swimming. The insulation of the large, red (aerobic) pectoral muscles by a thick layer of fat and connective tissue appears to allow for the conservation of internal heat. Researchers recorded pectoral muscle temperatures that are significantly elevated above ambient for freshly decked opah and for fish outfitted with intramuscular temperature loggers swimming at depth. The morphological work revealed *retia mirabilia* in the gills of the opah that appear to function as countercurrent heat exchangers to conserve heat derived from the pectoral muscles. The unique placement of these countercurrent exchangers potentially allows for warm blood to be distributed throughout the body. In addition to the pectoral muscle, temperatures in the heart, gut, and cranial region are all significantly elevated above ambient allowing for increased function at cold temperatures. Along with their large gill surface area these adaptations allow opah to maintain warm body temperatures and survive in low dissolved oxygen environments.

## IV. 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 (*A. 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 through various surveys and tagging studies. This information is provided to international, national, and regional fisheries conservation and management bodies having

stewardship for sharks.

**Abundance Surveys** – 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 fishery 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 sub-adult blue and shortfin mako sharks and neonate (0-1 year old) 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 SWFSC researchers 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 was 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 and the U.S.-Mexico border. 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 due to the tight relationship between the adult population and recruitment 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 2012, the SWFSC researchers conducted the nineteenth juvenile shark survey for mako and blue sharks since 1994. The annual abundance survey was completed between 20 June and 19 July 2012. Working aboard F/V *Ventura II*, a team of scientists and volunteers fished a total of 5,592 hooks during 28 daytime sets within seven focal areas of the SCB. The survey catch totaled 151 shortfin makos, 26 blue sharks, 16 pelagic rays (*Pteroplatytrygon violacea*), and 4 opah. The preliminary data indicate that the nominal survey catch rate was 0.53 per 100 hook-hours for shortfin mako and 0.15 per 100 hook-hours for blue sharks. The mako shark nominal CPUE was slightly higher than the previous year.

However, there is a declining trend in nominal CPUE for both species over the time series of the survey.

Additional research projects were also conducted during the shark survey research cruise. Six deep sets were completed targeting opah and swordfish during daytime hours. A longline shooter was used to deploy the gear between 200 and 300 meters depth over a horizontal distance ranging from five to ten miles. An average 170 branchlines, each 38 feet in length, were deployed during these sets. Four surface sets were also conducted targeting opah. Additionally, a total of 18 sets were conducted as part of an experiment to examine differences in catch rate, catch composition, and survivability between circle-type hooks and J-type hooks. Preliminary results indicated no differences.

In total, 56 longline sets including survey sets were completed. A total of 423 animals were caught; ancillary sampling resulted in 262 captures. Most animals were brought onboard, measured, tagged, and sampled for DNA biopsies before they were released. Spaghetti tags were released on 338 sharks to allow for movement and stock structure data. A total of 387 DNA samples were collected, including samples from 254 shortfin mako, 92 blue shark, 29 opah, 9 pelagic rays and 3 common thresher.

***Neonate Common Thresher Shark Survey*** – In 2012, the SWFSC team conducted the survey aboard the F/V *Outer Banks*. Fifty longline sets were made in relatively shallow, nearshore waters and a total of 5,000 hooks were fished during the 18-day cruise. A total of 367 fish including a range of species were sampled during the survey, 282 were common thresher sharks. Most of these sharks were tagged with a combination of conventional tags for movement and stock structure data and oxytetracycline (OTC) paired with plastic dorsal tags with information for fishers upon recapture of the animal to retain a portion of the vertebrae for ongoing age and growth studies. In addition, a pop-off archival GPS tag was released on a 151-cm female common thresher. Biological collections included DNA samples from most sharks captured, as well as stomachs, digestive tracts, and blood from a small number of sharks that did not survive.

The preliminary survey data indicate that the average nominal catch rate by set was 2.49 common thresher sharks per 100 hook-hours. This is a drop in CPUE from 2011 when the nominal catch rate was 5.57. The overall average trend since the start of the survey is increasing. However, 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 the SWFSC, including age and growth, feeding, and habitat utilization studies.

**Electronic Tagging Studies –** Since 1999, SWFSC scientists have been using satellite technology to study the movements and behaviors of large pelagic fish, primarily 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, Canadian colleagues at the Department of Fisheries and Oceans (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 characterization of 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 2012, a number of large pelagic fish were deployed with electronic tags in support of several collaborative projects. Five (5) shortfin mako sharks, 5 blue sharks, and 1 common thresher were tagged with either SPOT tags or towed GPS tags. Three (3) mako sharks, 2 blue sharks, and 6 opah were released with pop-off archival tags. In addition, 5 mako sharks were released with acoustic tracking tags.

SPOT tags continue to provide excellent information on the movements of blue and mako sharks. Data have been collected data for a decade for both species, which allows continued monitoring of the horizontal movement patterns on many different time scales. More recently, the focus is tagging of larger animals, for which there is less information. Historical data shows that the larger animals retain the tag longer and provide us with longer tracks. The average size of blue sharks (n=5) tagged with a SPOT in 2012 was 229 cm. Two of the five blue sharks were tracked for close to 200 days (Figure 2). Combined data from many years suggest that both sexes spend considerable time in the California Current, with the females possibly extending farther north and south. When offshore, generally, the females move south into the subtropical convergence zone, whereas the males make more westerly migrations. These patterns do vary though, and the two male blue sharks illustrated in Figure 2 demonstrated behavior more common to what has been observed for females. The track of the larger shark looks as though he may have been heading back to the California Current, which has been documented for many of the longer blue shark tracks. 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 raises the potential for local depletion where fisheries exist.

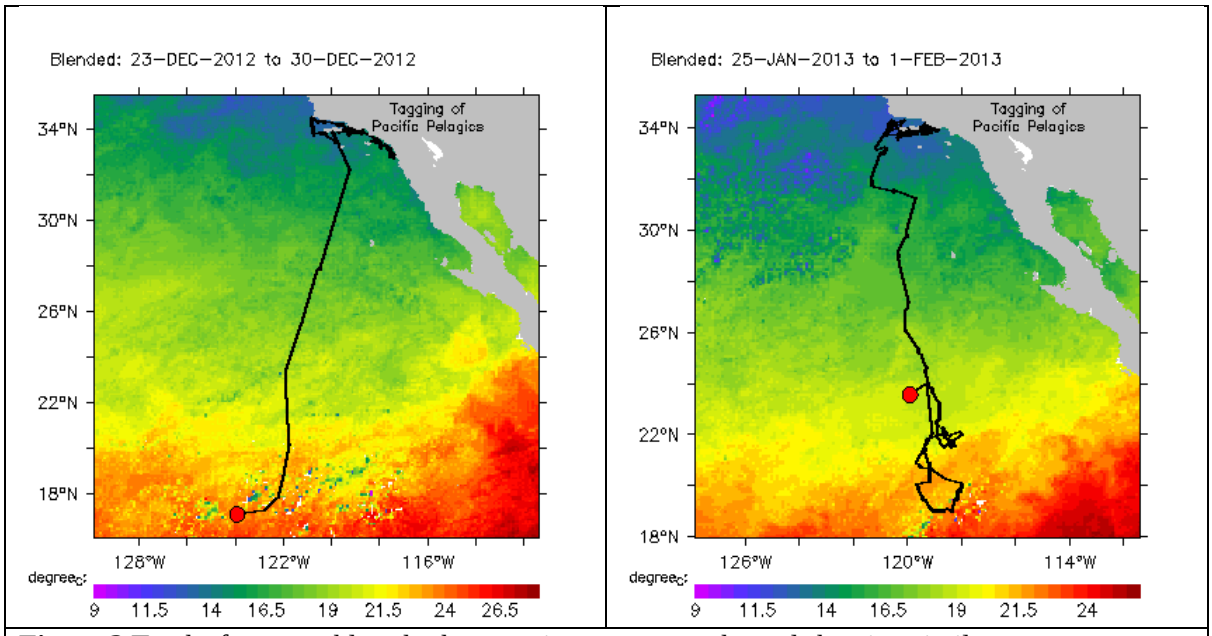


**Figure 2**.Tracks from two blue sharks spanning seven months and showing similar movement patterns into subtropical waters (left 221 cm FL male, right 241 cm FL male).

For mako sharks, three tags were still transmitting in early 2013 (Figure 3).All three sharks were deployed with SPOT tags in July, 2012. Tracking success has been very good for mako sharks, as they generally provide longer duration tracks than blue sharks, allowing the opportunity to examine seasonal movement patterns and regional fidelity. The smallest shark of the three, the male, traveled the greatest distance latitudinally, ranging from 14 to 38$^{o}$ N. The females both spent some time migrating south-westward, terminating near 120$^{o}$ W before returning to the coast on a similar path. All three sharks spent some time near or in San Sebastian Vizcaino Bay off Baja California, Mexico, which is an area of high use for makos based on combined data from several years. 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.

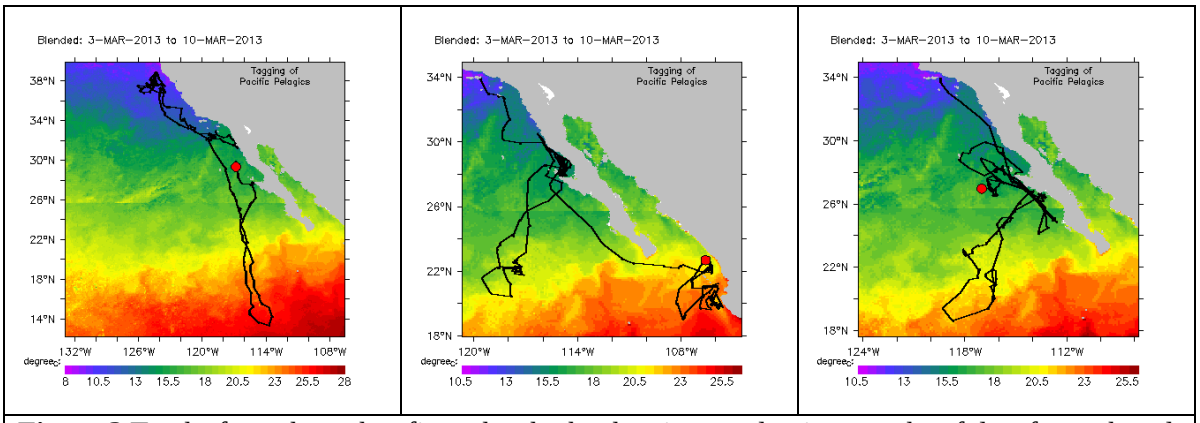


**Figure 3**.Tracks from three shortfin mako sharks showing nearly nine months of data for each and some similarities in movement patterns (left 167 cm FL male, center 173 cm FL female, right 241 cm FL female).

**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 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, 3,183 OTC-marked individuals have been released during juvenile shark surveys. Sharks tagged include 1,221 shortfin mako, 1,187 common thresher, 757 blue, 15 silky (*Carcharhinus falciformis*), and 3 pelagic thresher sharks.

***Oxytetracycline Age Validation of Juvenile Shortfin Makos*** –The results of OTC age validation of 29 juvenile shortfin mako sharks tagged with OTC in the Southern California Bight were recently published (Wells et al., 2013) and showed vertebral band pair deposition rates of two per year. The results of this study differ from two other studies on shortfin makos that used a direct age validation technique: one study validated a single band pair deposition rate in an estimated 18 year old shortfin mako shark tagged with OTC and recaptured in the Atlantic after one year at liberty; and the second used a bomb radiocarbon signal as a marker in 37 sharks collected in the Northwest Atlantic between 1950 and 1984 ranging in estimated ages of 1 to 31 years. Age and growth in shortfin mako sharks continues to be uncertain because growth curves estimated from length-frequency analysis and tag-recapture methods tend to show faster growth rates than obtained from vertebral counts based on deposition of a single band pair per year. Furthermore, this validation study applies to juvenile sharks in the northeast Pacific. This study raises questions about potential regional differences in band pair deposition rates or the possibility of an ontogenetic shift from a period of more rapid growth with two band pair deposition per year to slower growth and a switch to a band pair deposition rate of one per year. In winter 2013-2014, the ISC plans to convene its second Shark Age and Growth Workshop during which participants hope to resolve some of the uncertainties regarding shortfin mako age and growth.

***Oxytetracycline Age Validation of Juvenile Blue Sharks*** **–** The purpose of this study is to

validate vertebral band counts of blue sharks tagged and recaptured in the northeast Pacific Ocean. OTC-labeled vertebrae of 13 blue sharks have been obtained from tag-recapture activities and processed to determine timing of centrum growth band deposition. Several methodologies were used to examine blue shark vertebrae and digital images of the whole vertebrae centrum were determined to be the best. OTC-tagging of the recaptured sharks occurred off southern California from 2007 to 2009, with time at liberty ranging from 22 to 473 days. For vertebrae samples used in this study, shark size at release ranged from 90 to 276 cm total length (TL). OTC-marked vertebrae from at least 20 more sharks have been returned and will be processed to build upon this study. Results thus far from band counts of vertebrae distal to OTC marks indicate that a single band pair (one translucent and one opaque) is formed per year for blue sharks of the size range examined. These preliminary results corroborate annual deposition rates found in the only other OTC validation study for blue sharks and should aid in future blue shark age and growth studies in the Pacific Ocean.

**Foraging Ecology of Pelagic Sharks –** The California Current is a productive eastern boundary current that is an important nursery and foraging ground for a number of highly migratory predator species. To better understand niche separation and the ecological role of these spatially overlapping species, stomach content analyses have been ongoing at the SWFSC since 1999. Stomachs are obtained primarily from the CADGN observer program.

Stomach content analysis work has continued since the publication of Preti et al., 2012. From March 2012-March 2013 a total of 91 stomachs of several species of pelagic sharks have been analyzed from fishing seasons 2011 and 2012. Current levels of analysis have allowed us to identify some of the most frequently encountered prey species. Shortfin mako stomachs (n=30) contained market squid (F=8), Pacific saury (F=8), and Pacific sardine (*Sardinops sagax*) (F=7). Blue shark stomachs (n=7) contained Octopus squid (*Octopoteuthis spp.*) (F=4), market squid (F=4), and *Gonatus spp.* squid (F=4). Common thresher shark stomachs (n=44) contained market squid (F=21), Pacific mackerel (*Scomber japonicus)* (F=11), and Pacific sardine (F=11). Salmon shark stomachs (n=6) contained Pacific mackerel, duckbill barracudina, striped mullet (*Mugil cephalus*), unidentified rockfish, and market squid. Bigeye thresher stomachs (n=4) contained Pacific mackerel, market squid, and tunicates.

These very preliminary results already show a possible shift in feeding trends. In past seasons, jumbo squid were frequently found in the stomachs of examined predators, especially shortfin mako and blue shark (Preti et al. 2012), whereas current data indicate a decrease in the importance of jumbo squid to the diets of these species.

Data on shark foraging ecology were also used to develop a new approach for characterizing habitat use and improving understanding of ecological interactions. FRD scientists introduced 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, scientists 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. This method indicates a significant difference in foraging habitat

between predator species. Generally, blue sharks foraged more frequently in offshore habitats, threshers foraged mostly in nearshore epipelagic habitats, and shortfin 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 now under internal review.

***Algal Toxins in the Forage of Pelagic Sharks*** – In 2011, FRD scientists began to sample the stomach contents of several species to study algal toxins (domoic acid) in sharks. A blue shark contained 4172 ng/g of domoic acid in its stomach juices and its prey, a paper nautilus (*Argonauta* sp.), contained over 2000 ng/g. Three thresher shark stomachs with juices and prey also had high levels of the toxin, the highest being 1708 ng/g found in one thresher stomach with its prey of squid having a level exceeding 2000 ng/g.

These results confirm that the toxin is present in the food chain and can be transferred from the bottom up. 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 that catches the greatest number of each of these species. While thresher and mako sharks are landed, almost all blue sharks are discarded. Thresher and mako sharks are growing in popularity in regional recreational fisheries. 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 fish species taken in this fishery. Nearly all blue sharks 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, researchers from the SWFSC and the SWR began deploying PSAT tags on sharks released from the CADGN fishery to assess survivorship in order to determine more accurate estimates of fishery mortality for use in a blue shark stock assessment. As a part of the study, a set of criteria was developed to document the condition of all live blue sharks released: “good”, “fair” or “poor”.

Prior to the 2011-2012 season, 12 blue sharks (100 to 200 cm FL, median 149 cm) had been tagged by fishery observers. 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.

During the 2011-2012 season, fishery observers deployed three survivorship PAT (sPAT) tags, which are new, more economical tags, that record daily minimum and maximum depths and

temperatures and are programmed to pop off if the tag exceeds a certain depth or remains at a constant depth for several days. These tags are effective for determining the fate of tagged fish. Of the three sharks tagged (2 females of 134 and 162 cm FL, and one 161 cm FL male), two were in "poor" condition when released and one was considered in "fair" condition. Two of the three sharks died immediately and the third one died after eight days. These results, combined with the results from the prior years, suggest that sharks that are released in "good" condition are likely to survive, whereas those released in "poor" condition are likely to die. The study will continue during the 2012 season when the final three tags are deployed on sharks in "fair" or "poor" condition. Work will continue on compiling the data on the condition of all sharks released in order to be able to apply the survivorship estimates to the discarded population more accurately.

***Thresher Sharks Released from the Recreational Fishery*** – Researchers from the SWFSC, SWR, and PIER are conducting a three-phase 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 being captured using tail-hooking techniques (common practice in the southern California fishery). The results from this work revealed that survivorship is low for large sharks (>185 cm FL) that endure fight times that exceed 85 minutes (Heberer et al., 2010). The second and third phases of the research effort focused on assessing post-release survival in two modes of capture routinely observed in the southern California recreational fishery: (1) sharks that are caught using caudal-based angling techniques and unintentionally released with trailing gear left embedded, and (2) sharks that are caught and released using mouth-based angling techniques. Post-release survivorship was assessed using pop-up satellite archival tags. For the trailing gear investigation, seven sharks died shortly after release and two sharks survived the deployment period for an overall survivorship rate of 22%. For the mouth-based trials, all common thresher sharks survived the acute effects of capture (100% survivorship). The results from all phases of this study will be used to estimate the survival rates and incorporate best fishing practices into the fishery to reduce the mortality of released thresher sharks. A major component of this project is to promote fishing practices that enhance thresher shark catch and release survival by developing education and outreach tools for the recreational fishing community. A brochure on best practices for thresher shark fishing and handling was developed (http://www.pier.org/userdocs/images/images/flyers/BREP_thresher_brochure.pdf). An outreach video highlighting phase one of the research was produced by the Ocean Media Center (OMC) and posted on the NOAA Fisheries Home Page under the Video Gallery (http://www.nmfs.noaa.gov/gallery/videos/). A second video, highlighting phases two and three of the research effort, is currently under development by OMC and will be available for outreach events in the summer of 2013 and will be posted on the NOAA Fisheries website.

**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. Due to concern over basking shark populations along the West Coast, the basking shark was listed as endangered in Canada and as a Species of Concern in the United States in 2010. Given severe data gaps for this population, SWFSC scientists initiated a basking shark research program in 2010 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.

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. A tri-national team was developed with colleagues in Canada and Mexico to coordinate research efforts.

During the past year, SWFSC scientists continued to monitor basking shark sightings in order to collect and analyze data on patterns of occurrence and potentially deploy more satellite tags. A few constituents reported basking shark sightings in the SCB during the spring and early summer of 2012, although reports were sparse and sporadic. A couple of failed attempts were made to find sharks for tagging based on some of the reports. Significant progress has been made on the quantitative modeling of historical basking shark records with environmental variables.
Data from the three sharks tagged with satellite tags in 2010 and 2011 have been analyzed and are being prepared for publication. The three sharks showed impressive plasticity in vertical behaviors depending upon the region and distance from shore, as has been shown 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 Pelagic Sharks** – An understanding of stock structure is important in order to make accurate assumptions for stock assessments and to develop effective management objectives that take the species range, distribution, and life history into account. Various genetic analyses are useful to help identify differentiation between and within presumed stocks.

***Shortfin Mako Shark*** –As part of his Ph.D. work at University of California Davis and San Diego State University and in collaboration with the SWFSC, Dovi Kacev has developed a suite of 11 nuclear microsatellite markers and optimized an additional 5 to further refine the spatial and temporal resolution of shortfin mako stocks within the Pacific. In addition to studies of stock structure, these markers are being used to develop estimates of effective population size within the California Current region. Data analyses are ongoing and a manuscript is being drafted. 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 regularly encountered in temperate coastal marine fisheries but little is known about regional connectivity. In recent years, threshers have become part of an increasingly important recreational fishery in Southern California in addition to being a major component of local gillnet fisheries. In order to better understand population connectivity, Dovi Kacev has developed eight nuclear microsatellite markers for this species and successfully cross amplified three of the shortfin mako loci. These markers are being applied and data collection is ongoing.

***Silky Shark*** – Silky sharks are the most abundant shark encountered by tropical tuna fisheries world-wide. In an effort to better inform the first stock assessment for this species in the EPO,

~450 samples were added to an earlier study to examine stock structure in the Pacific. These samples filled in areas of previous low sample size (i.e. western Pacific) and areas for which there is specific EPO management concern (i.e. southeastern equatorial Pacific). The current dataset includes nuclear (9 microsatellite loci) and mitochondrial data (control region sequence) for ~730 animals, predominantly from the Pacific. These new data continue to support stock structure generally north and south of the equator with animals south of the Galapagos Islands in the EPO more closely allied with the northern stock. This spillover of the northern stock south of the equator is likely seasonal and is concordant with regional oceanography and size composition data.

***Pelagic Thresher Shark*** – Pelagic thresher sharks are landed in high numbers by artisanal fisheries throughout the tropical Pacific and Indian Oceans. Due to past misidentification with other thresher species there is little known regarding the biology and life history of this species. Recent genetic work by scientists at SWFSC, using both nuclear (five microsatellite loci) and mitochondrial DNA data (cytochrome oxidase sequence), has revealed the presence of very strong stock structure between eastern and western Pacific populations. Interestingly, the central Pacific seems to be an area of overlap for these two populations. Additional samples and genetic data are being added this year in collaboration with colleagues in Columbia to better characterize the stock structure for this species.

## V. IDCPA RESEARCH

The SWFSC research conducted under the International Dolphin Conservation Program Act (IDCPA) during 2012 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.

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 enhance 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 the stomach fullness and diet composition of planktivorous flyingfish were consistent with the increase in zooplankton biomass. Changes in the abundance and community composition of both seabirds and cetaceans were observed, but are confounded by seasonal migration. Fiedler et al. (2013) describes these results.

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, scientists conducted research on physical and biological oceanography (dolphin habitat); midtrophic-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) assessment of relative fishery exposure for ETP dolphins; (4) dolphin swimming kinematics research; (5) spotted dolphin form and function review; (6) investigations of dolphin reproductive biology; (7) ETP dolphin population genetic structure; (8) investigations of the ETP ecosystem and its change over time; (9) cephalopods as indicators of spatial variation in biochemical properties between marine systems; (10) seasonal and interannual patterns of ETP dolphin distributions from tuna vessel observer data (TVOD); and (11) conducting catch sampling to evaluate the impacts of smaller, unobserved purse-seine vessels on ETP dolphins.

**Investigations of Cetacean Biodiversity Hotspots** – The PRD continues to investigate species richness hotspots for 28 species of cetaceans in the ETP (ca. 20 million $km^2$) based on data collected using line transect methods aboard NOAA research vessels, August–November, in each of the 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. These results were robust to smoothing algorithm and spatial resolution. These regions are highly variable in space and time with respect to physical oceanographic properties. Current analyses are focused on identifying the mechanisms underlying the hotspot patterns.

**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. Mitigating these threats requires a transboundary, systematic planning approach. SWSFC scientists 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. Through collaborations with international colleagues, SWFSC scientists obtained 5,633 humpback whale sightings from breeding areas off Mexico, Columbia, Costa Rica, Panama, Ecuador, and the Galapagos Islands. Simple environmental envelope models are being used to describe the oceanographic conditions associated with these sightings. Scientists are also exploring the performance of MaxEnt, a more sophisticated presence-only modeling technique. SWFSC scientists have been systematically collecting data in the EPO for over twenty-five years; colleagues have collected additional cetacean sightings opportunistically or on non-systematic surveys. Habitat models have been successfully built for multiple species using the systematically collected SWFSC survey data (Forney et al., 2012). Following an approach similar to Forney et al. (2012), the systematically collected data will be used to develop generalized additive models (GAMs) of species density. The GAMs will be compared to MaxEnt models built with only the systematic data, a combination of systematic and opportunistic data, and only the opportunistic data.

**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 weighs 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. 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 there is 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 2013 and beyond 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. Immediate next steps include working with colleagues in the IATTC Directorate to identify mutually agreeable data access to facilitate completion of these important analyses.

**Dolphin Swimming Kinematics Research** – Based on the results of a series of research papers on various aspects of dolphin hydrodynamics published between 2002 and 2012, development has begun on a hydrodynamics-based energetics model that will investigate the potential for dolphin mother-calf separation and subsequent calf mortality due to tuna purse-seine chase in the ETP. The model is still in development stages and is projected for completion during 2013.

**Spotted Dolphin Form and Function Review** – A comprehensive review of literature regarding form, function and pathology of spotted dolphins (*Stenella attentuata)* has been completed and is currently in review prior to publication as a NOAA Technical Memorandum. The review summarizes and synthesizes all available information on these topics published through 2012, and is intended to serve as a resource for researchers interested in this species, with particular emphasis on data collected from the ETP, which forms the basis of most of the available information. A publication is anticipated during 2013.

**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 Biology 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 ($\geq$ 87 ng/g) indicates pregnancy, scientists 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 it was 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. Scientists 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. Using high-throughput DNA sequencing, Matthew S. Leslie (Ph.D. candidate at Scripps Institution of Oceanography) has collected DNA sequence data from 80 nuclear loci (84Kbp) and entire mitochondrial genomes (16Kbp) for a subset of biopsy samples (n=250). The mitogenomic data were analyzed using an integrated phylogenetic and population genetic framework to characterize variability and structure. Little population genetic structure across the ETP was detected in the mitochondrial genomes. The nuclear data are currently being analyzed for population structure.

Given the challenges in detecting genetic differences in dolphin populations with recent divergence, ongoing interbreeding and high variability, Leslie is now genotyping ETP spinner and spotted dolphins on a genome-wide scale. Using a method that targets restriction enzyme binding sites, he is sequencing millions of short portions of DNA dispersed throughout the genome in an effort to find tens-of-thousands of mutation sites for population structure analyses. This volume and type of data should have the power to detect genetic structure in these populations. These data will also be used to develop addition nuclear DNA assays to genotype additional modern and historical specimens. The goal of this integrative study is to provide a total-evidence, process-oriented analysis using morphology, genetics and environmental variables. Permission to sample and genotype museum specimens from the National Museum of Natural History has been requested.

The next steps are to: 1) publish the findings from the mitogenome analyses, 2) finish analyzing the 80 nuclear DNA loci, 3) finish collecting the genome-wide genotype data and 4) collect genetic material from museum specimens.

**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 published (Fiedler et al., 2013).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 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.

**Cephalopods as Indicators of Spatial Variation in Biochemical Properties between Marine Systems** – Ruiz-Cooley et al. (2013) investigated the ecology of the Humboldt (jumbo) squid (*D. gigas*) using specimens collected in the California Current during a cetacean and ecosystem assessment survey in 2008 to investigate their migration patterns and habitat use through biochemical analysis (stable isotopes from bulk and individual amino acids - Phenylalanine and

Glutamic acid). Data indicate that large squid feed in California Current waters but migrated from at least three different geographic origins, including regions within the ETP. This analysis confirms that both physical and biological factors in the ETP influence adjacent ecosystems, with the potential to significantly alter them. In this case, because *D. gigas* is abundant, prey of many large-bodied marine vertebrates, and a voracious predator, migrants from the ETP have the potential to restructure food webs in an adjacent ecosystem.

**Seasonal and Inter-annual Patterns of ETP Dolphin Distributions from Tuna Vessel Observer Data (TVOD)** – A study of the variability of spatial distributions of target stocks and relationships to seasonal and inter-annual changes in habitat has been initiated in cooperation with IATTC scientists. Although sampling is not as rigorous as on research vessel surveys (RVOD), tuna vessel observer data has more much more sighting effort with fewer gaps within and between years. Therefore, it is likely that patterns of variability that cannot be resolved by RVOD can be detected and related to environmental variability from remote sensors and data-assimilation models. Both seasonal and ENSO-scale (El Niño/La Niña) variability are important in the ETP and likely affect the distribution of motile top predators like dolphins.

**Conducting Catch Sampling to Evaluate the Impacts of Smaller, Unobserved Purse-seine Vessels on ETP Dolphins** – Despite achievements in dolphin conservation for the tuna purse-seine fishery of the EPO, debate continues about the magnitude and importance of dolphin mortality caused by small (unobserved) vessels. In-port sampling of tuna catch size composition is a potentially cost-effective means of identifying unobserved vessels that may be catching tunas associated with dolphins because yellowfin tuna caught in association with dolphins are larger, on average, than those caught in other types of purse-seine sets. A classification algorithm to predict purse-seine set type ("dolphin" vs. "non-dolphin") was built from port-sampling data on yellowfin tuna length-frequencies and the date and location of fishing of large (observed) vessels. This classification algorithm was used to screen the port-sampling data of small vessels collected by IATTC and NMFS samplers during 2006-2009, assuming the fishing practices of the two groups resulted in similar catch characteristics. From these results, hypothetical time series of dolphin mortality for small vessels were constructed and incorporated into a population dynamics model, along with mortalities of large vessels. Results suggest that any dolphin mortality of small vessels is unlikely to be substantially affecting trends in dolphin abundance. These results underscore the importance of in-port sampling, in combination with at-sea observation and fishery-independent surveys, to effective management. Additional project findings can be found in a paper published by Lennert-Cody et al. (2012).

**Challenge against the U.S. Dolphin-Safe Labeling Standard for Tuna** – In 2008, Mexico initiated World Trade Organization (WTO) dispute proceedings to challenge the Department of Commerce "dolphin safe" tuna label scheme as a violation of provisions of the WTO's General Agreement on Tariffs and Trade (GATT) and Agreement on Technical Barriers to Trade (TBT Agreement). A WTO dispute panel issued a mixed decision, finding in favor of the United States on most claims. In January 2012, the United States and Mexico cross-appealed to the WTO Appellate Body. The WTO Appellate Body issued its report on 16 May 2012, finding in favor of the United States in four out of five of Mexico's claims, and finding in favor of Mexico on its claim that the labeling scheme afforded less favorable treatment to Mexican tuna products. In the less favorable treatment finding, the Appellate Body concluded that the current US "dolphin

safe" labeling scheme does not set conditions for use of the label in a way that reflects risks faced by dolphins in fisheries outside the ETP. Under WTO rules, the United States must bring its non-conforming measure into compliance, and the deadline to do so will likely be in 2013.

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