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MAY 2014

THE SWFSC DIRECTOR'S 2014 REPORT ON RESEARCH REGARDING HIGHLY MIGRATORY SPECIES (HMS) AND THEIR FISHERIES IN THE NORTH PACIFIC OCEAN

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The Southwest Fisheries
Science Center

ADMINISTRATIVE REPORT LJ-14-04

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I. SUPPORTING U.S. OBLIGATIONS OF INTERNATIONAL AGREEMENTS

The United States is party to a number of international agreements for the conservation of highly migratory species (HMS) in the Pacific Ocean. As such, it is obligated to collect fishery statistics from U.S. HMS fisheries and to participate in advancing fishery science for species of interest. Scientists at the Southwest Fisheries Science Center (SWFSC) have been tasked to fulfill this obligation. In this section, some of the contributions and activities during the past year, May 2013–April 2014, are briefly described.

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 .The fisheries monitoring group under the Fisheries Resources Division (FRD) compiles and manages information on vessels, gears, effort, catch, bycatch, protected species interactions, landings, biological sampling, and observer data. 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 the eight HMS fisheries that the SWFSC monitors. The fishery harvests over 200,000 metric tons (t) of tropical tunas each year, generating millions of dollars in ex-vessel revenue. The data from the WCPO purse-seine fleet are managed 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, Oregon and central California, and albacore, bluefin, and yellowfin tunas (*Thunnus albacares*) in southern California and Mexican waters. The 2013 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	2013 CATCH IN METRIC TONS	NUMBER OF VESSELS
Central Western Pacific Ocean Purse Seine	254,348	40
North Pacific Albacore Troll and Pole-and-line	12,325	702
South Pacific Albacore Troll	390	6
Eastern Pacific Ocean Purse Seine		0
California Large-mesh Drift Gillnet	89	18
California Harpoon		
Longline (California-based)		< 3

North Pacific Albacore Troll and Pole-and-line **-** Total annual catch of albacore from the North Pacific albacore troll and pole-and-line fishery (a.k.a. albacore surface fishery) in 2013 totaled 12,325 t, a decrease of 13% from 14,149 t in 2012. The number of vessels also decreased from 840 vessels in 2012 to 702 vessels in 2013. The average weight of retained albacore in 2013 was 17.5 pounds compared to 15.4 pounds in 2012. 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 Fisheries Management Council in 2005.

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. Six vessels participated in the 2013 fishery, compared to nine vessels in 2012. Total catch of albacore in 2013 was 390 t, an increase of 44% from the 270 t landed in 2012. 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, Canada and U.S. West Coast ports.

Purse-seine Fisheries (WCPO and EPO) **-** 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, sardine, anchovy, and other coastal pelagic species and opportunistically 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 recent years very few of these vessels fished in the EPO. In 2013, 40 vessels caught 254,348 t of all species combined (yellowfin, bigeye (*Thunnus obesus)*, and skipjack (*Katsuwonus pelamis*) tunas) in the WCPO purse-seine fishery. No vessels fished for tuna in the small vessel EPO purse-seine fishery in 2013.

California Large-mesh Drift Gillnet **-** The California large-mesh drift gillnet (CADGN) fleet increased from 17 vessels in 2012 to 18 vessels in 2013. These vessels landed 89 t of swordfish in 2013 compared to 118 t of swordfish caught in 2012. The FRD staff manages the gillnet logbook database (including set net and small-mesh drift gillnet) on behalf of California Department of Fish and Wildlife (CDFW), and data editing and data entry are done by staff from both offices. The NOAA West Coast Regional office (WCR) runs a fishery observer program to monitor ~20% of the fishery effort and conducts on-board size sampling.

California Harpoon **-** The California harpoon fishery increased from 9 vessels in 2012 to 13 vessels in 2013. There was also a slight increase in swordfish caught, from 5 t in 2012 to 6 t of in 2013. No size sampling information is collected from this fishery. The logbook data from this fishery are also managed by FRD 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 currently based out of Hawaii .Logbook data from the West Coast are submitted to the West Coast Regional office in Long Beach, California (WCR) and maintained at SWFSC. During 2013, there was one California-based longline vessel targeting HMS. Data from this fishery are combined with the Hawaii longline data 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 decreased from 1,212 t in 2012 to 839 t in 2013. The recreational catch of bluefin tuna by U.S. recreational boaters increased from 615 t in 2012 to 984 t in 2013.

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 include 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). FRD staff compile and summarize a wide variety of fisheries statistics and group these summaries by various time and space resolutions for submission to the RFMOs and the ISC 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 – 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.

Key Results of the 13th Meeting – The13th ISC Plenary was held in Busan, Republic of Korea, from 17-22 July 2013. The meeting was attended by members from Canada, Chinese Taipei, Japan, Korea, Mexico, and the United States as well as the WCPFC. The Plenary reviewed results, conclusions, new data and updated analyses of the Billfish, Shark, and Pacific Bluefin Tuna working groups. The Plenary endorsed the findings that the Pacific blue marlin and North Pacific blue shark stocks are not overfished nor experiencing overfishing, and reiterated that Pacific bluefin tuna are overfished and experiencing overfishing. It further provided projections for managers to consider in crafting management measures for North Pacific albacore tuna, swordfish, and striped marlin, and updated the conservation advice of ISC12 based on these projections. A special seminar on Pacific Ocean ecosystem and tuna dynamics was held. The Plenary discussed formalizing the ISC structure and administration and began researching means of doing both. The Plenary also noted the strides Working Groups had made in incorporating best available scientific information (BASI) into stock assessment work, enhanced stock assessment reports, and the increased transparency in Working Group efforts. Observers from the Pew Charitable Trust, International Seafood Sustainability Foundation, and World Wildlife Fund attended. The ISC work plan for 2013-2014 includes completing new albacore tuna and swordfish stock assessments, and an updated Pacific bluefin tuna assessment in time for ISC14, completing a shortfin mako shark stock assessment in 2014, enhancing database and website management, and a tuna ageing workshop scheduled for November 2014 in Shimizu, Japan. The Plenary re-elected Gerard DiNardo for a second term as ISC Chair and welcomed Ziro Suzuki as the newly elected Pacific Bluefin Tuna Working Group Chair. The next Plenary will be held in Chinese Taipei in July 2014.

North Pacific Albacore Stock Assessment and Research – North Pacific albacore tuna supports the most important HMS commercial fishery on the U.S. West Coast and is an essential stock for recreational fisheries. In preparation for the stock assessment in April 2014, SWFSC researchers attended a data preparation workshop of the ISC Albacore Working Group (ALBWG), in Shizuoka, Japan, from 5-12 November, 2013. At the workshop, the ALBWG examined critical time series for the stock assessment including catch, abundance indices, size composition, and conditional age-at-length data. During the workshop, SWFSC scientists presented an analysis of the catch-per-unit-effort data (CPUE) of the U.S. and Canadian surface fleets, which led to improved abundance indices for these fisheries. After examining the data and preliminary model runs, the ALBWG agreed upon tentative fishery definitions, primary data sources, and important biological parameters.

A full stock assessment of North Pacific albacore tuna was completed by the ALBWG during a meeting at the SWFSC, La Jolla, from 14-28 April, 2014. Participants included scientists from SWFSC, IATTC, International Pacific Halibut Commission, National Research Institute of Far-Seas Fisheries, and National Kaoshiung Marine University. One of the key improvements to this stock assessment is the use of sex-specific growth models as recently published studies have shown strong evidence of sex-specific growth, with adult males growing to a larger size. The stock assessment was conducted using fishery data through 2012 and a seasonal, length-based, age- and sex-structured Stock Synthesis model (v3.24f). The stock assessment will have to be reviewed and endorsed by the ISC Plenary at the ISC Plenary meeting in July 2014 before being released.

In addition to the stock assessment, SWFSC scientists were involved in several studies that will improve the understanding of the population dynamics and biology of North Pacific albacore. SWFSC published a study (Wells et al., 2013) in *Fisheries Research* titled "Age and growth of North Pacific albacore (*Thunnus alalunga*): Implications for stock assessment," which provides a new growth curve for North Pacific albacore and examines the implications for future stock assessments. SWFSC scientists also participated in a tuna age determination workshop sponsored by the ISC in November 2013.

Bluefin Tuna Stock Assessment and Research – Pacific bluefin tuna historically supported an important commercial fishery for HMS on the U.S. West Coast. In recent years, however, the primary U.S. fishery targeting this species has been the U.S. sport fishery operating out of San Diego, California. There remains an important commercial fishery for Pacific bluefin tuna in Mexican waters. In February 2014, SWFSC hosted a meeting of the ISC Pacific Bluefin Tuna Working Group (PBFWG) to update the stock assessment of Pacific bluefin tuna. Participants included scientists from SWFSC, IATTC, Chinese-Taipei, Japan, Korea, and Mexico. The assessment was conducted using fishery data through June 2013 and a seasonal, length-based, age-structured Stock Synthesis (SS3) model. Results from this update assessment were highly similar to the full assessment conducted in November 2012.

Population dynamics were estimated using a fully integrated age-structured model (Stock Synthesis v3.23b) fitted to catch, size composition and CPUE data from 1952 to 2013, provided by ISC PBFWG members. Life history parameters included a length-at-age relationship from otolith-derived ages, and natural mortality estimates from a tag-recapture study and empirical-life history methods. A total of 14 fisheries were defined for use in the stock assessment model based on country and gear type stratification. Quarterly observations of catch and size compositions, when available, were used as inputs to the model to describe the removal processes. Annual estimates of standardized CPUE from the Japanese distant water and coastal longline fleets, the Taiwanese longline fleet, and the Japanese troll fleet were used as measures of the relative abundance of the population. The assessment model was fitted to the input data in a likelihood-based statistical framework. Maximum likelihood estimates of model parameters, derived outputs, and their variances, were used to characterize stock status and to develop stock projections.

While no single model run provided a good fit to all sources of data that were deemed reliable and estimates of current spawning stock biomass (SSB) varied, there was general agreement on the depleted state of the stock among all scenarios. Long-term fluctuations in SSB occurred throughout the assessment period (1952-2012) and in the most recent period SSB was found to have been declining for over a decade. The recruitment level in 2012 was estimated to be relatively low (the 8th lowest in 61 years), and the average recruitment level for the last five years may have been below the historical average level.

The updated stock assessment model was unable to adequately represent much of the updated data .Poor fit to the two adult indices of abundance and their associated size compositions in the last two years indicate results are highly uncertain. Improvements to the model are advisable before re-assessing, and the current results with regard to the recent trends in SSB should be

interpreted with caution. Using the updated stock assessment, the current (2012) SSB of 26,324 t is slightly higher than that estimated for 2010 (25,476 t). Across sensitivity runs in the updated stock assessment, it was considered that the estimates of recruitment were robust. Estimated age-specific fishing mortalities on the stock in the recent period (2009-2011) relative to 2002-2004 (the base period for the current WCPFC Conservation and Management Measure 2010-04) show 19%, 4%, 12%, 31%, 60%, 51%, and 21% increases for ages 0-6, respectively, and a 35% decrease for age 7+. Although no target or limit reference points have been established for the Pacific bluefin stock under the auspices of the WCPFC and IATTC, the current F (average 2009-2011) exceeds all target and limit biological reference points (BRPs) except for F_{loss}, and the ratio of SSB in 2012 relative to unfished SSB (depletion ratio) is less than 6%. In summary, based on reference point ratios, overfishing is occurring and the stock is overfished.

Historically, the Western Pacific Ocean (WPO) coastal fishery group has had the greatest impact on the Pacific bluefin stock, but since about the early 1990s the WPO Japanese purse-seine fleet has increased its impact, and the effect of this fleet is currently greater than any of the other fishery groups. The impact of the U.S. purse-seine fishery in the EPO was large before the mid-1980s, but decreased after the 1990s until the mid-2000s. The WPO longline fleets (Japan and Chinese-Taipei) has had a limited effect on the stock throughout the analysis period. The impact of a fishery on a stock depends on both the number and size of the fish caught by each fleet; i.e., catching a high number of smaller juvenile fish can have a greater impact on future spawning stock.

The current (2012) Pacific bluefin biomass level is near historically low levels and experiencing high exploitation rates above all biological reference points except for F_{loss}. Based on projection results, the recently adopted WCPFC Conservation and Management Measures (CMMs) and IATTC resolutions for 2014, if continued into the future, are not expected to increase SSB if recent low recruitment continues. Further substantial reduction of fishing mortality and juvenile catch over the whole range of juvenile ages should be considered to reduce the risk of SSB falling below its historically lowest level. If the low recruitment of recent years continues, the risk of SSB falling below the historically lowest level observed increases. This risk can be reduced with implementation of more conservative management measures.

Shark Stock Assessments - The SWSFC staff provide scientific advice on stock status of pelagic sharks to international and domestic RFMOs. 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 WCR are collaborating on multiyear efforts with Centro de Investigación Científica y de Educación Superior de Ensenada (CICESE), led by Dr. Oscar Sosa-Nishizaki. This collaboration is intended 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. Sampling has provided valuable data for international assessment efforts through the ISC as well as for a USA-Mexico partnership to assess the status of common thresher sharks. As a result of the sampling program, fishery data for pelagic sharks now includes some size and sex sampling as well as several years of species-specific catch information.

In 2013, the ISC produced its first assessment of blue sharks (*Prionace glauca*) in the North Pacific Ocean. Two assessment models, including a surplus production model and an age-structured model, were used to investigate stock status. The ISC accepted the assessments at its July 2013 Plenary meeting in Busan, South Korea. The assessments were subsequently submitted to the Scientific Committee (SC) of the WCPFC. The SC recognized these efforts, but requested further analyses to explore key aspects of uncertainty, including changes in targeting practices through time, the effect on estimated abundance indices, as well as additional exploration of the model process. The ISC SHARKWG is working to reassess the stock for a resubmission to the 2014 ISC Plenary and the WCPFC SC.

During the second half of 2014, the ISC SHARKWG will begin an assessment of shortfin mako sharks in the North Pacific. The first meeting focused on the shortfin mako assessment is scheduled to be held in Mexico, with participation from ISC members and observers from Canada, China, Chinese Taipei, Japan, Korea, Mexico, the U.S., IATTC, and potentially SPC.

Time permitting, a collaborative assessment of common thresher sharks will be conducted with Mexican colleagues in 2014 since much of the data needed for the assessment has been compiled.

II. SUPPORTING PACIFIC FISHERY MANAGEMENT COUNCIL ACTIVITIES

Center scientist Stephen Stohs continued serving on the Highly Migratory Species Management Team (HMSMT) of the Pacific Fishery Management Council (PFMC) over the past year. Suzanne Kohin completed her term of service on the HMSMT and was replaced by fellow Center biologist, Tim Sippel, after the June 2013 Council meeting.

The team met several times in 2013 and early 2014 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 a response to Pacific bluefin tuna overfished status; (2) continuing with work to develop a precautionary management framework for north Pacific albacore; (3) analysis of a proposed modification to the drift gillnet fishery Pacific Leatherback Conservation Area (PLCA) closure policy; and (4) preparing the 2013 Stock Assessment and Fishery Evaluation (SAFE) Report and planning for the 2014 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 biological data from albacore fishing vessels when they unload their catches in coastal ports. During 2012, 82,807 fish averaging 69.9 cm fork length (FL) were measured at various west coast ports. Two distinct size modes represent approximately 2.5 and 3.5 year old fish.

In recent years, with AFRF support, fishermen have also collected biological data during selected fishing trips. Following procedures established by SWFSC scientists in 2012, size data were collected from two cooperating vessels in 2012 and 2013, with 1422 and 736 fish measured, respectively. These onboard samples augment the size data collected through the port sampling program. These data are all sent to SWFSC for processing.

North Pacific Albacore Electronic Logbook Project – In 2005, a computer program was developed to allow albacore troll fishermen to enter their logbook data directly into a digital worksheet rather than completing the traditional paper forms. The advantages of recording the data through a computer program include implementing validation rules at the point of entry thus limiting data entry errors, saving time and money on data entry costs, and making the data available in a timelier manner. Since 2006, the program has been used by 5-10 fishermen annually and has received positive feedback on its functionalities and ease of use. During the 2013 season, logs for 63 trips were submitted electronically, representing 4.6% of all trips reported. In 2013, FRD staff developed a new, alternative electronic logbook in PDF format. The format mimics the current paper form and provides simpler computer installation, data entry functionality, and submission processes. The goal is to increase the use of electronic logbooks. Testing should be completed during the 2014 season.

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 878 archival tags have been deployed. One archival tagging trip was conducted during 2013 aboard the chartered F/V *Royal Dawn,* during which 74 tags were deployed. The trip started in Westport, Washington, on 23 October and made its way south, ending in San Francisco, California, on 1 November. In addition, collaborators from the Pfleger Institute of Environmental Research (PIER) opportunistically released 3 archival-tagged albacore off central California. Plans are being made to deploy over 100 tags during the 2014 season.

In 2013, three recaptured albacore all had tags that had been deployed during a single tagging trip in August 2011. Interestingly, a fourth fish from the same tagging trip was recaptured in 2012. The three fish recaptured in 2013 were at liberty for 684, 693 and 753 days representing some of the longest tracks yet recorded during the study. Of the three fish, two were recaptured by Japanese pole-and-line fishermen very close to the coast of Japan. The third was recaptured very close to where it was released, off the coast of Oregon. Although the sensors of one tag malfunctioned partway through its deployment, these recoveries provide remarkable multi-year data on juvenile albacore behavior and movement patterns throughout the Pacific Ocean.

Because of the broad range of movement patterns and behaviors recorded by juvenile albacore so far, 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. During 2013, in collaboration with scientists of the SPC and a cooperating artisanal handline fisherman in Hawaii, SWFSC researchers continued a pilot study to test the use of the new attachment anchors for mini pop-off satellite archival (mini-PSAT) tags and began to collect information on the movements and behaviors of adult albacore. One albacore (106.5 cm FL) was tagged off Kona, HI, in October with a novel monofilament loop attachment. This tag remained on the fish and collected good data for 13 days before releasing prematurely 41 miles from the tagging location. The behavior of the albacore was consistent throughout the track, descending below the thermocline to greater than 400 m during the day, while remaining in the upper 150 m in warmer water at night. The swimming behavior of this fish differed from that of most of the tagged juveniles, but juveniles display a very broad range of behaviors depending upon the region and season. More data will be needed to fully compare the behavior patterns of adults and juveniles.

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 working with a range of partners to collect biological samples of otoliths, muscle, liver, heart, fin spines, scales, vertebrae, DNA fin biopsies, and stomachs from a number of species along the U.S. West Coast. In 2007, the SWFSC and the Sportfishing Association of California initiated a sampling program to collect data on tuna and other HMS. While initially the program was focused in the Southern California Bight (SCB), the program was expanded to the northeast Pacific Ocean in 2009, working with commercial fishermen to collect 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, sampling effort for swordfish expanded to include Hawaii and Mexico to examine the potential for mixing of two purported stocks off California. Japanese colleagues of the National Research Institute of Far Seas Fisheries (NRIFSF) have also been collaborating with SWFSC scientists and contributing otoliths for ageing and microchemistry studies. Sample collection is ongoing and supports the ISC's 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.

Samples of albacore, Pacific bluefin, yellowfin, skipjack (*Katsuwonus pelamis*), yellowtail

(*Seriola lalandi*), opah (*Lampris guttatus*) and dorado (*Coryphaena hippurus*) have been collected through working cooperatively with commercial passenger fishing vessels (CPFV), the commercial albacore troll and pole-and-line fleet, and recreational anglers (Table 1).

Table 1. 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 aimed at providing an integrated picture of foraging and migration patterns of tunas and swordfish in the CC, (2) using otoliths to better characterize age and growth of albacore, (3) radioanalysis of cesium-134 and 137 found in the muscle tissue of Pacific bluefin tuna exposed to waters containing radionuclides discharged from the failed Fukushima nuclear power plant in Japan, combined with stable isotope analysis to determine migration rates and stock structure of juvenile Pacific bluefin tuna in the CC, (4) using otolith microchemistry to determine the dynamics and stock structure of albacore, bluefin, and swordfish 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.

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 of who is eating whom is critical to this approach. To determine the trophic relationships of highly migratory species in the CC, SWFSC scientists have been investigating the foraging ecology of a range of species since 1999.

Analyses of stomach contents of tunas conducted to date reveal a number of interesting patterns across species, regions and years. Looking across regions, a comparison of the top diet items of albacore collected in 2013 off Oregon/Washington, central California, and southern California show a clear difference in diet from north to south (Figure 1). Off Oregon/Washington, stomach contents were dominated by crustaceans, primarily krill that composed 43.5% of the Geometric Index of Importance (GII). Squid was only a minor component of the diet (5.8%). Off Central California, squid comprised 5 of the 7 top diet items making up a total of 48% of the dietary GII. Interestingly, although the sample number was low, the diet of albacore off southern California shows a similar degree of importance of squid as off central California, but crustaceans are slightly more important and fish less important farther south. This information is useful for pinpointing differences in habitat use and energetics across regions.

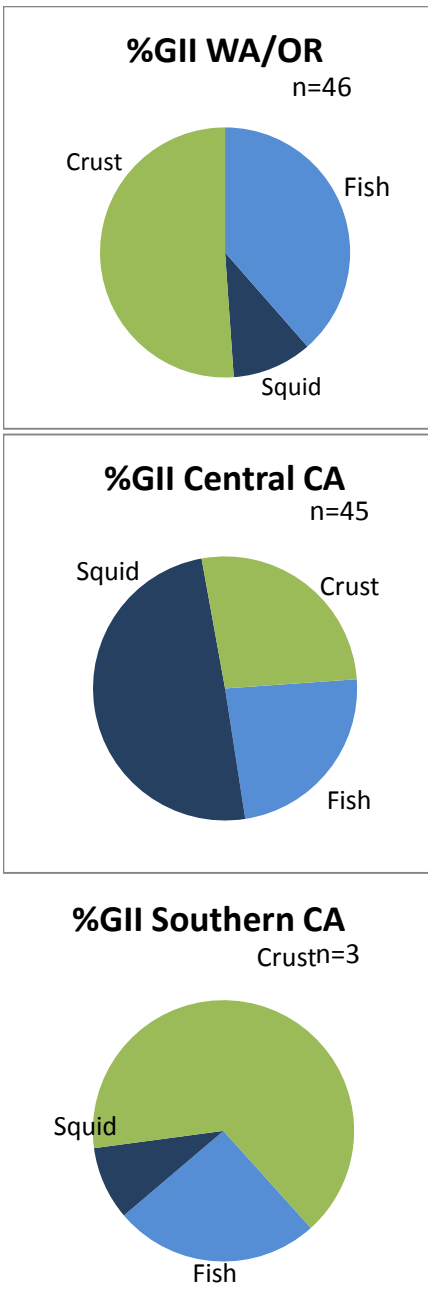

Figure 1. Pie charts showing the relative importance of squid (dark blue), crustaceans (green) and fish (light blue) in the diets of albacore from three regions in the California Current.

Given the long-term data series on stomach contents, is it also possible to examine diet shifts over time. By comparing these results to other studies across the years, it is apparent that over the last decade, tuna in the Southern California Bight show an increase in diet diversity, a reduced reliance on anchovies and sardines, and an increased reliance on squid and other fish species. This likely relates to shifts in prey availability associated with changes in oceanography that has also been reflected in other biological indices.

Albacore Age and Growth –A number of lines of evidence support the hypothesis that there are two different substocks of albacore in the California Current, divided at 40°N. A study recently published by SWFSC scientists in collaboration with the University of San Diego and Texas A&M University examined the daily rings in otoliths of 126 albacore from both regions to determine, age, growth rates, and hatching dates. Overall, fish from the southern region were larger than those in the north, concurring with other studies. Calculated age data reveal that although the size differences were primarily due to differences in age, the presence of significantly larger albacore in the southern population indicates a faster growth rate over some time period. Results showed that fish from both regions had protracted hatch dates from February-September with a peak from April-July and no significant difference between the two purported substocks. Additional research is needed to address the important questions: (1) why are the growth rates

different, (2) what are the mixing rates between the two regions, and (3) are there two distinct substocks or just differences in the locations to which the fish recruit into the California Current waters from spawning grounds to the western Pacific?

Radioanalysis of cesium-134 found in the muscle tissue of Pacific bluefin tuna–Understanding movement patterns of migratory marine animals is critical for effective management, but often challenging due to the cryptic habitat of pelagic migrators and the difficulty of assessing past movements. Chemical tracers can partially circumvent these challenges by reconstructing recent migration patterns. Radionucleotides released into the ocean off Japan provide a unique chemical tracer for animals occupying these waters including Pacific bluefin tuna. Pacific bluefin tuna inhabit the WPO and EPO, and current stock assessments indicate that they are overfished. Understanding age-specific eastward trans-Pacific migration patterns can improve management practices, but these migratory dynamics remain largely unquantified. A collaborative study with the State University of New York (SUNY) combined a Fukushima-derived radiotracer (^{134}Cs) with bulk tissue and amino acid stable isotope analyses of Pacific bluefin to distinguish recent migrants from residents of the EPO, and to time the migrations of juvenile bluefin as they cross the Pacific Ocean. The proportion of recent migrants to residents decreased in older year classes, though the proportion of older Pacific bluefin that recently migrated across the Pacific was greater than previous estimates. Using radioactive decay and bioenergetic turnover rates, it was possible to estimate the time when fish left Japan for their trans-Pacific migration. Of 33 fish samples, 25 are estimated to have left the waters off Japan in June. This novel toolbox of biogeochemical tracers can provide new insights into the dynamics of migration and can be applied to any species that crosses the North Pacific Ocean.

Microchemistry Analysis of Otoliths– Otolith chemistry is one approach to investigate population structure of tunas and other fish. The principal assumption is that the otolith acts as a natural tag because the chemical composition of the otolith is related to the physicochemical conditions of the ambient water. For Pacific bluefin, the purpose of the study is to examine stable isotope and trace element composition in both whole otoliths and serial samples collected in the WPO and EPO over several age classes of fish. Comparisons of otoliths from young of the year, juvenile, and adult bluefin will be used to characterize the dynamics of movement across the Pacific. Results will help determine how many Pacific bluefin migrate to the California Current, what proportion of the spawning stock biomass are California Current migrants and whether these California Current migrants come from one or both spawning grounds. Efforts to collect samples from the WPO spawning grounds were started in 2012 and are ongoing. Otoliths from the EPO have been collected since 2008. Efforts are part of a collaboration between U.S., Japanese, and Taiwanese scientists.

Stable Isotope Analysis of Muscle Tissue in Albacore and California Yellowtail – Stable isotope analysis (SIA) is another tool used by scientists at the SWFSC to examine both migrations and foraging ecology of HMS. SIA measures the amounts of isotopes of carbon (δ^{13}C) and nitrogen (δ^{15}N) in tissues. The approach is based on the principle that "you are what you eat" and the stable isotope signatures in predators will reflect that of their prey. The signature depends both on the predator's trophic level and on the isotope ratios of the primary producers in the region. Given information on regional differences at the base of the foodweb, it is possible, using both δ^{13}C and δ^{15}N, to get a sense for both where geographically fish are

foraging and at what trophic level. SIA is being conducted on a number of different species to answer a range of questions.

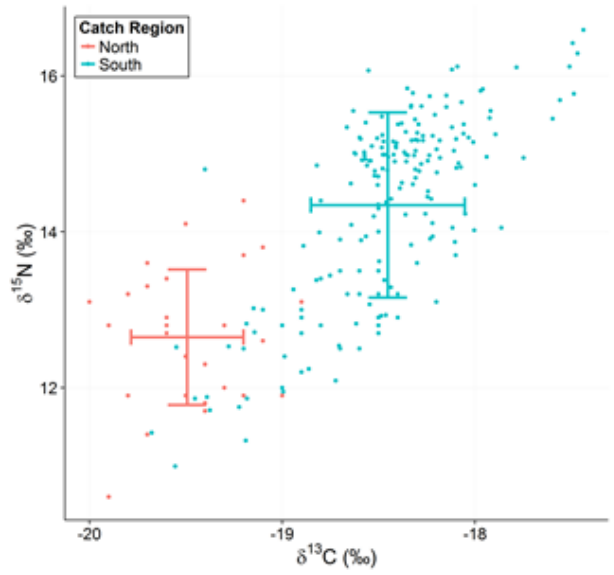

Figure 2: Mean (±SD) $\delta^{13}C$ and $\delta^{15}N$ values for albacore caught between 2008-2013.

SWFSC scientists are using SIA to complement the work on age and growth and otolith microchemistry in the examination of the difference between albacore north and south of 40°N. The signatures of tissue compared between the two regions will provide insight into the potential separation between the two groups and help determine in what water masses they typically forage, onshore versus offshore. By also conducting SIA analyses on regional prey species, it will be possible to examine potential differences in foraging ecology and trophic level over longer time periods than is possible using stomach contents alone.

An initial run of 66 muscle samples (33 northern, 33 southern) collected in 2012, was completed in September 2013, to examine the initial hypothesis of discernible separation between the two potential substocks. Data from the initial samples were also supplemented with samples collected from the SCB between 2008 and 2013 (n=159), as described in the Albacore Age and Growth section. These preliminary data support separation between the northern and southern albacore, with mean $\delta^{13}C$ and $\delta^{15}N$ values from the south showing enrichment compared to northern samples (Figure 2). The $\delta^{13}C$ values show distinct carbon sources being utilized by two potentially separate substocks with limited mixing, while $\delta^{15}N$ values are different but fall short of indicating distinct trophic levels.

The California yellowtail is found in both coastal and pelagic regions of the southern California Current Large Marine Ecosystem. Historical tagging data suggest that yellowtail migrate seasonally; they travel north from Baja California, Mexico into southern California during spring and summer months, spawn in pelagic waters, and return south during fall and winter. These migrations may reflect an ontogenetic shift in habitat use, with smaller individuals traveling long distances in pelagic water offshore before settling into nearshore coastal regions. SWFSC scientists used stable isotope analysis of carbon and nitrogen ($\delta^{13}C$ and $\delta^{15}N$) to determine the extent to which offshore- and inshore-caught yellowtail resemble their environment of capture, and to ascertain the size(s) over which the potential shift from pelagic to coastal waters takes place. $\delta^{13}C$ and $\delta^{15}N$ values were used to group yellowtail into ‘inshore’ or ‘offshore’ using discriminant analysis, with $\delta^{13}C$ and $\delta^{15}N$ values of a pelagic predator, yellowfin tuna, and a coastal predator, white sea bass (*Atractoscion nobilis*), serving as training data. SWFSC scientists also used two separate Bayesian mixing model approaches to determine the extent to which inshore- and offshore-yellowtail reflect; (1) pelagic and offshore prey inputs, and (2) their similarity to the predators above. Results show a shift in habitat use, based on changes in $\delta^{13}C$

and $\delta^{15}N$, between 81 and 96 cm (strait FL). Mixing models confirmed that smaller, offshore yellowtail largely reflected pelagic prey resources and SIA values were similar to yellowfin tuna. In contrast, larger, inshore yellowtail reflected higher input from inshore resources and were similar to white sea bass, though there was significant contribution (25-45%) of offshore prey to diet of inshore yellowtail. Future work on muscle tissue turn-over rates of captive yellowtail will help discern how changes in food sources could reflect the shift from offshore to inshore habitat use as yellowtail grow larger.

In addition to the work on albacore and yellowtail, a number of other projects are ongoing using SIA to examine migrations and foraging ecology. Two new projects were started in 2013. The first will expand the use of SIA to broadbill swordfish, shortfin mako, blue sharks, and thresher sharks. Like the above studies, tissue samples will be collected from both the predators themselves as well as prey found in their stomachs. This work seeks to strengthen results from traditional stomach content analysis on these species which has been ongoing at the SWFSC since 1999. In the second project, the stable isotopes of both the fin spines and muscles of swordfish will be used to examine stock structure. Currently it is thought that there are two stocks of swordfish in the North Pacific with the dividing line between the two of them starting off the Baja Peninsula, Mexico at 30°N and extending to the southwest reaching the equator at 170°W. Swordfish in the northwestern area support the second largest HMS fishery off the U.S. West Coast. Important management related questions are; (1) whether the two-stock hypothesis is supported by complementary datasets and, (2) if there are two stocks, what are the dynamics of mixing between the two stocks on eastern Pacific fishing grounds. Preliminary results reveal distinct differences in the isotope signatures between the "Hawaii fish" (i.e. from the northwestern area) and the "Mexican fish" providing a proof of concept for differentiating between the two in samples collected off California if they mix.

Albacore distribution and environmental effects - SWFSC scientists, in collaboration with scientists of Canada's Department of Fisheries and Oceans (DFO), received funding in 2012 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." As a result of this collaborative study, SWFSC scientists have submitted two manuscripts for review and publication in a special issue of *Progress in Oceanography*. These studies have improved the development of abundance indices for albacore in the Northeast Pacific.

Xu et al. (*In review*) examines the influence of subtropical fronts on the spatial distribution of albacore in the Northeast Pacific over the past 30 years by relating albacore CPUE from U.S. and Canadian logbooks with subtropical fronts derived from an analysis of sea surface temperature (SST) gradients using an improved version of the Cayula-Cornillion frontal detection algorithm (Nieto et al., 2012). Results suggest that areas with high albacore CPUE tend to occur in regions with high SST gradients, such as the North Pacific Transition Zone (NPTZ) and the North American coast. Approaching the North American coast along the NPTZ, SST gradients drop off substantially around 130°W before increasing rapidly near the coast, which corresponded to a similar pattern in albacore CPUE. In the NPTZ, the centroid of albacore CPUE showed a seasonal shift northwards in summer and southwards in fall, which coincided with seasonal spatial shifts of areas with high SST gradients. A similar pattern was found on an inter-annual

scale, with the exception of several years with limited fishery data in the NPTZ due to changes in fishery operations.

Nieto et al. (*In review*) examines coastal upwelling fronts as key habitat for albacore tuna in the Northeast Pacific Ocean. The study uses satellite-derived SST data to characterize coastal fronts in an automatic way and boosted regression trees (BRTs) to relate the effects of these fronts on albacore distribution. The results suggest that albacore CPUE distribution is strongly influenced by SST and chlorophyll at fishing locations, albeit with substantial seasonal and inter-annual variation. Albacore CPUEs were higher near warm, low chlorophyll oceanic waters, and near SST fronts. Sequential leave-one-year-out cross-validations were performed for all years and it was found that the relationships in the BRT models were robust for the entire study period. Spatial distributions of model-predicted albacore CPUE were similar to observations, but the model was unable to predict very high CPUEs in some areas.

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 2013 were the International Billfish Angler Survey and the Billfish Tagging Program.

International Billfish Angler Survey– In 2013, SWFSC researchers summarized the results from the 2012 Billfish Angler Survey. Initiated in 1969, the survey now provides a 44-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 index for billfish covering the entire Pacific. The CPUE, measured in number of billfish caught per angler fishing day, was 0.48 across all reporting areas in 2013. This was a slight improvement from the 2012 CPUE of 0.44, but below the five year average (2007-2011; 0.58 CPUE). Over 90% of survey angler fishing days during 2012 were spent at three locations: Hawaii, Southern California, and Baja California, Mexico. The greatest effort from survey respondents was off the coast of Hawaii. Over 3,500 fishing days were reported from the Hawaiian Islands. The 2012 Hawaii CPUE was 0.39 compared to the previous five-year average (2007-2011; 0.42 CPUE). Similarly, success off the coast of Southern California during 2012 was down from recent years with anglers reporting the second lowest CPUE (0.03) on record. Conversely, 2012 was a good fishing year off the coast of Baja California, Mexico. During 2012, anglers caught 0.82 billfish per fishing day, which was the sixth highest CPUE reported for this location in 29 years. However, compared to the previous 5 years, this CPUE was still below average (2007-2011; 1.08 CPUE). This five-year average was influenced by great results in 2007 and 2008 which were by far the two highest CPUEs on record.

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 3). Blue marlin CPUE off Hawaii and Tahiti was

down from the previous year and has trended down at each location over the last five years. However, the blue marlin CPUE reported from Baja California, Mexico, was up after a very slow 2011. Striped marlin CPUE was up from the previous year at two of the three highlighted locations. The slight increase in catch per fishing day off Southern California was not necessarily something to celebrate. This increase was following the lowest CPUE on record (0.02). The striped marlin CPUE throughout Mexico also increased in 2012 and appears to be trending in the right direction. Not shown was an increase in striped marlin CPUE off Baja California, Mexico, from 0.54 in 2011 to 0.69 in 2012. The 2012 result was above the five most recent year average (0.60). Sailfish CPUE reported throughout Mexico (0.15) was the lowest it has been in over 20 years.

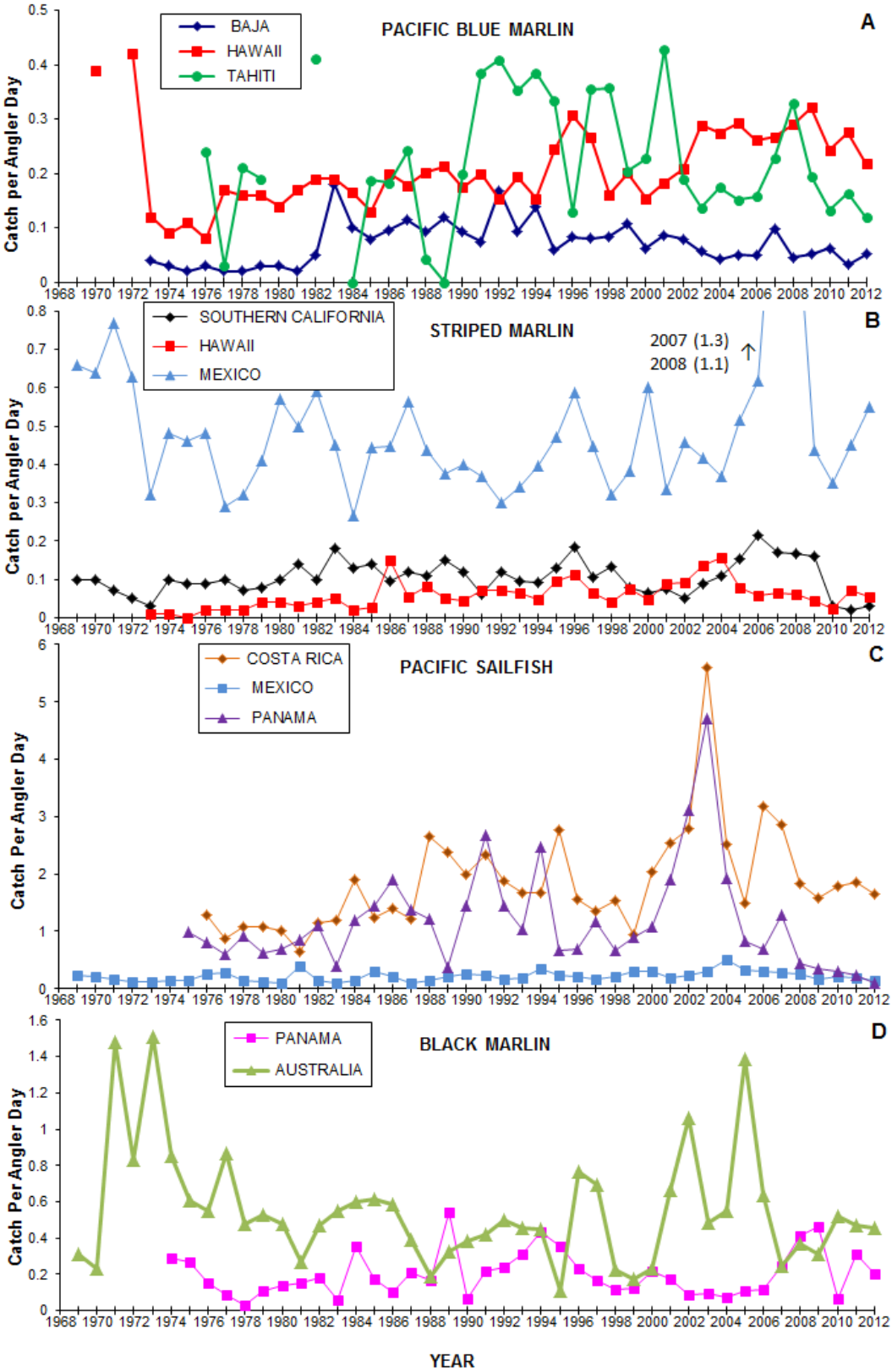

Figure 3. CPUE as catch-per-angler-day is shown from 1969 through 2012 for Pacific blue marlin, striped marlin, Pacific sailfish, and black marlin.

Recreational Billfish Tagging Program–The year 2012 marked the 51st 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 California Department of Fish and Wildlife, over 77,000 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 575 tags were released on billfish in 2012 through the efforts of captains and anglers. Most billfish were tagged and released in U.S. or Mexican waters; however, billfish were also tagged and released by anglers in many locations across the Pacific. Most tag releases occurred off the coast of Hawaii, the majority of these on blue marlin. The number of sailfish tag releases during 2012 (67) is worth highlighting because this was more than three times the number of sailfish releases in 2011.In fact, the number of sailfish tag releases had been on the decline for several years until 2012.The focus of this effort was centered along the central coast of Mexico where a group of dedicated anglers has made a big contribution by working with local charter operations out of Zihuatanejo. Table 2 shows the tagging effort for 2012 and tag recoveries throughout the program's history. The data include releases made by SWFSC scientists during research cruises.

Table 2. Summary of fish tagged through the Billfish Tagging Program in 2012 with releases and recoveries for 1963–2012, including SWFSC's ongoing research tagging.

SPECIES NAME	RELEASE 2012	RELEASE TOTAL	RETURN TOTAL	RETURN RATE (%)
Striped Marlin	123	23,235	348	1.5
Pacific Blue Marlin	328	11,718	94	0.8
Blue Shark	225	9,834	193	2.0
Sailfish	67	9,292	49	0.5
Shortfin Mako Shark	253	5,739	338	5.9
Billfish, unidentified	0	4,386	6	0.1
Black Marlin	0	3,392	69	2.0
Shortbill Spearfish	57	2,294	3	0.1
Common Thresher Shark	265	2,137	98	4.6
Albacore Tuna	81	930	30	3.2
Broadbill Swordfish	0	522	17	3.3
Yellowfin Tuna	0	349	25	7.2
Leopard Shark	1	225	12	5.3
Skipjack Tuna	0	100	2	2.0
Bigeye Tuna	0	79	2	2.5
Basking Shark	0	65	0	0.0

Hammerhead Shark	0	62	2	3.2
Bluefin Tuna	0	58	8	13.8
Bronze Whaler Shark	0	52	3	5.8
Whitetip Shark	0	44	1	2.3
Atlantic Blue Marlin	0	43	0	0.0
Soupfin Shark	1	41	1	2.4
Salmon Shark	0	36	3	8.3
Silky Shark	0	24	1	4.2
White Marlin	0	13	1	7.7
Longbill Spearfish	0	3	0	0.0
Other Tunas	0	21	1	4.8
All Others	6	2,803	125	4.5
TOTAL	**1,407**	**77,497**	**1,432**	**1.8**

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 Marine Mammal and Turtle Division (MMTD) and the NOAA WCR 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. While a large organized initiative has yet to be established, FRD and MMTD 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 habitat use patterns– Further progress has been made on characterizing the geographic habitat use patterns and behavior of leatherback sea turtles along the U.S. West Coast based on electronic tagging data. Satellite telemetry position data collected from leatherback turtles tagged at nesting beaches in the western Pacific and along the central coast of California between 2003 and 2011 were used to predict the foraging habitat in the California Current ecosystem. Environmental data (sea surface temperature, upwelling indices, chlorophyll concentration, etc.) were associated with each location. All observed locations in the PLCA were assumed to be associated with foraging .A predictive model was developed to infer foraging by leatherbacks at areas and times lacking turtle telemetry data. A high probability of foraging behavior occurred within the PLCA from August through November, but varied among years according to the annual variability in the environmental conditions. This telemetry research has helped understand leatherback turtle habitat and important behavioral patterns along the U.S. West Coast.

Combined with the geographic analyses, SWFSC scientists have been looking at vertical habitat use of leatherbacks along the U.S. West Coast and comparing it to that of swordfish. Based on preliminary data it appears there may be considerable vertical habitat separation between the two species that could be exploited to reduce bycatch. Swordfish make diel migrations between the

surface at night and deep waters during the day whereas preliminary data indicate that leatherbacks remain in near-surface waters both day and night. The dive data initially examined for leatherbacks was very limited and in other areas leatherbacks have been shown to dive to 1000m. To better quantify the vertical distribution of leatherbacks, MMTD researchers examined all dive data from satellite tagging efforts where locations were outside of critical habitat but inside the U.S. EEZ. Analyses of over 7,000 dives reveal that the majority of time is spent above 50 m with no dives below 100 m (Figure 4). In contrast, daytime depths of swordfish in the same region are expected to be from 250 to 500 m (when not basking). This indicates that targeting swordfish deep during the day may be a valid approach to reducing interactions with leatherbacks.

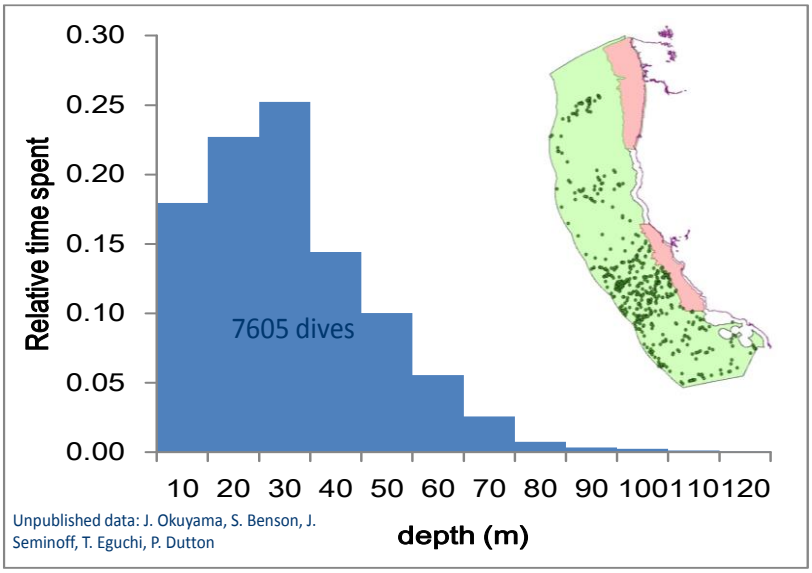

Figure 4. Histogram showing the depth distribution across all locations in the shaded green area. Inset map shows the locations of all associated dives. The area is red is the leatherback critical habitat.

Deep-set Longline Survey to Investigate Swordfish-Sea Turtle Habitat Separation– Heightened focus on minimizing bycatch of protected species has lead U.S. fisheries managers to implement combinations of gear restrictions and time-area closures. For example in 2001, to reduce sea turtle bycatch in swordfish fisheries, shallow-set longline (SSLL) fisheries were closed in the Atlantic and Central Pacific and a time-area closure was imposed on the CADGN fisheries. In response to the SSLL closures, fishers and scientists collaborated to develop gear modifications that reduced loggerhead and leatherback bycatch by 90% and 65%, respectively, leading to MSC certification of the Atlantic SSLL fishery. In contrast, the CADGN fishery has declined dramatically since implementing a large time-area closure in 2001. The goal of this project was to explore potential gear alternatives for targeting swordfish off California, building on previous efforts to reduce turtle bycatch in longline fisheries. The idea was to shift the longline gear to deeper water to capitalize on the difference is daytime depths; swordfish typically spend the daylight hours in waters deeper than 200 m whereas leatherbacks remain above 120 m.

On three cruises from 2011-2013, NOAA collaborated with longline fishers aboard the chartered F/V *Ventura II* off central and southern California to investigate the efficacy of targeting swordfish during the day using a deep-set longline (DSLL). During 47 sets, with average hook depths of 230-247 m and soak times of 2.7-4 hours, 111 marketable fish (including 8 swordfish, 67 opah, and 23 pomfret) and 352 non-marketable fish (including 328 blue sharks and 17 king-of-the-salmon) were caught. Short soak times were used to maximize fish condition for tagging; two swordfish, five opah and five blue sharks were released with satellite tags and the majority

of the remaining blue sharks were tagged with conventional tags and released. Based on previous research on blue shark post-release mortality, 81%-91% of blue sharks would be expected to survive after release. This study concluded that it is possible to catch swordfish and other marketable species below turtle habitat with a DSLL however, swordfish catch was low. Fishing conditions during these cruises were probably impacted by anomalous oceanographic conditions; swordfish catch for the CADGN fleet was very low over the same time periods. Efforts to collect additional data under more realistic fishing operations (i.e. fishing when and where conditions are best, over longer time periods) would provide a further test of the gear's potential. Given the experimental and small-scale nature of this research, these results are promising, but should not be projected beyond the study and warrant more research.

Swordfish Deep-Set Buoy Gear (DSBG) Research– The WCR Long Beach Sustainable Fisheries Division and PIER researchers are conducting research using a deep-set vertical hook and line configuration (buoy gear) to target swordfish within the exclusive economic zone off the coast of California. To minimize interactions with species of concern, the deep-set gear was designed to fish below the thermocline (270 to 350 m) during daylight hours. Gear trials were conducted during the 2011 and 2012 swordfish seasons off the coast of southern California using both research and cooperative fisher vessels. There were no interactions with species of concern, minimal interaction with non-target species (i.e., sharks), and swordfish were the primary catch. This work has been submitted for publication in 2013. Additional DSBG field experiments in 2013 focused on improving the test configuration, enhancing deployment and retrieval efficiency and preparing for cooperative trials in 2014. These data will be used in 2014 to trial DSBG from cooperative fisher platforms and to assess the domestic market niche for buoy-caught swordfish. Additional collaborative efforts of the WCR, SWFSC, and PIER in 2013 focused on documenting the depth distribution for swordfish in the PLCA. Scientists deployed 13 pop-off satellite archival tags and provided the first movement data for swordfish within the study region. These data will be analyzed and submitted for publication in 2014. Preliminary research results were presented at the March 2014 meeting of the Pacific Fishery Management Council.

Foraging Ecology of Swordfish in the SCB– In support of ecosystem based studies, the foraging ecology of swordfish is being investigated to examine predator-prey interactions and niche overlap with other pelagic predators. Stomach contents for this work have been predominantly provided through the CADGN observer program. Since 2012, 59 stomachs have been analyzed (35 from 2012 and 24 from 2013). Current levels of analysis have allowed SWFSC researchers to identify some of the most frequently encountered prey species (F=Frequency of prey occurrence). Broadbill swordfish stomachs in season 2012-13 contained jumbo squid (*Dosidicus gigas*) (F=48), *Gonatopsis borealis* squid (F=34), *Abraliopsis* sp. squid (F=32), *Gonatus* spp. squid (F=18). These preliminary results show a possible shift in feeding trends. In 2012-13 jumbo squid showed a resurgence in dietary importance for swordfish compared to the previous season.

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 have 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 2013 a total of 80 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. The increase in opah availability has provided an opportunity to begin collecting biological samples and data for a species about which little is known. The apparent increase in opah catch starting in 2009 is likely influenced by many factors including fishing methods and environmental variability. The research vessel historically used to conduct the survey, the 171 foot R/V *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 could have impacted catch rates, although the gear was configured to match that used on the DSJ in an effort to not change the survey methodologies. Further analyses of the variability in survey catch as well as examining opah catch using logbooks from the CADGN fishery and recreational sportfishing 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 94 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 making up the most important prey items (*Loligo opalescens, Gonatus* spp., *Dosidicus gigas*) based on the IRI (index of relative importance). Squid ranged from 30 mm (*Gonatus* spp.) to over 266 mm mantle length (*D. gigas*). 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 deep scattering layer (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 the diets of 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 some 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 off southern California prior to 2013. During 2013, an additional 6 tags were deployed on opah. All tagging was done during research longline cruises conducted by SWFSC scientists. The PSAT tags were programed to collect light level, depth, and temperature data for 240 days. Of the original eight tags for which the data have been analyzed, 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. Opah also appear to switch their diving behavior after leaving the SCB, staying further below the sea surface and making deeper dives into cooler water. 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 off Mexico the following March .One tag, deployed north of Point Conception in late October 2011, popped up northeast of Hawaii the following June.

Opah Physiology– Opah were collected on the 2013 shark cruise and DSLL cruise for determination of blood properties, examination of gill and cardiovascular 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. SWFSC scientists 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. A manuscript describing these results is currently being drafted.

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 (*Alopias vulpinus),* bigeye thresher (*A. superciliosus),* and pelagic thresher (*A. pelagicus)*. Center scientists are studying the sharks' biology, distribution, movements, stock structure, population status, and potential vulnerability to fishing pressure. This information is provided to international, national, and regional fisheries conservation and management bodies having stewardship for sharks.

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. While blue shark has little market importance in the U.S., it 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. 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. Surveys for neonate thresher sharks are conducted using a small commercial longline vessel in near shore waters.

Juvenile Mako and Blue Shark Survey– In 2013, SWFSC researchers conducted the twentieth juvenile shark survey for mako and blue sharks since 1994. The annual abundance survey was completed between 3 July and 26 July. Working aboard F/V *Ventura II*, a team of scientists and volunteers fished a total of 5,946 hooks during 28 daytime sets within seven focal areas of the SCB. The survey catch totaled 257 shortfin makos, 14 blue sharks, 11 pelagic rays (*Pteroplatytrygon violacea*), 8 opah, and 1 ocean sunfish (*Mola mola)*. The preliminary data indicate that the nominal survey catch rate was 1.08 sharks per 100 hook-hours for shortfin mako and 0.06 sharks per 100 hook-hours for blue sharks. The mako shark nominal CPUE was higher than the previous year. However, there is a declining trend in nominal CPUE for both species over the time series of the survey.

In addition to survey longline sets, other fishing methods were used to maximize time on the water and increase the opportunity for catching other large HMS. Longline gear was modified for ancillary sets in an effort to cover a greater vertical distribution of the water column by using longer branchlines and more hooks per basket.

In all, 35 longline sets were completed. A total of 317 animals were caught. Most animals were brought onboard, measured, tagged, and sampled for DNA biopsies before they were released. Conventional spaghetti tags were released on 267 sharks to collect data on movement and stock structure. In addition, sharks tagged with conventional tags were also injected with oxytetracycline (OTC) and tagged with plastic dorsal tags containing information for fishers upon recapture of the animal to retain a portion of the vertebrae for ongoing age and growth studies. 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.

Neonate Thresher Shark Survey– In 2013, SWFSC scientists and volunteers conducted the survey aboard the F/V *Outer Banks*. Forty-nine longline sets were made in relatively shallow, nearshore waters and a total of 4,916 hooks were fished during the 18-day cruise. A total of 336 fish across a range of species were sampled during the survey. Two hundred and eighty-five thresher sharks were captured. Most of these sharks were injected with OTC and tagged with a combination of conventional tags for movement and stock structure, and plastic dorsal tags containing return information for the age and growth study.

The preliminary survey data indicate that the average nominal catch rate by set was 2.49 thresher sharks per 100 hook-hours, equivalent to the CPUE from 2012. 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 sharks; primarily blue, shortfin mako, and common thresher sharks, while other species are tagged opportunistically. Shark tag deployments have been carried out in collaboration with a number of partners in the U.S., Mexico, and Canada. 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 a better understanding of how populations might shift in response to changes in environmental conditions over short or long time scales. SWFSC scientists have been collecting data on shortfin mako and blue sharks for over a decade and continue to look at horizontal and vertical movement patterns on many different time scales. In 2013, a number of sharks and other large pelagic fish were deployed with electronic tags in support of several collaborative projects. Four shortfin mako sharks and two blue sharks were tagged with satellite-linked radio position tags (SPOTs). Three mako sharks, three swordfish, one common thresher, one opah, and one albacore tuna were released with pop-off archival tags (PSATs).

Shortfin Mako Sharks– In 2012 the SWFSC began a collaboration with Fishtrack to deploy SPOT tags on larger makos during the longline survey. Four makos have been released with tags sponsored by Fishtrack. The tracking data are posted in near-real-time on their website (http://www.fishtrack.com/live-track/). Tags of two sharks tagged in 2012 and one tagged in 2013 were still reporting as of April 2014 (Figure 5).

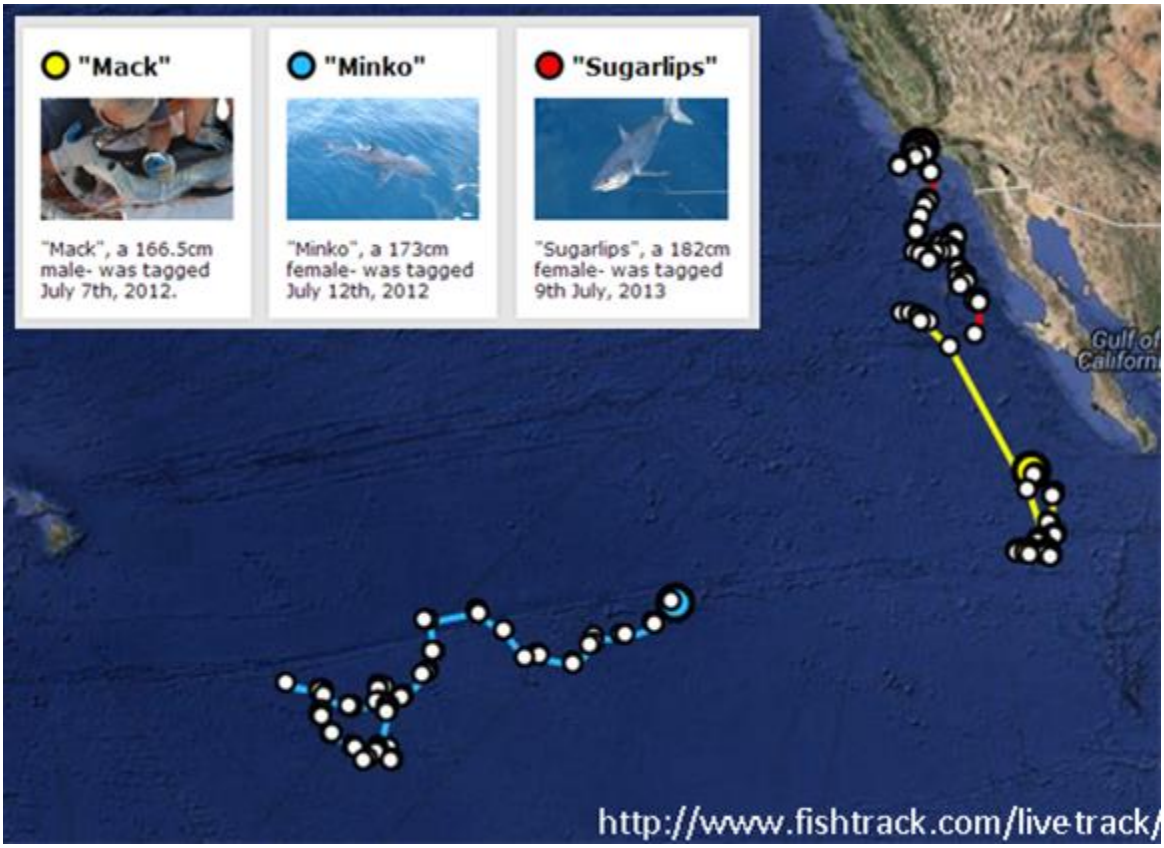

Figure 5. Tracks of three shortfin mako sharks tagged in collaboration with Fishtrack in 2012 and 2013.The tracks show two months of data representing movements during March and April 2014.

In 2013, the SWFSC began a collaboration with recreational anglers to deploy PSATs on very large shortfin mako sharks that are typically not caught in commercial fisheries nor on the SWFSC's fishery-independent shark survey. Three makos estimated at 250 kg or larger were tagged with PSATs in September and October 2013. SWFSC scientists are hoping to hear from the tags in May 2014.

SWFSC scientists have been synthesizing all the electronic tagging data for mako sharks. Tracking success has been very good for makos as they generally provide long duration tracks allowing an incredible opportunity to examine seasonal movement patterns and regional fidelity. Data from 85 SPOTs with deployment durations of 3 to 1025 days and 56 PSATs with durations of 18 to 227 days, including data from 40 double tagged sharks, have been analyzed. The sharks ranged from the surface to more than 600 m depth, with the majority of time spent in the top 100 m. The range of horizontal movements of tagged sharks spanned along the coast of North America, from the northern coast of Washington to just south of Puerto Vallarta, Mexico, and out to the Hawaiian Islands. Two sharks travelled as far south as 4˚ N but did not cross the equator. Sharks showed seasonal movements travelling out of the SCB in the fall and winter and returning in the spring and summer. A manuscript is currently being drafted.

Basking Shark–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 of North America, the basking shark was listed as endangered in Canada and as a Species of Concern in the U.S. in 2010. Given severe data gaps for this population, SWFSC scientists initiated a basking shark research program in 2010 that includes an electronic tagging study.

During 2013, data from the three sharks tagged with satellite tags in 2010 and 2011 were analyzed and the results 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. Figure 6 shows the track and vertical movements from one shark that moved to just north of Hawaii after 240 days. As it moved offshore, swimming depths increased and the shark avoided surface waters. While at depth, a distinct diel pattern was apparent with the shark remaining at shallower depths at night than during the day. These data support the hypothesis that when offshore, basking sharks forage on the deep scattering layer and not on aggregations of copepods in surface waters as seen near-shore.

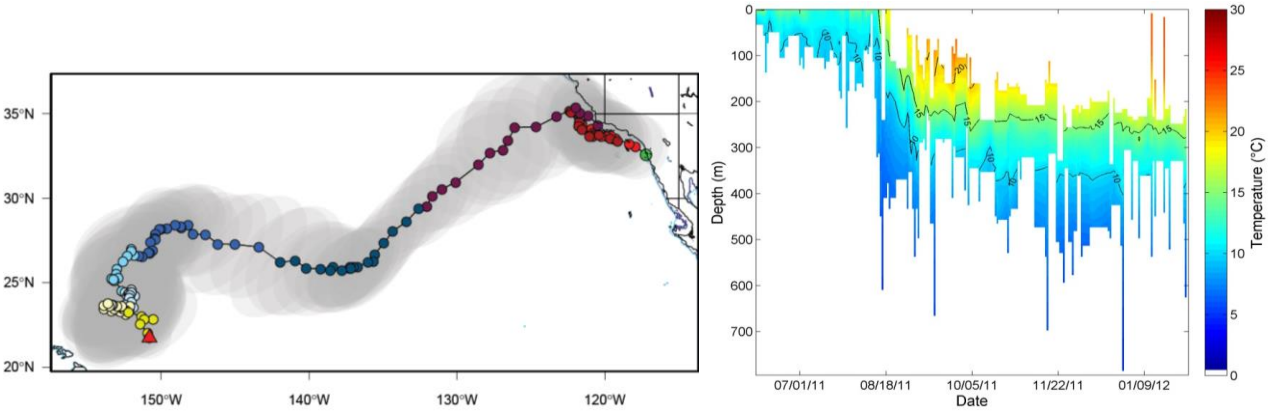

Figure 6. (Left) The track of a basking shark tagged on 6/7/2011 off San Diego. The tag released as programmed on 2/2/2012. (Right) The vertical movements of the same shark showing the shift in habitat use as it moved offshore.

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 ageing methods for these three species based on band deposition periodicity determined using OTC. 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, 3,718 individuals have been injected with OTC. During the 2013 SWFSC shark surveys, 243 shortfin mako, 259 thresher, and 68 blue sharks were injected with OTC and released.

The ISC SHARKWG has developed a collaborative research plan to address uncertainties about age and growth of pelagic sharks. As part of the plan, participating national scientists are collecting samples from blue and shortfin mako sharks for a reference collection. Band enhancement methods vary between labs and the reference collection will be used to corroborate

age reading across labs and ultimately develop improved growth models for these two species. SWFSC scientists collected samples during research cruises and through the fishery observer program during 2013 and has contributed those samples to the ISC SHARKWG age and growth specialists. In January 2014, the ISC convened its second Shark Age and Growth Workshop during which participants progressed on their work plan. The group hopes to provide the SHARKWG updated information on shortfin mako shark growth for use in their upcoming stock assessment.

Oxytetracycline Age Validation of Juvenile Shortfin Makos– Wells et al. (2013) recently published the results of OTC age validation of 29 juvenile shortfin mako sharks tagged in the SCB. The study showed vertebral band pair deposition rates of two per year for sharks up to about 4-5 years old in the northeast Pacific.

Oxytetracycline Age Validation of Blue Sharks– Vertebrae of 26 blue sharks marked with OTC were obtained from tag-recapture activities to determine timing of centrum growth band deposition. Length-frequency modal analysis was also used to obtain growth estimates from a 22-year data set of research and commercial catch data. Tagging occurred off southern California with time at liberty ranging from 22 days to 1.61 years including six returns at liberty over one year (390-587 days). For recaptured blue sharks used for age validation, shark size at initial capture ranged from 73 to 231 cm FL consisting of nine females and 17 males. Results from band counts distal to the OTC mark on each vertebrae indicate a single band pair (one translucent and one opaque) is formed per year for blue sharks ranging from one to eight years of age. Length-frequency analysis identified three age-class modes at 79, 108, and 133 cm FL with estimated growth rates of 29 and 25 cm FL for the first two years, respectively. Results provide support for annual vertebral band pair deposition in blue sharks in the northeast Pacific Ocean.

Oxytetracycline Age Validation of Common Thresher Sharks– A total of 1,454 common thresher sharks ranging in size from 45 to 230 cm FL have been injected with OTC. Vertebrae from 54 of these sharks (size range at tagging: 63-145 cm FL) have been returned with an average time-at-liberty of 342 days. Sample processing is underway and the preliminary results suggest an annual deposition rate for the size classes studied.

Record Shortfin Mako Shark Studied– Predatory sharks can be difficult to study, especially for the larger size classes which are infrequently encountered and rarely landed in commercial and recreational fisheries. In the Northeastern Pacific Ocean, shortfin mako sharks are important predators, and while data are increasing for smaller size classes, there is a paucity of data regarding large adults. On 3 June 2013, a record-breaking female shortfin mako shark (total length = 373 cm, mass = 600.1 kg) was captured by a recreational angler off Huntington Beach, California, and was subsequently donated to the SWFSC and California State University Long Beach for research. Samples of various tissue types were collected and analyzed to gain more information about the shark's anatomy, physiology, ecology, and life history. The shark was found to have an approximately three-year old female sea lion carcass in its stomach. This confirms the presence of pinnipeds in the diet of larger shortfin makos, which are available prey items year round in southern California. The spiral valve contents included two species of cestode parasite including 20 specimens of a tetraphyllidea tapeworm and two of a trypanorhyncha tapeworm. Two damaged specimens of a capillaria nematode were also found,

but as this genus is not known to parasitize sharks, it is likely that they were ingested along with their teleost hosts. Two ageing methods, thin sectioning with microscopy and x-ray imaging, were used to age the vertebrae of this mako, producing counts of 26 and 27 band pairs, respectively. Given that shortfin mako sharks in the northeast Pacific deposit two band pairs in vertebrae per year through age 5 (Wells et al., 2013) and the uncertainty regarding band pair deposition rates in older specimens, the estimated age range of this shark was 13-22 years old. Organic contaminants and total mercury were measured in the liver and muscle tissue of the shark and were found to be substantially greater than most animals previously measured in southern California (total DDTs: 0.2 mg/g wet weight; total PCBs: 0.03 mg/g wet weight); however, the potential implications of this contaminant burden are unknown. Mercury levels were much higher than FDA recommendations for human consumption. This rare opportunity allowed for the collection of important data and contributes to the knowledge about the life history characteristics of large shortfin mako sharks.

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 spatially overlapping species, SWFSC researchers have been analyzing the stomach contents of pelagic sharks 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). The stomachs of several species of pelagic sharks caught during the 2012 and 2013 fishing seasons have been analyzed. Current levels of analysis have allowed SWFSC scientists to identify some of the most frequently encountered prey species. For the 2012 and 2013 seasons, shortfin mako stomachs (n=39) contained Pacific saury (F=23; F=Frequency of prey occurrence), jumbo squid (F=7), market squid (F=6), and octopus squid (*Octopoteuthis spp.*) (F=4). Blue shark stomachs (n=13) contained *Gonatus spp*. squid (F=11), octopus squid (F=5), and paper nautilus. Common prey in thresher shark stomachs (n=12) was market squid (F=6) and Pacific saury (F=4). Jumbo squid was found in mako stomachs for the 2012 season only. Not all stomachs for the 2013 season have been analyzed, however, and the absence of jumbo squid in mako stomachs is preliminary pending completion of all the analyses.

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 west coast commercial fishery which catches the greatest number of each of these species. While thresher and mako sharks are landed, almost all blue sharks are discarded. Regional recreational fisheries have also seen a rise in the popularity of thresher and mako sharks. 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 WCR 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 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 2012-2013 season, 15 blue sharks (100 to 200 cm FL) had been tagged by fishery observers. Three of the 15 sharks were released in "good" condition, 10 were released in "fair" condition, and 2 in "poor" condition. The two sharks that were released in "poor" condition as well as one released in "fair" condition did not survive the acute effects of capture in the CADGN fishery. These results, suggest that sharks that are released in "good" condition are likely to survive, whereas those released in "poor" condition are likely to die. No tags were released during the 2013-2014 season due to low effort and few blue sharks caught during the time the tags were available to observers, but SWFSC scientists hope to complete the study during the 2014-2015 season.

Thresher Sharks Released from the Recreational Fishery – Researchers from the SWFSC, WCR, and PIER have conducted a three-phase study to assess the post-release survival of thresher sharks caught by recreational anglers. The first phase of the study, which was completed in 2010, involved releasing sharks which had been 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, six sharks died shortly after release, one died after several weeks, 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). These results indicate that trailing gear left embedded in sharks can negatively affect post-release survivorship, while mouth-based angling, when performed properly, can result in high survivorship of released sharks. The second publication for this project, based on results from phases two and three, has been submitted and is currently undergoing peer review in the journal Fisheries Research. Overall, the results from all phases of this study indicate that methods which maximize mouth-based capture and reduced fight times should be adopted as best fishing practices by 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. 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/) in 2012. A second video, highlighting phases two and three of the research effort, is still under development by OMC.

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 population range, distribution, and life history into account. Various genetic analyses are useful to help identify differentiation between and within presumed stocks. During 2013, sample collection and processing continued to examine stock structure for a number of shark species including shortfin mako, common thresher, silky, and pelagic thresher sharks. In addition, samples of blue shark tissue have been sent to colleagues in Japan as part of a Pacific-wide collaboration. DNA samples were collected during research cruises in 2013 from 263 shortfin makos, 72 blue sharks, 262 common threshers, 6 leopard sharks (*Triakis semifasciata*), and 1 brown smoothhound (*Mustelus henlei*). Additional samples were obtained by fishery observers on CADGN trips.

V. IDCPA RESEARCH

The SWFSC research conducted under the International Dolphin Conservation Program Act (IDCPA) during 2013 was focused on evaluating assumptions in line-transect methods used to estimate marine mammal abundance at sea 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) continued analysis of data collected during a 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. A study of changes in regional ecosystem structure induced by a tropical storm was published (Fiedler et al., 2013a).

Ecosystem data were collected during STAR-LITE 2007. 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. Kiko mixed water from beneath the strong, shallow thermocline to the surface. As a result, surface temperature decreased by 0.6°C, the thermocline and chlorophyll maximum layer shoaled by 10-20 m, stratification decreased by 27%, and chlorophyll increased by 33% at the surface and 35% over the euphotic zone. These changes persisted for at least four weeks. Zooplankton biomass increased by 59% about three weeks after the phytoplankton increase. Changes in the stomach fullness and diet composition of planktivorous flyingfish were consistent with the increase in zooplankton biomass. Among top predators, the sighting rate of dolphins declined, while the response of seabirds varied by species and was confounded by seasonal migration patterns. Tropical cyclones

are a recurrent disturbance in this region. They initiate a bottom-up forcing of the ecosystem, creating persistent patches of higher primary and secondary production, and may be regarded as a disturbance regime.

Research conducted in 2007 represented 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, SWFSC 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 Stenella Abundance Research (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 and pantropical spotted dolphins, *Stenella longirostris* and *S. attenuata*, respectively) are conducted with an ecosystem approach. In addition to investigating the status and trends of these dolphin stocks, auxiliary projects are conducted to improve the understanding of their surrounding environment. Recent data analyses, processing, and publications included: (1) investigations of cetacean biodiversity hotspots; (2) identifying critical habitat for large whales; (3) ecosystem modeling; (4) assessment of relative fishery exposure for ETP dolphins; (5) dolphin swimming kinematics research; (6) investigations of dolphin reproductive biology; (7) ETP dolphin population genetic structure; (8) investigations of the ETP ecosystem and its change over time; (9) metrics of ecosystem impact of the ETP purse-seine fishery; (10) cephalopods as indicators of spatial variation in biochemical properties between marine systems, and (11) comparative analysis of ETP ecosystem services.

Investigations of Cetacean Biodiversity Hotspots– Kaschner et al. (2011) uses a model to predict cetacean species richness patterns, and validates the model with empirical data, including data collected during SWFSC research surveys in the ETP. SWFSC scientists also investigated species richness hotspots for 28 species of cetaceans in the ETP (ca. 20 million km^2) based on data collected aboard NOAA research vessels, August–November, in each of 10 years during a 21-year period (1986-2006). Density was converted to presence/absence on a species-specific basis, and species richness (number of species recorded in a particular grid cell) was mapped for all years combined. Richness hotspots were defined as any grid cell that contained greater than 40% of the total species pool (≥ 11 species) and were clearly evident in three distinct regions: the Equatorial Front, the Costa Rica Dome, and waters to the southwest of the Baja California peninsula. Although these hotspots encompassed areas of highest density for a few species, the correlation between richness and density for any given species was generally low (mean 0.25, range 0.03 to 0.44), as was the proportion of cells where a particular species was present and encompassed by a hotspot (mean 0.20, range 0.04 to 0.56). A manuscript on this topic is in preparation.

Identifying Critical Habitat for Large Whales– Many species of baleen whales migrate long distances between breeding and feeding areas. These species are exposed to anthropogenic threats in their feeding and breeding areas and along their migration routes; threats include entanglement in fishing gear, ship strikes, ocean noise, contaminants, and climate change. Mitigating these threats requires a transboundary, systematic planning approach. To facilitate planning efforts in the EPO, the SWFSC partnered with the Permanent Commission for the South Pacific (CPPS) to host an international workshop. The workshop was attended by participants from Chile, Colombia, Ecuador, Panama, Costa Rica, the United States' National Oceanic and Atmospheric Administration, and CPPS. Scientific presentations were given summarizing the state of risk assessment in EPO waters. For example, representatives from the SWFSC gave presentations on assessing the risk of ships striking large whales in marine spatial planning and tools to develop species distribution models. These presentations used over 20 years of large-scale survey effort conducted by SWFSC researchers in offshore waters and over 1,000 opportunistic sightings held by CPPS in their Regional Information System on Biodiversity and Protected Areas. Participants, particularly those representing government agencies from the various countries, also addressed the following questions:

- How can you help to improve species distribution and threat data?
- How can you contribute to marine spatial planning efforts for the eastern Pacific?
- What are the institutional opportunities and barriers for resource protections in your country?
- How can you help move large whale conservation forward during the coming year?

Ecosystem Modeling– Development of an ecosystem model to explore patterns of cetacean distribution, migration, feeding, and breeding is underway. In the future, SWFSC scientists will use these ecosystem variables and models to help explain current cetacean ecological patterns and predict future changes.

Assessment of Relative Fishery Exposure for ETP Dolphins – For the past half century, the purse-seine fishery for yellowfin tuna has been a significant factor in the lives of dolphins in the ETP. However, little is known about how frequently an individual dolphin is exposed to the fishery, and no methods are available for accurately assessing the prior exposure of dolphins encountered at sea. Archer et al. (2010) developed a method to estimate an index of exposure based on a model of dolphin movement derived from data collected from multiple tracking studies. Planned studies for this index include examining its relationship to evasive behavior, calf production as assessed from aerial photographs, and reproductive rates as measured from skin biopsies.

Dolphin Swimming Kinematics Research– The results from a series of nine publications investigating various aspects of swimming kinematics of mother and calf dolphins between 2004 and 2011 are being integrated into a hydrodynamics-based energetics model to investigate the potential for dolphin mother-calf separation and subsequent calf mortality due to tuna purse-seine chase in the ETP. The model will contribute to understanding of indirect fishery effects on populations of dolphins targeted by the ETP tuna purse-seine fishery. In addition to progress on model development during 2013, a comprehensive review was published of form, function, and physiology in the most-often targeted species in the ETP, the pantropical spotted dolphin

(*Stenella attenuata*), by Edwards, E.F, N.M. Kellar, and W.F. Perrin in 2013.

Investigations of Dolphin Reproductive Biology– Kellar et al. (2013) published *Pregnancy patterns of pantropical spotted dolphins (*Stenella attenuata*) in the eastern tropical Pacific determined from hormonal analysis of blubber biopsies and correlations with the purse-seine tuna fishery*. This paper examined reproductive patterns of these dolphins by measuring blubber progesterone (BP) concentrations in biopsy samples to assess pregnancy state. Blubber progesterone was quantified in 212 biopsies from female offshore dolphins sampled between 1998 and 2003 in the northeastern tropical Pacific, and SWFSC scientists found that 11.5% of biopsied females were pregnant. The relationship between pregnancy and fishing effort was analyzed using the relative exposure index developed in Archer et al. (2010), and SWFSC scientists found that pregnant females were exposed to significantly less activity than non-pregnant ones ($p=0.022$), suggesting that the fishery may have an inhibitive effect on pregnancy. Additional spatial analysis indicated that pregnancy was more aggregated than random ($p<0.05$) at a scale up to 180-nmi, with the highest proportion pregnant in the mouth of the Gulf of California, an area with relatively low reported activity.

ETP Dolphin Population Genetic Structure– Research is underway to examine 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. Updated population structure information is needed to ensure stock boundaries and abundance estimates remain accurate, as they are necessary to calculate dolphin stock mortality limits.

In 2011, work began quantifying the levels of genetic structure in spinner and spotted dolphin populations in the ETP. A Ph.D. student at Scripps Institution of Oceanography working in collaboration with SWFSC, has collected mitochondrial genomes (mtDNA) and nuclear SNPs from 111 spinner and 89 spotted dolphins to test for genetic structure using DNA capture arrays and next-generation sequencing. MtDNA shows differences between whitebelly and both eastern and Central American spinners, but not between the latter two (accepted subspecies). SNP analyses show differences between all three forms. Structure was not detected between spotted dolphin subspecies in the mtDNA; nuclear SNP analyses are ongoing. Results support current management boundaries for spinners, but were limited in the ability to detect substructure below the level of subspecies due to limited samples and power to detect genetic structure. The results suggest the need for additional data to determine the accuracy of stocks of spotted dolphins. Matt is currently writing this work for publication and now collecting restriction site associated (RAD) markers to test subspecies hypotheses in spotted dolphins and structure with the subspecies of spinner dolphins. Additional samples are being sequenced from throughout the spinner and spotted dolphin distributions in order to place these populations within a global phylogeographic context.

Investigations of the ETP Ecosystem and Its Change over Time– Fiedler et al. (2013b) published an analysis of variations in thermocline depth and stratification in the ETP and North Pacific. Time series from 1958-2008 were decomposed into seasonal, inter-annual cycle, and long-term trend components using state-space techniques. 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 analyses will investigate seasonal and inter-annual variability of the thermocline in this region.

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

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

Cephalopods as indicators of spatial variation in biochemical properties between marine systems– Ruiz-Cooley et al. (2010) and Ruiz-Cooley and Gerrodette (2012) quantified two biochemical tracers ($d^{13}C$ and $d^{15}N$) from epi-mesopelagic squid tissues, the jumbo squid (*D. gigas*) and purple back squid (*Stenotheuthis oualaniensis*), to investigate ontogenetic shifts in diet, habitat use and differentiate distinct groups or subpopulations based on the unique biochemical properties of their habitat along the eastern Pacific. These two squid species are key components in food webs from the ETP and potential prey of tuna and dolphins as well as other pelagic fish and odontocetes. For the first time, Ruiz-Cooley and Gerrodette revealed that $d^{13}C$ and $d^{15}N$ measured from tissues of these squid species can serve to track large-scale latitudinal, longitudinal, and geographic variability in the biochemical distribution of carbon and nitrogen along the eastern Pacific. Furthermore, the results from this study can serve for future studies investigating pelagic food web dynamics using stable isotope analysis.

Ruiz-Cooley et al. (2013) built on this research by using stable isotopes to track origin of jumbo squid captured in the California Current ecosystem. Coincident with climate shifts and anthropogenic perturbations, the highly voracious jumbo squid reached unprecedented northern latitudes along the Northeast Pacific margin post 1997–98. The physical or biological drivers of

this expansion, as well as its ecological consequences remain unknown. Novel analysis from both bulk tissues and individual amino acids (Phenylalanine; Phe and Glutamic acid; Glu) in both gladii and muscle of jumbo squid captured in the Northern California Current System (NCCS) documents for the first time multiple geographic origins and migration. Phe d15N values, a proxy for habitat baseline $d^{15}N$ values, confirm at least three different geographic origins that were initially detected by highly variable bulk $d^{15}N$ values in gladii for squid at small sizes (.30 cm gladii length). In contrast, bulk $d^{15}N$ values from gladii of large squid (.60 cm) converged, indicating feeding in a common ecosystem. The strong latitudinal gradient in Phe $d^{15}N$ values from composite muscle samples further confirmed residency at a point in time for large squid in the NCCS. These results contrast with previous ideas, and indicate that small squid are highly migratory, move into the NCCS from two or more distinct geographic origins, and use this ecosystem mainly for feeding. These results represent the first direct information on the origins, immigration and habitat use of this key ‘‘invasive’’ predator in the NCCS, with implications for understanding both the mechanisms of periodic jumbo squid population range expansions, and effects on ecosystem trophic structure.

Seasonal and inter-annual variability of dolphin distributions– An analysis of tuna-vessel observer data is underway in collaboration with the IATTC. These data, collected by observers aboard tuna purse seiners that fish tunas associated with dolphins, can be processed to yield sightings and effort data. While of lower quality than data collected on research vessel surveys, the data are continuous from 1980 to the present and thus can much more effectively resolve seasonal and inter-annual changes. These changes will be related to environmental variability.

Comparative analysis of ETP ecosystem services– Beginning in 2011, research conducted by a Ph.D. student at Scripps Institution of Oceanography and SWFSC provides a case study in the analysis and valuation of open ocean ecosystem services, with a view toward evaluating tradeoffs among commercial fisheries, biodiversity conservation, and carbon storage and sequestration. Until recently, many ecosystem services were assumed to hold no economic value because they were not traditionally traded in markets. Society has made decisions to maximize economic value by choosing something that has monetary value (e.g., commercial fisheries) over something that has no monetary value (e.g., biodiversity). Ecosystem service valuation for the ocean has primarily focused on coastal systems, such as coral reefs, mangroves and estuaries, with much less emphasis on open ocean ecosystems. However, as management for open ocean ecosystems moves toward more holistic approaches, efforts to value their services will need to progress. Making use of extensive historical datasets from the SWFSC, the IATTC, and NMFS Office of Science and Technology (economic data on fisheries imports), they are documenting and quantifying the major ecosystem services provided by the ETP, identifying the major user groups of these services, and quantifying some economic values of these services using existing data from commercial fisheries and biodiversity conservation efforts in the region, as well as global carbon markets. Results will contribute to the challenging but critical movement toward ecosystem-based management for the open ocean.

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