SOUTHWEST FISHERIES SCIENCE CENTER

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JUNE 2018

2018 HIGHLY MIGRATORY SPECIES ANNUAL REPORT

by

The Southwest Fisheries Science Center

ADMINISTRATIVE REPORT LJ-18-01

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The United States is obligated to collect U.S. fisheries statistics and participate in advancing fishery science for species of interest. Fishery information feeds into domestic and international fishery management. Scientists at the National Oceanic and Atmospheric Administration Southwest Fisheries Science Center (NOAA SWFSC) have been tasked to fulfill this obligation. This report focuses on work of SWFSC scientists on highly migratory fish species (HMS) and their fisheries. Contributions and activities of the past year, April 1, 2017 – March 31, 2018, are briefly described.

I. MONITORING U.S. HIGHLY MIGRATORY SPECIES (HMS) FISHERIES

Monitoring U.S. HMS Fisheries

Southwest Fisheries Science Center (SWFSC) scientists monitor six U.S. HMS fisheries in the Pacific, providing information from these fisheries to HMS researchers, fisheries managers, and international management organizations in support of the conservation and management of HMS stocks in the Pacific. The Fisheries Monitoring Group (FMG) under the Fisheries Resources Division (FRD) compiles and manages information on vessels, gear, effort, catch, bycatch, protected species interactions, landings, biological sampling, and observer data collected from these HMS fisheries. This information is routinely summarized into data products that are provided to researchers and fisheries management organizations, as well as other customers. FMG staff collaborate with staff from other National Marine Fisheries Service (NMFS) regional science centers, regional offices, headquarters, as well as fisheries councils, commissions, state fisheries agencies, and others to collect and share information from HMS fisheries in the Pacific.

The Eastern Pacific Ocean (EPO) is home to a number several commercial and recreational fisheries that target various HMS. The U.S. Pacific tuna purse-seine fishery, which was historically a large vessel fleet fishing throughout the tropics, has dwindled to a few smaller coastal purse seine vessels that occasionally target tunas in southern California waters. The North Pacific albacore (*Thunnus alalunga*) troll and pole-and-line fishery is the largest HMS fishery based on the West Coast. This fishery began in the 1940s and its fishing grounds have expanded and contracted over 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 California targets swordfish (*Xiphias gladius*) and thresher sharks (*Alopias vulpinus*) off the coast of central and southern California. The California harpoon fishery targets swordfish mostly in the California bight. 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 fishing vessels that target albacore off of Washington, Oregon, and central California, and albacore, bluefin (*Thunnus orientalis*), and yellowfin tunas (*Thunnus albacares*) in southern California and Mexican waters. The total catch in 2016 for the HMS fisheries monitored by FMG is shown in **Table 1**.

Table 1. Landed catch in the U.S. commercial HMS fisheries. Catches cannot be reported for fisheries for which fewer than three vessels participated.[1]

FISHERY	2016 CATCH IN METRIC TONS	NUMBER OF VESSELS
North Pacific Albacore Troll and Pole-and-line	10,686	571
South Pacific Albacore Troll	257	6
Eastern Pacific Ocean Purse Seine	669	9
California Large-mesh Drift Gillnet	241	20
California Harpoon	26	19

North Pacific Albacore Troll and Pole-and-line

Total annual catch of albacore from the North Pacific albacore troll and pole-and-line fishery in decreased 7.5% from 11,558 t in 2015 to 10,686 t in 2016. The number of vessels decreased from 578 vessels in 2015 to 571 vessels in 2016. The average weight of retained albacore in 2016 was 16.6 pounds, compared to 15.8 pounds in 2014. Logbook data from this and other HMS fisheries are required to be submitted to SWFSC under the HMS Fishery Management Plan (FMP) enacted by the Pacific Fisheries Management Council (PFMC) 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 each season. Six vessels participated in the fishery in 2016 and in 2015. Total catch of albacore in the 2016 fishery was 257 t, an increase of 13% from the 224 t landed in 2015. 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.

California Large-mesh Drift Gillnet

The California large-mesh drift gillnet fleet increased from 18 vessels in 2015 to 20 vessels in 2016. These vessels landed 176 t of swordfish, 28 t of common thresher, and 22 t of other HMS species in 2016 compared to 97t of swordfish, 31 t of common thresher, and 16 t of other HMS species caught in 2015. The FMG staff manage the gillnet logbook database (including set net and small-mesh drift gillnet) in collaboration with California Department of Fish and Wildlife (CDFW). Data editing and data entry are managed by staff from both offices. The NOAA West Coast Regional Office (WCRO) observer program monitors approximately 20% of the fishery effort and conducts on-board size sampling.

California Harpoon

The California harpoon fishery increased from 12 vessels in 2015 to 19 vessels in 2016. Twenty-five metric tons of swordfish were caught in 2016 compared with five metric tons caught in 2015.

[1] Numbers taken from RFMO submissions made in 2017.

No size sampling information is collected from this fishery. The logbook data from this fishery are also managed by FMG staff in cooperation with CDFW.

Longline (California-based)

Deep-set longlining for tuna is permitted under the PFMC FMP for HMS. In 2016, one vessel was based in California but several Hawaii-based longline vessels operated out of west coast ports. These Hawaii vessels fished under their Hawaii longline permit. Since 2015, Hawaiian and west coast longline logbook data have been consolidated and are managed by Pacific Islands Fisheries Science Center (PIFSC).

Recreational HMS Fisheries

Several different fleets of recreational vessels target HMS along the U.S. West Coast. Albacore are targeted by both Commercial Passenger Fishing Vessels (CPFV) and private vessels off the coasts of Washington and Oregon. In recent years, very few albacore have been caught by anglers in Southern California; however, recreational catches of bluefin and yellowfin tunas in Southern California and Mexican waters have generally increased, though both experienced a decrease in 2016. The recreational catch of albacore by vessels that target albacore off the West Coast decreased from 926 t in 2015 to 675 t in 2016. The catch of bluefin tuna by U.S. recreational anglers decreased from 382 t in 2015 to 298 t in 2016. The recreational catches of yellowfin tuna decreased from 1,785 t in 2015 to 643 t in 2016.

Miscellaneous Fisheries

HMS caught incidentally in other commercial fisheries are summarized from the Pacific Fisheries Information Network (PacFIN) database where state landings data from marine fisheries are maintained. These fisheries caught 81 t of HMS in 2016 compared to 48 t of HMS caught in 2015.

II. SUPPORTING U.S. OBLIGATIONS OF INTERNATIONAL AGREEMENTS

The major customers that require detailed information on U.S. HMS fisheries in the Pacific Ocean include: the South Pacific Tuna Treaty (managed by the Forum Fisheries Agency), the U.S.-Canada Albacore Troll Treaty, 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). FMG staff compile and summarize a wide variety of fisheries statistics that are grouped by various time and space resolutions for submissions to the Regional Fishery Management Organizations (RFMO) and the Regional Fisheries Organizations (RFO) 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.

North Pacific Albacore

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. The stock assessments of this stock of albacore tuna is performed by the ISC Albacore Working Group (ALBWG). After the completion of the most recent stock assessment in 2017, the ISC ALBWG turned its attention towards completing the first round of management strategy evaluation (MSE) for this stock. The initial MSE for this stock is scheduled to be completed in 2018.

As part of the MSE process, the ISC ALBWG organized the 3rd ISC MSE workshop for managers, stakeholders, and scientists in Vancouver, Canada, during November 17 - 19, 2018. The primary objectives of the workshop was to (1) review management objectives and performance metrics previously proposed during the 2nd ISC MSE Workshop (Yokohama, May 2016), (2) identify acceptable level of risk for each objective to be used in evaluating performance of management strategies, (3) develop a preliminary set of candidate reference points and harvest control rules for testing and (4) review the work plan and timeline for conducting the MSE.

The ISC ALBWG has scheduled a workshop at the SWFSC, La Jolla, during April 30 – May 5, 2018. The primary objectives of the workshop are to evaluate the results of the initial MSE and develop a report for the ISC Plenary, and respective RFMOs. The MSE results will have to be reviewed and endorsed at the 18th meeting of the ISC Plenary in July 2018 before being released.

Pacific Bluefin Tuna

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 March 2018, SWFSC hosted a meeting of the ISC Pacific Bluefin Tuna Working Group (PBFWG) to conduct the updated stock assessment (base-case run) of Pacific bluefin tuna. Participants included scientists from SWFSC, IATTC, Taiwan, Japan, Korea, and Mexico.

Population dynamics were estimated using a fully integrated length-based and age-structured model (Stock Synthesis v3.24f) fitted to catch size composition, and catch-per-unit of effort (CPUE) data from 1952 to 2017 (fishing year 1952-2016), provided by ISC PBFWG members and non-ISC countries. The basic structure remains the same as the 2016 assessment. Life history parameters included a length-at-age relationship from otolith-derived ages, natural mortality estimates from a tag-recapture study and empirical-life history methods, and maturity at age. A total of 19 fleets were defined for use in the stock assessment model based on country/gear/season/region 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, off-shore 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. Various diagnoses of the assessment model and sensitive analyses were conducted.

Projections requested by the Northern Committee of the Western Center Pacific Fisheries Commission (WCPFC) and Inter-American Tropical Tuna and Commission (IATTC) were conducted. Alternative harvesting scenarios (several combinations of fishing mortality and catch limit) and recruitment scenarios based on the WCPFC Harvest Strategy (Harvest Strategy 2017-02) were evaluated.

The results assessment and projection is subject to be endorsed by the ISC Plenary meeting in July and will be present at the IATTC SAC meeting, the WCPFC Scientific Committee in August 2018, and WCPFC Northern Committee in September 2018.

Sharks

SWSFC staff provided scientific advice on stock status of pelagic sharks to international and domestic fishery management organizations. SWFSC participation in international collaborations on pelagic shark stock assessments is organized primarily through the Shark Working Group (SHARKWG, chaired by Dr. Mikihiko Kai, National Research Institute of Far Seas Fisheries) of the ISC. SWFSC scientists involved in the ISC SHARKWG worked on a new shortfin mako shark assessment with the goal of producing a full stock assessment early in 2018.

North Pacific Shortfin Mako Shark

In 2017, the ISC SHARKWG prepared data to conduct an assessment of shortfin mako sharks in the North Pacific in 2018. The objective was to update the fishery data time-series from the 2015 indicator analysis (ISC 2015), review the latest biological research, and develop a fully integrated age-structured model. Participants from Japan, Taiwan, Mexico, Canada, and the U.S. contributed data and/or analytical work.

SWFSC and PIFSC scientists provided full catch time-series of mako sharks caught, landed, and released in U.S. commercial and recreational fisheries (Kinney et al. 2017) as well as information on the size and sex composition of mako sharks taken in several observed fisheries. The SHARKWG is developing two models for consideration at the April 2018 working group meeting in La Jolla. The first is a fully integrated assessment model developed with Stock Synthesis (SS) (Carvalho *et al.* in prep), and the second will be a virtual population analysis (VPA) model (Kanaiwa *et al.* in prep). The SS model will likely take a matrix approach where several base-case scenarios are considered in order to account for uncertainty in many key model parameters. The VPA model will be developed primarily to provide a point of comparison to the SS model. The SHARKWG will provide the results of both approaches in the April 2018 meeting.

Scientists from the SWFSC and PIFSC will be responsible for the bulk of the writing of the assessment report. This assessment report will closely follow the structure of the previous assessment report on blue sharks in the North Pacific Ocean (ISC 2017), which was completed by the ISC SHARKWG in 2017. One key difference, however, will be that the stock assessment report for mako sharks is unlikely to contain future projections.

Common Thresher Shark

The SWFSC is also involved in shark assessments outside of the ISC. Scientists from SWFSC and the Centro de Investigación Científica y de Educación Superior de Ensenada (CICESE) collaborated to complete a stock assessment of common thresher sharks along the west coast of North America (Teo *et al.* 2016 and 2018). This is the first stock assessment of common thresher sharks along the west coast of North America that incorporates information from all fisheries exploiting the population. This assessment was peer reviewed by a panel from NOAA's Center for Independent Experts (CIE) during June 26 – 28, 2017. The reproductive biology of the common thresher shark was the major axis of uncertainty in the assessment, and more work will need to be done on this subject before the next assessment of this stock.

III. SUPPORTING PACIFIC FISHERY MANAGEMENT COUNCIL ACTIVITIES

Center economist Dr. Stephen Stohs continued serving on the Highly Migratory Species Management Team (HMSMT) of the PFMC over the past year. The team met several times in 2017 and early 2018 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 issues facing the HMSMT and the Council over the past year have been: (1) assisting the Council with the process of completing and adopting HMS FMP Amendment 4; (2) aiding the Council with approving exempted fishing permit operations to test alternative methods of targeting swordfish off the West Coast; (3) providing guidance on scoping requirements for authorizing deep-set buoy gear as a swordfishing method off the West Coast; (4) providing recommendations for international management activities; (5) aiding the Council with amending the HMS FMP to create a federal drift gillnet permit; and (6) preparing the 2017 Stock Assessment and Fishery Evaluation (SAFE) Report.

IV. 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 environment on the 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. The SWFSC contracts and works with state fishery personnel to collect size data from albacore fishing vessels when they unload their catches in coastal ports. During 2016, 33,850 fish averaging 71 cm fork length (FL) were measured at various west coast ports.

North Pacific Albacore Electronic Logbook Project

In 2005, a computer program was developed to allow albacore troll fishermen to enter their logbook data into a computer program 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. The program has received positive feedback on its functionalities and ease of use. During the 2016 season, logs for 31 trips were submitted electronically. In 2015, FRD staff began developing a new, alternative electronic logbook in PDF format to upgrade the existing version and increase the use of electronic logbooks. Development is nearly complete and distribution of the new electronic logbook will begin in 2018.

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. Tags are deployed in cooperation with the albacore troll/pole-and-line fleet near the main fishing ground off Oregon and Washington, as well as in cooperation with the recreational charter fleet off southern California and northern Baja, Mexico, when the fish are present. The total number of tags deployed to date is 1,086. In 2016 and 2017, logistical problems prevented deploying additional tags. A total of 37 archival tags have been recovered resulting in data from more than 15,000 days at liberty.

Recent efforts have focused on further analyzing the data recovered from all tags since publication of the first paper on the migrations of juvenile albacore in the North Pacific (Childers *et al.* 2011) and incorporating these data into new analyses.

Stephanie Snyder, a recent PhD graduate from SIO, is working collaboratively with SWFSC and AFRF on the albacore tagging data to understand influences of the environment on albacore thermoregulation, movements, and behavior. She examined the inherent properties of the temperature sensors on the tags and established an algorithm to accurately interpret time lags in water and peritoneal temperature changes (Snyder and Franks 2016). Additional analyses have been conducted on exploitation of frontal features by tagged albacore (Snyder, et al, 2017). Additional analyses are being conducted on the extremely large amount of data collected from this program.

Bluefin Tuna Modeling Research

Evaluation of alternative modelling approaches to account for spatial effects due to age-based movement

Spatial patterns due to age-specific movement have been a source of un-modelled process error. Modeling movement in spatially-explicit stock assessments is feasible, but hampered by a paucity of data from appropriate tagging studies. Lee *et al.* (2017) used simulation methods to evaluate alternative model structures that either explicitly or implicitly account for the process of age-based movement in a population dynamics model. They simulated synthetic population using a two-area stochastic population dynamics operating model. Two different states of nature governing the movement process were explored. The model that includes the correct spatial dynamic is the only one that results in unbiased and precise estimates of derived and management quantities. In a single area assessment model, using the fleets as area (FAA) approach and estimating both length-based and time-varying, age-based selectivity to implicitly account for the contact selection and annual availability may be the second best option. A FAA approach, assuming each fleet represents a combination of gear and area and adds additional observation error, performed nearly as well. Future research could evaluate which stock assessment method is robust to uncertainty in movement and is more appropriate for achieving intended management objectives.

Bluefin Close-Kin Mark Recapture Research

The bluefin close-kin genetics study is a parentage based mark-recapture research program to develop an independent abundance estimate for Pacific bluefin tuna. During 2017, fin clips for genetics were collected from U.S. recreationally and commercially caught bluefin for the ISC-led project. The U.S. fisheries will be sampled indefinitely in support of the project, and other nations reported at the ISC Plenary in July 2016 that sampling was occurring North Pacific-wide. A proposed meeting of international genetic experts to decide upon standardized methodologies for generating genotypic data was not funded in 2017, thus processing of the U.S. samples has not yet begun.

Petition to List Pacific Bluefin Tuna as Endangered or Threatened Under the U.S. Endangered Species Act

On June 20, 2016 the National Marine Fisheries Service (NMFS) received a petition from the Center for Biological Diversity (CBD) and 13 co-petitioners requesting that Pacific Bluefin tuna, *Thunnus orientalis* (PBF), be listed as endangered or threatened under the Endangered Species Act (ESA) throughout all or a significant portion of its range. After review of the petition, NMFS published a positive 90-day finding in the Federal Register (81 FR 70074) on October 11, 2016, concluding that the petitioned actions may be warranted and announcing that a formal status review would be conducted as required by the ESA. A Status Review Team (SRT) was tasked to conduct this review.

On August 8, 2017, the NMFS published a 12 month finding on this petition and determined that, based on the best scientific and commercial data available, including the status review report, and after taking into account efforts being made to protect the species, listing of the Pacific bluefin tuna was not warranted. NMFS concluded that the Pacific bluefin tuna is not an endangered species throughout all or a significant portion of its range, nor likely to become an endangered species within the foreseeable future throughout all or a significant portion of its range.

Information on the petition and final determination, including the status review report, may be found at http://www.westcoast.fisheries.noaa.gov/fisheries/migratory_species/pbt_esa_status_review.html

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, DNA fin biopsies, gonads, 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. Initially the program was focused on the Southern California Bight (SCB). Since that time the program has been expanded to include a broader geographic range and increased number of species. In 2009 scientists began working with commercial fishermen in the Northeast Pacific to collect samples from albacore off Oregon and Washington. In 2010, additional efforts were made to include central California (Monterey Bay and San Francisco) where albacore are sometimes encountered from August through November. Finally in 2017, the program was again expanded to include opah and bigeye tuna caught by high-seas longliners landing their catch in California. Sample collection is ongoing and supports the ISC's proposed 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*), California yellowtail (*Seriola lalandi*), opah (*Lampris guttatus*), and dorado (*Coryphaena hippurus*) have been collected during NOAA research surveys and through cooperative programs with commercial passenger fishing vessels (CPFV), seafood processors, the commercial fisheries operations, and recreational anglers (**Table 2**).

Table 2. Summary of all fish collected in the SWFSC cooperative biological sampling program for tuna and related species.

Species	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	Total
Pacific Bluefin	0	75	78	54	189	294	181	156	120	487	253	1887
Albacore: Washington/Oregon	0	0	42	191	49	60	60	39	50	1	34	526
Albacore: Central California	0	0	0	0	27	31	43	0	0	0	0	101
Albacore: Southern California	116	35	93	118	7	62	3	0	0	0	0	434
Yellowfin	15	45	95	71	128	132	112	134	50	112	127	1021
Skipjack	0	5	9	8	15	16	25	0	0	0	0	78
California Yellowtail	0	0	7	30	190	186	90	36	30	0	0	569
Opah	0	0	1	11	16	64	30	30	15	0	80	247
Dorado	0	43	39	0	40	18	0	3	12	0	0	155

These biological samples are used to address an array of questions. Initial efforts centered on characterizing diets of tunas in the SCB using stomach contents to investigate 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, opah, yellowtail, sharks, and swordfish in the California Current (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 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, (7) developing a sex-linked genetic marker for albacore and California yellowtail, (8) characterizing the diet, age and growth, fecundity, and physiology of opah, (9) exploring mercury dynamics in pelagic predators, (10) examining the reproductive maturity of Pacific Bluefin tuna in the SCB, (11) correlating larval abundances of prey species captured in CalCOFI surveys with tuna gut contents to model how changes in prey species affect predator abundancies and foraging success, (12) developing methods to use tuna as biological samplers of prey species, 13) supporting genetic analyses on a range of species including close-kin genetic analyses of bluefin tuna, and 14) examining contaminant levels in mako, thresher and blue sharks across ontogeny to determine factors that influence contaminant concentrations.

Tuna Foraging Ecology

There has been a move towards ecosystem-based management since the reauthorization of the Magnuson-Stevens Fishery Conservation and Management Act in 2006, and more recently highly migratory species have been included in Integrated Ecosystem Assessments. Understanding temporal and spatial patterns of predators and prey 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 years for albacore and yellowfin tuna, it is apparent that there was a shift in the available prey species in the SCB from 2007-2008. In 2007 juvenile anchovy and sardine dominated the diets of both albacore and yellowfin (**Figure 1** and **Figure 2**). In contrast, few to no anchovy and sardine were present in 2008; diets became more diverse and were dominated by small squid, octopus, and other fish (juvenile rockfish [*Sebastes*], myctophids, and jack mackerel [*Trachurus symetricus*]). Diets in 2009, 2010, and 2011 were similar to 2008, with high squid diversity, other fish, and increased numbers of crustaceans. Bluefin diet was similar to albacore and yellowfin during 2008-2014 (squid, fish, and crustaceans; **Figure 3**), although in 2015 and 2016 their diet was dominated by pelagic red crabs (*Pleuroncodes planipes*). Also of interest is the reappearance and increase of anchovy in bluefin tuna stomachs during 2014-2016.

By comparing these results to other studies and across years, it is apparent that during certain years tuna in the SCB showed an increase in diet diversity, with a reduced reliance on anchovies and sardines and an increased reliance on squid, crustaceans, and other fish species. This likely relates to prey availability shifts associated with changes in oceanography, similarly documented in other biological indices and surveys conducted in the SCB reflecting the ability of tuna to exploit a diverse prey base. Stomach content analysis is helping to better understand both tuna behavior and how fluctuations in the availability of forage fish relate to changes in oceanography, such as the influx of pelagic red crab into the SCB during El Niño associated years (2015 and 2016).

Detailed data on tuna behavior and forage fish abundance are important for stock assessments and integral to making informed management decisions. Stomach content data may be reflective of the abundance of juvenile fish and other forage in the SCB and could provide an additional metric to be used in stock assessment models for forage fish. As tuna feed primarily on juvenile fish and squid, stomach content analysis can further our understanding of how egg and larval trawl data translates into the availability of forage for larger predators later in the year. Stomach content processing is currently ongoing with samples collected through 2017. Species availability complicates inter-annual comparisons. A manuscript is being drafted for publication containing the current results.

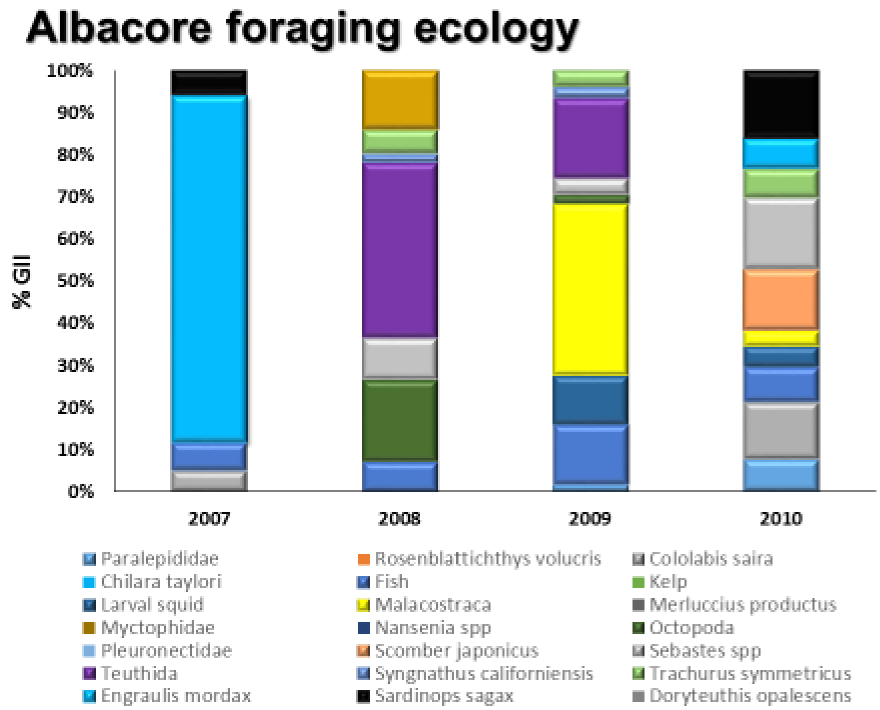

Figure 1. Relative importance of anchovy, sardine, other fish, squid, and crustaceans in the diets of albacore tuna by year based on a modified Geometric Index of Importance.

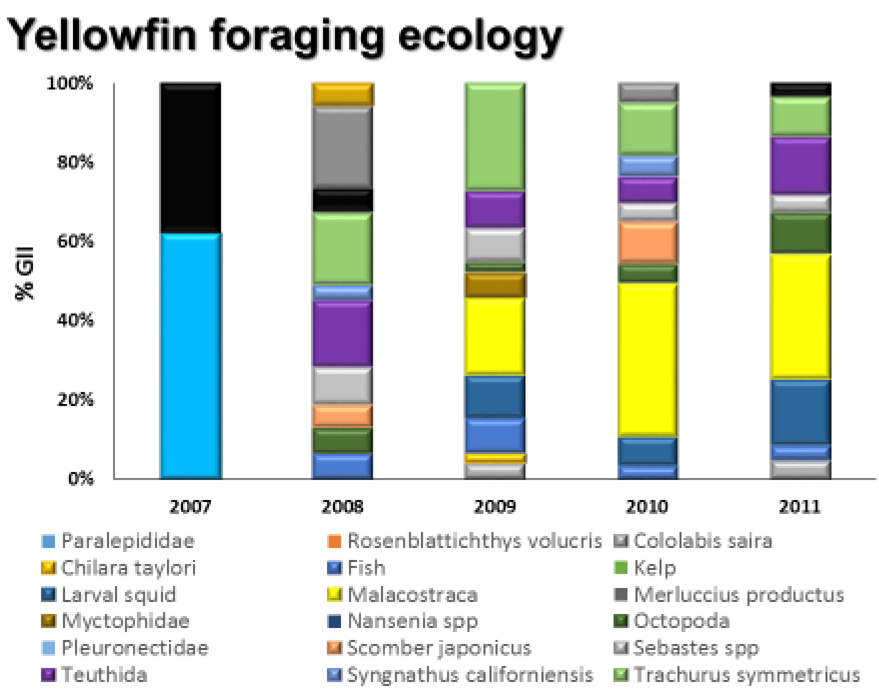

Figure 2. Relative importance of anchovy, sardine, other fish, squid, and crustaceans in the diets of yellowfin tuna by year based on a modified Geometric Index of Importance.

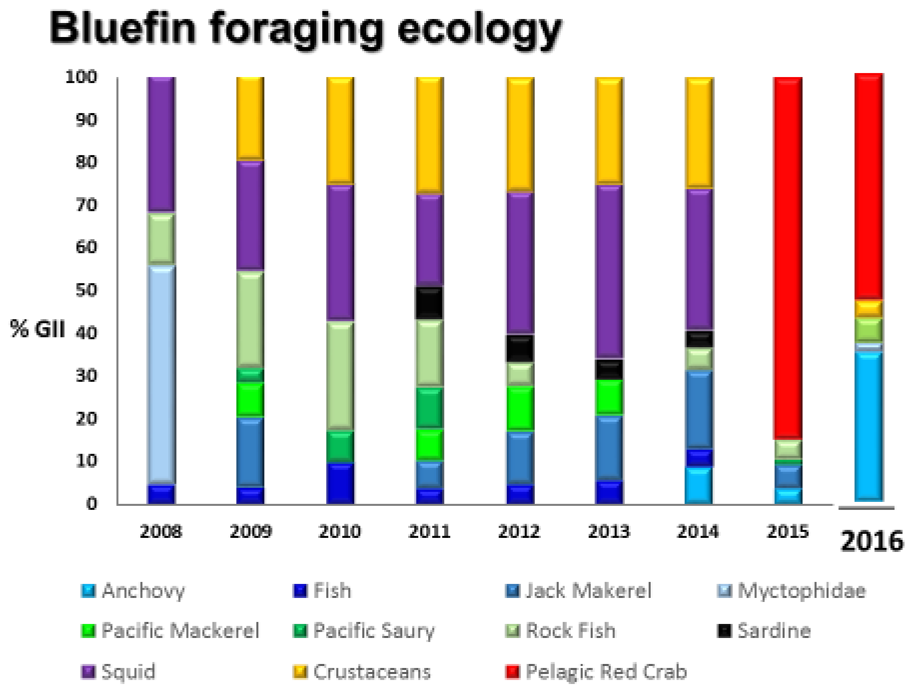

Figure 3. Relative importance of anchovy, sardine, other fish, squid, pelagic red crabs, and other crustaceans in the diets of bluefin tuna by year based on a modified Geometric Index of Importance.

Modeling Mercury Dynamics in the Pacific Bluefin tuna

Pelagic ecosystems are changing due to environmental and anthropogenic forces, with uncertain consequences for the ocean's top predators. Epipelagic and mesopelagic prey resources differ in quality and quantity, but relative inputs into predator diets have been difficult to track. In a collaboration with Harvard University, Monterey Bay Aquarium, and SWFSC, scientists measured mercury (Hg) stable isotopes in Pacific bluefin tuna (PBFT) and their prey species to explore the influence of foraging depth on growth and methylmercury (MeHg) exposure. A systematic decrease in prey δ^{202}Hg and Δ^{199}Hg with increasing depth of occurrence and discrete isotopic signatures of epipelagic prey (δ^{202}Hg: 0.74 to 1.49‰; Δ^{199}Hg: 1.76 – 2.96‰) and mesopelagic prey (δ^{202}Hg: 0.09 to 0.90‰; Δ^{199}Hg: 0.62 – 1.95‰) allowed the use of mercury isotopes to track PBFT foraging depth. An isotopic mixing model was used to estimate the dietary proportion of mesopelagic prey in PBFT, which ranged from 17-55%. Increased mesopelagic foraging was significantly correlated with slower growth and increased MeHg concentrations. The slowest observed growth rates suggests that prey availability and quality could reduce the production of PBFT biomass. The results from this work were recently submitted for publication.

Using Chemical Tracers (Stable Isotopes and Cesium-134) to Characterize Migratory Patterns 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. Typically, stable isotopes are used in studies of migrations, however the radionucleotides released into the ocean off Japan after the 2011 tsunami provided a unique chemical tracer for animals occupying these waters, including Pacific bluefin tuna. Pacific bluefin tuna are hatched in the Western Pacific Ocean (WPO) before some portion migrates to the EPO. Understanding age-specific eastward trans-Pacific migration patterns can improve management practices, but these migratory dynamics have been challenging to quantify.

A collaborative study with the State University of New York (SUNY) and Harvard University 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 (Madigan *et al.* 2013). The presence of ^{134}Cs, while detectable only until 2013, provided the opportunity to validate estimates using stable isotopes alone. Using additional samples, a more robust study was completed in 2016 (**Figure 4**, Madigan *et al.* 2017). The results from this work show that the proportion of recent migrants to residents decreased in older year classes. All fish smaller than 70 cm FL were recent migrants, confirming that fish caught locally are from the western Pacific. Looking across age classes, the number of recent migrants decreased from ~ 80% for 1-2 year olds to ~30% for 2-3 year olds and ~2% for 3-4 year olds. The peak arrival time from the western Pacific is April and May. This information provides important insight into the dynamics of movements across the Pacific. By linking relative arrivals to climate variability on both sides of the Pacific, we should gain insights into the forcing mechanisms behind the high degree of variability in trans-Pacific migrations (Madigan *et al.* 2017).

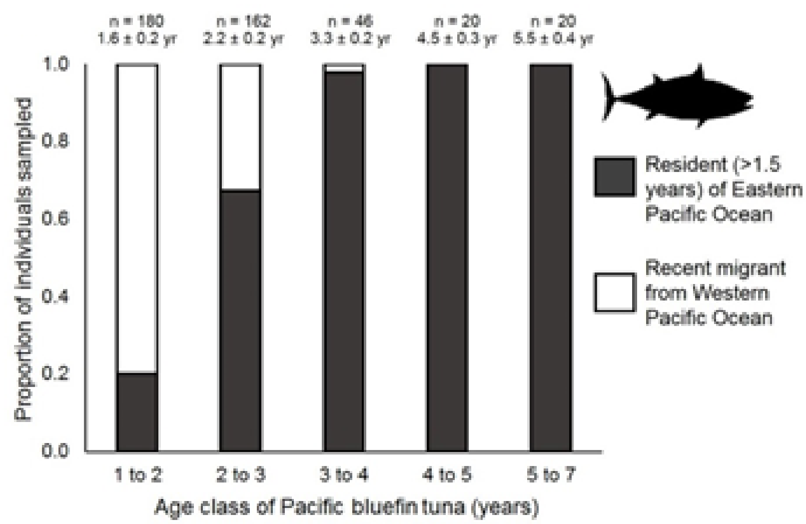

Figure 4. Migration dynamics of 428 age 1-7 Pacific bluefin tuna sampled from 2012 to 2015. Proportion of residents to migrants by year class. Residents and migrants were categorized by radiocesium and stable isotope analysis. Sample size and mean age (± SD) are shown above bar for each year class. All residents in year class 1-2 were 1.6 to 2.0 years old.

This novel toolbox of biogeochemical tracers has also been used to gain insights into the potential for continued influx of radionucleotides from the WPO. In an examination of stable isotopes and radionucleotides in 16 diverse species collected across the Pacific, only the olive ridley sea turtle had detectable levels of ^{134}Cs by 2015. Species where stable isotopes indicated at WPO origin did not show elevated ^{134}Cs or ^{137}Cs levels. This includes bluefin (previous study) where ^{134}Cs was detected in recent migrants in 2012 and 2013, but not in 2014 or 2015. These results confirm that the public need not be concerned about Fukushima derived radiation in marine organisms in the EPO. Stable isotope analyses also demonstrated limited movements across species between the WPO and that of the EPO or Central Pacific Ocean. Results from this work were published in the fall of 2017 (Madigan *et al*. 2017).

Cooperative Research with Billfish Anglers

SWFSC researchers have been working alongside the billfish angling community for over 50 years to promote ethical angling and further our understanding of various aspects of billfish biology and ecology. Billfish research conducted over the years as a result of this collaboration has included recreational fishery monitoring, biological research into the life history and ecology of specific billfish species, and determining the economic importance of billfish resources. Current ongoing efforts include two major components, the International Billfish Angler Survey and the Billfish Tagging Program. The Angler Survey was initiated in 1969 and the Tagging Program in 1963. The 2016 results of these programs were collected during 2017 and are summarized below.

International Billfish Angler Survey

More than 180 anglers submitted surveys in 2016 to report 1,893 fishing days and more than 1,360 billfish caught from destinations in the Pacific, Atlantic, and Indian Oceans. Less billfish were caught in 2016 compared to 2015, however, effort was also down, resulting in similar regional nominal catch per unit efforts (nCPUE; number of billfish per day) between the two years. The majority of fishing effort was reported off Hawaii, Southern California, and Baja California, Mexico.

Anglers from Hawaii have consistently reported the greatest number of fishing days for the past 5 years and in 2016, they accounted for nearly 67% of the total reported fishing days. In their 1,263 combined fishing days, Hawaiian anglers caught 773 billfish, the most billfish in 2016, with Pacific blue marlin remaining the most-caught species followed by shortbill spearfish (*Tetrapturus angustirostris*) and striped marlin.

The regional nominal catch per unit of effort (nCPUE; number of billfish per day) off Southern California was down to 0.18 in 2016 from 0.24 reported from the previous year. Southern California showed a general decrease in effort and catch with striped marlin remaining the most-caught species for the region with a total of 42 caught. However, the striped marlin catch in Southern California was dwarfed by the phenomenal 150 striped marlin caught by anglers in Baja California. The 2016 nCPUE for Baja was 1.43, the highest it has been for more than five years. The region is historically extremely productive for billfish fishing. Although striped marlin was the major species caught, blue marlin and sailfish were also caught and reported.

The nCPUE time-series were examined for Pacific blue marlin, striped marlin, Pacific sailfish, and black marlin in the main fishing areas (Hawaii, Baja California, Mexico, Southern California, Costa Rica, Panama, and Australia; **Figure 5**).

The 2016 Hawaii blue marlin nCPUE was 0.35, which is lower than the 2015 nCPUE of 0.47 but higher than the recent 10-year average of 0.30. In contrast, Baja's blue marlin nCPUE increased to 0.11 in 2016 from the 0.04 reported for 2015. This is the highest blue marlin nCPUE for the region since 1999.

Since 2011, the Southern California striped marlin nCPUE has been steadily increasing, but the 2016 value sharply declined to 0.18 from the high 0.45 reported in 2015. This 2016 value is similar to the results seen between 2004 and 2013, where the average nCPUE was 0.11. Like the blue marlin effort, the striped marlin fishing for the Baja California region was the highest it has been since 2008, at an nCPUE of 1.2. Similarly, Hawaii also experienced a major uptick in striped marlin catches with a nCPUE of 0.60, as compared to the single digit nCPUE values of 0.04-0.08 occurring since 2005.

The Costa Rica sailfish nCPUE has remained the highest for the three main locations since 2003, and anglers there reported a nCPUE of 1.80 for the 2016 season. Although neighbors, the 2016 sailfish nCPUE in Panama (0.48) was largely below that of Costa Rica and has been since 2003. This 2016 season marked an increase in nCPUE for Panama after two consecutive years of downward trends in nCPUE. The Mexico sailfish nCPUE value is based on fishing effort reported from locations across the entire country's west coast, including the mainland and the Baja Peninsula. The 2016 sailfish nCPUE was identical to last year's value, 0.38, which was a drop from the 2014 value (0.63) but still remains higher than the 5- and 10-year averages (0.38 and 0.23, respectively,) and the region's overall nCPUE (0.23). Unlike Costa Rica and Panama, the sailfish nCPUEs of Mexico have not exceeded 1.0 in the history of the program. This may be in part due to the expansive and diverse coastline of the country, which includes temperate waters as opposed to the strictly tropical waters off Costa Rica and Panama which sailfish tend to prefer.

The 2016 black marlin nCPUE for Australia, 0.47, shows a slight drop from the 2015 value (0.48), although this is higher than the five-year average (0.46), but lower than the overall regional average nCPUE of 0.54. Black marlin fishing has stayed fairly consistent in the last five years and has remained between 0.38 and 0.48 since 2011. The runner-up for black marlin nCPUE is Panama, which reported an nCPUE of 0.14 for 2016. This is a decrease from the previous year (0.17), but above the five-year average for the region (0.13). Papua New Guinea, Malaysia, Guatemala, and Thailand have all reported black marlin catches in the past, however, the consistent standouts for the species have been Panama and Australia since the early 1970s.

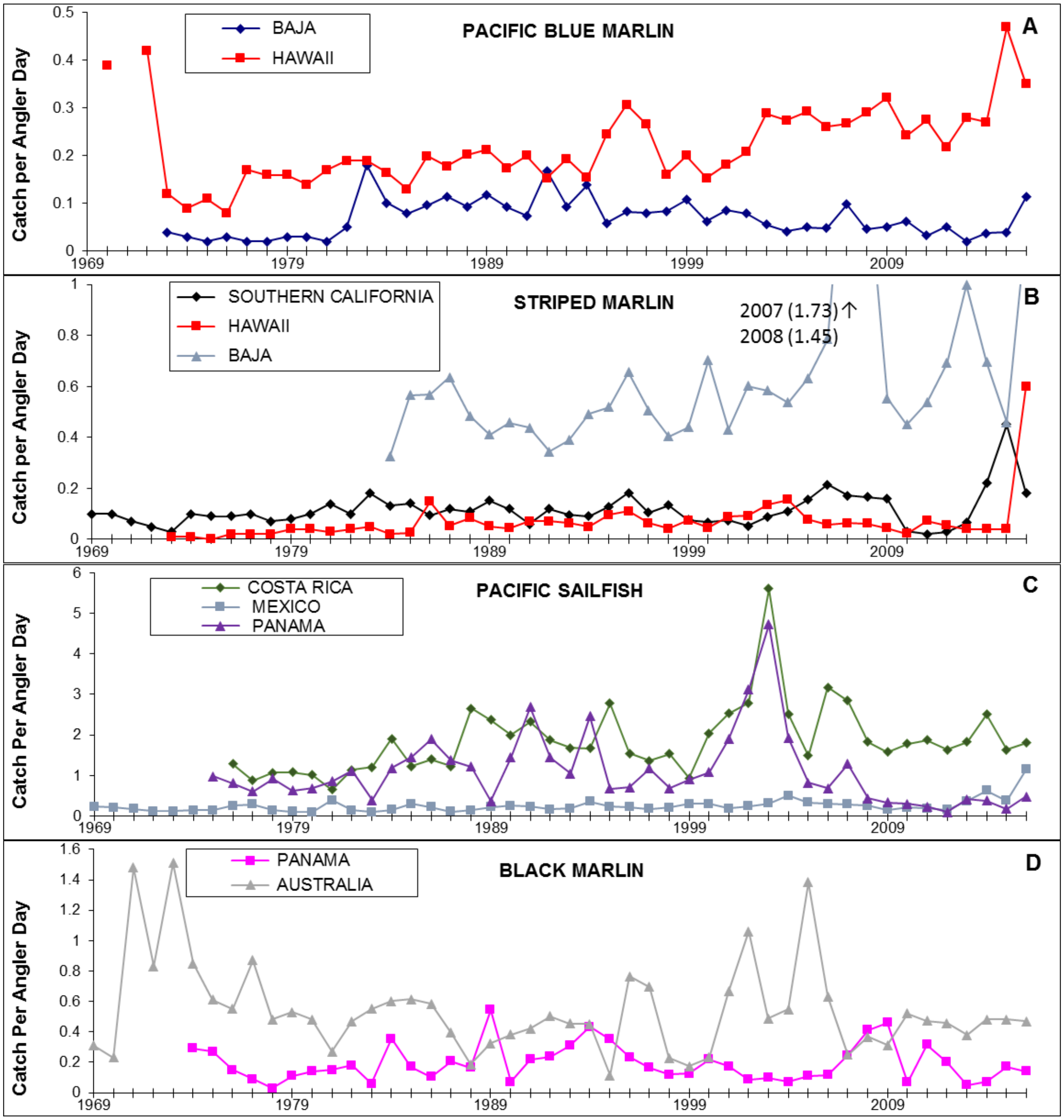

Figure 5. CPUE as catch-per-angler-day is shown from 1969 through 2016 for Pacific blue marlin, striped marlin, Pacific sailfish, and black marlin.

Recreational Billfish Tagging Program

The SWFSC's angler-based Billfish Tagging Program began in 1963 and has provided tagging supplies to billfish anglers for over 50 continuous years. Tag release and recapture data are used to examine movement and migration patterns, species distribution, and age and growth. This volunteer tagging program depends on the participation and cooperation of recreational captains and anglers, sportfishing organizations, and commercial fishers. In collaboration with the CDFW, over 80,000 fish have been tagged and released since the start of the program.

Anglers released 986 tags on billfish in 2016 (**Table 3**). Anglers in the Hawaiian Islands tagged the greatest number of billfish in 2016, a total of 741 tags, followed by Acapulco/Ixtapa-

Zihuatanejo with 112 tags and then Southern California with 38 tags. These results are very typical for the program, with Hawaii carrying more than 75% of the tagging effort.

Tag recoveries (recaptures) provide data to assess growth and migration patterns. Ten tags were recovered in 2016, including six Pacific blue marlin, one striped marlin, two shortbill spearfish, and one black marlin. For the nine fish where tag release information was available, the fish were at liberty for a collective average of 215 days (range 21-438 days).

Table 3. Summary of billfish tagged during 2016 by region.

Location	Species	Tag totals
Southern California	Striped Marlin	36
Southern California	Pacific Blue Marlin	2
Florida	Sailfish	1
Hawaii	Pacific Blue Marlin	567
Hawaii	Shortbill Spearfish	130
Hawaii	Striped Marlin	41
Hawaii	Black Marlin	2
Hawaii	Sailfish	1
Baja California/La Paz	Sailfish	2
Baja California/La Paz	Striped Marlin	2
Baja California/La Paz	Pacific Blue Marlin	1
Baja California	Striped Marlin	14
Baja California	Pacific Blue Marlin	1
Mazatlan/Sinaloa	Striped Marlin	10
Mazatlan/Sinaloa	Sailfish	2
Mazatlan/Sinaloa	Pacific Blue Marlin	2
Manzanillo/Colima	Sailfish	2
Acapulco/Ixtapa/Zihuatanejo/Guerrero	Sailfish	90
Acapulco/Ixtapa/Zihuatanejo/Guerrero	Pacific Blue Marlin	15
Acapulco/Ixtapa/Zihuatanejo/Guerrero	Striped Marlin	7
Costa Rica	Sailfish	2
Costa Rica	Striped Marlin	1
Guatemala	Sailfish	20
Guatemala	Striped Marlin	2
Guatemala	Pacific Blue Marlin	1
New Zealand	Sailfish	1
Tahiti	Pacific Blue Marlin	1
Samoa	Pacific Blue Marlin	17
Samoa	Sailfish	10
Samoa	Shortbill Spearfish	3

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, MMTD and now Environmental Research Division (ERD) 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 reduce bycatch. ERD has taken a lead row in developing a predictive model, EcoCast that integrates habitat probabilities across species. Additional research examines bycatch to better characterize difference among gear types and examine fin-fish bycatch. The research has been presented to the PFMC and should help managers make more informed decisions about potential gear alternatives.

Swordfish Habitat Use in the Pacific Leatherback Closed Area (PLCA)

Information on geographic and vertical habitat use in regions of overlap between swordfish and leatherbacks is critical to understanding habitat separation. While a relatively large number of satellite tags have been deployed on swordfish in the SCB, prior to these efforts, no tags had been deployed north of Point Conception where leatherbacks are known to aggregate and where the majority of bycatch occurred in the California drift gillnet fishery. In collaboration with the Pfleger Institute of Environmental Research (PIER), 13 satellite tags were deployed in the Pacific Leatherback Conservation Area Closure (PLCA) to quantify habitat use. The 11 tags reported show more variable habitat use than in the SCB, with more time spent in the mixed layer during the day. Similar to tags deployed elsewhere, basking decreased as swordfish moved offshore and the mixed layer depth increased (**Figure 6**). Findings suggest that vertical habitat use may be less predictable in the PLCA, which could impact efforts to target swordfish at depth, but that offshore catchability may improve. A manuscript describing this work has been accepted for publication (Sepulveda et al. *in press)*.

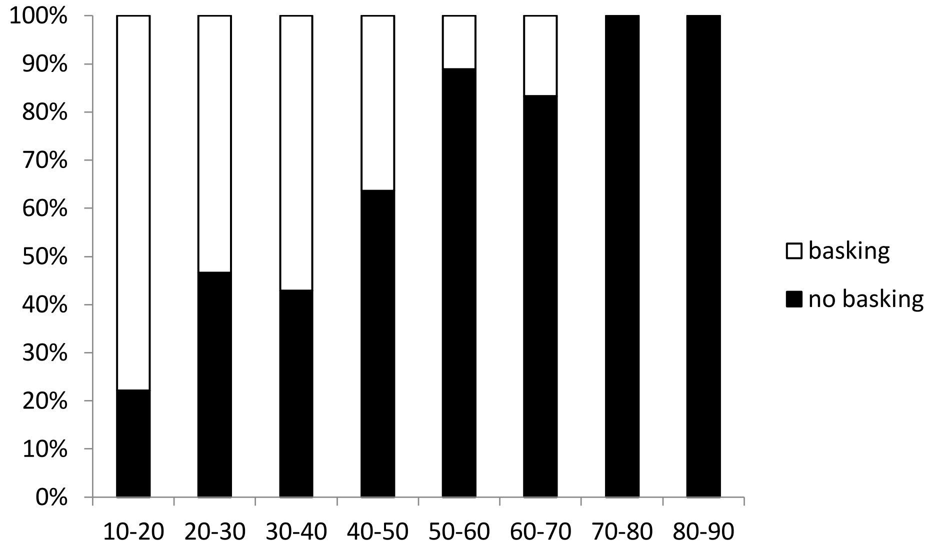

Figure 6. Percentage of days during which basking behavior was documented, along the y axis, in relation to the depth of the mixed layer in meters, along the x-axis.

Foraging Ecology of Swordfish in the SCB

In support of ecosystem based studies, SWFSC researchers are investigating the foraging ecology of swordfish 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. Data are finalized for the period 2007-2014. During this period jumbo squid was the most important prey item by weight, number and combined indices. The boreopacific gonate squid (*Gonatopsis borealis*) was the second most important prey by GII and IRI, but the most important for frequency of occurrence. Other dominant cephalopod prey included *Abraliopsis* sp. squid, *Gonatus* spp. squid, and market squid (*Doryteuthis opalescens*). Pacific hake (*Merluccius productus*) ranked 6th and was the highest among teleost prey. Swordfish also preyed on barracudinas (*Paralepididae*), coastal pelagic fishes (jack mackerel, Pacific sardine, Pacific saury, northern anchovy), luvar (*Luvarus imperialis*), king-of-the-salmon (*Trachipterus altivelis*), halfmoon (*Medialuna californiensis*) and seven species of the Myctophidae family.

New progress was achieved in 2018 with the completion of ecological indices estimations.

Univariate indices were calculated to estimate richness, diversity, similarity of diet for swordfish and to compare them to sharks.

Rarified diet richness, estimated with Menhinick’s index, was significantly lower in swordfish than in mako and blue sharks and higher than thresher sharks. Swordfish presented a significantly higher species richness (*1/D*) than the thresher. The diversity of a diet or unevenness estimated with the Shannon entropy index was significantly higher for swordfish than bigeye thresher and thresher sharks. The similarity indices differed in their rankings. Sørensen similarity results suggested that swordfish and mako diets were the most similar, followed by swordfish and blue and the least similar were swordfish and thresher diets. Simplified Morisita-Horn (SMH) results on the other hand suggested that swordfish and bigeye diets had the greatest similarity, followed by swordfish and mako and swordfish and thresher were again the least similar. Niche overlap estimated with the Pianka index was the greatest for swordfish and bigeye, followed by swordfish and mako and the lowest overlap was for swordfish and thresher.

As a guide to whether levels of similarity differ significantly between pairs of species, non-overlap of 95% confidence limits can be used. Thus for the Sørensen index, the similarity between swordfish and mako is significantly greater than the similarities between swordfish-thresher and swordfish-bigeye thresher. In the case of the SMH and Pianka indices, the similarity between swordfish and thresher is significantly lower than the similarity between swordfish and bigeye thresher.

Generalized Additive Models, Redundancy Analysis, were also finalized and are being compiled in a manuscript to determine how the prey of swordfish is affected by environmental and biological variables.

Opah Research in the Eastern Pacific Ocean

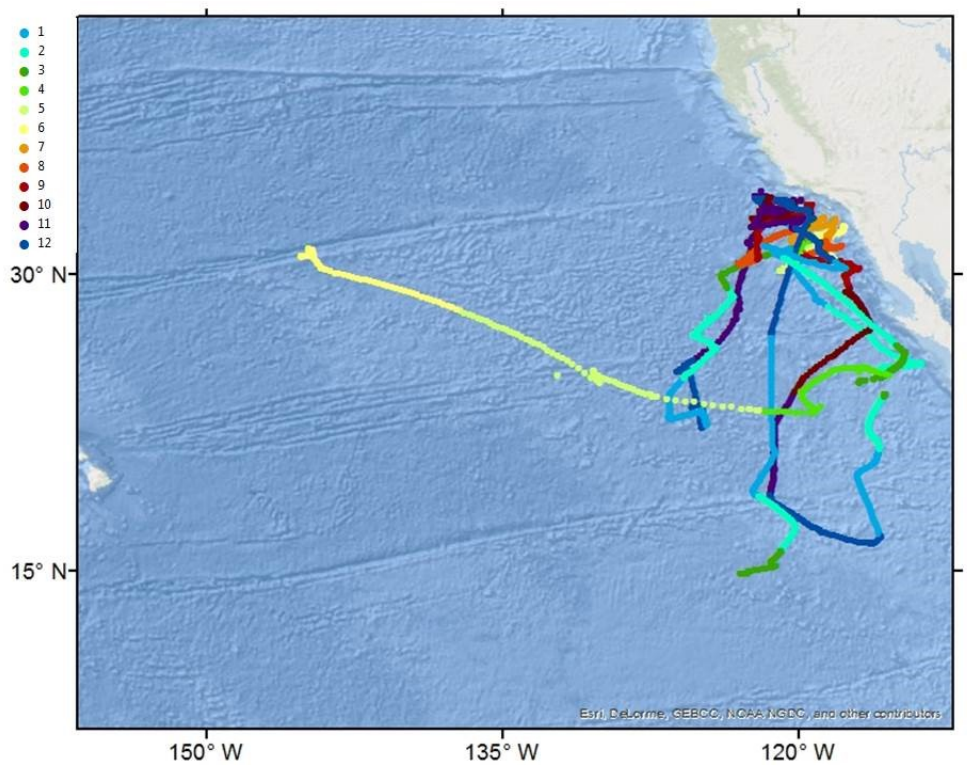

Figure 7. Light-based geolocation estimates for four opah tagged off California. Months are indicated by color.

The opah is a large, mid-water pelagic fish that occurs seasonally in the SCB. While they are not a primary target species, they are taken incidentally in both local recreational fisheries for tuna and the CA DGN fishery targeting swordfish. In addition, in recent years, deep-set longline fishers permitted in Hawaii have started to offload opah to the U.S. West Coast. As a consequence the supply of opah has increased and opah have become increasingly popular in seafood markets. Despite their value and popularity, little research on the basic biology and ecology of opah has been conducted, especially in the SCB. They are currently not listed on the HMS management plan and there is little data on foraging ecology, size composition in fisheries, essential habitat, and stock structure, among other important information. In order to fill some of the data gaps, SWFSC scientists began collecting biological samples from caught opah in 2009 and initiated an electronic tagging program in 2011. In 2017-18, the SWFSC has been working collaboratively to sample opah landed by California-based longliners. A cooperative research project with the California Pelagic Fisheries Association (CPFA) and Catalina Offshore Products aims to sample up to 50 opah per month to study life history including age and growth, reproductive biology, foraging ecology, and fishery catch composition by size, sex, and genetic lineage. Currently scientists are working with Catalina Offshore to develop methods to collect the needed samples which requires added coordination with fishers to ensure that the fish are intact when landed.

Additional work on opah focuses on habitat preferences and population dynamics. The small-eye opah, which occurs in the California Current, extends to the waters east of Hawaii. Unfortunately the connectivity between coastal and off-shore waters is not known. Efforts to examine migratory patterns and stock dynamics are ongoing and include use of both satellite telemetry and isotope analyses. In previous years, nine longer-term satellite tags deployments were carried out on opah. Average deployment durations were 150 days, with five tags remaining attached for 240 days when they were programmed to release. A preliminary examination of vertical habitat use shows a very consistent diel pattern across fish, where opah make regular deep dives during the day but remain shallower and typically at the bottom of or below the mixed layer at night. Nighttime maximum depths are significantly shallower (90 +/-10 m versus 205 +/-20 m). There was no significant difference between the minimum depths (~40 m) and opah seldom came to the surface. Analyses of tracks shows that opah typically move offshore to the south or southwest in the fall and winter with some individuals returning to the California Current the subsequent year. This type of annual cycle is common among highly migratory species that forage seasonally in the rich waters of the California Current. While most remained in the eastern North Pacific, one opah moved west to the waters off Hawaii. The plan is to deploy additional satellite tags this spring.

In an additional effort, scientists are using EcoCast[2] to model the distribution and habitat preferences of opah using the logbook data from the California Drift Gillnet Fishery. This work is being done in collaboration with ERD and Climate Action Fellow, Samantha Leigh, from UC Irvine. Preliminary results show that opah are caught primarily over the continental shelf, and slope and bathymetry explained the greatest percentage of variability followed by sea surface temperature, sea surface height, and isothermal layer depth. Thus, while opah are typically considered to be pelagic they are also coastal. Shifts in distribution and with season and El Nino suggests a northward shift in distribution with climate change, indicating implications for fisheries. Additional steps will use climate models to more precisely predict shifts in abundance with climate variability.

Taxonomic Review of Opah (Genus Lampris)

The genus Lampris (Lampridae) currently comprises two species, *Lampris guttatus* (Brünnich 1788) and *L. immaculatus* (Gilchrist 1905) commonly known as Opah and Southern Opah, respectively. Adult *L. immaculatus* differ from adult *L. guttatus* primarily in lacking spots, having a more slender body, and differences in fin-ray counts (Parin and Kukuyev, 1983). *Lampris immaculatus* has a circum-global distribution in sub-Antarctic waters. *Lampris guttatus* is presently known from both hemispheres in all oceans from tropical, temperate and sub-polar

[2] Hazen, E.L., Scales, K.L., Maxwell, S.M., Briscoe, D.K., Welch, H., Bograd, S.J., Bailey, H., Benson, S.R., Eguchi, T., Dewar, H. and Kohin, S., 2018. A dynamic ocean management tool to reduce bycatch and support sustainable fisheries. Science advances, 4(5), p.eaar3001.

waters.

Though no directed fishery currently exists for opahs, their common occurrence as bycatch and growing culinary popularity make these fishes a valued, and thus retained, addition to HMS commercial fisheries. The Hawaii-based pelagic longline fishery (including vessels flagged in Hawaii and California) reported 29,470 opahs landed by vessels targeting tuna and swordfish in 2015 (NMFS Hawaii Longline Fishery Logbook Statistics; http://www.pifsc.noaa.gov/fmb/reports.php, accessed September 13, 2017).

Hyde et al. (2014) presented DNA sequence data which revealed the presence of five distinct, monophyletic lineages within *L. guttatus*. Two of these lineages co-occur in the central and eastern Pacific and overlap with the Hawaii based longline fishery. Given the uncertainty in habitat uses by these two lineages and that the fisheries which retain opah utilize fishing grounds that may contain one or both of these lineages, the taxonomic status of these opahs is of great importance.

Researchers from NOAA NMFS found that morphological and meristic data supported the presence of five species previously subsumed within *L. guttatus* (Brunnich 1788). The commonly used name for Opah (*Lampris guttatus*) was found to be restricted to north Atlantic, and the fisheries which retain opahs in the Hawaii based HMS longline fishery of the central and east Pacific harvest two distinct species of opah: the smalleye Pacific opah (*Lampris incognitus*), and the bigeye Pacific opah (*Lampris megalopsis*).

V. ADVANCING PELAGIC SHARK RESEARCH

The SWFSC's shark research program focuses on pelagic sharks that occur along the U.S. Pacific coast, including shortfin mako, blue sharks, basking sharks (*Cetorhinus maximus)*, and three species of thresher sharks: common thresher, bigeye thresher (*Alopias superciliosus)*, and pelagic thresher (*Alopias 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.

Electronic Tagging Studies and Habitat Modeling

Starting in 1999, SWFSC scientists have used 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, including the Tagging of Pacific Predators (TOPP) program. The goals of these projects are to document and compare the movements and behaviors of these species in the eastern North Pacific and California Current and to link these data to physical and biological oceanography.

In recent years scientists in the Life History Program have teamed up with researchers at ERD to incorporate both electronic tagging data and catch data into habitat models. These models combine location information with environmental data from ROMs models and satellite imagery to provide a quantitative estimate of habitat preferences across physical and biological oceanographic parameters. The modeling approach being used, known as EcoCast, has a number of applications. The information on habitat preferences provides insight into abundance and distribution and how these might shift seasonally and with climate variability. By combining habitat envelopes from target and non-target species it is possible to create maps that allow fisheries to avoid bycatch species and maximize efficiency. There are currently a number of ongoing project using the

EcoCast framework (see above for opah).

Shortfin Mako Shark

Since 2002, over one hundred shortfin mako sharks have been tagged with either SPOT or PSAT tags, or both, during the SWFSC's collaborative electronic tagging study. Partners include the Tagging of Pacific Pelagics program, CICESE, the Guy Harvey Institute, and several recreational anglers.

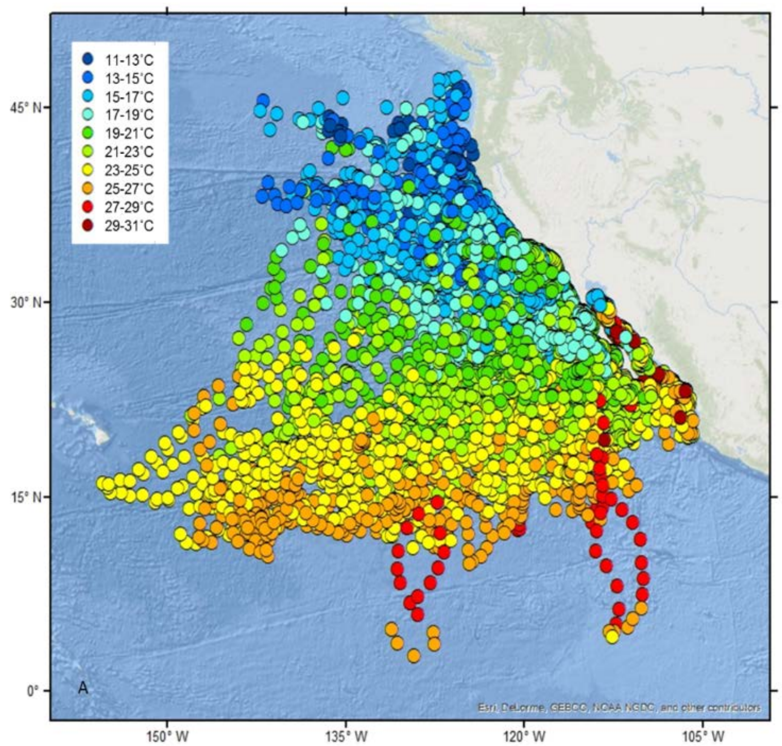

Figure 8. All filtered SPOT data colored according to remotely sensed SST.

Data from 55 PSAT tags and 89 SPOT tags are currently being analyzed and prepared for publication. This is an enormously rich data set that includes tracks throughout a large part of the eastern North Pacific. Tracks range from near the U.S.-Canada border to the subtropics, into the Sea of Cortez and out near Hawaii. These data provide new insights into the range of sharks from the eastern North Pacific and fill data gaps in regions where there are currently no available catch data, including from the U.S. EEZ to 140 W and in tropical waters. Tracks longer than six months showed that mako sharks tagged in the summer spent the summer and fall months near southern California after which they dispersed to the north, south, and offshore. Tags which recorded data for more than 12 months showed that the majority of tagged makos returned to the SCB the following summer. Larger sharks spent more time offshore and outside the U.S. EEZ than smaller sharks. Across their distribution they experience a broad range of sea surface temperature (11.2 - 31.2°C) and are not constrained to a narrow range as has been suggested in other studies using limited datasets (**Figure 8**). Their movements along the coast are linked to shifts in primary productivity with movement both to the north and south in the California Current being linked to pulses of higher chlorophyll *a* concentrations at lower and higher latitudes. A comparison of habitat-use across regions show considerable diversity in vertical movements. In some areas, a distinct diel pattern is apparent whereas in others there is no obvious pattern (**Figure 9**). There is some indication that vertical water column structure influences dive patterns. The high degree of variability in dive patterns suggests that they are likely foraging throughout the water column which is consistent with their diverse diet.

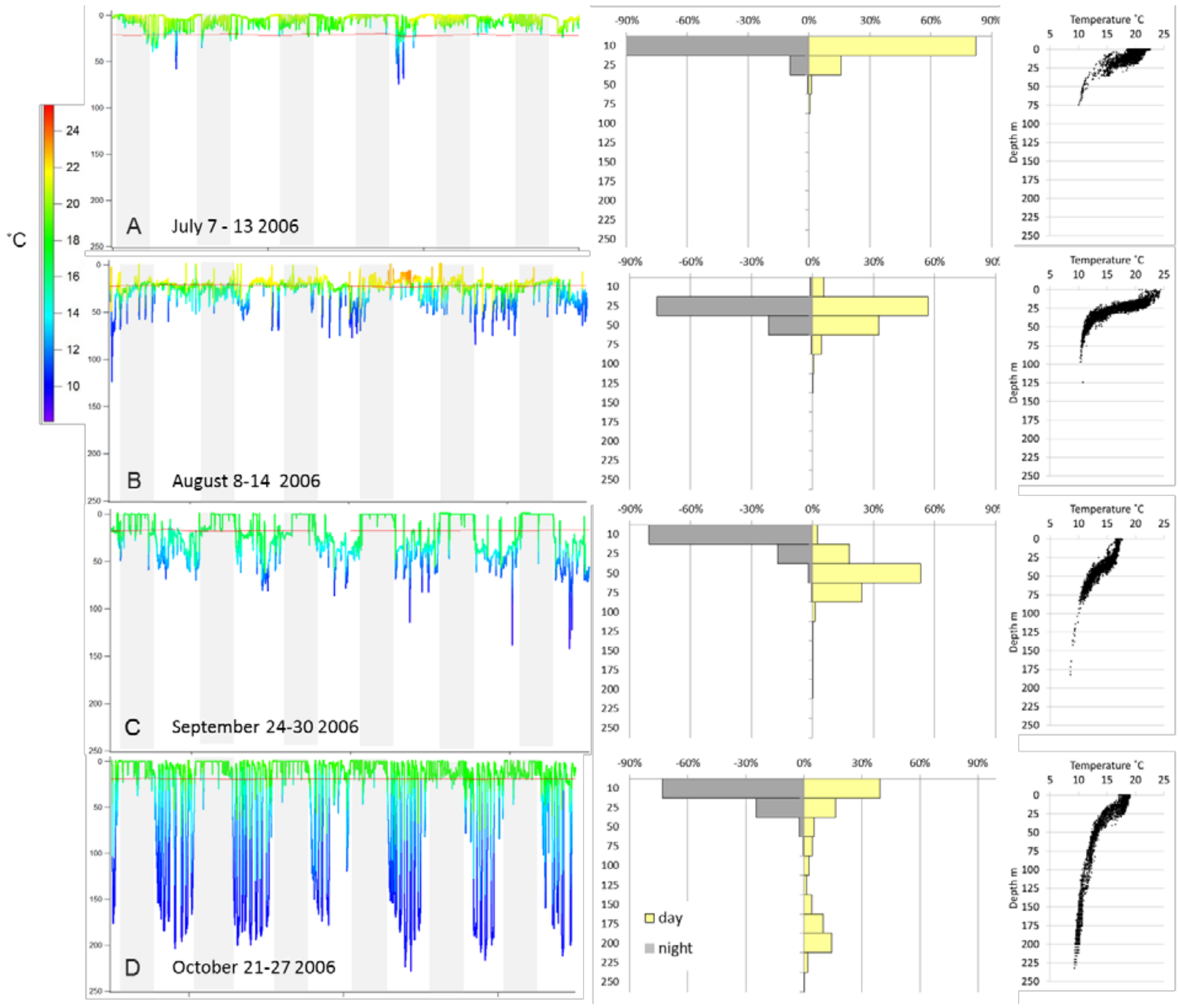

Figure 9. Vertical patterns from recovered PSAT data from tag 06-3PS, (174 cm FL M), overlaid with color coded temperature. Each plot displays 11 days of data A) in SCB between Santa Cruz Island and Catalina Island, B) in Sebastian Vizcaino Bay, Baja California, Mexico, C) just off Point Conception and D) SCB in the nearshore Santa Monica Bay

Blue Shark

The SWFSC has been deploying satellite tags on blue sharks since 2002 to examine movements and habitat use in the eastern North Pacific. To date, a total of 100 sharks (51 males and 49 females) have been tagged with some combination of SPOT (n=95) and/or PSAT tags (n=60), with 55 sharks carrying both tag types. The majority of sharks were tagged in the SCB, with a few additional deployments off Baja California Sur, Mexico, or southwest Canada. Five sharks died shortly after tagging and seven PSAT tags were recovered providing archival data on temperature, depth, and light levels. Satellite tag deployment durations for both tag types are substantially shorter than for mako sharks. For the 37 PSAT tags that provided data only 8 remained attached until the programmed pop-up date and the average deployment duration was 115 days. The mean SPOT tag track duration was 88 days, however, six tags transmitted for 337 days or more allowing for an examination of seasonal patterns.

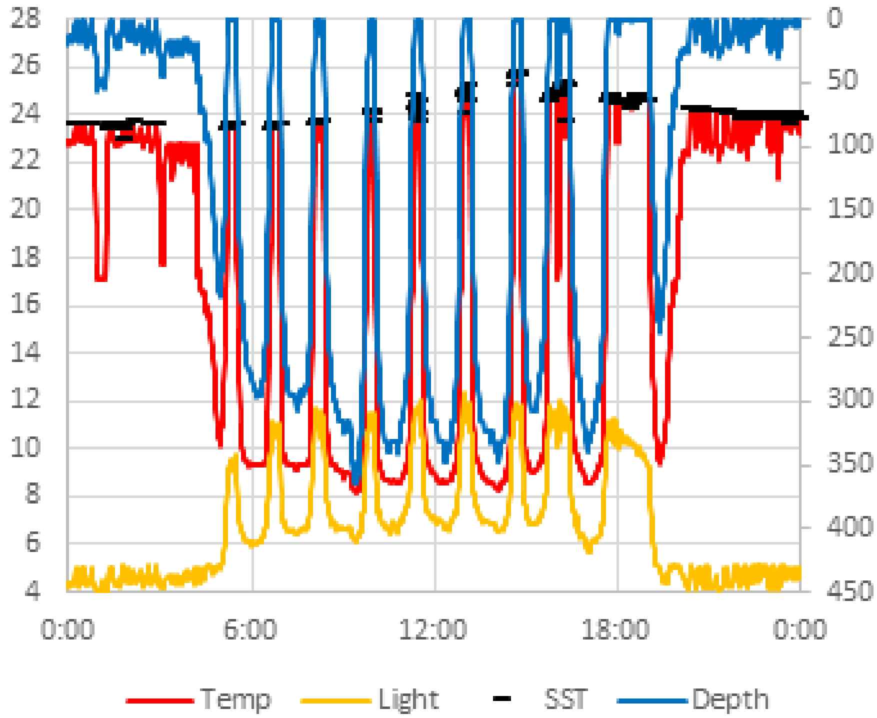

Figure 10. Archival data collected showing the 2oC increase in afternoon temperature associated with solar heating and not frontal activity.

Efforts to characterize habitat often focus on frontal activity where prey tend to accumulate. Fronts are often inferred from a change in SST. A close examination of archival data collected from blue sharks revealed that significant increases in SST can also be associated with warming during the day and not linked to frontal activity. In some instance the temperature increased by 2ºC in the early afternoon associated with solar heating. The fact that the increase in SST was not due to sharks being on a front was confirmed by examining the temperature depth profile over the same time period. Solar heating may confer some advantage for behavioral thermoregulation, allowing sharks to warm more quickly after dives into deep water. This result has important implications for using archival data to characterize habitat and for correcting light-based geolocations estimates by matching the SST recorded by the satellite tags to satellite derived SST. Both measurements should be taken at night.

EcoCast

Both electronic tagging data and catch data for blue sharks in the California Current have been incorporated into EcoCast to help fishers avoid blue sharks during Drift gillnet fishing activities. Motivations to reduce blue sharks landings include reducing bycatch as blue sharks have no marketable value and are discarded at sea. In addition, catching blue sharks increases haul back time, reduces efficiency and can damage gear. Given that the overall viability of a fishery depends on target species catch, EcoCast combines habitat preferences for both target (swordfish) and non-target species which includes sea lions and leatherback sea turtles in addition to blue sharks. The resulting product is updated daily based on environmental conditions and can be used by fishers to identify locations where target catch is maximized and bycatch is minimized (**Figure 11**). Current efforts are focused on beta testing EcoCast with fishers.

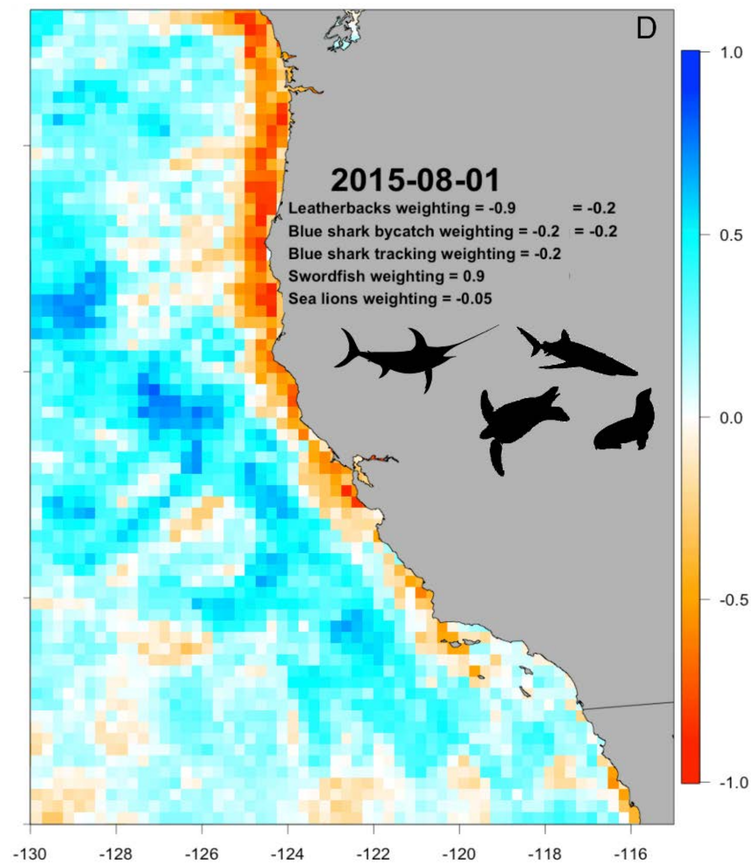

Figure 11. EcoCast model predictions for August 1, 2015, integrating habitat probabilities for swordfish, leatherback turtles, blue sharks, and California sea lions.

Common Thresher Shark

Since 2004, scientists at the SWFSC have been opportunistically tagging common thresher sharks with electronic tags during the annual neonate thresher shark and HMS abundance surveys. To date 29 common thresher sharks have been released with either PSAT3, SPOT4, or both since 2004. Depth data indicate that threshers spend much more time near the surface in the mixed layer than they do at greater depths, and that vertical excursions below the mixed layer primarily occur during the day, potentially due to their unique hunting strategy which relies on visual prey detection. Work in 2015, 2016, and 2017 focused on developing a Bayesian movement model to provide a quantitative approach to inferring the effects of various environmental conditions on the horizontal movement of threshers. This work resulted in a 2017 (Kinney et al. 2017) publication which focused on the method of applying this Bayesian approach to limited movement data, such as what is available for thresher sharks.

Using this Bayesian movement model, SWFSC researchers aim to understand what biological and environmental variables influence whether threshers remain within the SCB or move into the surrounding waters in a predictable manner. Analysis suggests that fork length and the spring season are the strongest predictors of thresher shark movement out of the SCB, with their posteriors shifted furthest from zero. A paper on threshers using this data limited Bayesian method is nearing completion and will be published sometime in 2018 (Kinney et al. in prep).

Shortfin Mako Shark

During 2017 shortfin mako vertebra from an established reference collection, made up of vertebra from ISC member nations (U.S., Japan, Mexico, Taiwan) were used to create a conditional age at length dataset to use in the mako shark assessment. Researchers formatted this data for SS and included it in the current mako shark assessment SS data file. It is currently unclear how this dataset will affect the outcome of the model (which is set to be completed in 2018), but it is a step forward in terms of using aeging data within the model to help estimate growth.

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 oxytetracycline (OTC). Since the beginning of the program in 1997, more than 4000 individuals have been injected with OTC. While the SWFSC is no longer running surveys we occasionally receive sharks that have been injected with OTC from fishers and ageing studies are ongoing. In addition, the SWFSC has been leading shark international efforts to standardize ageing methods through the ISC shark working group. This effort has including hosting workshops and creating a reference vertebra library to allow for comparison of results across labs around the Pacific Basin.

Foraging Ecology of Pelagic Sharks

The California Current is a productive eastern boundary current that functions as 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 CA DGN observer program, but with decreasing effort in the fishery, fewer shark stomachs have been available for analysis in recent years.

Stomach Content Analysis

Stomach content analysis of blue, shortfin mako, thresher, and bigeye thresher sharks is ongoing. Data are finalized for the period 2002-2014.

For the mako shark, jumbo squid was the most important prey item by weight and combined indices. Pacific saury (*Cololabis saira*) was the second most important prey by GII and IRI but the most important for frequency of occurrence and the most abundant by number. Other dominant teleost prey included Pacific sardine, Pacific mackerel, striped mullet (*Mugil cephalus*) and jack mackerel. Makos also preyed on marine mammals and other elasmobranchs. One mako preyed on a short-beaked common dolphin (*Delphinus delphis*), blue sharks were found inside five mako stomachs, and one mako fed on four tope sharks (*Galeorhinus galeus*).

Squids of the genus *Gonatus* ranked first for GII and IRI and frequency of occurrence for the blue shark. Jumbo squid ranked second for GII and IRI but they were the most important in weight. Other dominant prey included octopuses of the genus *Argonauta*, and the flowervase jewell squid

(*Histioteuthis dofleini*). One blue shark fed on an unidentified cetacean and another one fed on elephant seal (*Mirounga angustirostris*). Three blue sharks fed on elasmobranchs spiny dogfish (*Squalus acanthias*) and tope shark, and one ingested a common tern (*Sterna hirundo*). Forty-seven blue shark stomachs (23% of all stomach samples) contained prey that was bitten in chunks and were found in a fresh state of digestion (states 1 and 2) which were interpreted as prey caught in the net. One blue shark stomach contained a skipjack tuna head with a piece of net in his mouth. Other net-caught prey taxa included scombridae (F=31), ocean sunfish (*Mola mola*) (F=8), broadbill swordifish (F=3), opah (F=2), unidentified elasmobranchs (F=2), and Pacific pomfret (*Brama japonica*) (F=1). One stomach contained 21 pork steaks wrapped in paper and another stomach contained vegetables (onions, bell peppers, shredded carrots) and a tea bag, all these items were likely discarded at sea and scavenged by the blue sharks. Similar fresh chunks of prey were observed in one mako stomach and no thresher or bigeye thresher shark stomachs.

For the thresher shark, northern anchovy (*Engraulis mordax*) ranked first in both the GII and IRI and had the highest number and weight. Pacific sardine ranked second in both the GII and IRI. Other dominant identified prey included market squid, Pacific hake, and Pacific mackerel. Pacific saury, Jack mackerel (*Trachurus symmetricus*) and Duckbill barracudina (*Magnisudis atlantica*) were found in at least 16 stomachs. Pelagic red crab was the most frequent crustacean (F=12).

Jumbo squid was the most important prey (for GII and IRI) for the bigeye thresher shark, it was also the most frequent prey with the highest weight. Duckbill barracudina and other Paralepididae ranked second and third. Other important prey included Pacific hake, Pacific mackerel, Pacific saury and *Gonatus* spp. squids. Fourteen individuals of king-of-the-salmon were present in two bigeye thresher stomachs.

New progress was achieved in 2018 with the completion of ecological indices estimations.

Univariate indices were calculated to estimate richness, diversity, similarity of diet for the four shark species.

Across species, rarified diet richness estimated with Menhinick's index was significantly lower in thresher than in the other three species. Mako had a significantly higher richness than bigeye thresher. Bigeye thresher presented a significantly higher species richness (*1/D*) than the thresher. The diversity of a diet or unevenness estimated with the Shannon entropy index was significantly lower for thresher than in the other three species.

Different similarity indices give somewhat different results. Sørensen similarity results suggested that mako and blue shark diets were the most similar, followed by mako and bigeye, and the least similar were blue and thresher diets. SMH results on the other hand suggested that mako and bigeye diets had the greatest similarity, followed by thresher and bigeye and blue and thresher were again the least similar. Niche overlap estimated with the Pianka index was the greatest for mako and bigeye thresher, followed by thresher and bigeye and the lowest overlap was for blue and thresher.

As a guide to whether levels of similarity differ significantly between pairs of species, non-overlap of 95% confidence limits can be used. Thus, for the Sørensen index, the similarity between mako and blue is significantly greater than the similarities between any other pair of species. The similarity between blue and thresher is significantly lower than the similarity between bigeye thresher and the other species (and significantly lower than the similarity between blue and mako, as already evident from the previous result). In the case of the SMH and Pianka indices, none of the differences in similarity are significant (for both indices, all six sets of 95% confidence limits are overlapping, although in a few cases the overlap is small).

Generalized Additive Models, Redundancy Analysis, were also finalized and are being compiled in a manuscript to determine how the prey of these four sharks is affected by environmental and biological variables.

Thresher Reproductive Biology

In 2015, the Southwest Fisheries Science Center, in collaboration with Centro de Investigación Científica y de Educación Superior de Ensenada (CICESE), initiated the first bilateral Northeast Pacific common thresher shark stock assessment which was published in 2016. This assessment used reproductive parameters estimated by Smith et al. (2008) for the Northeast Pacific. However, given the dramatic differences in the estimates of age at first reproduction for females for the Atlantic and Pacific Oceans (216 cm FL versus 160 cm FL respectively), SWFSC scientists reexamined the data and specimens used by Smith in her study. Due to concerns about the species ID and other inconsistency, it was determined that additional analyses and samples would be needed to provide a validated estimate for the eastern North Pacific. The SWFSC is currently working towards examining and obtaining additional specimens where the species ID can be validated. Until that time the stock assessment is being run with life history parameters derived in the Atlantic Ocean.

VI. IDCPA RESEARCH

The SWFSC research conducted under the International Dolphin Conservation Program Act (IDCPA) during 2017-2018 was focused on mining existing Eastern Tropical Pacific Ocean (ETP) datasets to (1) evaluate the use of tuna vessel observer data in assessments, (2) clarify cetacean population structure and life history, (3) identify critical habitat for large whales, (4) advance our understanding of ecosystem structure and function and (5) determine the trophic status and diet of the most abundant sea turtle in the ETP, the olive ridley.

Evaluating the Use of Tuna Vessel Observer Data in Assessments

Variability of Dolphin Distribution Based on Tuna-Vessel Observer Data

Dr. Paul Fiedler, in collaboration with the IATTC, has completed an analysis of seasonal and inter-annual variability of dolphin distribution based on fisheries observer data from the yellowfin tuna purse-seine fishery that fishes tunas associated with dolphins (TVOD). Cetacean species distribution patterns in the ETP have been described and analyzed several times from a series of rigorous NOAA research vessel surveys conducted sporadically between 1986 and 2009. However, survey coverage is not adequate to describe seasonal and ENSO-related changes in distribution. Scientists used TVOD to construct a binned spatiotemporal data set of the probability of presence of spotted, eastern spinner, and common dolphins by month from 1986 through 2015. Generalized additive models of predicted presence from surface temperature, surface salinity, thermocline depth, a stratification index, and distance to coast showed seasonal and interannual changes in preferred habitat based on environmental variability in time and space. Spotted and spinner dolphins respond to seasonal changes in the position and size of the eastern Pacific warm pool and avoid the equatorial cold tongue in summer-fall. Common dolphins respond to seasonal and ENSO-related changes in the Costa Rica Dome, the cold tongue, and in coastal upwelling habitat along Baja California and Peru-Ecuador. The predictions based on tuna vessel observer data were validated with research vessel sightings. The results were presented at the 2017 Marine

Mammal Conference and a paper is in revision for Journal of Biogeography.

Clarifying Cetacean Population Structure and Life History

Population Structure of Spotted and Spinner Dolphins

Multiple subspecies of spinner (*Stenella longirostris*) and spotted dolphins (*S. attenuatta*) have been described based on morphology but previous molecular studies have struggled to corroborate these intraspecific differences. Several demographic and evolutionary factors (high historical abundance, permeable barriers and high mobility) combine to obscure patterns of population genetic structure in these long-lived pelagic animals. Questions of population structure in these species were the subject of the PhD dissertation of Dr. Matthew Leslie, a former graduate student at Scripps Institution of Oceanography, working with Dr. Phil Morin (SWFSC). This work pioneered two novel approaches to collect DNA sequence data using existing skin samples from the SWFSC tissue archive:

Mitochondrial Genomes

To characterize genetic structure whole mitochondrial genomes were collected from 104 spinner and 76 spotted dolphins using capture array library enrichment and highly paralleled DNA sequencing. Mitochondrial genome results showed weak but significant differences between recognized subspecies of both spinner and spotted dolphins. There was very little support for the division of offshore stocks of spotted dolphins and no support for Tres Marias spinner dolphins. This work contributes to the identification of management units for the conservation of these highly depleted populations. A manuscript is in final revision with the scientific journal Marine Mammal Science (Leslie et al., submitted).

Restriction-Site Associated DNA Sequencing

This project targeted DNA sequencing near restriction enzyme cut-sites to search for variation across many individuals. Over 3500 SNPs per species resulting from this method provided statistical power to test hypotheses of smaller alternative stocks. There was support for all existing stocks and evidence for differentiation of the Tres Marias Islands stock. In addition to ETP samples, this study has included samples from each ocean basin to provide context for the unique diversity of the ETP. Scientists found highly structured populations throughout the range of spinner and spotted dolphins. Interestingly, ETP endemics are very genetically separated from western and central Pacific populations. Moreover, the northern Australia population of dwarf spinner dolphins may be a unique population different from Indonesia and the rest of the dwarf spinner dolphins. The first publication, focused on subspecies and populations within the ETP, was published in 2016 (Leslie and Morin, 2016). A second manuscript focused on global patterns of differentiation in spinner and spotted dolphins is in final revisions for publication in the journal Royal Society Open Science.

Group Size Estimation

Estimating dolphin group size is a challenging task. To assess the accuracy and precision of dolphin group size estimates, observer estimates were compared to counts from large-format vertical aerial photographs. During 11 research cruises, a total of 2,435 size estimates of 434 groups were made by 59 observers. Observer estimates were modeled as a function of the photo count in a hierarchical Bayesian framework. Accuracy varied widely among observers, and somewhat less widely among dolphin species. This research has been accepted for publication

(Gerrodette, T, Perryman, W.L., and Oedekoven, C.S. In press. Accuracy and precision of dolphin group size estimates. Marine Mammal Science).

Phylogeographic and Population Genetic Analyses of Toothed Whales

Two projects are underway to evaluate population structure of toothed whales in the ETP (short-finned pilot whales and sperm whales,) in the context of population and phylogeographic patterns in the North Pacific and globally.

Short-finned pilot whales (*Globicephala macrorhynchus*) are a highly social species and top predator in the ETP. They exhibit extremely low mitochondrial DNA diversity, but previous studies have determined that there may be two or three genetically distinct stocks in the North Pacific. Amy Van Cise, a former PhD student at Scripps Institution of Oceanography working with Phillip Morin (SWFSC), has evaluated mtDNA variation from samples in the SWFSC Marine Mammal and Sea Turtle Research (MMASTR) tissue and DNA collection, and shown that the two types of short-finned pilot whales previously described from Japan form distinct populations across the north Pacific, with the "Shiho" type found in North Japan and the eastern Pacific, while the "Naisa" type is found in southern Japan and the western Pacific, including the Hawaiian islands (Van Cise et al. 2016). A project to expand sampling globally and to use complete mitochondrial genomes and nuclear SNPs to further investigate taxonomic status and phylogeography of this species in the ETP and elsewhere suggests that the Shiho type in the ETP meets several criteria for designation as a subspecies. Data from the Indian Ocean and eastern Atlantic are limited, but it is possible the Atlantic population may also be a separate subspecies (pending additional research). A manuscript is in preparation for submission to the journal Heredity.

Sperm whales (*Physeter macrocephalus*) also exhibit very low mtDNA diversity, with the majority of samples having one of three common haplotypes globally, so it has been difficult to use the traditional sequencing approach based on short mtDNA sequences to understand sperm whale phylogeography and population structure. Past studies have shown very low levels of population structure in the Pacific, but have also been limited in statistical power to detect additional structure that may exist. Phil Morin (SWFSC) led a project based on 175 complete mitochondrial genome sequences that provides phylogeographic evidence for isolation of female populations in the Pacific and Atlantic oceans, and inference of a late-Pleistocene expansion of sperm whales globally, likely from a small population in the Pacific. These data are important for assessing the global status of sperm whales post whaling, and provide new tools to assess population structure within ocean basins for better assessment of trends in abundance. A manuscript has been submitted to the journal Molecular Ecology.

Common Dolphin Reproduction and Population Structure

Several research projects compared reproductive rates of long- (LB) and short-beaked (SB) common dolphins in the northern part of the eastern tropical Pacific, off Baja, Mexico. The studies combined data collected during a dedicated research cruise to study these species in 2009 with data collected from fishery bycaught specimens. Kellar et al. (2013, 2014) measured blubber progesterone concentrations in biopsy samples to examine spatial variability in pregnancy rates, and Chivers et al. (2016) estimated calf production and characterized calving seasons. The proportion of females pregnant was 22.1% (n = 45) for SB and 28.1% (n = 85) for LB, and there were strong geographic patterns observed in both species suggesting that some areas are more conducive to pregnant females. Off Baja, the highest proportions of pregnant females were observed in the vicinity of Punta Eugenia. Calf production was significantly lower: 4.5% in SB and 6.9% in LB, than the pregnancy rates reported by Kellar et al. (2014), and they also varied regionally. Mean calving seasons occurred during winter and were offset by about three months with SB calving occurring earlier in the winter season than LB. Chivers et al. (2016) also reported regional variability in adult female size of LBs, suggesting that there may be additional structure within the population which is not currently recognized. The morphological and biological differences presented in these studies as well as those previously documented in the literature between long- and short-beaked common dolphins support recognition of these two forms as separate species in the eastern North Pacific, and the recent genetic study by Segura-Garcia et al. (2016) provides additional support for recognition of the long-beaked common dolphin as a species.

Coastal Spinner Dolphin Life History and Population Structure

Analyses of morphological data collected from photogrammetric images of coastal spinner dolphins during the 2006 *Stenella* Abundance Research (STAR) cruise identified them as Central American spinner dolphins. These data were collected by Mr. Wayne Perryman and colleagues in the nearshore waters off Guerrero, Mexico, where the presence of spinner dolphins had not been previously documented. These are the northernmost records for this subspecies whose range was previously described as being from Panama to the Gulf of Tehuantepec to off Guerrero, Mexico. North of Guerrero off Nayarit, Mexico, the Tres Marias spinner dolphins are found. In addition to the range extension for Central American spinner dolphins, Dr. Susan Chivers and colleagues combined the photogrammetric data from 2006 with those collected during earlier research cruises and those collected by observers from fishery by-caught specimens to characterize the calving season for all forms of spinner dolphins recognized in the eastern tropical Pacific. This research provides the first biological data for coastal spinner dolphin populations, which provides additional support for the recognition of the Tres Marias spinner dolphin as a distinct coastal form with a relatively restricted range off the coast of Nayarit, Mexico.

Short-finned Pilot Whale Population Structure and Distribution

Adult size data for short-finned pilot whales (SFPWs) sampled from fishery by-catch, stranding events and vertical aerial photographs were combined to investigate the range of northern and southern form whales in the eastern North Pacific Ocean (ENP). Dr. Susan Chivers and colleagues assembled data from Hawaii, California, and the eastern tropical Pacific for this study. Results revealed that the northern, larger, form ranges from the pelagic waters off California south through the eastern tropical Pacific (ETP), and that the southern, smaller, form inhabits the waters around the main Hawaiian Islands. These findings are consistent with the presence of northern form genotypes in the ETP (Van Cise et al. 2016). The addition of these morphological data for the ENP will ultimately facilitate resolving the taxonomic status of SFPWs by providing additional context for interpretation of the genetic data given that geographic variability in body size is likely genetically rather than ecologically driven.

Identifying Critical Habitat for Large Whales

Review of Spatial Habitat Modeling for Large Whales

A study comparing two commonly-used methods for spatial habitat modeling of large whales has been completed and is in preparation for submission. The paper shows that systematic survey data can be modeled either with presence-absence GAM or with MaxEnt presence-only methodologies, giving similar predictions in both geographical and ecological (niche) space. The paper also shows that Maxent models must be corrected for sampling biases that are present in stratified research vessel sampling and especially in opportunistic presence-only data. (Fiedler *et al.,* in prep.).

Advancing Understanding of Ecosystem Structure and Function

Ecosystem Indicators

A critical component of ecosystem-based management (EBM) is the development and use of indicators. Data characterizing the physical environment are commonly used as indicators but in this research fishery data are used to predict additional biological characteristics of the ecosystem. Focusing on the ETP, Dr. Summer Martin (Pacific Islands Fisheries Science Center) and Lisa T. Ballance (SWFSC) use two sources of spatially explicit data (2° x 2° grid) for 1986-2006: (1) yellowfin tuna (*Thunnus albacares*) catch and effort data from the Inter-American Tropical Tuna Commission (IATTC), and (2) cetacean sightings and effort data from SWFSC's Cetacean and Ecosystem Assessment Surveys. Metrics for 3 types of purse-seine sets ("dolphin," "log," and "school"), including number of sets ("Sets"), tons of yellowfin tuna ("Catch"), and tons of yellowfin tuna per day ("CPUE") were computed and related to sightings per hour ("SPUE") for 19 taxa of cetaceans. Canonical correspondence analysis indicated associations between: (1) dolphin fishing metrics (Sets, Catch) and SPUE of offshore spotted and eastern spinner dolphins (*Stenella attenuata* and *S. longirostris orientalis*), rough-toothed dolphins (*Steno bredanensis*), and dwarf sperm whales (*Kogia sima*); (2) log fishing metrics (Sets, Catch) and SPUE of sperm whales (*Physeter macrocephalus*), Bryde's whales (*Balaenoptera edeni*), and short-finned pilot whales (*Globicephala macrorhynchus*); (3) school fishing metrics (Sets, Catch, CPUE) and SPUE of blue whales (*Balaenoptera musculus*), bottlenose dolphins (*Tursiops truncatus*), Risso's dolphins (*Grampus griseus*), and offshore common dolphins (*Delphinus delphis*). Predictive maps of cetacean densities, constructed from generalized additive models with fishery metrics as predictors, were qualitatively similar to those developed using environmental variables. They captured historically observed ranges and sightings rates remarkably well for 11 taxa. These regularly-collected fishery data may prove valuable in understanding general characteristics of cetacean distribution and density when expensive at-sea surveys are not an option, and provide a proof of concept for applying EBM principles to oceanic ecosystems. This research is in manuscript form and will be submitted to a peer-reviewed journal in 2018.

Ecosystem Services

Dr. Summer Martin (Pacific Islands Fisheries Science Center, PIFSC) and Lisa T. Ballance (SWFSC) were contacted by Dr. Richard Rikoski, a member of the NOAA Ocean Exploration Advisory Board (OAEB) regarding their 2016 publication on ecosystem services in Frontiers in Marine Science (Martin *et al.* 2016). Dr. Rikoski is interested in the ideas from the publication, particularly that of ocean carbon storage and the economic value of rebuilding depleted megafauna populations. He indicated that this research could help guide NOAA's OAEB in setting priorities for future research in oceanic systems. Summer, Lisa, and their coauthor Dr. Ted Groves (UCSD Department of Economics) discussed ideas with Dr. Rikoski in January and will follow up with a meeting in March.

Influence of Tropical Pacific Processes on California Current Variability

Dr. Paul Fiedler, in collaboration with Nathan Mantua of SWFSC/FED, has completed a study of relationships between warm and cool events in the tropical Pacific and the California Current System. The record of warm and cool events in the California Current System (CCS) for 1950-2016 was updated. Composite sea level pressure (SLP) and surface wind anomalies were used to explore the different atmospheric forcing mechanisms associated with tropical and CCS warm and cold events. CCS warm events are associated with negative SLP anomalies in the NE Pacific – a strong and southeastward displacement of the wintertime Aleutian Low, a weak North Pacific High and a regional pattern of cyclonic wind anomalies that are poleward over the CCS. Scientists use a first-order auto-regressive model to show that regional North Pacific forcing is predominant in SST variations throughout most of the CCS, while remote tropical forcing is best correlated in the far southern portion of the CCS. Cool events in the CCS tend to be more closely associated with tropical La Niñas than warm events in the CCS are with tropical El Niño; the forcing of co-occurring cool events is analogous, but nearly opposite, to that of warm events. This paper has been published (Fiedler and Mantua, 2017).

Cetacean Community Patterns

Dr. Lisa Ballance, Dr. Robert Pitman, Dr. Paul Fiedler, and Dr. Jessica Redfern are collaborating to identify distinct communities of cetaceans in the eastern tropical Pacific and the ecosystem variables that describe their distributions. For example, we might expect that different variables are needed to describe the habitat of species that are deep divers compared to species that feed at the surface. This project uses the 10-year time series of eastern tropical Pacific data and will increase our understanding of ecosystem structure and function.

Trends in Spotted Dolphin Abundance

Dr. Jessica Redfern and Dr. Jay Barlow are collaborating to explore the ecosystem variables that describe spotted dolphin distributions. They will use these variables to examine trends in stock abundance. In particular, they will estimate spotted dolphin abundance using stock boundaries defined by the ecosystem variables and compare these estimates to abundance estimates made using existing stock boundaries, which are defined by static longitude and latitude coordinates.

Olive Ridley Turtle Trophic Ecology Research In The Eastern Tropical Pacific

In a paper by Lindsey Peavey and colleagues (2017), the research team was interested in exploring the trophic ecology of olive ridley sea turtles (*Lepidochelys olivacea*) in the eastern Tropical Pacific. Information on sea turtle trophic ecology is difficult to access via conventional dietary analyses and the authors thus used stable isotope analysis of bulk tissue and individual amino acids in olive ridley skin. Skin samples were collected from turtles captured via small boat operations during research cruises operated by NOAA-SWFSC from 2003 to 2009. The team sampled a total of 346 turtles at-sea to empirically explore the spatiotemporal variability in trophic status and diet of olive ridley turtles. Olive ridleys range across >3 million km2 of the tropical and subtropical eastern Pacific Ocean and their trophic ecology in open ocean areas had not yet been adequately described prior to this research. Based on their stable isotope analyses, the team gathered that trophic position (TP) did not vary across age or sex. They also found that median TP of adults remained constant (~3.1). This study underscored the value of large-scale in-water olive ridley sea turtle research across oceanic foraging habitats to confirm anecdotal understanding of trophic roles and susceptibility to environmental change. Further, it underscores trophic flexibility as a possible mechanism accounting for why this species is now abundant in the eastern Pacific Ocean.

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