Southwest Fisheries Science Center

NOAA FISHERIES - NATIONAL MARINE FISHERIES SERVICE - SOUTHWEST FISHERIES SCIENCE CENTER

JULY 2019

2019 HIGHLY MIGRATORY SPECIES ANNUAL REPORT

by

The Southwest Fisheries
Science Center

ADMINISTRATIVE REPORT LJ-19-01

Accessibility information

NOAA Fisheries Southwest Fisheries Science Center (SWFSC) is committed to making our publications and supporting electronic documents accessible to individuals of all abilities. The complexity of some of SWFSC's publications, information, data, and products may make access difficult for some. If you encounter material in this document that you cannot access or use, please contact us so that we may assist you.
Phone: 858-546-7000

JULY 2019

2019 HIGHLY MIGRATORY SPECIES ANNUAL REPORT

Southwest Fisheries Science Center
National Marine Fisheries Service
National Oceanic & Atmospheric Administration
8901 La Jolla Shores Drive
La Jolla, CA 92037-1509

ADMINISTRATIVE REPORT LJ-19-01

TABLE OF CONTENTS

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, 2018 – March 31, 2019, 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, and biological sampling 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 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 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 Southern 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 2017 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	2017 CATCH IN METRIC TONS	NUMBER OF VESSELS
North Pacific Albacore Troll and Pole-and-line	7,216	494
South Pacific Albacore Troll	554	13
Eastern Pacific Ocean Purse Seine	2,206	9
California Large-mesh Drift Gillnet	234	17
California Harpoon	25	21

North Pacific Albacore Troll and Pole-and-line

Total annual catch of albacore from the North Pacific albacore troll and pole-and-line fishery decreased 34% from 10,796 t in 2016 to 7,216 t in 2017. The number of vessels decreased from 571 vessels in 2016 to 494 vessels in 2017. The average weight of retained albacore in 2017 was 18.3 pounds, compared to 17 pounds in 2016. 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. Thirteen vessels participated in the fishery in 2017 compared to six vessels in 2016. Total catch of albacore in the 2017 fishery was 554 t, an increase of 216% from the 256 t landed in 2016. 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 decreased from 25 vessels in 2016 to 17 vessels in 2017. These vessels landed 176 t of swordfish, 39 t of common thresher, and 19 t of other HMS species in 2017 compared to 193 t of swordfish, 31 t of common thresher, and 24 t of other HMS species caught in 2016. 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 19 vessels in 2016 to 21 vessels in 2017. Twenty-four metric tons of swordfish were caught in 2017 compared with twenty-five metric tons caught in 2016. 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.

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

Longline (California-based)
Deep-set longlining for tuna is permitted under the PFMC FMP for HMS. In 2017, 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. Both Commercial Passenger Fishing Vessels (CPFV) and private vessels target albacore off the coasts of Washington and Oregon. In recent years, anglers have caught very few albacore in Southern California. The recreational catch of albacore by vessels that target albacore off the West Coast decreased from 675 t in 2016 to 372 t in 2017. The catch of bluefin tuna by U.S. recreational anglers increased from 286 t in 2016 to 369 t in 2017.

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 107 t of HMS in 2017 compared to 97 t of HMS caught in 2016.

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.

Contributing to the Work of the ISC
The 18th ISC Plenary, held in Yeosu, Republic of Korea from July 11 to 16, 2018, was attended by Members from Canada, Chinese Taipei, Japan, Korea, Mexico, and the United States as well as the Western and Central Pacific Fisheries Management Commission. The Plenary reviewed results, conclusions, new data, and updated analyses of the Billfish, Albacore, Shark and Pacific Bluefin tuna working groups. The ISC Plenary endorsed the findings that the North Pacific shortfin mako shark (SMA) stock is likely not in an overfished condition and overfishing is likely not occurring relative to MSY-based abundance and fishing intensity reference points, and considers the 2018 benchmark stock assessment to be the best available scientific information. The ISC Plenary also endorsed the findings that the Western and Central North Pacific (WNCPO) swordfish (SWO) stock is not likely overfished and is not likely experiencing overfishing relative to MSY-based or 20% of unfished spawning biomass-based reference points and considers the WNCPO

SWO stock assessment to be best available scientific information. An updated assessment of Pacific bluefin tuna (PBF) found that the stock is overfished and experiencing overfishing and that the probabilities of attaining the first and second rebuilding targets under current management measures were 98% and 96%, respectively. The ISC Plenary endorsed these findings and considers them to be the best available scientific information on PBF. The ISC Plenary re-iterated stock status and conservation information provided at ISC17 for North Pacific albacore, Pacific blue shark, Eastern Pacific Ocean Swordfish, WNCPO striped marlin, and Pacific blue marlin. A science seminar on ecosystem-based fisheries assessment and management was held and the ISC Plenary agreed to a template to standardize stock status and conservation information to the extent possible. Meetings were schedule for the Ad-hoc Working Group assessing the feasibility of developing an multinational PBF tagging program and the PBF Close-kin genetic project. Observers from Pew Charitable Trusts, World Wildlife Fund for Nature – Japan, Monterey Bay Aquarium, and the Western Pacific Fisheries Management Council attended. The ISC work plan for 2018-19 includes completing WNCPO Striped Marlin assessment, updating information on biological reference points for ISC species of interest improving catch and CPUE time series and advancing biological information for shark species, conducing the second PBF MSE workshop, reviewing initial simulation results from the ALB MSE process, and enhancing database and website management. The next ISC Plenary will be held in the Chinese-Taipei in July 2019.

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 for 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 was completed in March 2019.

As part of the MSE process, the ISC ALBWG organized the 4th ISC MSE workshop for managers, stakeholders, and scientists in Yokohama, Japan, during March 5 - 7, 2019. The primary objectives of the workshop were to (1) examine the preliminary results of the initial round of MSE for NPALB with managers and stakeholders; (2) collate feedback from managers and stakeholders on future MSE improvements; and (3) develop recommendations for the WCPFC NC and IATTC. The participants at the 4th ISC MSE Workshop recommended that the MSE work continue for a second round, with a more focused set of reference points and harvest control rules to evaluate. Results of the initial MSE will be presented to and reviewed by the ISC Plenary in July 2019.
The ISC ALBWG has scheduled a workshop at the National Research Institute of Far Seas Fisheries, Shizuoka, Japan, from November 12 – 18, 2019. The primary objective of the workshop is to review the data to be used for the upcoming stock assessment in March 2020. Subsequently, the ISC ALBWG has scheduled a workshop at the SWFSC, La Jolla, from March 16 – 23, 2019. The primary objectives of the workshop are to develop the stock assessment model and perform the stock assessment for North Pacific albacore tuna.

Pacific Bluefin Tuna

Pacific bluefin tuna historically supported an important HMS commercial fishery 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, though there remains an important commercial fishery for Pacific bluefin tuna in Mexican waters. In March 2019, a meeting of the ISC Pacific Bluefin Tuna Working Group (PBFWG) convened in Korea to update latest fishery data (catch, CPUE and size compositions data), review additional projection results, and discuss potential areas of model improvement for the 2020 stock assessment of Pacific bluefin tuna. Participants included scientists from SWFSC, IATTC, Taiwan, Japan, Korea, and Mexico.

Population dynamics were estimated in the last (2018) stock assessment 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 2018 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. The WG defined 19 fleets to 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, offshore 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. The WG used maximum likelihood estimates of model parameters, derived outputs, and their variances to characterize stock status and to develop stock projections. The WG conducted various diagnoses of the assessment model and sensitive analyses.

Since there is no assessment conducted in 2019, the WG used the latest fishery data as interim indictors of stock status and the conclusion of the stock status would have to be generated from stock assessment model. Updated CPUE from the Japanese distant water longline fleet and Taiwanese longline fleet that catch adults (spawners) did not show a decreasing trend after 2016 (fishing year). Updated CPUE in 2017 (fishing year) from the Japanese troll fleet that catch age-0 fish (recruitment) was slightly lower than that 2016 but similar to the historical average, whereas CPUE in 2017 and 2018 (fishing year) from Japanese recruitment monitoring program that catch age-0 fish (recruitment) increased compared to the 2016 estimate. In addition to the CPUE, larger fish are apparently becoming more abundant in the eastern Pacific Ocean.

Additional projections requested by the Northern Committee of the Western Center Pacific Fisheries Commission (WCPFC) and Inter-American Tropical Tuna and Commission (IATTC) in September 2018 were reviewed during the March 2019 meeting. The evaluated projections included alternative harvesting scenarios to increase the catch limit of PBF.

The review of the latest fishery data and projection results will be presented and are subject to be endorsed by the ISC Plenary meeting in July 2019. Thereafter they will be forwarded to the IATTC-WCPFC NC Joint Working Group meeting and WCPFC Northern Committee in September 2019.

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 shortfin mako shark assessment in 2018 and produced the first full stock assessment for this species in the North Pacific. SWFSC scientists are also working to prepare for the upcoming assessment of blue sharks in 2020.

North Pacific Shortfin Mako Shark

In 2017-18, the ISC SHARKWG conducted an assessment of shortfin mako sharks in the North Pacific. The Working Group analyzed fishery data, updated biological parameters, and developing a fully integrated age-structured model. Participants from Japan, Taiwan, Mexico, Canada, and the U.S. contributed data and/or analytical work to the assessment.

SWFSC and PIFSC scientists provided full catch time-series of mako sharks caught, landed, and released in U.S. commercial and recreational fisheries as well as information on the size and sex composition of mako sharks taken in several observed fisheries (Carvalho 2017, Kinney et al. 2017). The SHARKWG developed two models for shortfin makos in 2017-18, the first was a fully integrated assessment model developed with Stock Synthesis (SS) (ISC 2018), and the second was a virtual population analysis (VPA) model (Kanaiwa et al. 2017). The VPA model was primarily used to provide a point of comparison to the SS model. The 2018 ISC North Pacific shortfin mako shark stock assessment was presented at the ISC plenary in Korea (July 2018), and later to the Scientific Committee of the WCPFC in Taiwan (August 2018), where it was accepted as the best scientific information available for stock status determination. The results indicated that the stock is likely not in an overfished condition and overfishing is likely not occurring relative to MSY-based abundance and fishing intensity reference points.

Blue Shark

In November 2018, SWFSC scientists attended the ISC SHARKWG meeting in Taiwan to discuss future projects and research directions for the upcoming blue shark assessment in 2020. The group laid out a work plan and prioritized projects for the coming assessment. SWFSC scientists presented preliminary work on redefining Hawaiian longline fisheries with spatiotemporal consideration of blue shark size data (Kinney et al. 2018). This work was presented to the group as a proof of concept and was intended to encourage the sharing of spatially explicit size and sex information for blue sharks in order to allow the same analysis to be done on the wider data set of blue sharks caught in various longline fisheries in the North Pacific. The work was positively received and each nation is currently providing their data to allow this work to carry forward. Participants from Japan, Taiwan, and Mexico also presented updates to catch and important biological parameters for use in the upcoming blue sharks assessment.

III. SUPPORTING PACIFIC FISHERY MANAGEMENT COUNCIL ACTIVITIES

Fisheries Resources Division economist Dr. Stephen Stohs continued serving on the Highly Migratory Species Management Team (HMSMT) of the Pacific Fishery Management Council

(Council) over the past year. The HMSMT met several times in 2018 and early 2019 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 Council over the past year have been: (1) developing a range of alternatives to authorize a deep-set buoy gear fishery for swordfish off the West Coast; (2) continuing to aid the Council with approving exempted fishing permit operations to test alternative methods of targeting swordfish; (3) providing recommendations for international management activities; and (4) preparing the 2018 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 2017, state fishery personnel measured 36,660 fish averaging 73 cm fork length (FL) at various west coast ports.

North Pacific Albacore Electronic Logbook Project

In 2015, FRD staff developed a new, alternative electronic logbook as a fillable PDF form. The form is available on the NOAA Fisheries West Coast Region HMS web page. A secure web application was also developed to allow anglers to submit their completed PDF forms to SWFSC after each trip.

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. In a cooperative effort with the tagging program, vessels in the albacore troll/pole-and-line fleet near the main fishing grounds off Oregon and Washington deploy tags, as does the recreational charter fleet off southern California and northern Baja, Mexico, when the fish are present. The total number of deployed tags to date is 1,086. In 2016 and 2017, logistical problems prevented deploying additional tags. Thirty-seven archival tags have been recovered, resulting in data from more than 15,000 days at liberty.

Habitat modeling

Within the California Current the distribution, abundance, and foraging behaviors of juvenile albacore are strongly variable inter-annually. These factors impact catchability for the local fleet and the inability to predict patterns has been a point of frustration for fishers. We use catch logbook data and trawl survey records to investigate how juvenile albacore in the California Current use their oceanographic environment, and how their distributions overlap with the habitats of four key forage species. Findings show that anchovy (*Engraulis mordax*) and hake (*Merluccius productus*) habitat is associated with productive coastal waters found further inshore of core juvenile albacore habitat, whereas sardine (*Sardinops sagax*) and boreal clubhook squid (*Onychoteuthis borealijaponica*) habitat overlaps more consistently with that of albacore. Our results can improve understanding of how albacore movements relate to foraging strategies, and why prey-switching behavior occurs. This has relevance for understanding catchability of albacore in U.S. fisheries, the development of ecosystem models, and for the eventual implementation of ecosystem-based fishery management (EBFM). A paper describing these results has been submitted to CalCOFI (Muhling et al., *submitted*).

Bluefin Tuna Modeling Research

Evaluation of fishery dependent recruitment indices using the age-structured production model diagnostic and randomization test: An example using Pacific bluefin tuna

One of the primary goals of stock assessment modeling is to measure the effects of fishing on stock abundance. Simple surplus production models were built around that concept, where fishing was mediated by a production function to predict observed trends in abundance or biomass. Nowadays, applied stock assessment has moved to integrated assessment models with the ability to deal with the variability in the production function. The age-structured production model (ASPM) is an integrated age-structured version of the production model that has been used to diagnose misspecification of the systems processes that control the shape of the production function. Lee *et al.* (in review) expanded the use of the ASPM diagnostic, which uses catch and the production function to predict adult observed trends in abundance and estimate stock depletion relative to the spawning biomass in the first year, to evaluate alternative fishery-dependent indices of abundance of age-0 Pacific bluefin tuna (*Thunnus orientalis)*. The recruitment implied by each alternative age-0 index was treated as process variability of the production function. Improvement in predictions of adult observed trends and estimate of depletion were interpreted as evidence that the implied recruitment was consistent with catch, adult indices, and the production function. Recruitment variability described from the western side of Japan improved the models prediction and estimate of depletion, while those from the eastern side degraded predictions and estimate of depletion. Randomization of recruitment reveal that large, small, and even moderate fluctuations in recruitment from the western side were connected to adult abundance trends. The results support use of the age-0 index derived from the troll fishery on the western side of Japan, however, similar analyses will have to be routinely conducted to ensure that this series is a good predictor of recruitment if management significantly reduces the fishing mortality on age-0 fish.

Bluefin Close-Kin Mark Recapture Research

The Pacific bluefin Tuna (PBF) close-kin genetics study is a parentage-based, mark-recapture research program to develop an independent estimate of abundance for this highly migratory species. Beginning in 2016, fin clips used for genetic identification have been collected from U.S. recreationally and commercially caught PBF for this ISC-led project. Catch from U.S. fisheries will be sampled indefinitely in support of the project, and other ISC member countries have continued to sample Pacific bluefin in parallel with the U.S. effort. In May 2019, a strategic planning workshop was held in Jeju, Korea. Representatives from several ISC member countries attended and each country presented updates on their progress in collecting tissues and development of methods. All countries reported favorable progress in sample collection, and the Japanese delegation presented preliminary marker development and methods.

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 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 tuna (*Thunnus alalunga*), Pacific bluefin tuna (*Thunnus orientalis*), yellowfin tuna (*Thunnus albacares*), bigeye tuna (*Thunnus albacares*), skipjack tuna (*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, 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	2018	TOTAL
Pacific Bluefin tuna	0	75	78	54	189	294	171	156	120	487	253	236	2113
Albacore: WA/OR	0	0	42	191	49	60	60	39	50	1	34	64	590
Albacore: Central CA	0	0	0	0	27	31	43	0	0	0	0	0	101
Albacore: Southern CA	116	35	93	118	7	62	3	0	0	0	0	0	434
Yellowfin tuna	15	45	95	71	128	132	112	134	50	112	127	75	1096
Skipjack tuna	0	5	9	8	15	16	25	0	0	0	0	12	90
Bigeye tuna	0	0	0	0	0	0	0	0	0	0	100	611	711
California Yellowtail	0	0	7	30	190	186	90	36	30	0	0	0	569
Opah	0	0	1	11	16	64	30	30	15	0	80	194	441
Dorado	0	43	39	0	40	18	0	3	12	0	0	3	158

These biological samples 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. As sample collections increased over time, the research program expanded to include:

- 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)
- Using otoliths to better characterize age and growth of albacore
- 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
- Using otolith microchemistry to determine the dynamics and stock structure of albacore, Pacific bluefin, and swordfish in the North Pacific
- Characterizing the genetic diversity of California yellowtail in preparation for commercial aquaculture production off southern California
- Comparing inshore- versus offshore-caught California yellowtail with respect to ontogeny and migration patterns using stable isotope analysis and lab derived trophic discrimination factors
- Developing a sex-linked genetic marker for albacore and California yellowtail
- Characterizing the diet, age and growth, fecundity, and physiology of opah
- Exploring mercury dynamics in pelagic predators
- Examining the reproductive maturity of Pacific bluefin tuna in the SCB
- 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

- Developing methods to use tuna as biological samplers of prey species
- Supporting genetic analyses on a range of species including close-kin genetic analyses of bluefin tuna
- Examining contaminant levels in mako, thresher and blue sharks across ontogeny to determine factors that influence contaminant concentrations
- Explore maturity of tunas in the CC

From 2013-2018, lengths have been taken from total of 4024 Pacific bluefin tuna landed at the docks in San Diego and was provided to John Childers at the SWFSC. This information is critical to understanding catch composition of the local fleet. Pacific bluefin tuna results revealed an increase in the average size of fish landed in San Diego consistent with the increase in average age and fish remaining in the California Current up to seven years old. Over the same period, biological samples were taken from 1637 fish, with the 2018 collection totaling 236 fish.

Reproductive Biology

Despite the presence of large Pacific bluefin tuna (4-8 years old) in the California Current (CC) during recent years, there is no evidence of spawning occurring in the eastern Pacific. Histological analyses of ovaries from 14 females collected in 2018 reveal that eggs were either unyolked or in the early stages of yolking with no evidence of active spawning.

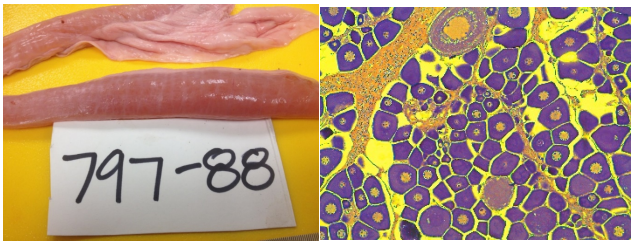

Figure 1. Recently collected ovary prior to processing, Eggs unyolked or in early stages of yolking.

Otolith Microchemistry

An analysis of the otolith microchemisty of larval Pacific bluefin tuna collected around Japan demonstrates the ability to determine natal spawning ground and the importance of year class matching. Assignment probabilities range from 75% to 95% and should improve with higher sample sizes. The first estimates of relative recruitment to the CC from the two spawning grounds will be available this spring. Additional efforts include life history transects which will allow us to determine the relative number of bluefin on the spawning grounds that forage in the CC and how this number changes over time.

Foraging Ecology

Studies of bluefin stomach contents across the years reveals dramatic shifts in diet (see **Figure 2** below). Note the shift at 2014-2015 from cephalopods to pelagic red crabs. There has also been an increase in anchovy consumption in recent years (2016-2018), matching results from CalCOFI surveys. SWFSC researchers are examining the link between diet shifts over the years to environmental variability in the CC.

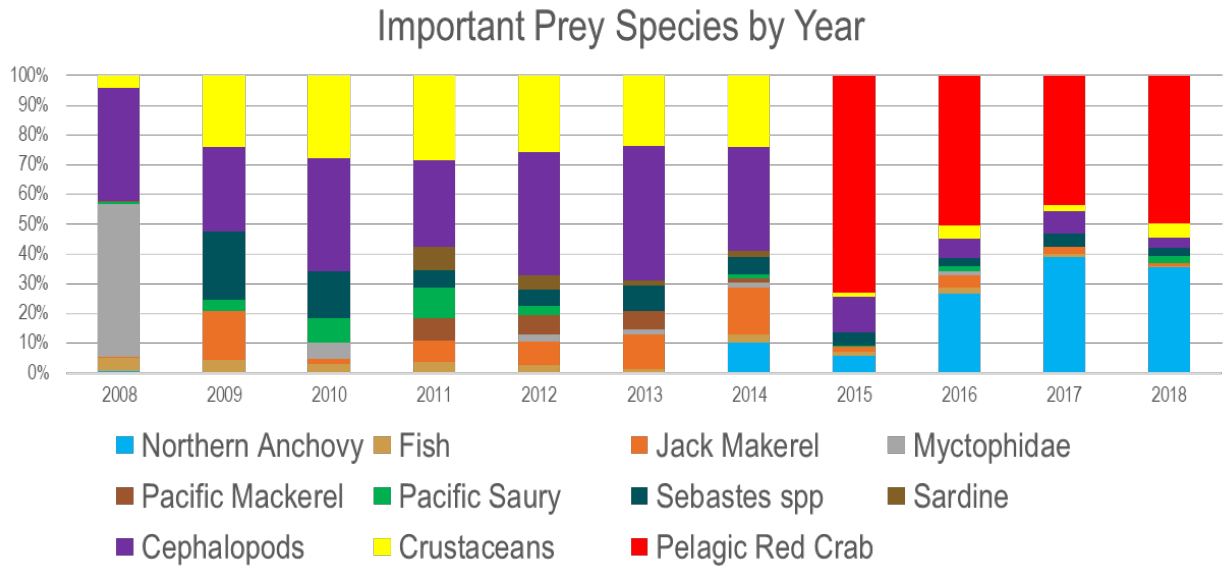

Figure 2. Relative importance of anchovy, sardine, other fish, squid, pelagic red crabs, and other crustaceans in the diets of bluefin tuna by year based on a modified Geometric Index of Importance.

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 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 2017 results of these programs were collected during 2018 and are summarized below.

International Billfish Angler Survey

Due to program changes, the 2017 surveys were sent solely by email, resulting in lower participation. Fifty-five surveys were completed for 2017, reporting 387 billfish caught in 324 fishing days in the Pacific, Atlantic, and Indian Oceans (**Table 3**). The majority of fishing effort was reported off Hawaii, Southern California, and Baja California. Mexico and the overall nCPUE for all locations, aside from Acapulco/ Ixtapa/Zihuatanejo/ Guerrero, increased from the previous year.

Table 3. Summary of reported billfish caught in the Pacific, Atlantic, and Indian Oceans in 2017.

LOCATION	ANGLER FISHING DAYS	TOTAL BILLFISH	NCPUE	MAJOR SPECIES
Hawaii	125	92	0.73	BM
Southern CA	48	0	0.0	--
Baja California	52	81	1.55	SM
Panama	12	20	1.66	SF
Acapulco/Ixtapa/Zihua/Guerrero	20	18	0.90	SF
Costa Rica	9	21	2.23	SF
Tahiti	1	1	1.00	BK
Australia	19	16	0.84	BK
Bermuda	1	3	3.00	BM
Malaysia	20	89	4.45	SF
Guatemala	3	40	13.33	SF
Japan	7	3	0.42	BM
New Zealand	2	1	0.50	SWO

Hawaiian anglers have consistently reported the greatest number of fishing days for the past five years and in 2017, they accounted for 38% of the total reported fishing days. In their 125 fishing combined fishing days, Hawaiian anglers caught 92 billfish, with Pacific blue marlin remaining the most-caught species followed by shortbill spearfish (*Tetrapturus angustirostris*) and striped marlin.

Southern California anglers reported catching no billfish in the 48 combined fishing days from the 2017 calendar year, resulting in a CPUE of 0.00 for the first time in the history of the program. In contrast to Southern California's lack of billfish, Baja's 2017 nCPUE of 1.55 is one of the highest values for the region in more than five years. The Baja 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 3**).

Pacific Blue Marlin

Despite low reporting, the 2017 Hawaii blue marlin nCPUE was 0.40, showing a general uptick in catch. However, the 2017 Baja blue marlin nCPUE decreased significantly from 0.11 to 0.01, which may also shine some light on the lack of blue marlin catch in neighboring Southern California for the 2017 calendar year.

Striped Marlin

The Southern California striped marlin nCPUE, which sharply declined in 2016 from 0.45 to 0.18 in 2015, bottomed out to 0.00 in 2017. Again, this may be due to a lack of reporting in 2017. Like the blue marlin effort, the striped marlin fishing for the Baja California region was the highest it has been since 2008, with an nCPUE value of 1.48 in 2017. In fact, in order to reflect the high, double-digit nCPUE values for Baja, we added a second axis on **Figure 3**. Hawaii experienced a slight uptick in striped marlin catches, with an nCPUE of 0.16 reported for the area.

Indo-Pacific Sailfish

The Costa Rica sailfish nCPUE remained high in 2017 at 1.44. Although neighbors, the nCPUE in Panama was largely below that of Costa Rica—1.00—and has been since 2003. 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 2017 sailfish nCPUE dropped in 2017 to 0.27, but remains higher than the 10-year average (0.23) 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 that sailfish tend to prefer.

Black Marlin

The 2017 nCPUE for black marlin increased considerably to a value of 0.78 in 2017, the highest it has been since 2005 (1.38). Black marlin fishing has stayed 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 0.08 in 2017. This is a decrease from the previous year (0.38) and below 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.

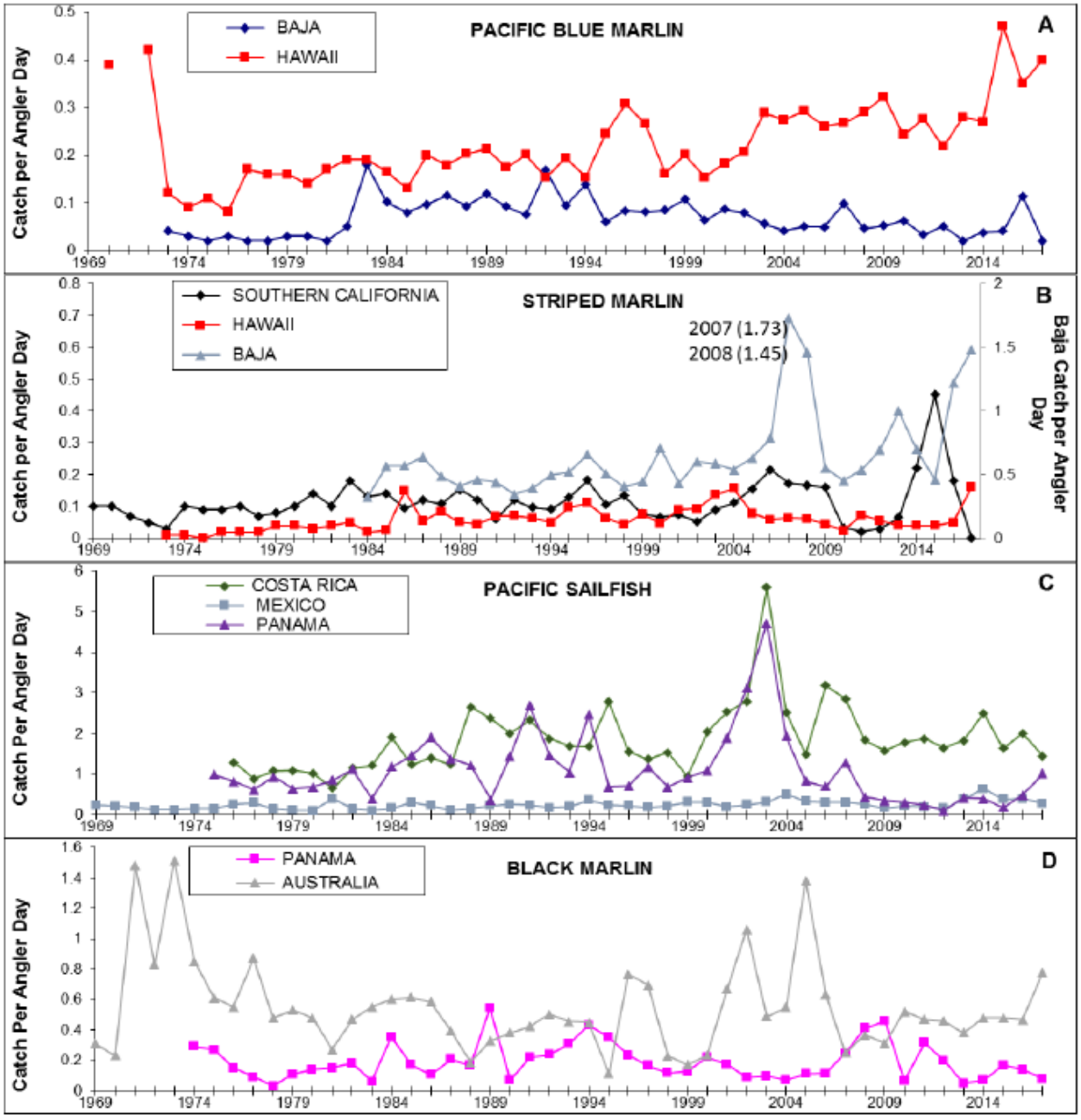

Figure 3. CPUE as catch-per-angler-day shown from 1969-2017 for Pacific blue marlin, striped marlin, Pacific sailfish, and black marlin.

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. Researchers use tag release and recapture data 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 662 tags on billfish in 2017 (**Table 4**). Anglers in the Hawaiian Islands tagged the greatest number of billfish in 2017, a total of 447 tags, followed by Acapulco/Ixtapa-Zihuatanejo with 152 tags mostly released on sailfish. 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. Only two tags on Pacific blue marlin were recovered in 2017, both by commercial fishing operations near or out of Hawaii. No tag release information was submitted, so days at liberty or distance traveled could not be computed.

Table 4. Summary of billfish tagged during 2017 by region.

LOCATION	SPECIES	2017 TAG TOTALS
Southern California	Striped Marlin	8
Southern California	Pacific Blue Marlin	2
Southern California	Sailfish	1
Gulf of Mexico	Pacific blue marlin	3
Hawaii	Pacific Blue Marlin	379
Hawaii	Shortbill Spearfish	58
Hawaii	Striped Marlin	9
Hawaii	Unidentified	1
Baja California/La Paz	Striped Marlin	34
Manzanillo/Colima	Pacific Blue Marlin	1
Acapulco/Ixtapa/Zihuatanejo/Guerrero	Sailfish	118
Acapulco/Ixtapa/Zihuatanejo/Guerrero	Pacific Blue Marlin	2
Acapulco/Ixtapa/Zihuatanejo/Guerrero	Striped Marlin	25
Acapulco/Ixtapa/Zihuatanejo/Guerrero	Shortbill spearfish	7
Costa Rica	Sailfish	1
Costa Rica	Pacific Blue Marlin	9
Costa Rica	Black Marlin	1
Fiji	Sailfish	2
Samoa	Sailfish	1
Totals	--	662

Swordfish Research

Swordfish support the second largest fishery for HMS off the U.S. West Coast. Since 2006, SWFSC researchers have been studying swordfish in the SCB to examine migratory patterns, foraging ecology, and local stock structure in support of management. These efforts include collaboration with ERD in the development of EcoCast (see below). Briefly, EcoCast is a modeling tool that characterizes the habitat of target and non-target species, including swordfish and leatherbacks, to identify where habitat separation is maximized (Hazen et al. 2018).

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 and are in the process of being submitted for publication. 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 sixth 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.

Researchers calculated univariate indices 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 swordfish prey is affected by environmental and biological variables.

Stomach samples collected from the drift gillnet from 2015 through the present are being dissected, contents sorted and identified, and data is prepared for future summaries and statistics. New samples collected from deep-set buoy gear are also being processed.

Opah Research in the Eastern Pacific Ocean

The opah is a large, mid-water pelagic fish that occurs seasonally in the SCB. While they are not 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 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 a research program in 2009. Initial efforts focused on biological sample collection, physiological studies and electronic tagging. Sample collection expanded in 2017 when the SWFSC began working collaboratively with the California Pelagic Fisheries Association (CPFA) and Catalina Offshore Products. Sample collection supports life history studies as well as providing insight into catch composition.

Since the program began, 791 opah have been sampled for DNA and lengths, with additional biological samples taken from 167 fish. The additional samples included tissues for isotope analyses, gonads for reproductive biology, hard parts for ageing, and stomachs for foraging ecology. A preliminary examination of the ovaries reveals active spawning in the winter months for fish caught offshore based on the presence of hydrated oocytes (**Figure 4**). This is the first documentation of spawning in the small eye opah and positions us to characterize their reproductive biology. To examine age and growth, we are currently examining the potential for using otoliths, vertebrae, or fin spines. An examination of the scales revealed no regular banding pattern that could be used for aging. Interestingly, the otoliths had been previously discounted as a potential option for aging because they are made of vaterite, which is very fragile and does not lay down rings in distinguishable patterns. One of the three otoliths (one not typically used for aging) is however, robust and may turn out to be useful. Efforts to compare hard parts for use in aging are underway, as are studies of foraging ecology using stomach contents and isotopes.

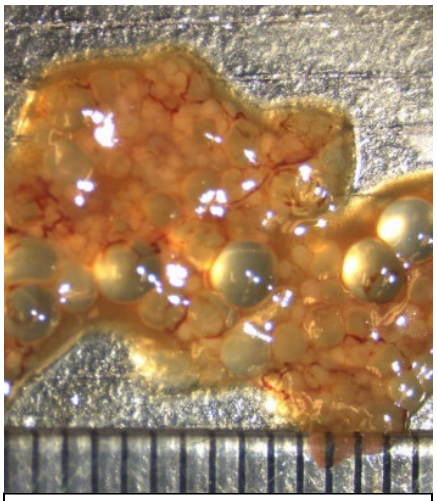

Figure 4. Image showing the hydrated eggs from an opah.

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, Life History Program scientists have teamed up with researchers at ERD to incorporate 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 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 (Hazen et al. 2018).

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 TOPP program, CICESE, the Guy Harvey Institute, and several recreational anglers. In 2018, researchers analyzed data from 55 PSAT tags and 89 SPOT tags and prepared multiple papers for publication. The first paper described the overall patterns of movements across seasons and size classes in the eastern North Pacific. The main findings were presented in previous directors reports.

The second paper explores whether vertical movements are consistent with optimal foraging theory, and constrained when animals are in a prey patch. In pelagic environments prey tend to be patchily distributed in time and space both horizontally and vertically. Optimal foraging theory states that it is in a predator's best interest to maximize time in a prey patch and minimize time traveling between patches. This has been demonstrated for horizontal movements, where movements are constrained during foraging, but not for vertical movements. Using data from double tagged mako sharks, researchers examined vertical movements during transient and resident behaviors where animals were presumed to be foraging. Results indicate that, as with horizontal movements, maximum depths are significantly shallower and vertical movements are more constrained during periods of resident behavior. Additionally, water column structure also influenced vertical habitat use, with sharks using more of the water column in warmer waters. Results suggest an expansion of vertical habitat use when sharks switch to transient behaviors, which may increase the probability of locating prey resources, and that temperature may influence the degree of habitat expansion.

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, 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. **Figure 5** shows the geolocation data for both SPOT and PSAT data as a function of month. PSAT data was recently analyzed, and preliminary analysis indicates apparent patterns. Similar to mako sharks, blue sharks traveled to the North Equatorial Current where they exhibited residential behavior. A few large individuals with longer tracks returned to the Southern California Bight in subsequent years. Researchers are currently preparing analyzations of general patterns of movement and behavior for publication.

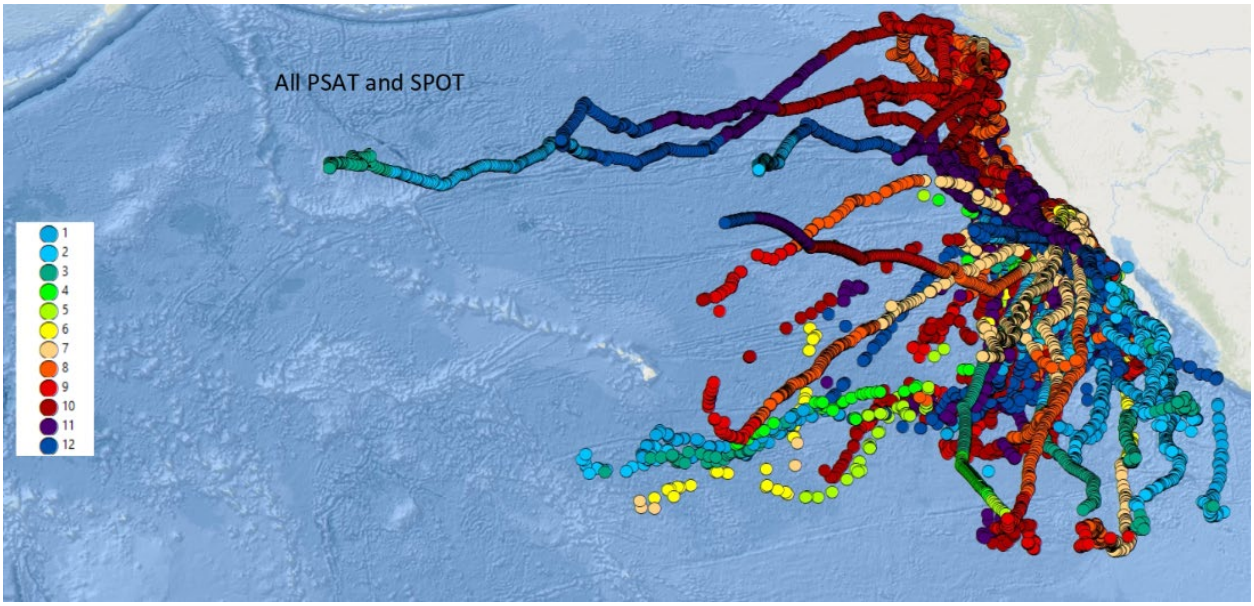

Figure 5. Argos based geolocations from SPOT tags and light and SST based geolocation estimates from PSAT tags for blue sharks tagged since 2002.

One important element for management is determining whether there are differences in distribution with sex and size. Blue sharks have clear habitat separation between sex and size in the open ocean (Nakano and Seki 2003). Using solely the SPOT data, researchers compared the mature males and immature females in coastal waters (**Figure 6** below). The sample size for mature females and immature males was not large enough to include. Researchers found that immature females are found at higher latitudes in the summer months and undergo a seasonal southward migration along the U.S. West Coast, similar to patterns observed in the North Atlantic (Vandeperre *et al.*, 2014). This more northern distribution translated into small females experiencing cooler SST (12-15C) than the larger males (>15C). Researchers also found some overlap between adult males and immature females in the fall months, indicating the importance of the Southern California Bight for multiple size classes. Additional work is needed to better characterize the full range of mature females and immature males. This work was accepted for publication in Diversity and Distributions (Maxwell et al. *in press).*

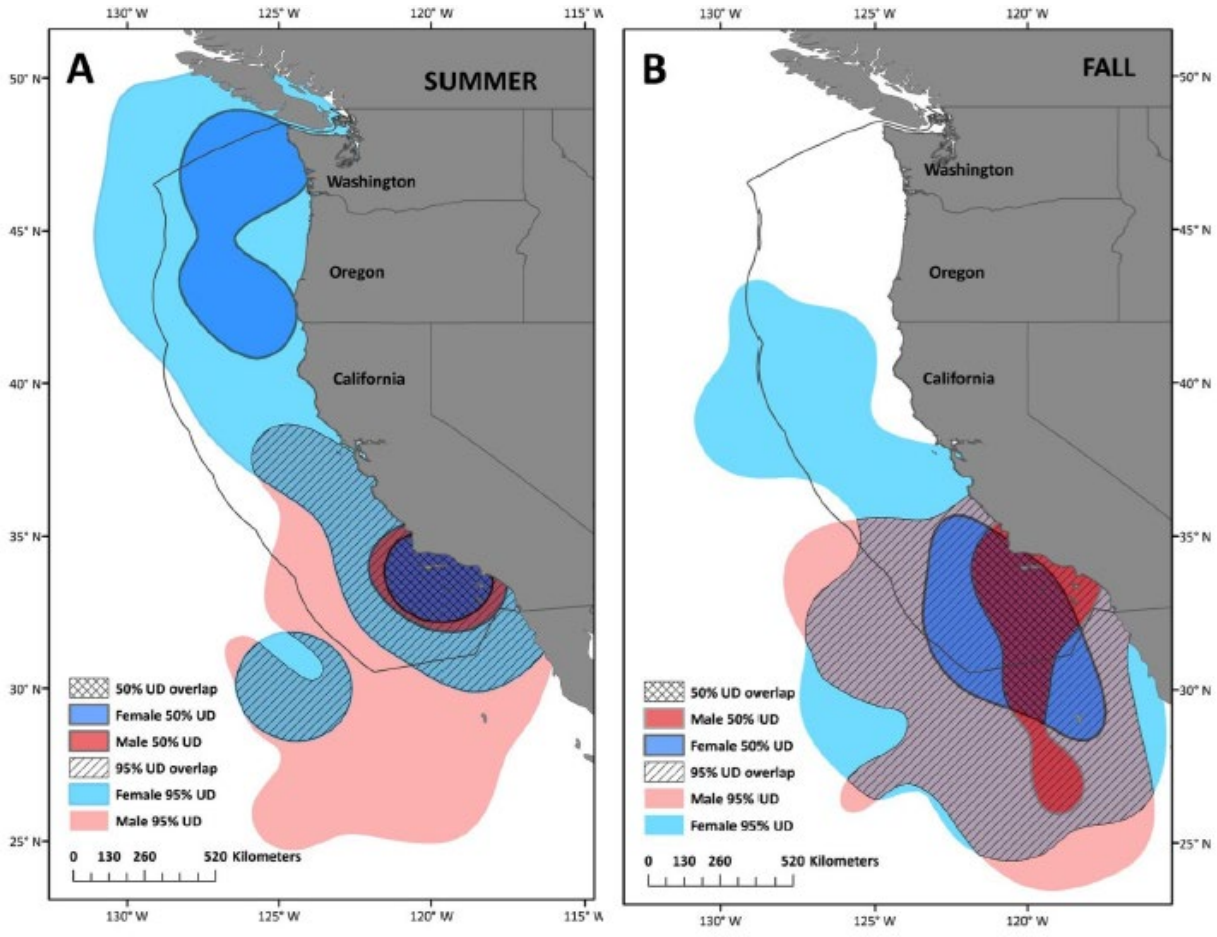

Figure 6. Home range (50 and 95% utilization distributions, UDs) for immature females (blue shades) and mature males (red shades) in the (A) summer and (B) fall. Overlap of 50 and 95% UDs indicated via hatching. The solid black line indicates the U.S. Exclusive Economic Zone.

Age Validation Studies

Researchers are estimating the age and growth of mako, common thresher, and blue sharks 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, scientists occasionally receive sharks that have been injected with OTC from fishers and work is ongoing. A publication on the age validation of common thresher sharks is currently in preparation. In addition, the SWFSC has been leading 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. This reference library formed the basis for the new age at length curve used in the most recent ISC stock assessment for shortfin mako sharks in the Pacific.

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. SWFSC obtains these stomachs 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 and are in the process of being submitted for publication.

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*), five mako sharks had ingested blue sharks, 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 bitten in chunks and 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. Similarly, 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.

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.

Stomach samples collected from the drift gillnet from 2015 through the present are being dissected, contents sorted and identified and data is prepared for future summaries and statistics. New samples collected from deep-set buoy gear are also being processed.

Spiral valve parasites of blue and thresher sharks as indicators of shark feeding behavior and ecology

As an addition to classic diet analyses, this study is a preliminary attempt to analyze the parasite faunas of blue and thresher sharks caught in the California Current Large Marine Ecosystem (CCLME) north of the Mexican border, with the ultimate objective of investigating possible links between parasites, shark diet and the environment. The spiral valves of 18 blue and 19 thresher sharks caught in the CCLME from 2009 and 2013 were examined for parasites. Seven parasite taxa were found in blue sharks and nine in threshers. The tetraphyllidean cestode *Anthobothrium caseyi* (78% prevalence) was the most common parasite of blue sharks and the phyllobothriid cestode *Paraorygmatobothrium* sp. (90% prevalence) was the most common in threshers. A nematode of the genus *Piscicapillaria* found in threshers may be a new species. The adult form of the nematode *Hysterothylacium incurvum* – a parasite specific to swordfish – was found in both shark species, indicating predation on swordfish, probably via feeding on juvenile swordfish or on

discards from fisheries. The adult acanthocephalan *Rhadinorhynchus cololabis* and remains of the parasitic copepod *Pennella* sp. – both specific to Pacific saury, *Cololabis saira* – were found in the intestines of threshers, indicating recent feeding on saury. This study paves the way for a wider one including more samples and more shark species with a view to providing a greater understanding of shark feeding behavior, migrations and stock structure. This study is under internal review and will be submitted to *Fisheries Research.*

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. In the spring of 2018, SWFSC collected seven common thresher sharks in collaboration with local fishers, five females and two males. Four of the females under 200 cm FL were immature while a 234 cm FL female was pregnant with four pups ranging in length between 68 and 71 cm FL (**Figure 7**). The stomachs of the pups were distended and filled with yolk. Until the analyses of age at first reproduction is complete, the stock assessment is being run with life history parameters derived in the Atlantic Ocean.

Figure 7. Picture shows the four pups and distended uterus from a large female common thresher shark caught off Oceanside California in May of 2018.

VI. IDCPA RESEARCH

The SWFSC research conducted under the International Dolphin Conservation Program Act (IDCPA) during 2018-19 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, abundance estimation methods, behavior, and life history, (3) identify critical habitat for large whales, and (4) advance our understanding of ecosystem structure and function.

(1) Evaluating the Use of Tuna Vessel Observer Data in Assessments

Variability of Dolphin Distribution Based on Tuna-Vessel Observer Data

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. Researchers 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. Research vessel sightings validated the predictions based on tuna vessel observer data. A paper is in revision for the Journal of Cetacean Research and Management.

(2) Clarifying Cetacean Population Structure, Abundance Estimation Methods, Behavior, 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 Matthew Leslie, a former graduate student at Scripps Institution of Oceanography, working with 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. This work was published in the scientific journal Marine Mammal Science (Leslie et al., 2018).

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. We 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 has been published in the journal Royal Society Open Science (Leslie and Morin, 2018).

Phylogeographic and Population Genetic Analyses of Toothed 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. Research has 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 currently in revision for publication in the journal *Molecular Ecology*.

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 (Morin et al., 2018). 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.

False killer whales (*Pseudorca crassidens*) are a highly social delphinid distributed throughout the offshore waters of the tropical and temperate oceans. Previous genetic analyses led by Karen Martien (SWFSC) revealed that the main Hawaiian Islands resident population of false killer whales is genetically isolated from the adjacent offshore population, which extends from the ETP to the western Pacific. Furthermore, samples from the western north Atlantic Ocean exhibited possible species- or subspecies-level differences from Pacific Ocean samples. We further examining patterns of differentiation within the species using full mitogenomes and SNP genotypes from an expanded global sample set. There is a high probability that the data will suggest a taxonomic revision is necessary, with separate species or subspecies in the Atlantic versus Indo-Pacific Oceans. Results will also provide further clarity on the evolutionary distinctness of the main Hawaiian Islands (MHI) insular population, which is currently listed as an Endangered DPS under the ESA. Researchers will use the data to estimate divergence times between the MHI insular population, Northwest Hawaiian islands insular population, and offshore population (which includes the ETP).

Taxonomy of Long- and Short-beaked Common Dolphins

Tom Jefferson and Eric Archer are collaborating on a morphometric and genetic re-analysis of long and short beaked common dolphins (*Delphinus* sp.) in the eastern Pacific. The project compares a suite of skull measurements and mitochondrial DNA sequences to establish a foundation to re-describe the long-beaked common dolphin, previously referred to as *D. capensis,* and now regarded as a subspecies within *D. delphis* as a separate species, *D. bairdii*.

Cranial Variation of Bottlenose dolphins

Eric Archer is collaborating with Ana Costa of the University of Glasgow on a morphometric study of bottlenose dolphin skulls from the western Pacific, eastern tropical Pacific, and California Current. This study will help inform a much-needed taxonomic revision of this wide-ranging species.

Group Size Estimation

Estimating dolphin group size is a challenging task. To assess the accuracy and precision of dolphin group size estimates, researchers compared observer estimates to counts from large-format vertical aerial photographs. During 11 research cruises, 2,435 size estimates of 434 groups were made by 59 observers. Researchers modeled observer estimates as a function of the photo count in a hierarchical Bayesian framework. Accuracy varied widely among observers, and somewhat less widely among dolphin species. Most observers tended to underestimate, and the tendency increased with group size. Groups of 25, 50, 100, and 500 were underestimated by <1%, 16%, 27%, and 47%, respectively, on average. Precision of group size estimates was low, and estimates were highly variable among observers for the same group. Predicted true group size, given an observer estimate, was larger than the observer estimate for groups of more than about 25 dolphins. Predicted group size had low precision, with coefficients of variation ranging from 0.7 to 1.9.

Studies that depend on group size estimates will be improved if the tendency to underestimate group size and the high uncertainty of group size estimates are included in the analysis. This research has been published in Marine Mammal Science (Gerrodette et al., 2018).

Using Passive Acoustics to Estimate the Fraction of Dolphins Missed by Visual Observers

Estimation of cetacean abundance often relies on shipboard visual line-transect surveys, where it is assumed that all animals on the trackline are detected. Mark-Recapture Distance Sampling (MRDS) may be used to identify the fraction of animals detected on the trackline when it is suspected that animals may have been missed. MRDS typically employs a secondary visual observation team for data on species that are known to be difficult to detect using visual observation methods, such as deep-diving species or those with cryptic surfacing behavior. Here researchers examine the potential use of passive acoustic detection as a secondary platform for MRDS of rough-toothed dolphins (*Steno bredanensis)* during a combined visual and acoustic shipboard line-transect cetacean survey in the Eastern Tropical Pacific Ocean (ETP). The emphasis of this study is on future research needs and method development, to inform future best practices in the ETP and elsewhere, rather than providing reliable results estimates of trackline detection probabilities $p(0)$ that can be used for population estimates of *S. bredanensis*. This research is being prepared for submission to the peer-reviewed journal *Methods in Ecology and Evolution*.

Behavior

Sarah Mesnick completed a review of the social ecology of dolphin communities in the eastern tropical Pacific with a focus on spotted and spinner dolphins. The review covered broad aspects of the social lives of dolphins and the environmental factors, including oceanographic patterns, distribution of prey, and risk of predation that shape behavior. The chapter also considered the impacts of the tuna purse seine fishery on the lives of the affected dolphins and discussed likely effects on behavior, learning, social bonds and population dynamics. The research mined the long time series of life history data on ETP dolphins and relied heavily upon published and unpublished data and reports from the SWFSC, IATTC and University of California researchers. The review will be published in an upcoming book on the behavioral ecology of odontocetes (Ed. by B. Würsig) and aims to increase our understanding of how behavioral and social factors may help determine a species ability to recover from depletion caused by human activities.

(3) 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 published (Fiedler et al., 2018). 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.

(4) 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 three 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 2019.

Cetacean community patterns

Lisa Ballance, Robert Pitman, Paul Fiedler, and 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
Jessica Redfern and 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.

Seabird abundance and trends
Trevor Joyce, Robert Pitman, and Lisa Ballance are collaborating to develop updated model-based estimates of abundance for two endangered, endemic Hawaiian seabirds, the Newell's Shearwater (*Puffinus newelli*) and the Hawaiian Petrel (*Pterodroma sandwichensis*). This research is based on seabird strip transect survey data that was collected aboard NOAA research cruises in the Central and Eastern Tropical Pacific from 1998 to 2017. Dr. Joyce presented revised estimates employing a zero-inflated negative binomial (ZINB) generalized additive model (GAM) framework at the most recent Pacific Seabird Group meeting (February 2019), and will submit a revised manuscript based on these results later in 2019.

Seabird distribution and habitat relationships
Trevor Joyce, Robert Pitman, and Lisa Ballance are collaborating to develop an atlas of seabird distribution patterns in the Central and Eastern Tropical Pacific based on NOAA research cruises from 1988 to 2017. This data has been synthesized into standardized map outputs and will be developed as a NOAA Technical Memorandum or monograph manuscript in the coming year(s).

VII. PUBLICATIONS CITED

Carvalho, F. 2017. Standardized Catch Rates of Shortfin Mako Shark (Isurus oxyrinchus) caught by the Hawaii-based Pelagic Longline Fleet (1995-2016). Book ISC/17/SHARKWG-1/10

Fiedler, P. C., and N. J. Mantua. 2017. How are warm and cool years in the California Current related to ENSO? J Geophys Res, Oceans 122.doi:10.1002/2017JC013094.

Fiedler, P. C., et al. 2018. Prediction of large whale distributions: A comparison of presence–absence and presence-only modeling techniques. Front Mar Sci 5:419. doi: 10.3389/fmars.2018.00419

Gerrodette, T., W.L. Perryman, and C.S. Oedekoven. 2018. Accuracy and precision of dolphin group size estimates. Mar Mammal Sc DOI:10.1111/mms.12506

ISC. 2018. Stock Assessment of Shortfin Mako Shark in the North Pacific Ocean through 2016. Book ISC/18/ANNEX/15

Kanaiwa, M., Y. Semba, and M. Kai. 2017. Stock Abundance Indices for Mako Shark estimated by observer data of Japanese longline data in the North Pacific Ocean. Book ISC/17/SHARKWG-1/06

Kellar, N. M.et al. 2013. Are there biases in biopsy sampling? Potential drivers of sex ratio in projectile biopsy samples from two small delphinids. Mar Mammal Sci 29:E366-E389.

Kellar, N. M., et al. 2014. From progesterone in biopsies to estimates of pregnancy rates: large scale reproductive patterns of two sympatric species of common dolphin, Delphinus spp. off California, USA, and Baja, Mexico. Bulletin of the Southern California Academy of Sciences, 113:58-80.

Kinney, M.J., F. Carvalho., and S. Teo. 2018. Preliminary results of redefining of Hawaiian longline fisheries with spatiotemporal consideration of BSH size data. Book ISC/18/SHARKWG-3/02

Kinney M.J., F. Carvalho, and S. Teo. 2017. Length composition and catch of shortfin mako sharks in U.S. commercial and recreational fisheries in the North Pacific Ocean. Book ISC/17/SHARKWG-1/04

Lee, H.H., K.R. Piner, M.N. Maunder, and H. Fukuda. In review. Evaluation of fishery dependent recruitment indices using the age-structured production model diagnostic and randomization test: An example using Pacific bluefin tuna.

Lee, H.H., K.R. Piner, M.N. Maunder, and H. Fukuda. In revision. Evaluation of reliability of recruitment estimates from age-0 fishery index using integrated model and production relationship. Fisheries Sci.

Leslie, M.S. and Morin, P.A., 2016. Using Genome-Wide SNPs to Detect Structure in High-Diversity and Low-Divergence Populations of Severely Impacted Eastern Tropical Pacific Spinner (*Stenella longirostris*) And Pantropical Spotted Dolphins (*S. attenuata*). Front Mar Sci 3, 253.

Leslie, M.S. and Morin, P.A., 2018. Structure and phylogeography of two tropical predators, spinner (*Stenella longirostris*) and pantropical spotted (*S. attenuata*) dolphins, from SNP data. Royal Society Open Science 5, 171615.

Leslie, M.S., Archer, E.I., and Morin, P.A., 2018. Mitogenomic differentiation in spinner (*Stenella*

longirostris) and pantropical spotted dolphins (*S. attenuata*) from the eastern tropical Pacific Ocean. Mar Mammal Sci (early online; DOI 10.1111/mms.12545).

Mesnick, S. In review. Chapter 9. Oceanic Dolphin Societies: Diversity, Complexity, and Conservation. In B. Würsig, Ethology and Behavioral Ecology of Toothed Whales and Dolphins. Switzerland: Springer International Publishing AG.

Morin, P.A., et al. 2018. Demography or selection on linked cultural traits or genes? Investigating the driver of low mtDNA diversity in the sperm whale using complementary mitochondrial and nuclear genome analyses. Mol Eco 27, 2604-2619.

Nakano, H. and M. Seki. 2003. Synopsis of biological data on the blue shark, Prionace glauca Linnaeus. Bulletin-Fisheries Research Agency Japan, 18-55.

Redfern, J.V., et al.e 2017 Predicting cetacean distributions in data-poor marine ecosystems. Divers Distrib, 23, 394-408.

Van Cise, A., et al. 2016. Redrawing the map: mtDNA provides new insights into the distribution and diversity of short-finned pilot whales in the Pacific Ocean. Mar Mammal Sci 32, 1177-1199.

Vandeperre, F., at al. 2014a. Movements of blue sharks (Prionace glauca) across their life history. PLoS One, 9, e103538.

VIII. SWFSC PUBLICATIONS

Published

Boyra, G., et al.2018. Target strength of skipjack tuna (*Katsuwanus pelamis*) associated with fish aggregating devices (FADs). Ices J Mar Sci 75(5):1790-1802.

Brodie, S., et al. 2018. Integrating dynamic subsurface habitat metrics into species distribution models. Front Mar Sci 5, p. 219.

Carlisle, A., et al. (Submitted) Cold Seas, Warm Sharks: Thermal Constraints, Ontogeny, and Migration in Endothermic Sharks. PLOS1.

Crone, P., M.N. Maunder, H.H. Lee, and K.R. Piner. 2019. Good practices for including environmental data to inform spawner-recruit dynamics in integrated stock assessments: small pelagic species case study. Fish Res. DOI: https://doi.org/10.1016/j.fishres.2018.12.026

Carvalho, F., Lee, H.H., K.R. Piner, M. Kapur, and S. Clarke. 2018. Can the status of pelagic shark populations be determined using simple fishery indicators? Biol Conserv. 228: 195-204. DOI: https://doi.org/10.1016/j.biocon.2018.09.034

Dewar, H., et al. 2018. Basking Shark (Cetorhinus maximus) Movements in the Eastern North Pacific Determined Using Satellite Telemetry. Front Mar Sci 5:163. DOI: 10.3389/fmars.2018.00163

Farchadi, N., M.G. Hinton, A.R. Thompson, and Z-Y. Yin, 2018. Habitat Preferences of Blue Marlin (*Makaira nigricans*) and Black Marlin (*Istiompax indica*) in the Eastern Pacific Ocean. Thesis. 32. https://doi.org/10.22371/02.2018.016

Harrison, A., et al. 2018. The political biogeography of migratory marine predators. Nature Ecology and Evolution. https://doi.org/10.1038/s41559-018-0646-8

Hazen, E., et al. 2018. A dynamic ocean management tool to reduce bycatch and support sustainable fisheries. Science advances 4(5), p.eaar3001. DOI: 10.1126/sciadv.aar3001

Huveneers, C. et al. 2018. Future research directions on the 'elusive' white shark. Front Mar Sci 17. https://doi.org/10.3389/fmars.2018.00455

Kapur M, Yau A. 2018. Size compositions and sex ratios of oceanic whitetip sharks and giant manta rays for longline fisheries in the Pacific Islands region. Pacific Islands Fisheries Science Center, PIFSC Data Report, DR-18-012, 22 p. https://doi.org/10.25923/67hf-bn93.

Kwan, G.T., J.B. Wexler, N.C. Wegner, M. Tresguerres. 2019. Ontogenetic changes in cutaneous and branchial ionocytes and morphology in yellowfin tuna (*Thunnus albacares)* larvae. J Comp Physiol B. (1):81-95. doi: 10.1007/s00360-018-1187-9.

Landry, M.R., Beckley, L.E., Muhling, B. 2018. Climate sensitivities and uncertainties in food-web pathways supporting larval bluefin tuna in subtropical oligotrophic oceans. Ices J Mar Sci Volume 76, Issue 2. 10.1093/icesjms/fsy184.

Lee, H.H., K.R. Piner, I.G. Taylor and T. Kitakado (2019) On the use of conditional age at length data as a likelihood component in integrated population dynamics models. Fish. Res. (216) 204-211.

Lyons, K., et al. (Accepted). Ontogenetic changes in organochlorine contaminants in blue, mako and thresher sharks. Ecological Applications.

Lyons, K., et al. (Submitted). Using contaminants as a tool for examining niche partitioning in pelagic sharks. Ecological Applications.

Madigan, D.J., O. Snodgrass, N. Fisher. 2018. From migrants to mossbacks: tracer- and tag-inferred habitat shifts in the California yellowtail Seriola dorsalis. Mar Ecol Prog Ser 597. DOI: 10.3354/meps12593

Madigan, D.J., et al.2018. Mercury stable isotopes reveal influence of foraging depth on mercury concentrations and growth in Pacific bluefin tuna. Envir Sci Tech 52(11). DOI: 10.1021/acs.est.7b06429

Mason, J.G., E.L. Hazen, S.J. Bograd, H. Dewar, and L.B. Crowder. 2019. Community-level effects of spatial management in the California Drift Gillnet Fishery. Fish Res 214, pp.175-182.

Maxwell, S., et al. (Accepted). Oceanographic Drivers of Spatial Segregation in Blue Sharks by Sex and Size Class (*Prionace glauca*). Divers Distrib.

Mohan, J.A., et al. 2018. Elements of time and place: Manganese and barium in shark vertebrae reflect age and upwelling histories. P Roy Soc B-Biol Sci. Volume 285, Issue 1890. DOI: 10.1098/rspb.2018.1760

Muhling, B., et al. (Submitted). Dynamic habitat use of albacore and their primary prey species in the California Current System. CalCOFI.

Nasby-Lucas, N., et al. (Submitted) Movements of electronically tagged Shortfin Mako sharks (*Isurus oxyrinchus*) in the eastern North Pacific Ocean Animal Biotelemetry.

Piner, K.R., J. McDaniel, H.H. Lee., K. Hill, and B. Macewicz. 2018. Evaluation of the influence of age and length on Pacific sardine (Sardinops sagax) maturation and characterization of its temporal variability. CalCOFI V59. http://calcofi.org/publications/calcofireports/v59/Vol59-Piner_et_al.pdf

Piner, K.R., H.H. Lee, and L.R. Thomas. 2018. Bias in estimates of growth when selectivity in models includes effects of gear and availability of fish. Fish Bull 116(1): 75-80. http://dx.doi.org/10.7755/FB.116.1.8

Purcell, C.M., A.S. Seetharam, O.E. Snodgrass, S. Ortega-García & J.R. Hyde. 2018. Insights into teleost sex determination from the Seriola dorsalis genome assembly, BMC Genomics 19:31. DOI 10.1186/s12864-017-4403-1

Runcie, R., et al.2018. Environmental associations of Pacific bluefin tuna (*Thunnus orientalis*) catch in the California Current system. Fish Oceanogr. 10.1111/fog.12418.

Schwebel, L., K. Stuart, M.S. Lowery, N. Wegner. 2018. Swim bladder inflation failure affects energy allocation, growth, and feed conversion of California Yellowtail (*Seriola dorsalis*) in aquaculture. Aquaculture, 497. 10.1016/j.aquaculture.2018.07.050.

Underkloffler, K.E., M.A. Sundberg, J.R. Hyde, M.T. Craig. 2018. A taxonomic review of Lampris guttatus (Brunnich, 1788) (Pisces; Lampridae) with descriptions of three new species. Zootaxa. 4413(3):551-565. doi: 10.11646/zootaxa.4413.3.9.

Wegner, N.C., M. Drawbridge, J.R. Hyde. 2018. Reduced swimming and metabolic fitness of aquaculture-reared California Yellowtail (*Seriola dorsalis*) in comparison to wild-caught conspecifics. Aquaculture, 486: 51-56.

Approved by the Science Director

Franck, J.P.C., E. Slight-Simcoe, N.C. Wegner. In Prep. Endothermy in the smalleye opah (Lampris incognitus): a potential role for the uncoupling protein sarcolipin

Lee, H.H., K.R. Piner, I.G. Taylor, and T. Kitakado. In Review. On the use of conditional age at length data as a likelihood component in integrated population dynamics models. Fisheries Research.

Lyons K., D. Kacev, A. Preti, D. Gillett, H. Dewar, S. Kohin: In Press. Contaminant concentrations and signatures in three species of pelagic sharks: influence of ecology and physiology across ontogeny.

Lyons K., D. Kacev, A. Preti, D. Gillett, H. Dewar: Submitted. Organochlorine contaminants as an ecological tool to explore niche partitioning in three species of pelagic sharks. American Naturalist.