Southwest Fisheries Science Center

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

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2020 HIGHLY MIGRATORY SPECIES ANNUAL REPORT

by

The Southwest Fisheries
Science Center

ADMINISTRATIVE REPORT LJ-21-01

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The Southwest Fisheries Science Center

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National Marine Fisheries Service
National Oceanic & Atmospheric Administration
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The United States is obligated to collect U.S. fisheries statistics and participate in advancing fishery science for species of interest. Fishery information feeds into domestic and international fishery management. Scientists at the National Oceanic and Atmospheric Administration Southwest Fisheries Science Center (NOAA SWFSC) have been tasked to fulfill this obligation. This report focuses on work of SWFSC scientists on highly migratory fish species (HMS) and their fisheries. Contributions and activities of the past year, April 1, 2019 – March 31, 2020, are briefly described.

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

Monitoring U.S. HMS Fisheries

Southwest Fisheries Science Center (SWFSC) scientists monitor seven 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 HMS 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 a number of commercial and recreational fisheries that target various HMS. The U.S. Pacific tuna purse-seine fishery, which was historically a large vessel fleet fishing throughout the tropics, has dwindled to a few smaller coastal purse seine vessels that occasionally target tunas in southern California waters. The North Pacific albacore (*Thunnus alalunga*) troll and pole-and-line fishery is the largest HMS fishery based on the West Coast. This fishery began in the 1940s and its fishing grounds have expanded and contracted over decades from southern California and Baja waters to the international dateline, to the southern Pacific Ocean in the austral summer months (creating an entirely new fishery in 1986), and most recently back to the coastal waters off Washington and Oregon. The large-mesh drift gillnet fishery off California targets swordfish (*Xiphias gladius*) and common thresher sharks (*Alopias vulpinus*) off the coast of central and southern California. The California harpoon fishery targets swordfish mostly in the California bight. The longline fishery that targets swordfish and tunas used to be based out of California but most vessels have since relocated to Hawaii. The recreational fisheries that target HMS are composed of private and Commercial Passenger Fishing Vessels that target albacore off of Washington, Oregon, and central California, and albacore, Pacific bluefin (*Thunnus orientalis*, PBF), and yellowfin tunas (*Thunnus albacares*) in southern California and Mexican waters. The hook and line fishery consists of mostly skiffs and smaller vessels that target tunas and in more recent years swordfish in coastal offshore waters mostly using gear similar to the recreational fishery. The total catch in 2018 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	2018 CATCH IN METRIC TONS	NUMBER OF VESSELS
North Pacific Albacore Troll and Pole-and-line	7,728	452
South Pacific Albacore Troll	429	13
Eastern Pacific Ocean Purse Seine	598	46
California Large-mesh Drift Gillnet	204	21
California Harpoon	10	14
Hook and Line	40	100

North Pacific Albacore Troll and Pole-and-line

Total annual catch of albacore from the North Pacific albacore troll and pole-and-line fishery increased 4% from 7,430 t in 2017 to 7,728 t in 2018. The number of vessels decreased from 518 vessels in 2017 to 452 vessels in 2018. The average weight of retained albacore in 2018 was 15 pounds, compared to 18.3 pounds in 2017. Logbook data from this and other HMS fisheries are required to be submitted to SWFSC under the HMS Fishery Management Plan 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 2018 which was the same number as 2017. Total catch of albacore in the 2018 fishery was 598 t, an increase of 8% from the 554 t landed in 2017. No size sampling has been done in this fishery since 2007. In recent years, vessels from this fishery have sold their catches in French Polynesia, Canada, and U.S. west coast ports.

California Large-mesh Drift Gillnet

The California large-mesh drift gillnet fleet increased from 18 vessels in 2017 to 21 vessels in 2018. These vessels landed 148 t of swordfish, 26 t of common thresher, and 30 t of other HMS species in 2018 compared to 179 t of swordfish, 42 t of common thresher, and 19 t of other HMS species caught in 2017. 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 decreased from 25 vessels in 2017 to 14 vessels in 2018. Ten metric tons of swordfish were caught in 2018 compared with twenty-eight metric tons caught in 2017. No

[1] Numbers taken from RFMO submissions made in 2019.

size sampling information is collected from this fishery. The logbook data from this fishery are also managed by FMG staff in cooperation with CDFW.

Longline (California-based)

Deep-set longlining for tuna is permitted under the PFMC FMP for HMS. In 2018, less than three vessels were based in California but several Hawaii-based longline vessels operated out of west coast ports. These Hawaii vessels fished under their Hawaii longline permit. Since 2015, Hawaiian and West Coast longline logbook data have been consolidated and are managed by Pacific Islands Fisheries Science Center (PIFSC).

Recreational HMS Fisheries

Several different fleets of recreational vessels target HMS along the U.S. West Coast. Albacore are targeted by both Commercial Passenger Fishing Vessels and private vessels off the coasts of Washington and Oregon. In recent years, very few albacore have been caught by anglers in Southern California. The recreational catch of albacore by vessels that target albacore off the West Coast increased from 372 t in 2017 to 381 t in 2018. The catch of Pacific bluefin by U.S. recreational anglers increased from 450 t in 2017 to 505 t in 2018.

Hook and Line Fisheries

The hook and line fisheries target primarily tunas in Southern California waters with an emphasis on Pacific bluefin in recent years. The fishery has also begun targeting swordfish using rod and reel style gear in deep waters in the past several years. The hook and line catch increased from 30 t and 30 participating vessels in 2017 to 40 t and 100 vessels in 2018. The catch of Pacific bluefin increased from 18 t in 2017 to 31 t in 2018.

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 93 t of HMS in 2018 compared to 86 t of HMS caught in 2017.

II. SUPPORTING U.S. OBLIGATIONS OF INTERNATIONAL AGREEMENTS

The major customers that require detailed information on U.S. HMS fisheries in the Pacific Ocean include: the South Pacific Tuna Treaty (managed by the Forum Fisheries Agency), the U.S.-Canada Albacore Troll Treaty, the Western and Central Pacific Fisheries Commission (WCPFC), the Inter-American Tropical Tuna Commission (IATTC), and the International Scientific Committee for Tuna and Tuna-like Species in the North Pacific Ocean (ISC). FMG staff compile and summarize a wide variety of fisheries statistics that are grouped by various time and space resolutions for submissions to the Regional Fishery Management Organizations (RFMO) and the Regional Fisheries Organizations (RFO) in order to fulfill the U.S. membership obligations. Statistics range from annual catch and bycatch estimates to size composition of the catches and estimations of fishing effort.

North Pacific Albacore

North Pacific albacore tuna supports the most important HMS commercial fishery on the U.S. West Coast and is an essential stock for recreational fisheries. The ISC Albacore Working Group (ALBWG) performs the stock assessments of this stock of albacore tuna. Scientists from SWFSC/FRD are the lead modelers and vice-Chair of the ALBWG. The primary focus of the ALBWG from 2019 – 2020 was completing an assessment of the stock in early 2020. In addition, the ALBWG continued working on the second round of management strategy evaluation (MSE) for this stock, which is due to be completed in 2021.

In preparation for the stock assessment, the ALBWG conducted a workshop in Shizuoka, Japan, from November 12 – 18, 2019. The primary objective of this workshop was to prepare data and diagnose potential problems before the assessment. SWFSC/FRD scientists prepared two documents for the workshop that documented U.S. data preparation for the longline and surface fisheries. The ALBWG had planned for an assessment workshop in La Jolla, California, U.S.A., March 16 – 23, 2020. However, the COVID-19 situation led to the ALBWG changing the workshop to a web meeting from April 5 – 14, 2020, and April 20, 2020 (PDT). SWFSC/FRD scientists prepared four documents for the workshop on: 1) progress of the MSE; 2) review of the current age and growth of north Pacific albacore; 3) potential biological sampling plans to improve the age and growth of albacore; and 4) preliminary model development for the assessment.

Despite the difficulties of conducting an assessment through an online meeting, the assessment workshop was successfully concluded. The ISC Plenary will review the assessment in July and, if approved, will forward the assessment results to the Northern Committee of the WCPFC. Subject to approval of the ISC Chair, the ALBWG will also present preliminary results of the assessment to the Scientific Advisory Committee of the IATTC at a date to be determined.

After the completion of the stock assessment in 2020, the ALBWG will turn its attention towards the second round of MSE for this stock. The ALBWG is planning to hold web meetings later in 2020 on the progress on the MSE and review the MSE results. Subsequently, the ALBWG is planning to hold a workshop for managers, stakeholders, and scientists in February or March 2021. The primary objectives of that MSE workshop will be to (1) examine the preliminary results of the second round of MSE with managers and stakeholders; (2) collate feedback from managers and stakeholders; and (3) develop recommendations for the WCPFC NC and IATTC.

Pacific Bluefin Tuna

Pacific Bluefin tuna (PBF) supported an important commercial fishery for HMS on the U.S. West Coast between the 1950s and 1990s. In the past decade, however, the primary U.S. fishery targeting this species has been the U.S. sport fishery, including both private boaters and publicly chartered Commercial Passenger Fishing Vessels operating in U.S. and Mexican waters. There remains an important commercial fishery for PBF in Mexican waters.

In November 2019, a data preparation meeting of the ISC Pacific Bluefin Tuna Working Group (PBFWG) was held in La Jolla, California, U.S.A., to prepare biological and fishery data (catch, catch-per-unit of effort [CPUE], and size compositions data) and review projection methodology for the 2020 PBF stock assessment. The benchmark stock assessment and stock projections were then completed in the March 2020 meeting. Participants included scientists from SWFSC, Inter-American Tropical Tuna and Commission (IATTC), Taiwan, Japan, Korea, and Mexico.

Population dynamics were estimated in the 2020 benchmark stock assessment using a fully integrated length-based and age-structured model (Stock Synthesis v3.30) fitted to catch, unseen kills, size compositions, and CPUE data from 1952 to 2019 (the fishing year 1952-2018), provided by ISC PBFWG members and non-ISC countries. The 2020 structure generally remains the same as the 2018 assessment. Life history parameters included a length-at-age relationship from otolith-derived ages, natural mortality estimates from a tag-recapture study and empirical-life history methods, and maturity at age. A total of 25 fleets were defined in the stock assessment model based on country/gear/season/region/size stratification. Quarterly observations of catch, unseen kills, and size compositions, when available, were used to describe the removal processes. Annual estimates of standardized CPUE from the Japanese distant water, offshore, and coastal longline fisheries, the Taiwanese longline fishery, and the Japanese troll fishery were used as measures of the relative abundance of the population. The assessment model was fitted to these input data in a likelihood-based statistical framework. Maximum likelihood estimates of model parameters, derived quantities, and associated variances were used to characterize stock status. Simulation-based stock projections requested by the Northern Committee of the Western Center Pacific Fisheries Commission (WCPFC) and IATTC were completed. Various diagnoses of the assessment model and sensitivity analyses were conducted.

The results of the stock assessment and stock projections are subject to endorsement by the ISC Plenary meeting in July 2020. The assessment will then be forwarded to the IATTC-WCPFC NC Joint Working Group meeting and WCPFC Northern Committee.

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. There were no assessments conducted in 2019, the main focus was on preparations for the upcoming assessment of blue sharks (*Prionace glauca*) in 2020. This included a Webinar to review the assessment schedule in November and a data prep meeting in Shimizu Japan in December. At the time this was prepared there was no report available on either meeting.

III. SUPPORTING PACIFIC FISHERY MANAGEMENT COUNCIL ACTIVITIES

FRD economist Dr. Stephen Stohs continued serving as co-chair of the HMS Management Team (HMSMT) of the Pacific Fishery Management Council (Council) over the past year. The HMSMT met several times in 2019 and early 2020 to review fishery information, complete assignments from the Council, and evaluate provisions of the Fishery Management Plan for U.S. West Coast Fisheries for HMS. The main issues facing the HMSMT and the Council over the past year have been: (1) continuing to aid the Council with approving exempted fishing permit operations to test alternative methods of targeting swordfish; (2) developing drift gillnet fishery performance metrics for finfish species; (3) authorizing a deep-set buoy gear fishery for swordfish off the West Coast (final Council action to authorize this fishing method was taken in September 2019); (4) scoping an amendment authorizing the use of shallow-set longline gear to target swordfish outside of the west coast exclusive economic zone; (5) scoping a review of essential fish habitat for HMS fisheries; (6) providing recommendations for international management activities; and (7) preparing the 2019 Stock Assessment and Fishery Evaluation (SAFE) Report.

IV. ADVANCING RESEARCH ON TUNAS, BILLFISH, AND OPAH

SWFSC scientists have a long history of conducting research on tunas and tuna-like species in the Pacific Ocean including but not limited to Pacific bluefin, yellowfin tuna, albacore, swordfish and opah (*Lampris sp.)*. Studies use a range of methods and quantitative approaches to 1) examine movements and behaviors and associated environmental drivers, 2) characterize their position in marine food webs and 3) fill life history data gaps to improve stock assessments and support management. This information is provided to international, national, and regional fisheries conservation and management bodies having stewardship for tuna and tuna-like species. Described here are studies that have been recently completed or are ongoing. Many of these studies are collaborative and involve stakeholders and 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 2018, 25,004 fish averaging 67.5 cm fork length (FL) were measured at various west coast ports.

HMS Logbook Form Redesign

In 2018, the HMS fishery monitoring group created the new HMS logbook paper forms for all the west coast HMS fisheries (Pacific Albacore Troll fishery, Surface Hook and Line Fishery, Harpoon fishery, Gillnet fishery and Deep-set buoy fishery). Currently, these newly designed logbook form has been distributed to the fishery permit holders through NOAA WCRO.

Newly Developed HMS Data Entry Web Application Project.

The HMS fishery monitoring group developed a modernized oracle apex HMS logbook data entry and data report web application, the application has been not only used by SWFSC HMS group but also used by PacFIN and West Coast Regional Office staff for logbook data entry, Albacore port sampling program and referenced by logbook non-compliance PacFIN report.

Photo Identification Guide of U.S. West Coast Tunas

The Life History Program of the SWFSC FRD created a photographic identification guide for recreational anglers, the general public, and citizen scientists interested in the basic visual identification of tuna species encountered off California, Washington, and Oregon. The guide includes information about the U.S. West Coast tuna industry and management and features nine species of *Scombrids* that occur in the region: Pacific bluefin, yellowfin tuna, bigeye tuna (*Thunnus obesus*), albacore tuna, skipjack tuna (*Katsuwonus pelamis*), black skipjack tuna (*Euthynnus lineatus*), bullet tuna (*Auxis rochei*), frigate tuna (*Auxis thazard*), and Pacific bonito (*Sarda chiliensis*). For each species, the guide highlights other common names in multiple languages and provides information on size and reproduction, habitat, diet, fishing, and U.S. West Coast seasonal range (see example page below). Key visual diagnostic features are identified on high resolution images of tuna. Tuna Species of the U.S. West Coast: A Photographic Identification Guide is currently published online and will be printed in full-color and free for public distribution.

Heberer, L. N., Dewar, H., Snodgrass, O. E., & Itano, D. G. (2019). Tuna Species of the US West Coast: A Photographic Identification Guide. U.S. Department of Commerce, NOAA Technical Memorandum NMFS-SWFSC-624.

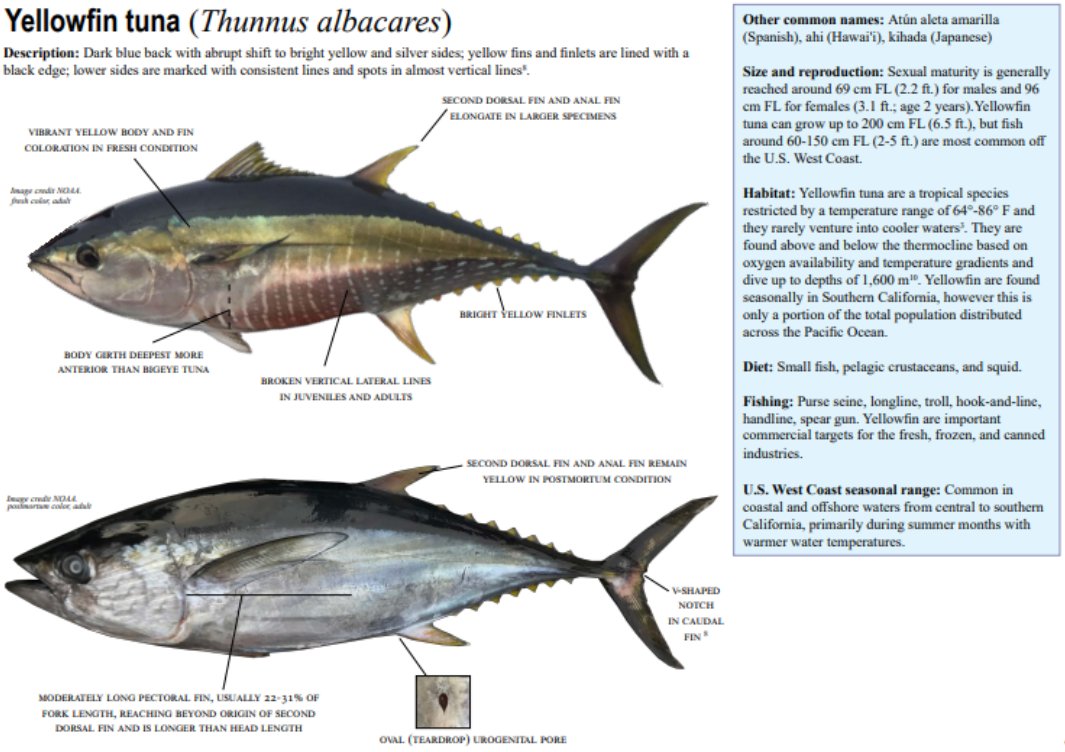

Figure 1: Fresh and postmortem identifying features of yellowfin tuna (*Thunnus albacares)*

Updated Size Composition Data from the Recreational Fishing Fleet

Introduction/Background

Pacific bluefin (PBF) are landed in both U.S. commercial and recreational fisheries in the Eastern Pacific Ocean. Currently, the vast majority of Pacific bluefin catch in the U.S. is landed from recreational fisheries, including both private boaters and publicly chartered Commercial Passenger Fishing Vessels. Together, these operations comprise Fleet 15, the Eastern Pacific Ocean Sport Fishery, included in the ISC stock assessment. The size composition data collected by the National Oceanic and Atmospheric Administration (NOAA) Pacific Bluefin Tuna Port Sampling Program is considered the best available data to represent the Pacific bluefin caught by Fleet 15. Due to inconsistent sampling prior to 2014 and a short time series after 2014, the size composition data for Fleet 15 have not been used to inform the fleet selectivity in previous stock assessments. The goal of this paper was to present to the WG both the methods of data collection and the time series of data collected since 2014 for potential inclusion into the stock assessment.

Methods

Total number of PBF kept by month and year was calculated as the sum of the PBF caught by California CPFV logbooks and private fleets between February 2014 and December 2018. This data comes from the California state logbooks and CRFS (CA Recreational Fisheries Survey). Length data for PBF caught by the CPFV fleets based out of San Diego were sampled between July 2014 and October 2019. A two-stage sampling design (Stage 1: trip, Stage 2: individual fish) was used to randomly sample whole PBF unloaded from short-range (SR; ≤ 3 days duration) and long-range trips (> 3 days duration) from the main sportfishing landings and fish processing facilities in San Diego, CA. Straight fork length (FL) from the closed mouth to the fork in the caudal fin was measured to the nearest millimeter for 40 fish per trip (2014-2015 seasons) or 30 fish per trip (2016-2019 seasons). The fish to be measured were determined by randomly selecting angler numbers from vessels prior to sampling. Trip metadata collected included: vessel name, trip type (SR or LR), trip length (number of days), departure date, return date, total PBF landed on the trip, and total PBF sampled on the trip. Monthly average FL and standard deviation were calculated by month and year. Lengths were binned into 1-cm bins for length frequency distribution and analysis.

Results

A total of 4,593 PBF were measured from 337 trips on 45 unique vessels between July 2014 and October 2019. Size composition data (total PBF sampled/total PBF caught) represented 4.0% of the total reported catch and 40.7% coverage of the possible sampling months over the course of the whole study. Between February 2014 and December 2018, more than 75% of the total PBF reported caught in the recreational fishery were landed in the months of August (30.8% of total catch), July (27.7%), and September (18.1%) (**Figure 2**). The coincident size sampling during this same time period reflected these peaks in monthly catch, indicating that the sampling efforts overlaps the patterns in catch. More than 80% of the PBF measured in this study were sampled in August (40.0% of sampling total), July (23.4%), and September (22.3%) (**Figure 2**). Sampled fork lengths ranged from 46.1 cm to 210.2 cm, with an average of 98.7 ± 26.8 cm FL. The length frequency distribution for the 4,593 PBF sampled from San Diego from 2014-2019 was multimodal, which is expected when sampling a cohort of juveniles spending years foraging and growing in the EPO (**Figure 3**): 68 cm FL (age 1), 92 cm FL (age 2), 122 cm FL (age 3), and two smaller modes of 151 cm FL (age 4) and 173 cm FL (age 5) according to the age-length-weight

relationship derived from the von Bertnalanffy growth curve and length-weight relationship used in the 2018 ISC stock assessment (ISC, 2018).

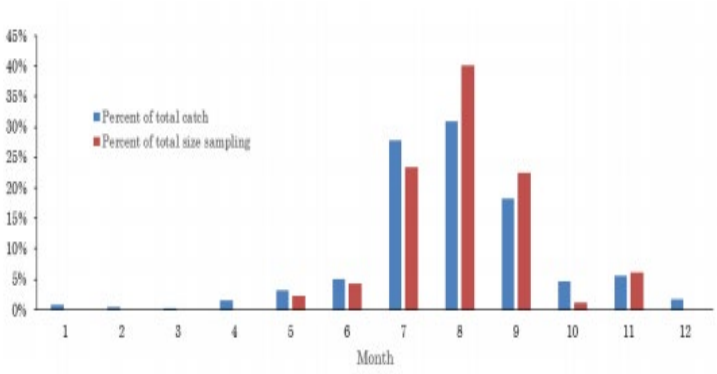

Figure 2. Monthly catch as a percentage of the aggregate 2014-2018 catch and monthly size composition sampling as a percentage of aggregate 2014-2018 size composition sampling.

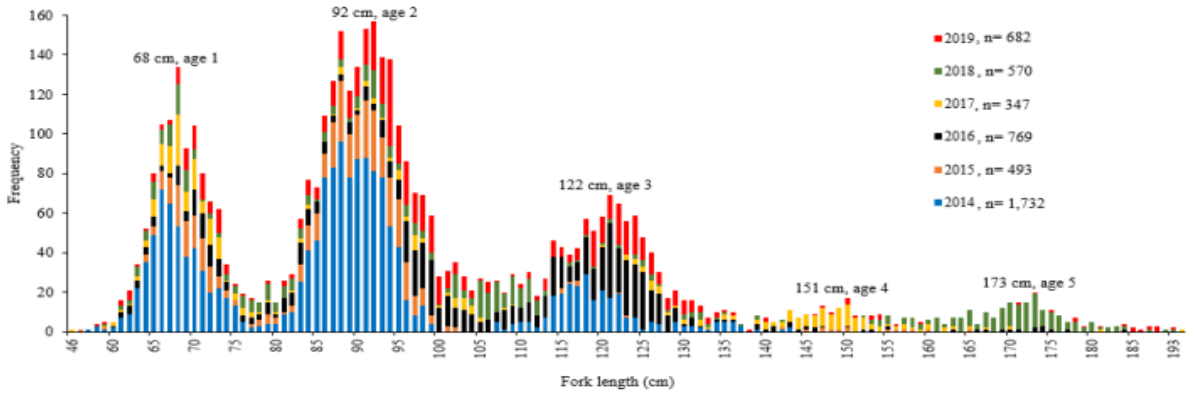

Figure 3. Frequency distribution of the 4,593 PBF lengths measured from July 2014 - October 2019. Estimated ages are indicated above modes.

Discussion/ Significance

Since 2014, the National Oceanic and Atmospheric Administration (NOAA) Pacific Bluefin Tuna Port Sampling Program has measured about 2-6% of PBF kept in California every year. Ages ranged from 1-5 years based on the age-length relationship and size distributions. Increased abundance and larger fish caught in recent years by the recreational fleet result in a mismatch between the selectivity pattern of this fishery and the US commercial fleets. The information collected for Fleet 15 was presented to the PBF working group and subsequently considered for use in the most recent 2020 ISC stock assessment for Pacific bluefin.

Heberer, L. N., & Lee, H. H. (2019). Updated size composition data from the San Diego Commercial Passenger Fishing Vessel (CPFV) recreational fishery for Fleet 15: Eastern Pacific Ocean Sport Fisheries, 2014-2019. ISC/19/PBFWG-2/06.

Natal Origin of Pacific Bluefin Tuna from the California Current Large Marine Ecosystem

Introduction/Background

Pacific bluefin are widely distributed throughout the North Pacific Ocean and western South Pacific Ocean, although the dynamics within this range are not well understood and uncertainties about stock structure continue to complicate fisheries management. PBF is managed under the assumption of a single stock in the Pacific Ocean with two discrete spawning areas in the western Pacific Ocean (WPO): one located around the Philippines north to the Ryukyu Islands (hereafter: East China Sea, ECS) and the second in the Sea of Japan (SoJ). Age-0 PBF remain in waters around Japan, but at age 0.5-2 years, an unknown portion of the fish migrate east across the Pacific Ocean and enter the California Current Large Marine Ecosystem (CCLME), where they remain for several years before returning to the WPO. While the general pattern of these trans-Pacific migrations has been documented, questions remain about the origin of PBF in the CCLME and the contribution rates of recruits from the two spawning areas.

Methods

For this study we used natural chemical tags in PBF otoliths to identify natal origin of individuals after their trans-Pacific migration to the CCLME. First, we examined chemical signatures of multiple cohorts of age-0 PBF from both spawning areas (ECS and SoJ) to obtain yearly baseline chemical signatures. Next, core material of the otolith from subadult PBF in the CCLME was analyzed to estimate the relative contribution of each spawning area. Here, we present the first predictions of the natal origin of PBF in the CCLME using otolith chemistry.

Results

Otoliths from 119 age-0 PBF (ca. 30 per year) collected from 2014-2017 were analyzed to establish baseline signatures for each spawning area. Element:Ca ratios in otolith cores of age-0 PBF significantly differed both between ECS and SoJ spawning areas and among years ($p<0.01$). Significant interactions between spawning area and year highlights the necessity of obtaining element:Ca baselines for age-0 PBF each year from both the ECS and SoJ.

The natal core of age-1 fish (40 per year) collected from CCLME were analyzed for assignment to spawning region matched to age-class. Mixed-stock analysis of age-1 PBF collected in the CCLME indicate that migrants from both the ECS and SoJ recruited into the Eastern Pacific Ocean (**Figure 4**). Contribution rates varied from year to year, with both spawning areas contributing significant numbers of recruits to the CCLME with a minimum value of 20% contribution (**Figure 4**).

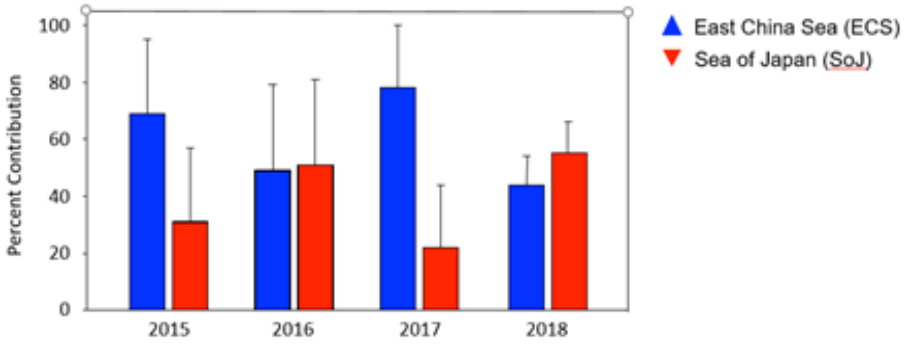

Figure 4. Natal origin contribution estimates (mean ± SD percent contribution) of sub-adult (age-1) Pacific bluefin tuna collected in the California Current Large Marine Ecosystem (CCLME).

Discussion

Results highlight the importance of both the ECS and SoJ spawning areas to the PBF fishery in the CCLME. In the western Pacific, there have been multiple efforts to identify natal origin, all capitalizing on the difference in spawning time between the two spawning areas. These studies have each had their own limitations and have not provided insight into the relative contribution of the spawning ground to the CCLME. Our study provides a four-year assessment sourcing the natal origin of recruits in the Eastern Pacific Ocean using laser ablation with high spatial resolution sampling. Inter-annual variability observed in element:Ca ratios emphasizes the need to have annual baseline samples of age-0 PBF collected from both spawning areas to enable age-class matching. Interestingly, both spawning grounds make a significant contribution to the population of fish in the CCLME, with variability in the relative contribution across years. This insight will improve our ability to examine the environmental forcing mechanisms associated with the westward migrations and recruitment. Results also support the utility of the approach to examine sourcing of PBF and movement dynamics throughout the Pacific Ocean.

Bluefin Tuna Reproduction

Introduction/Background

The only known Pacific bluefin spawning grounds are in the West Pacific in the Sea of Japan and East China Sea. After they are spawned, juvenile bluefin distribute to foraging grounds. For some Pacific bluefin, this involves a ~8000 km migration to the California Current. Typically, bluefin migrate across the Pacific in their first or second year and remain in the California Current for a number of years before returning to the West Pacific. Consequently, the fish landed by eastern Pacific fisheries are typically relatively small (1-3 year old fish). In recent years, however, there has been an overall increase in the average size of catch and landings and fish as old as 10 have been caught based on size estimates. These fish are at a similar age and size to fish found on the spawning grounds, primarily in the Sea of Japan. This observation has led to speculation that bluefin may also be spawning in the California Current. To determine whether bluefin were spawning in the Eastern Pacific Ocean (EPO), the SWFSC initiated a study on the reproductive condition of bluefin.

Materials and Methods

For this study, we collected biological samples including gonads from locally caught bluefin over a range of sizes. From each fish, male and female, an approximately 1 cm section from the central portion of the gonad was removed and preserved to allow for histological analyses of the stages of development to determine whether they were mature or immature.

Results and Discussion:

From 2015-2019 a total of 64 PBF gonads were collected from fishers in the Southern California Bight. Of these, 28 were male, ranging in size from 142-183 cm (4-8 years old), and 36 were female ranging in size from 125-188 cm (3-8 years old). Histological analyses of the ovarian tissues revealed that all individuals were immature. The oocytes in the ovaries of 34 of 36 females were classified as unyolked. Ovaries from two females (147 and 157 cm) collected in July of 2015 contained oocytes classified as early-yolked (**Figure 5**). Of the 28 males, 7 were classified as functionally mature due to the presence of milt during sampling, although no evidence for spawning was observed based on the histological analyses and the remaining males were classified as immature. Although a few males contained milt, spawning requires mature, active males and

females. Consequently, based on histological evaluations of ovarian and testicular tissues, there is no evidence that females are spawning in the EPO. This information was presented to the ISC PBF Working Group in La Jolla, CA, in November of 2019 and a corresponding manuscript has been submitted for SWFSC review.

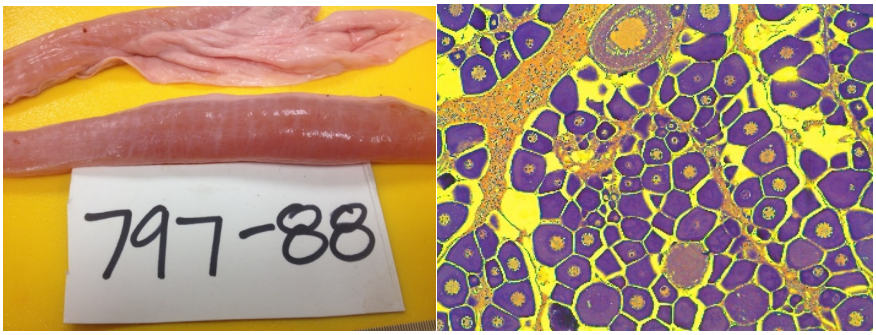

Figure 5. Recently collected ovary prior to processing. Eggs unyolked or in early stages of yolking.

Albacore Tuna Diet and Foraging Ecology in the Northern California Current

Introduction/Background

Albacore tuna are an important commercial and recreational fish species that demonstrates high levels of variability in their abundance and distribution. Currently, the mechanisms leading to this variability, which influences catch and profitability, are poorly understood. One important but not well-characterized driver is likely to be foraging ecology (diets), including offshore of Washington and Oregon on the U.S. West Coast, which is a key feeding ground for juvenile albacore. This study examines albacore diet and foraging ecology over an extended time-period and covering a range of oceanographic conditions. Sampling years include El Niño, La Niña, El Niño neutral, and the anomalous marine heatwave of 2013 - 2016. This relatively long dataset provides the opportunity to examine the influence of oceanography on diets and prey assemblages and how this relates to fisheries landings.

Methods

Juvenile albacore tuna diets were assessed using samples provided by commercial and recreational fishermen offshore of Oregon and Washington. Stomach contents were identified by visual inspection of remains including hard parts, whole bodies, and crustacean eyes. For analysis, stomachs were pooled by year and we calculated the percent numeric abundance (which can overemphasize small, numerous prey like euphausiids over larger prey like fish), percent frequency of occurrence, and a metric combining the two called a geometric index of importance.

Results/Discussion

Juvenile albacore diet appears to be more variable through time than assumed from previous studies. **Figure 6** shows the percent contribution of each prey group to the diet using the geometric index of importance for each year. The major groups are fish in purple, cephalopods in brown, and crustaceans in red. In the early part of the time series, the pacific decadal oscillation was negative, sea surface temperatures were lower, and anchovy dominated the diet. Later, PDO became positive, with warmer temperatures, and euphausiids began to dominate the count. Squid were important in colder years, consistent with recruitment models. Work is continuing on this project, including reconstructing the lengths and weights of digested prey so that the percent weight can

be calculated, which will de-emphasize the smaller euphausiids compared to fish. We are also analyzing more samples to expand the time series to include 2009, 2017, and 2019. These data will then be compared to similar data from Central and Southern California. Future ecosystem models may need to account for these more complex feeding behaviors.

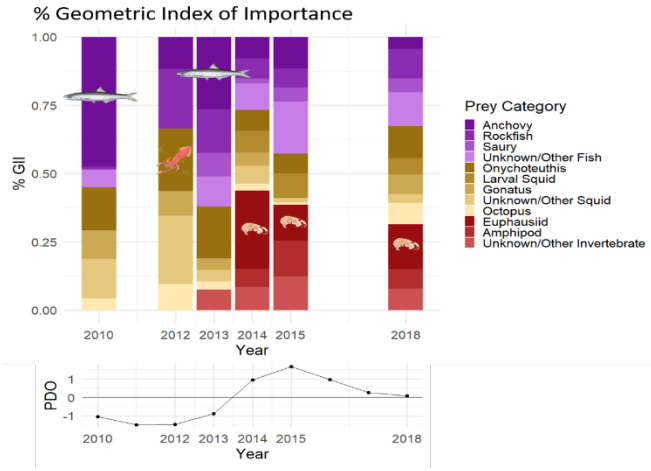

Figure 6. The geometric index of importance of the different prey groups across years. The Pacific Decadal Oscillation is also shown for comparison.

Catherine Nickels presented these results at the Ocean Sciences Meeting on behalf of co-authors Owyn Snodgrass, Heidi Dewar, and Barbara Muhling in February 2020.

Predictability of species distributions deteriorates under novel environmental conditions in the California Current System

Introduction/Background

Spatial distributions of marine fauna are determined by complex interactions between environmental conditions and animal behaviors. As climate change leads to warmer, more acidic, and less oxygenated oceans, species are shifting away from their historical distribution ranges, and these trends are expected to continue into the future. Correlative Species Distribution Models (SDMs) can be used to project future habitat extent for marine species, with many different statistical methods available. However, it is vital to assess how different statistical methods behave under novel environmental conditions before using these models for management advice, and to consider whether future projections based on these techniques are biologically reasonable. This approach is relevant to studies of HMS both because anchovies and sardines are key prey for HMS in the California Current and because SDMs are used to project shifts in the distribution of tuna, billfish and sharks.

Methods

In this study, we built SDMs for adults and larvae of two keystone pelagic fishes in the California Current System: Pacific sardine (*Sardinops sagax*), and northern anchovy (*Engraulis mordax*), using NOAA Fisheries survey data. We used five different SDM methods, ranging from simple (thermal niche model) to complex (artificial neural networks).

Results

Our results show that some SDMs trained on data collected between 2003 and 2013 lost substantial predictive skill when applied to observations from more recent years (2014 – 2018), when ocean temperatures associated with a marine heatwave were outside the range of historical measurements (**Figure 7**). This decrease in skill was particularly apparent for adult sardine, which showed non-stationary relationships between catch locations and sea surface temperature through time. While sardine adults and larvae shifted their distributions markedly during the marine heatwave, anchovy largely maintained their historical spatiotemporal distributions. This was particularly evident for larval anchovy, resulting in the persistence of SDM skill between the two time periods.

Discussion/ Significance

Our results suggest that correlative relationships between species and their environment can become unreliable during anomalous conditions. Understanding the underlying physiology of marine species is therefore essential for the construction of SDMs that are robust to rapidly changing environments. Developing distribution models that offer skillful predictions into the future for species such as sardine and anchovy, which are migratory and include separate sub-stocks, may be particularly challenging. Future work will investigate several methods to improve SDMs, such as the inclusion of non-local or lagged predictors, or the incorporation of information from physiological laboratory studies. These results were presented at the 2019 PICES Annual Meeting in Victoria, BC, and are currently being prepared for publication.

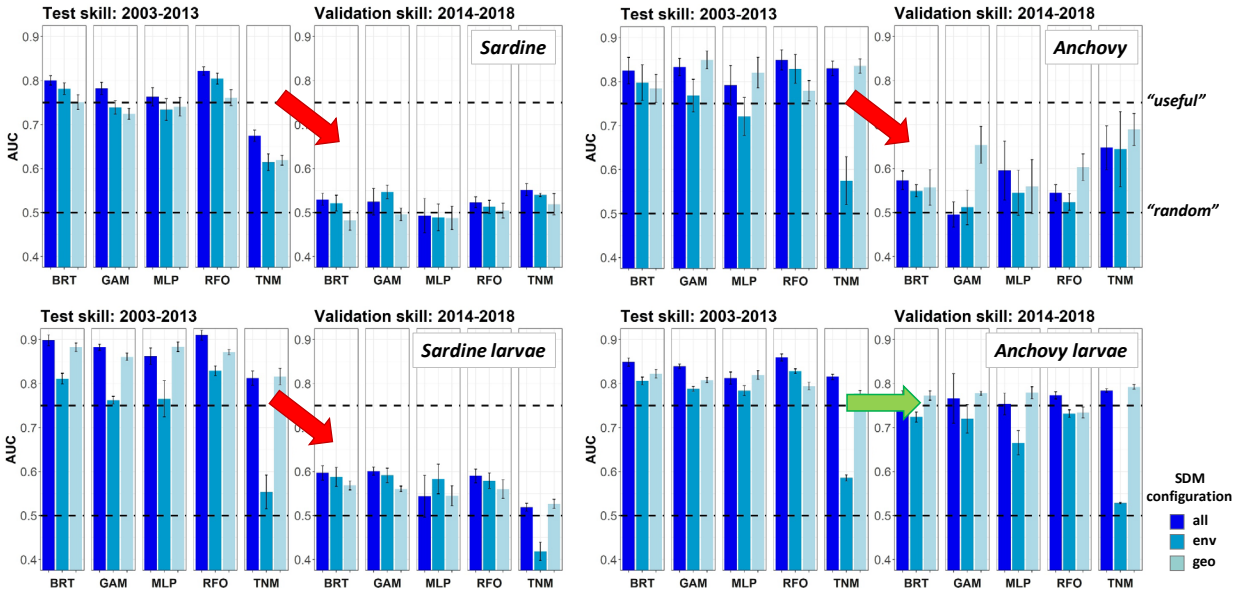

Figure 7. Area under the Receiver Operating Curve (AUC) skill metrics for SDMs trained on near-average years (2003 – 2013), and externally validated on data from 2014 -2018. Means and standard deviations across all SDM ensembles are shown for each life stage of each species. Colors of bars denote the SDM configuration ("all", "env", or "geo"). The SDM type is shown on the x-axis: "GAM" denotes Generalized Additive Models, "BRT" Boosted Regression Trees, "MLP" Multilayer Perceptrons, "RFO" Random Forests, and "TNM" Thermal Niche Models. The horizontal black dashed lines show AUC values of 0.5 (no better than a random model), and 0.75 (a rough approximation of a "useful" model), for reference.

Past and future shifts in the distribution of fisheries for juvenile albacore in the eastern North Pacific Ocean

Introduction/Background

Environmentally-driven shifts in the distributions of managed species can cause problems if stock assessment and management frameworks are not robust to changes in availability among different fleets. Such shifts have implications for transboundary management, and exploitation of shared resources among nations, as well as the future effectiveness of current arrangements between states and countries. These management measures may be increasingly challenged as climate change will continue to result in novel environmental conditions across the North Pacific. North Pacific albacore support the largest commercial fishery for a highly migratory species off the U.S. West Coast. However, coast-wide landings, and areas of highest catch, are strongly variable interannually. This appears to be a result of both variability in local habitat use in the California Current, and variability in migration paths and timing in the broader North Pacific.

Methods

In this study we used fishery-dependent data and archival tag returns to describe how distribution and migration paths of juvenile albacore respond to decadal-scale oceanographic variability in the eastern North Pacific, and how these may continue to change into the future. We used environmental variables from satellite sensors and ocean models to show overall favorable conditions for juvenile albacore, and calculated the Heat Increment of Feeding (HIF) from tagged animals to link potential foraging success to movement and migration patterns.

Results

Albacore habitat was strongly defined by temperature, with catches in the commercial fishery and daily positions of tagged fish associated with surface temperatures of 11 - 21°C (**Figure 8**). Fish migrated westwards in the fall and returned eastwards in the spring, adjusting their latitude based on seasonal movement of isotherms.

Albacore had generally higher mean HIF (and thus higher putative foraging success) in the California Current in summer, and in the offshore North Pacific transition zone in winter. In some years (e.g., 2011-12), albacore moved much further west during winter and spring than in other years. This appeared to be related to poorer feeding success in fall, as fish moved offshore along the transition zone.

Fisheries logbook records extending back to the 1970s showed strong decadal-scale shifts in the distribution of the fishery. Vessels were concentrated onshore in the California Current in the 1970s before moving well offshore in the early 1980s and returning inshore again in the early 2000s. This cycle was found to be correlated with the offshore latitude of the transition zone, but the precise mechanism is not yet clear. Future work modeling the drivers of albacore movements, including switching between migratory and foraging behaviors, may provide more information on these dynamics.

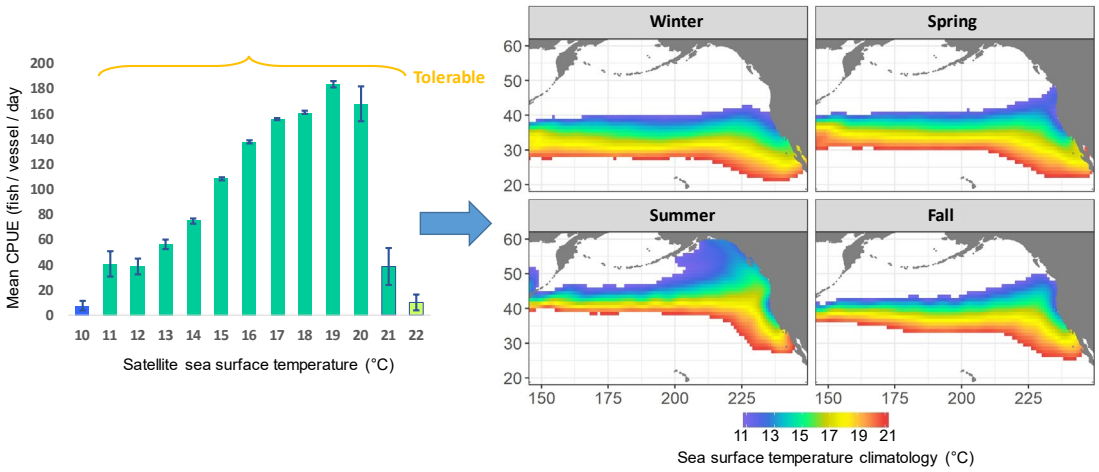

Figure 8. Left: Mean catch per unit effort (fish/vessel/day) in the U.S. surface fishery with satellite sea surface temperature. Right: Climatological distribution of tolerable temperature conditions by season in the central and eastern North Pacific

Discussion/Significance

Latitudinal shifts in favorable fishing areas for the U.S. and Canadian surface fleets in the California Current System have implications for transboundary management and exploitation of a shared resource. In contrast, apparent longitudinal shifts in east-west migration patterns can cause large fluctuations in fishing costs for both fleets. This can limit the utility of albacore as an open access "insurance" fleet, which West Coast fishermen rely on when other species are depleted or subject to closures. Our results have relevance for the prediction of future albacore movements across international boundaries, and for their effective management as climate change continues to result in novel environmental conditions in the North Pacific. These results were presented at 2019 PICES Annual Meeting in Victoria, BC, and 2020 Ocean Sciences Meeting in San Diego, CA, and are being prepared for publication.

Feeding ecology of broadbill swordfish (*Xiphias gladius*) in the California Current

Introduction/Background

Broadbill swordfish are the most widely distributed billfish and occur worldwide in tropical, subtropical and temperate waters from around 50°N to 50°S. Throughout this range they are found primarily in areas where prey are aggregated, including in convergence zones, on sea mounts, and in productive boundary currents. Swordfish command a high economic value in both commercial and recreational fisheries. In the CCLME swordfish is commonly taken by both the U.S.A. and Mexican fisheries by long lines, deepset buoy gear, harpoons and drift gillnets (DGN). While the CCLME is known to be an important foraging ground for swordfish during certain times of year, the feeding habits of swordfish in this region are not well documented. To date, there have been two extensive studies of swordfish feedings habits in the CCLME and a few other reports, though none are recent. The objectives of this study were to analyze the relative importance of different prey types and examine variability across years, regions, and body size.

Methods

Swordfish stomachs were collected by federal fishery observers aboard DGN vessels during years 2007-2014. The distribution of this fishery has shifted due to time area closures and, in recent years, the majority of the fishery has operated in the Southern California Bight (SCB) between Point Conception, California, and the U.S.-Mexico border. Prey were weighed, counted, and identified to the lowest taxonomic group possible. Data analyses included prey accumulation curves and relative indices of importance including the IRI and GII. A number of additional analyses were conducted including redundancy analysis (RDA) and generalized additive modelling (GAM) to examine patterns in prey importance, including the impacts of size, regions, season, and sea surface temperature,

Results

A total of 299 broadbill swordfish stomachs were collected of which 292 stomachs contained prey from 60 different prey taxa. While the cumulative prey curve did not reach an asymptote, the shape of the curve indicates that the vast majority of prey taxa present in the diet of the swordfish were represented in these analyses.

Squid dominated stomach contents and constituted the top six most important prey based on the GII with the Jumbo squid (*Dosidicus gigas*) and boreopacific gonate squid (*Gonatopsis borealis*) ranking first and second, respectively. For fish prey, Pacific hake (*Merluccius productus*) ranked sixth with other fish observed including barracudinas (Paralepididae), coastal pelagic fishes (jack mackerel, Pacific sardine, Pacific saury, northern anchovy), and the Myctophidae family. Some variation in prey composition with swordfish body size was apparent. Northern anchovy was found only in the small size group while luvar (*Luvaris imperialis*) was eaten only by large swordfish. Jumbo squid, *Gonatus* spp., and Pacific hake were significantly more important in larger swordfish than smaller swordfish. Differences in prey composition were also apparent across region and years. **Figure 9** shows a shift in diets which were dominated by squid at the beginning of the times series and fish towards the end. RDA explained only 6% of the variability. GAMs revealed a range of patterns depending on prey species with differing impact of the explanatory variables, size, year, subseason, region, SST, and area**.**

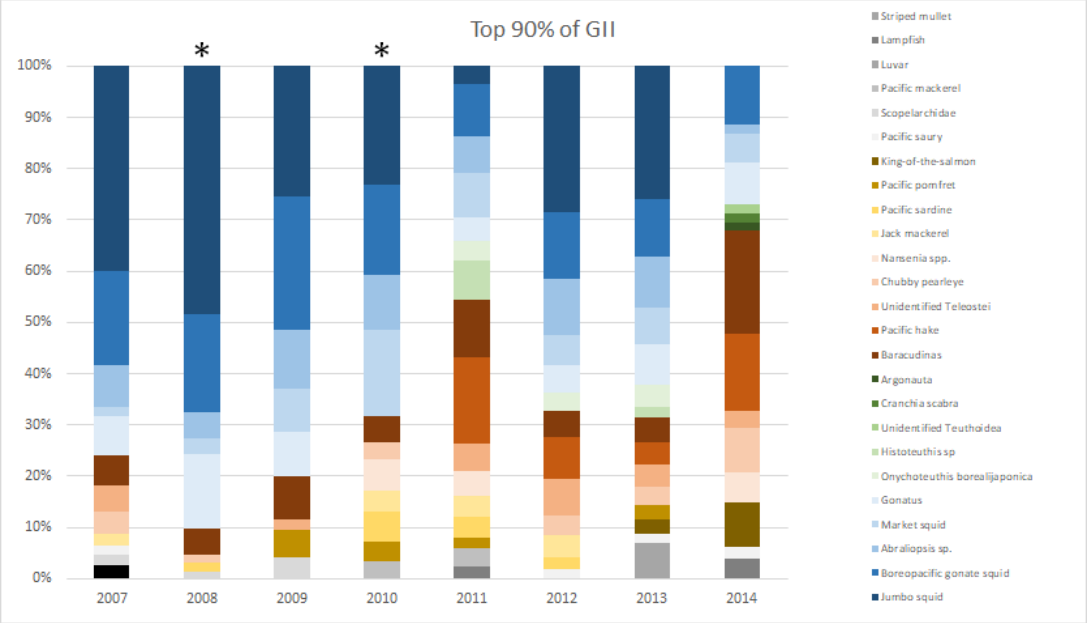

Figure 9. The Geometric Index of Importance (GII) for species groups across the study period. *indicates years with samples sizes 16 or less.

Discussion

Results from this research are consistent with the biology and ecology of swordfish and are in broad agreement with other studies which found they consume cephalopods and epipelagic and mesopelagic teleosts, although the relative importance of fish and teleosts varies across studies. Differences across explanatory variables provide some insight into foraging ecology. While Jumbo squid were the most important prey across size classes, they were significantly more important for larger swordfish indicating that larger fish may be more adept a capturing larger cephalopods. Regional differences in diet likely reflect the distributions of species. For example, Jumbo squid (*Gonatus* spp.) and market squid were significantly more important within the SCB while *Gonatopsis borealis* and Pacific hake were more important beyond the SCB.. The fluctuations across years can, in part, be linked to oceanographically-driven variation in prey availability. The most obvious shift was the transition from 2010 to 2011 from Jumbo squid to Pacific hake being the most important prey item. This reflects the range expansion of Jumbo squid from 2002-2010 during a period when water temperatures were cooler.

Overall there is considerable overlap with other predators in the CCLME. For example, jumbo squid are also important in the diets of mako sharks and squid overall are important in the diets of blue sharks. A key difference is that the mesopelagic teleosts in the diets of swordfish have not been observed in any shark species examined in the SCB. This suggests that swordfish may be foraging in mesopelagic waters more frequently than any of the shark species studied. Future studies would benefit from a larger and more extensive sampling regime and a more detailed examination of the impacts of environment on the distribution of prey. Overall, results indicate that swordfish are generalists that can forage across the water column. Consequently, diet studies could provide a valuable tool for examining shifts in the availability of prey including the mesopelagic realm.

Preti, A. 2020. Trophic ecology of nine top predators in the California Current. Ph.D. Dissertation. The School of Biological Sciences, University of Aberdeen, Scotland, UK

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 (*Isurus oxyrinchus*), 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' life history, foraging ecology, distribution, movements, stock structure, and potential vulnerability to fishing pressure. This information is provided to international, national, and regional fisheries conservation and management bodies having stewardship for sharks. Described here are studies that have been recently completed or are ongoing. Many of these studies are collaborative and involve stakeholders and colleagues both in the U.S. and abroad.

Shortfin Mako Shark 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.

Introduction/Background

Most information on shortfin makos in the eastern North Pacific (ENP) has historically come from fisheries data and short-term tracking studies. Although range has been inferred from catch and conventional tag data, little is known about the migration patterns and behavior throughout the ENP. This long-term electronic tagging study was designed to examine in detail the movement patterns and behavior of makos in the ENP.

Methods/Results

In this study, a total of 113 mako sharks (104-280 fork length) were tagged in the California Current between 2002 and 2014 with Argos satellite tags, including 93 satellite-linked radio transmitting (SLRT) tags and 71 pop-up satellite archival tags (PSATs). Track durations from SLRT data averaged 337 days (max 1025), and PSAT tags averaged 136 days (max 272). Estimated minimum distance traveled in 1 year ranged from 6,945 to 18,800 km/yr. Habitats utilized included the entire California Current, the Sea of Cortez, and offshore in the areas of the North Pacific Subtropical Gyre, North Pacific Transition Zone, and North Equatorial Current (**Figure 10a**). Seasonal movements within the California Current coincided with periods of higher primary productivity and Chlorophyll *a*, and sea surface temperatures (SST) between 15 and 25˚C. SST ranged from 11 to 31˚C throughout the range, indicating a broad thermal tolerance (**Figure 10a**).

Discussion

Some of the key findings include the discovery of a high degree of variability between individuals in their vertical and horizontal movements, a strong influence of body size and season on mako shark movements, and the repetitive use of certain areas by individuals (**Figure 10b**). These results expand our understanding of the distribution of mako sharks in the ENP. Although mako sharks are thought to comprise a single stock throughout the North Pacific, horizontal distribution of tagged mako sharks in this study was limited to the ENP demonstrating some spatial sub-structure.

This study provides important data that can be used to identify fishery and gear vulnerabilities and inform management.

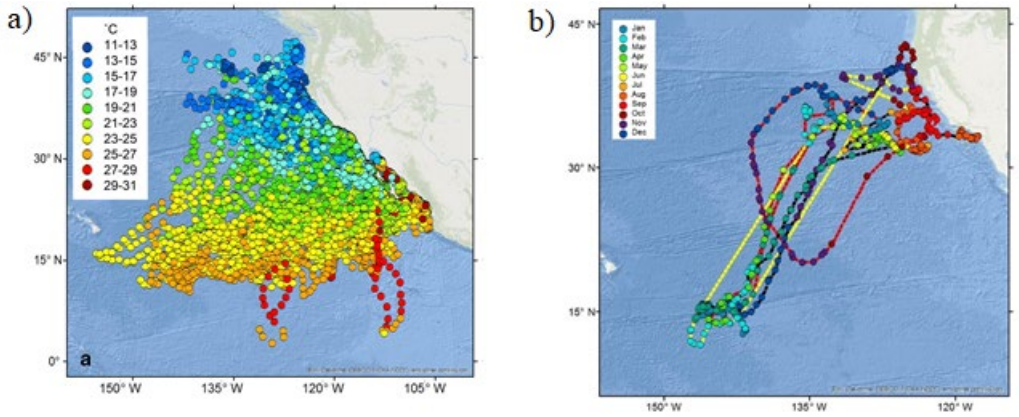

Figure 10. (a) All filtered SLRT data colored by extracted remote sensing Sea Surface Temperature; (b) Tracking data for shark a 205 cm FL female mako shark shows similar offshore tracks over three consecutive years. Dashed line indicates the year of tracking with black = first year, yellow = second year, and red = third year.

Nasby-Lucas, N., Dewar, H., Sosa-Nishizaki, O., Wilson, C., Hyde, J. R., Vetter, R. D., Wraith, J., Block, B., Kinney, M.J., Sippel, T., Holts, D. B., & Kohin, S. (2019). Movements of electronically tagged shortfin mako sharks (*Isurus oxyrinchus*) in the eastern North Pacific Ocean. *Animal Biotelemetry*, *7*(1), 12.

Foraging Ecology of Pelagic Sharks

The California Current is a productive eastern boundary current that provides important habitat for a number of highly migratory shark species. One of the main reasons sharks come to the California Current is to take advantage of the seasonally high abundance of prey. Consequently, understanding foraging ecology and food-web connections is critical as we move towards ecosystem management and also for predicting shifts in abundance and distribution with short- and long-term climate change. To better understand the foraging ecology of pelagic sharks in the California Current, SWFSC researchers have been analyzing the stomach contents since 1999.

Introduction/Background

The diets of shortfin mako, blue (*Prionace glauca*), common thresher and bigeye thresher (*Alopias superciliosus*) sharks caught in the U.S. commercial drift gillnet fisheries in the California Current Large Marine Ecosystem (CCLME) were investigated as a part of the Ph.D. thesis recently completed by Antonella Preti (Preti 2020). These species are all landed in regional fisheries either as a secondary target or bycatch, with both common thresher sharks and mako sharks being important recreational targets.

Methods

The goal of this research was to better understand the foraging ecology including how and why diets changes in space, time, and with size and sex. This study also examines dietary diversity and niche overlap in the four species to help us understand resource competition. In total, 501 mako, 205 blue, 613 thresher and 51 bigeye thresher shark stomachs were collected during 332 observed trips throughout the CCLME during 1998 to 2014. Stomachs were processed in the lab and prey

items were separated, identified to the lowest possible taxonomic level, enumerated, measured and weighed. Importance of each prey type was summarized using percent frequency of occurrence (%F); percent composition by number (%N); and percent composition by weight (%W). Several univariate and multivariate statistical methods were used to describe the diets and assess differences.

Results/Discussion

A comparison across the species reveals some important differences and similarities (**Table 2**). Mako sharks fed primarily on teleosts, cephalopods, elasmobranchs and marine mammals. Jumbo squid and Pacific saury were the most important species in their diet. Blue sharks consumed primarily cephalopods; *Gonatus* spp. and jumbo squid were their most important prey. They also fed on teleosts, elasmobranchs and occasionally on marine mammals. Thresher sharks fed heavily on coastal pelagic species such as northern anchovy, Pacific sardine and market squid. Bigeye threshers ate primarily jumbo squid and barracudinas. All shark species showed differences in diets by size, area, and years. Thresher sharks presented the least diverse diet compared to other sharks. Makos and blues had the most similar diet while diets of blues and threshers were least similar. Bigeye thresher shark presented a broader niche than mako or thresher.

Diving behavior, horizontal movements and body features of sharks, as well as oceanographic conditions and consequent prey availability, were some of the co-occurring factors likely to have influenced the observed differences in diets. Understanding the feeding ecology of these species is relevant for managing fisheries especially as we move towards ecosystem management. Future diet studies would benefit from information on prey distribution and abundance and size of prey.

Table 2. Species richness estimated with Menhinick's index (Whittaker 1977); species diversity estimated with Simpson's index (*D)* (Simpson 1949), evenness ($\frac{1}{D}$) and Shannon entropy's index (Shannon 1948). Mean value of the index based on 10000 bootstraps estimates; in parenthesis: lower 95% confidence limit - upper 95% confidence limit. All sample types combined. M=shortfin mako, B=blue shark, T=thresher shark, BT= bigeye thresher shark.

_	Mako (M)	Blue (B)	Thresher (T)	Bigeye thresher (BT)	Significant differences
Number of samples	366	150	434	45	_
Menhinick	1.4 (1.31-1.49)	1.3 (1.03-1.55)	0.38 (0.36-0.41)	1.02 (0.81-1.23)	T<M,B,BT
Menhinick	1.4 (1.31-1.49)	1.3 (1.03-1.55)	0.38 (0.36-0.41)	1.02 (0.81-1.23)	M>BT
Simpson (D)	0.16 (0.11-0.21)	0.14 (0.09-0.28)	0.22 (0.19-0.27)	0.12 (0.09-0.17)	T>BT
Evenness (1/D)	6.44 (4.67-8.83)	8.05 (3.56-10.61)	4.54 (3.69-5.39)	8.6 (5.87-11.35)	BT>T
Shannon entropy	2.6 (2.37-2.82)	2.48 (1.98-2.70)	1.82 (1.69-1.94)	2.41 (2.16-2.61)	T<M,B,BT

Preti, A. 2020. Trophic ecology of nine top predators in the California Current. Ph.D. Dissertation. The School of Biological Sciences, University of Aberdeen, Scotland, UK

Spiral Valve Parasites as Indicators of Shark Feeding Behavior and Ecology

Introduction/Background

As an addition to classic diet analyses, this study is a preliminary attempt to analyze the gut 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.

Methods/Results/Discussion

The spiral valves of 18 blue and 19 thresher sharks caught in the CCLME from 2009 to 2013 were examined for parasites. Seven parasite taxa were found in blue sharks and nine in threshers. The tetraphyllidean cestode *Anthobothrium* sp. (78% prevalence) was the most common parasite of blue sharks and the phyllobothriid cestode *Paraorygmatobothrium* sp. (90% prevalence) was the most common in threshers. An adult nematode of the genus *Piscicapillaria* was found in threshers for the first time and may be a new species (**Figure 11**). Adult individuals of *Hysterothylacium* sp. were found in both shark species. The adult acanthocephalan *Rhadinorhynchus cololabis* and remains of the parasitic copepod *Pennella* sp. – both parasites of Pacific saury, *Cololabis saira* – were found in the intestines of threshers, indicating recent feeding on saury. This study paves the way for a more comprehensive examination, including more samples and a wider variety of shark species, to provide a greater understanding of shark feeding behavior and possibly provide information on shark population biology.

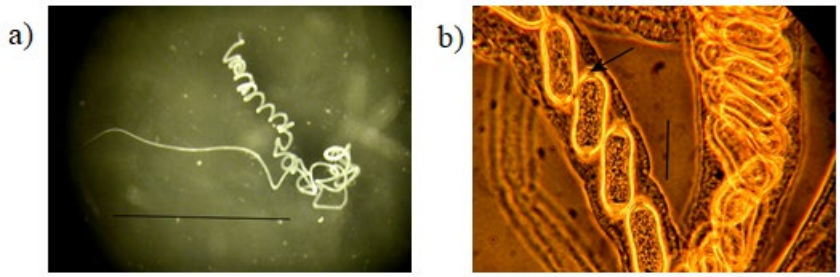

Figure 11. (a) Piscicapillaria sp.: a whole nematode; (b) Eggs with the protruding polar pugs arrowed. Scale bars: a = 1 mm, b = 50µm.

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VI. IDCPA RESEARCH

The SWFSC research conducted under the International Dolphin Conservation Program Act (IDCPA) during 2019-20 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, and (3) advance our understanding of ecosystem structure and function.

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 has been published in the Journal of Cetacean Research and Management (Fiedler and Lennert-Cody, 2019).

Clarifying Cetacean Population Structure, Abundance Estimation Methods, Behavior, and Life History

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 northern 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). Results of this study were published in the journal Molecular Ecology (Van Cise et al. 2019)

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 are now 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). An improved understanding of the taxonomy and evolutionary history of false killer whales will inform future management decisions under the Endangered Species Act.

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*. This re-description will better describe the biodiversity of cetaceans in the eastern Pacific, provide a more solid foundation for classifying stranded and bycaught individuals to taxa, and properly delineate taxa for management under the ESA as well as the MMPA.

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. It will also provide a context for the delineation of taxa and ESA and MMPA management units, especially offshore and coastal bottlenose dolphins in California and Mexico.

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*. Accurate estimation of the fraction of animals missed on the trackline during shipboard line-transect surveys is critical for proper abundance estimation. Our results suggest that for an appropriately designed study, passive acoustics may provide a strong alternative for estimating the animals missed by the visual observation team. In fact, for species with small group sizes and cryptic behavior or in regions where inclement weather may affect sighting conditions, passive acoustics may serve as a preferred method. This paper has been published in the journal of Environmental and Ecological Statistics (Rankin, Oedekoven, Archer, 2020).

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 Ethology and Behavioral Ecology of Odontocetes was published in August 2019 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. (Mesnick et al., 2019)

Advancing Understanding of Ecosystem Structure and Function

Healthy populations of species directly targeted for a fishery ultimately depend on healthy ecosystems. In this context, research on components of the ecosystem that are linked to these directly targeted species can facilitate their sustainable use.

Cetacean community patterns

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

Seabird abundance

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*). These species are often involved in multi-species feeding flocks that also involve highly migratory species targeted by purse-seine fisheries. 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 a revised manuscript is in the process of internal review and will be submitted to *Endangered Species Research* in late-spring 2020. In addition to abundance estimates, the species density models derived in this effort also provide quantitative distribution information that could be useful in evaluating potential ecosystem impacts of purse-seine fisheries on Endangered Species Act listed species.

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). Seabirds are important components p[./l9of the multi-species feeding aggregations targeted by purse-seine fisheries and the distribution maps produced in this effort will provide important baseline information in working towards ecosystem based fisheries management.

VII. PUBLICATIONS CITED

Fiedler, P. C. & C. E. Lennert-Cody. (2019). Seasonal an d interannual variations in the distributions of tuna-associated dolphins in the eastern tropical Pacific Ocean. J. Cetacean Res. Manage. 20:67-79.

Heberer, L. N., Dewar, H., Snodgrass, O. E., & Itano, D. G. (2019). Tuna Species of the US West Coast: A Photographic Identification Guide. U.S. Department of Commerce, NOAA Technical Memorandum NMFS-SWFSC-624.

Heberer, L. N., & Lee, H. H. (2019). Updated size composition data from the San Diego Commercial Passenger Fishing Vessel (CPFV) recreational fishery for Fleet 15: Eastern Pacific Ocean Sport Fisheries, 2014-2019. ISC/19/PBFWG-2/06.

Mesnick S.L., Ballance L.T., Wade P.R., Pryor K., & Reeves R.R. (2019). Oceanic Dolphin Societies: Diversity, Complexity, and Conservation. In: Würsig B. (eds) Ethology and Behavioral Ecology of Odontocetes. Ethology and Behavioral Ecology of Marine Mammals. Springer, Cham. https://doi.org/10.1007/978-3-030-16663-2_9

Nasby-Lucas, N., Dewar, H., Sosa-Nishizaki, O., Wilson, C., Hyde, J. R., Vetter, R. D., Wraith, J., Block, B., Kinney, M.J., Sippel, T., Holts, D. B., & Kohin, S. (2019). Movements of electronically tagged shortfin mako sharks (*Isurus oxyrinchus*) in the eastern North Pacific Ocean. Animal Biotelemetry, 7(1), 12.

Preti, A. (2020). Trophic ecology of nine top predators in the California Current. Ph.D. Dissertation. The School of Biological Sciences, University of Aberdeen, Scotland, UK

Rankin, S, Oedekoven, C, & Archer, F. (2020). Mark Recapture Distance Sampling: Using Acoustics to Estimate the Fraction of Dolphins Missed by Observers During Shipboard Line-Transect Surveys. Environmental and Ecological Statistics.

Wells, R.J.D., Mohan, J.A., Dewar, H., Rooker, J.R., Tanaka, Y., Snodgrass, O.E., Kohin, S., Miller, N.R., & Ohshimo, S. (2020). Natal origin of Pacific bluefin tuna from the California Current Large Marine Ecosystem. Biol. Lett., 16: 20190878. https://doi.org/10.1098/rsbl.2019.0878

Van Cise, A.M., Morin, P.A., Baird, R.W., Lang, A.R., Robertson, K.M., Chivers, S.J., Brownell Jr., R.L., & Martien, K.K. (2016) Redrawing the map: mtDNA provides new insight into the distribution and diversity of short-finned pilot whales in the Pacific Ocean. Mar. Mam. Sci. 32:4; 1177-1199. https://doi.org/10.1111/mms.12315

Van Cise, A.M., Baird, R.W., Baker, C.S., Cerchio, S., Claridge, D., Fielding, R., Hancock-Hanser, B., Marrero, J., Martien, K.K., Mignucci-Giannoni, A.A., Oleson, E.M., Oremus, M., Poole, M., Rosel, P.E., Taylor, B.L., & Morin, P.A. (2019). Oceanographic barriers, divergence, and admixture: Phylogeography and taxonomy of two putative subspecies of short-finned pilot whale. Molecular Ecology 28, 2886-2902.

VIII. SWFSC PUBLICATIONS

Published

Farchadi, N., Hinton, M., Thompson, A., & Yin, ZY. (2019). Modeling the dynamic habitats of mobile pelagic predators (*Makaira nirgricans* and *Istiompax indica*) in the eastern Pacific Ocean. Mar. Ecol. Prog. Ser. 622. 10.3354/meps12996.

Fiedler, P. C. & C. E. Lennert-Cody. (2019). Seasonal and interannual variations in the distributions of tuna-associated dolphins in the eastern tropical Pacific Ocean. J. Cetacean Res. Manage. 20:67-79.

Franck, J., Slight-Simcoe, E., & Wegner, N.C. (2019). Endothermy in the mesopelagic opah (*Lampris incognitus*): A potential role for the uncoupling protein sarcolipin. J. Comp. Physiol. Biochem. 233A: 48-52. DOI: 10.1016/j.cbpa.2019.03.024

Heberer, L. N., Dewar, H., Snodgrass, O. E., & Itano, D. G. (2019). Tuna Species of the US West Coast: A Photographic Identification Guide. U.S. Department of Commerce, NOAA Technical Memorandum NMFS-SWFSC-624.

Heberer, L. N., & Lee, H. H. (2019). Updated size composition data from the San Diego Commercial Passenger Fishing Vessel (CPFV) recreational fishery for Fleet 15: Eastern Pacific Ocean Sport Fisheries, 2014-2019. ISC/19/PBFWG-2/06.

Kinney, Michael & Kacev, D & Sippel, T & Dewar, H & Eguchi, T. (2020). Common thresher shark *Alopias vulpinus* movement: Bayesian Inference on a data limited species. Mar. Ecol. Prog. Ser. 639. 10.3354/meps13271.

Lee, H.H., Piner, K.R., Taylor, I.G., & Kitaka, T. (2019). On the use of conditional age at length data as a likelihood component in integrated population dynamics models. Fish. Res. 216: 204-211. https://doi.org/10.1016/j.fishres.2019.04.007

Lyons K., Kacev D., Preti A., Gillett D., Dewar H., & Kohin S. (2019). Species-Specific Characteristics Influence Contaminant Accumulation Trajectories and Signatures Across Ontogeny in Three Pelagic Shark Species. Environ. Sci. Technol. 53(12):6997-7006. doi:10.1021/acs.est.8b07355

Maxwell, S., Scales, K., Bograd, S., Briscoe, D., Dewar, H., Hazen, E., Lewison, R., Welch, H., & Crowder, L. (2019) Seasonal spatial segregation in blue sharks (*Prionace glauca*) by sex and size class in the Northeast Pacific Ocean. Diversity and Distributions. 10.1111/ddi.12941.

Mesnick S.L., Ballance L.T., Wade P.R., Pryor K., & Reeves R.R. (2019). Oceanic Dolphin Societies: Diversity, Complexity, and Conservation. In: Würsig B. (eds) Ethology and Behavioral Ecology of Odontocetes. Ethology and Behavioral Ecology of Marine Mammals. Springer, Cham. https://doi.org/10.1007/978-3-030-16663-2_9

Muhling, B., Brodie, S., Snodgrass, O.E., Tommasi, D., Jacox, M., Edwards, C., Snyder, S., Dewar, H., Xu, Y., & Childers, J. (2019). Dynamic habitat use of albacore and their primary prey species in the California Current System. CalCOFI Rep., Vol. 60.

Nasby-Lucas, N., Dewar, H., Sosa-Nishizaki, O., Wilson, C., Hyde, J. R., Vetter, R. D., Wraith, J., Block, B., Kinney, M.J., Sippel, T., Holts, D. B., & Kohin, S. (2019). Movements of electronically tagged shortfin mako sharks (*Isurus oxyrinchus*) in the eastern North Pacific

Ocean. Animal Biotelemetry, 7(1), 12.

Nosal, A.P., Cartamil, D.P. Wegner, N.C. (SWFSC/FRD), Lam, C.H, & Hastings, P.A. (2019). Movement ecology of young-of-the-year Blue Sharks *Prionace glauca* and Shortfin Makos *Isurus oxyrinchus* within a putative binational nursery area. Mar. Ecol. Prog. Ser. 623: 99-115.

Preti, A. (2020). Trophic ecology of nine top predators in the California Current. Ph.D. Dissertation. The School of Biological Sciences, University of Aberdeen, Scotland, UK

Rankin, S, Oedekoven, C, & Archer, F. (2020). Mark Recapture Distance Sampling: Using Acoustics to Estimate the Fraction of Dolphins Missed by Observers During Shipboard Line-Transect Surveys. Environmental and Ecological Statistics.

Wells, R.J.D., Mohan, J.A., Dewar, H., Rooker, J.R., Tanaka, Y., Snodgrass, O.E., Kohin, S., Miller, N.R., & Ohshimo, S. (2020). Natal origin of Pacific bluefin tuna from the California Current Large Marine Ecosystem. Biol. Lett., 16: 20190878. https://doi.org/10.1098/rsbl.2019.0878

Van Cise, A.M., Baird, R.W., Baker, C.S., Cerchio, S., Claridge, D., Fielding, R., Hancock-Hanser, B., Marrero, J., Martien, K.K., Mignucci-Giannoni, A.A., Oleson, E.M., Oremus, M., Poole, M., Rosel, P.E., Taylor, B.L., & Morin, P.A. (2019). Oceanographic barriers, divergence, and admixture: Phylogeography and taxonomy of two putative subspecies of short-finned pilot whale. Molecular Ecology 28, 2886-2902.

Accepted for Publication

Preti, A., MacKenzie, K., Spivey, K.A., Noble, L.R., Jones, C.S., Appy, R.G., & Pierce, G.J. (In Prep). Spiral valve parasites of blue and common thresher sharks as indicators of shark feeding behavior and ecology. Journal of Fish Biology. https://doi.org/10.1111/jfb.14363.

Approved by Science Director

Walker, J. & Teo, S. (In Prep) Distribution and relative abundance trends of Opah in California waters.

Madigan, D.J., Snodgrass, O.E., Hyde, J.R., & Dewar, H. (In Prep). Stable isotope turnover rates and fractionation in captive California yellowtail (*Seriola dorsalis*): insights for application to field studies.