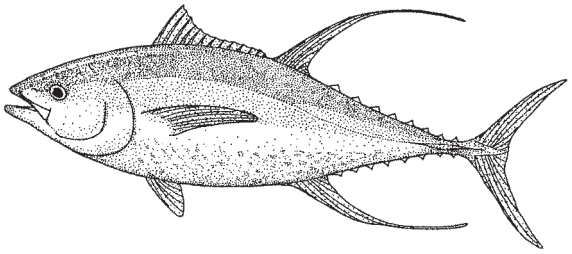
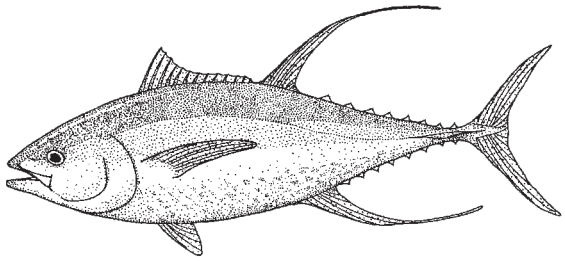
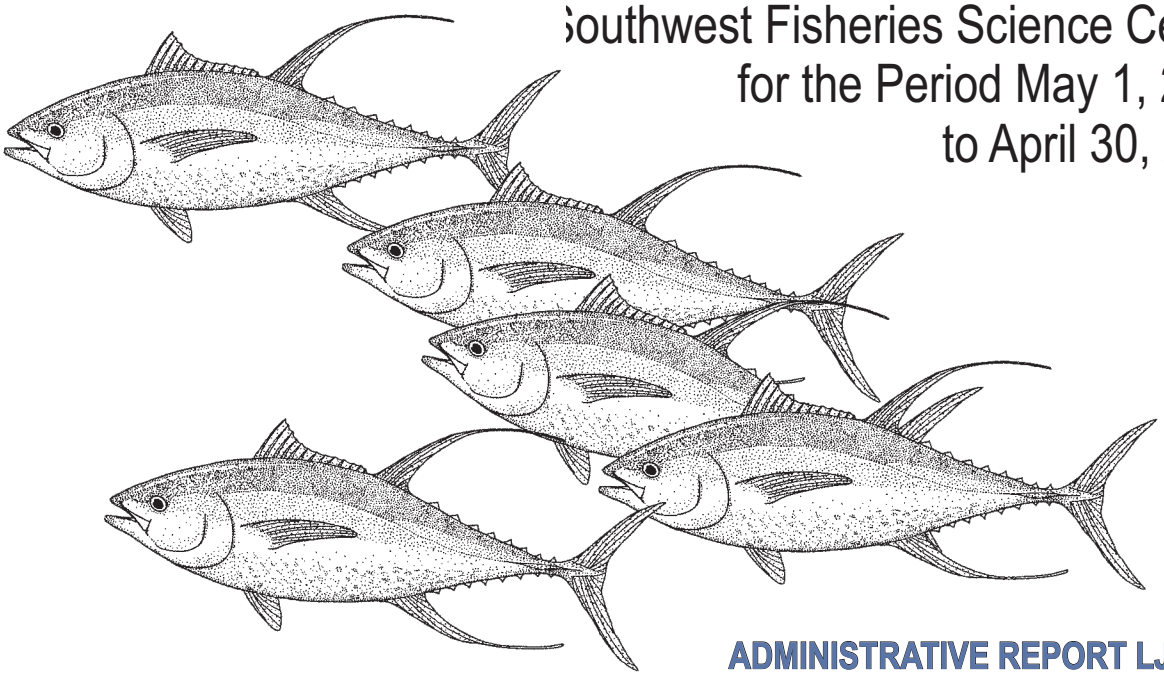
National Marine Fisheries Service
Southwest Fisheries Science Center

Director's Report to the 62nd Tuna Conference





On Tuna and
Tuna-Related Activities at the
Southwest Fisheries Science Center
for the Period May 1, 2010
to April 30, 2011



ADMINISTRATIVE REPORT LJ-11-02

DIRECTOR'S REPORT TO THE 62st TUNA CONFERENCE ON TUNA AND TUNA-RELATED ACTIVITIES AT THE SOUTHWEST FISHERIES SCIENCE CENTER FOR THE PERIOD MAY 1, 2010 TO APRIL 30, 2011

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May 2011

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Introduction

To begin on a personal note, I am pleased to introduce myself as the new Science and Research Director of the Southwest Fisheries Science Center. Previously, I was the Director of the Institute of Marine and Coastal Sciences at Rutgers University. Before joining Rutgers, I was on the faculty at Dartmouth College's Thayer School of Engineering (1984-89), the Skidaway Institute of Oceanography (1989-93), and from 1993 to 2008 at the University of North Carolina at Chapel Hill's Marine Sciences Department. At UNC-CH, I served as department chairman from 2000 to 2007 and was the George and Alice Welsh Distinguished Professor. From 2002 to 2007, I served as the chairman of the GLOBEC (Global Ocean Ecosystems Dynamics) International Scientific Steering Committee and co-chaired the PICES MODEL Task Team. Presently, I am the co-editor-in-chief of the journal Progress in Oceanography.

My research has included the study of the structure and function of marine ecosystems, ocean circulation physics, and the development and implementation of ocean and coastal observing and forecasting systems. I have also researched the development of physical and biological models for marine ecosystems in the Northwest Atlantic, the U.S. South Atlantic Bight and the North Pacific. I have co-authored over 90 refereed publications and collaborated with many colleagues at NOAA on important programs, including the Global Ecosystem Dynamics Program, Comparative Analysis of Marine Ecosystem Organization, Integrated Ocean Observing System, and various projects related to climate change and fisheries. My formal education includes a Bachelor of Science degree in Mathematics in 1978, a Masters in 1981, and a Ph.D. in Oceanography from the University of Washington in 1984.

Getting back to the purpose of this report, the following pages contain highlights of research conducted by the Center during the past year relating to Pacific tunas, billfishes, oceanic sharks, and protected species associated with their fisheries. The aim of the data collection and analysis is to maintain healthy U.S. and world fisheries, populations of protected marine species, and fish habitat and to ensure that the most effective fishing regulations and international treaties are carried out.

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I. SUPPORTING U.S. OBLIGATIONS OF INTERNATIONAL AGREEMENTS

The United States is party to a number of international agreements for the conservation of highly migratory species (HMS) in the Pacific Ocean. As such, it is obligated to collect fishery statistics from U.S. HMS fisheries and to participate in advancing fishery science for species of interest. Scientists at the Southwest Fisheries Science Center (SWFSC) have been tasked to fulfill this obligation. In this section, brief descriptions of some of the contributions and activities during the past year, May 2010–April 2011, are described.

Monitoring the Purse Seine Fishery in the Western-Central Pacific Ocean – The National Marine Fisheries Service (NMFS) collects and manages data from the U.S. purse seine fishery for tropical tunas in the western-central Pacific Ocean as part of U.S. obligations under the South Pacific Tuna Treaty. Information from U.S. vessels licensed to fish under the treaty is collected by the NMFS Pacific Islands Region (PIR) field office in American Samoa and transmitted to the SWFSC in La Jolla, California, where information from logbooks, landings and biological data from port sampling are processed.

The size of the U.S. purse seine fleet decreased in 2010 to 36 vessels from 39 vessels in 2009. Preliminary estimates of the 2010 catch (245,524 metric tons or t) decreased 13% from the 283,218 t caught in 2009. Skipjack tuna (*Katsuwonus pelamis)* dominated the 2010 catch (88%), followed by yellowfin tuna (*Thunnus albacares)* (10%), and bigeye tuna (*T. obesus)* (2%).

Purse seine sets on floating objects (logs and fish aggregation devices) in 2010 accounted for 44% of the total sets, a decrease from 50% of total sets recorded in 2009. Sets on free-swimming schools accounted for 56% of sets, an increase from 50% in 2009. The overall catch rate (CPUE) was 31 t per day fished in 2010, an 11% decrease from 35 t per day fished in 2009.

Size samples collected from the U.S. purse seine tuna catch provide estimates of sizes of fish for each species. Length measurements were taken from yellowfin, skipjack, and bigeye tunas landed in Pago Pago, American Samoa, and in other ports. Preliminary estimates of average fork lengths (FL) of fish sampled in 2010 are not yet available, and approximately one half of the 2010 catch and sampling data have not yet been received or processed.

Contributing to the Work of the ISC – The United States is a member of the International Scientific Committee for Tuna and Tuna-like Species in the North Pacific Ocean (ISC), along with Canada, China, Chinese Taipei, Japan, Korea, the North Pacific Marine Science Organization (PICES), the Secretariat of the Pacific Community (SPC), and the Food and Agriculture Organization. The purpose of the ISC is to enhance scientific research and cooperation for conservation and rational utilization of species of tuna and tuna-like fishes which inhabit the North Pacific Ocean, and to establish the scientific groundwork for the conservation and rational utilization of these species in the region through a multilateral regime. The ISC is organized into five Working Groups—statistics, Pacific bluefin tuna, albacore, billfish and sharks—that meet intercessionally and report to a Plenary body. The overall chairman of the ISC is Gerard DiNardo of the Pacific Islands Fisheries Science Center (PIFSC). Results of the ISC are made available to participating members and to HMS regional fisheries management organizations of the Pacific Ocean.

The 10th Plenary meeting of the ISC was held in Victoria, Canada, 21-26 July 2010. Scientists from Canada, Chinese Taipei, Japan, Korea, Mexico, the United States, and PICES participated. A member of the Western and Central Pacific Fisheries Commission (WCPFC) Secretariat attended as an observer. SWFSC Acting Director Usha Varanasi led the U.S. delegation at this meeting.

Key Results of the 10th Meeting – The ISC Plenary reviewed the results of work performed by the Working Groups since the 9th meeting. Considerable progress was made in stock assessment research and towards understanding the status of the North Pacific stocks. The plenary reviewed results and conclusions, which were based on new data and updated analyses, of the billfish and Pacific bluefin tuna (*Thunnus orientalis*) working groups. The Plenary endorsed the findings that the eastern Pacific stock of swordfish (*Xiphias gladius*) is healthy and in good condition and that the fishing mortality rate of Pacific bluefin tuna, particularly juveniles, needs to be decreased. The Plenary maintained the conservation advice of ISC9 with minor changes for clarification for the following stocks: (1) albacore (*T. alalunga*), the mortality rate should not be increased; (2) striped marlin (*Tetrapterus audax*) fishing mortality should be reduced; and (3) the western and central North Pacific stock of swordfish: no conservation advice because the stock is healthy.

Miscellaneous matters were also addressed during the 10th meeting; a special seminar on oceanographic and low trophic-level habitat in the North Pacific Ocean was held. The Plenary agreed to dissolve its bycatch working group and create a shark working group in order to implement the recommendations of its shark task force. The Albacore, Pacific Bluefin, and Billfish Working Groups provided information on candidate biological reference points for northern stocks of highly migratory species in the North Pacific Ocean which the Plenary endorsed. These were forwarded for consideration at the 6th regular session of the Northern Committee of the WCPFC in September 2010. The ISC work plan for 2010-11 includes completing a new stock assessment for albacore and striped marlin by ISC11, continuing preparations for Pacific bluefin tuna and blue marlin (*Makaira nigricans*) stock assessments in 2012, implementing improved database and website management, and updating and clarifying ISC operations procedures. After serving five years as chairman of ISC, Gary Sakagawa of SWFSC stepped down. The Plenary elected Gerard DiNardo to serve as chairman for 2010-13. The next Plenary will be held in the United States in July 2011.

Albacore Stock Assessment and Research – The commercial surface-albacore fishery is the most important fishery for HMS on the U.S. West Coast. As participants in the ISC Albacore Working Group, SWFSC researchers have been preparing for a full stock assessment of North Pacific albacore scheduled for early 2011. The working group is expected to move from a VPA-type model, used in previous assessments, to a length-based SS3 model for the upcoming stock assessment.

To prepare for this stock assessment, a manuscript was recently completed that describes changes in the distribution of catch and effort of the troll fishery from 1960 to 2008. One of the interesting changes has been the intense concentration of effort in the waters off Oregon and Washington over the past decade. From the 1970s to 1990s, a large proportion of the catch effort occurred along the transition zone of the North Pacific. However, from 2000 to 2008, ~75% of the catch and effort was concentrated in a 5° x 10° area off the Oregon and Washington coasts.

We also investigated the CPUE and length-composition time series in 4 subareas (dividing lines at 40°N and 130°W). The range of lengths caught by the albacore troll fishery was similar in all areas (corresponding to approximately age-2, -3, and -4 year classes). Length compositions in all areas were multimodal, with the strongest mode at age-3 (~65 cm FL). However, areas south of 40°N showed a relatively higher proportion of age-4 fish, which helps explain the higher mean lengths reported by previous studies. The areas south of 40°N also showed a relatively higher variability in the relative proportions of age-3 and -4 cohorts as compared with the areas north of 40°N, which has age-3 fish dominating the catch for most years. While the CPUE indices for the area south of 40°N were unreliable due to a lack of data, the CPUE indices for the other areas were relatively similar and highly correlated with each other (r ranged from 0.57 to 0.96, $p << 0.001$ for all correlations).

In addition to analyzing the catch data for the troll fishery, other efforts related to albacore stock assessments are ongoing at the SWFSC. Currently, we are investigating the reliability and applicability of using albacore CPUE indices from pelagic longlines as indicators of spawning stock biomass as well as exploring options for suitable reference points. Longline CPUE indices may be useful for examining trends in abundance for the years between stock assessments that are typically conducted only every few years. SWFSC scientists are also investigating the effects of short- and long-term environmental change on the catch and population dynamics of North Pacific albacore tuna by incorporating information from traditional fisheries (catch and effort) and tagging (both electronic and conventional) into a coupled environmental-population dynamic model.

Otolith Collections to Support Stock Assessments – Given the uncertainty surrounding current growth models and stock structure for North Pacific albacore, scientists at the SWFSC have expanded on the biological sampling program started in the Southern California Bight. This and other ongoing studies support the ISC's recent proposal for a North Pacific-wide sampling program to address the uncertainties with current growth models and stock structure for albacore in the eastern Pacific Ocean. Two objectives of the sampling program that relate most directly to stock assessments are age and growth, and population structure using otolith-based methods.

Age and growth – Age and growth of North Pacific albacore were assessed by examining annual growth increments in sagittal otoliths from 338 fish collected throughout the North Pacific Ocean. A wide size range of albacore (53-128 cm fork length, FL) was collected in the western, central, and eastern Pacific Ocean in an attempt to incorporate size-at-age information over juvenile, sub-adult, and adult life history stages. Overall, ages ranged from 1 to 15 years with the majority of fish between 2 to 4 years of age. Growth models fit otolith-based size-at-age well, and a bias-corrected form of Akaike's Information Criterion indicated that the specialized von Bertalanffy (VB) model provided the best fit (Fig. 1). Biological parameters of the specialized VB model included L_∞=120.0, K=0.184, and t_0=-1.945. Several albacore otoliths were processed for daily increments and confirmed our results using the annual method. In addition to otolith-based techniques, dorsal fin spines and length frequency (LF) analysis were used to generate estimates of size-at-age.

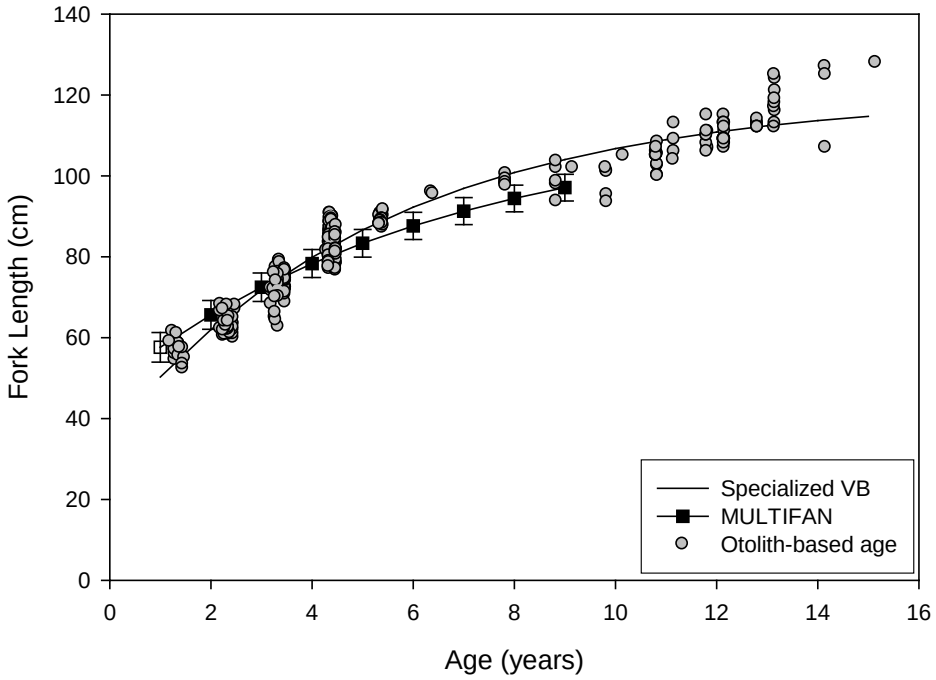

Figure 1. Length-at-age of albacore using otolith-based methods and associated growth model fits. Von Bertalanffy growth model fit from MULTIFAN length frequency analysis is also included.

In general, fin-spine ages matched otolith-derived ages (85% of samples). The VB growth model generated from LF analysis provided similar size-at-age for the first five age classes but estimated smaller sizes for fish ages 6 to 9. This may be a product of the limited size distribution from fishery-dependent data (Fig. 1). Results from this preliminary age and growth research suggest North Pacific albacore are a relatively long lived tuna species and provides updated biological parameters that may be useful to future stock assessment models incorporating age-specific, life-history information.

Population structure – Population structure of North Pacific albacore appears to be more complex than the current single stock hypothesis given the apparent regional differences in growth rates and movement patterns in the eastern Pacific Ocean. Accurately characterizing population structure and stock mixing is critical to effective management. Otolith chemistry is one approach to investigate population structure of tunas and other fish. The principal assumption is that the otolith acts as a natural tag because the chemical composition of the otolith is related to the physicochemical conditions of the water mass inhabited. As such, the purpose of this study is to examine otolith stable isotopes of carbon ($\delta^{13}C$) and oxygen ($\delta^{18}O$) in addition to several trace elements in whole otoliths of albacore collected in two regions of the eastern Pacific Ocean that have shown limited mixing: northern region (offshore Oregon and Washington, > 40°N) and southern region (offshore southern California and northern Baja California, Mexico, < 40°N). Samples from three age classes (ages 2-4) were collected from each region through recreational and commercial fishing vessels from July to October of 2010. Significant differences existed in otolith chemistry from fish collected between the two regions ($P < 0.05$), and overall cross-validated classification success to respective collection region was

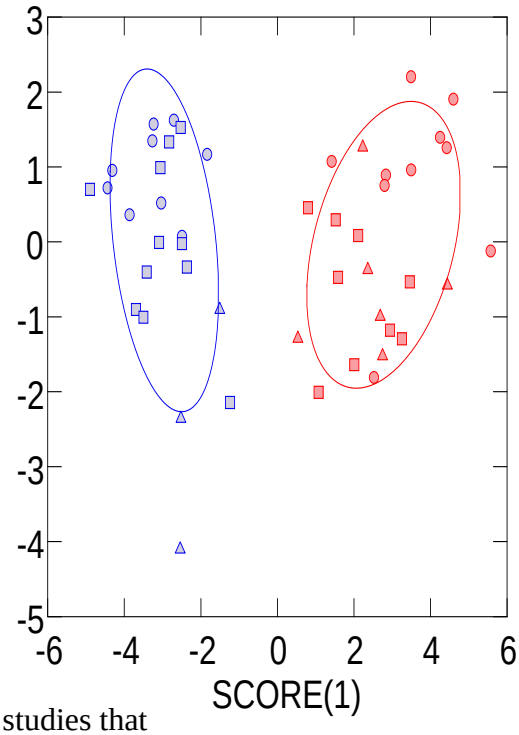

Figure 2. Otolith chemistry results separating albacore collected from the northern (blue symbols; > 40° N) and southern (red symbols; < 40° N) regions of the eastern Pacific. Symbols are coded by age-class (age-2=circles, age-3=squares, age-4=triangles).

100% with age-specific comparisons exceeding 90% success (Fig. 2). Otolith $\delta^{18}O$ was significantly enriched in the southern region relative to the northern region, similar to reported seawater $\delta^{18}O$ differences. In addition, significantly higher concentrations of sodium and magnesium, combined with lower phosphorus in otoliths from fish collected in the southern region, is consistent with regional physicochemical conditions (i.e., salinity, temperature, phosphate). Our preliminary findings support previous studies that have shown limited regional mixing of albacore in the eastern Pacific Ocean and provide life history information useful for sustainable management of North Pacific albacore.

Bluefin Tuna Stock Assessment and Research – Pacific bluefin tuna was historically an important commercial fishery for HMS on the U.S. West Coast. In recent years, however, the primary U.S. fishery targeting this species has been the U.S. sport fishery operating out of San Diego, California. There remains an important commercial fishery for bluefin tuna operating in Mexican waters.

As members of the ISC Pacific Bluefin Working Group (PBFWG), SWFSC researchers are preparing for a full stock assessment of Pacific bluefin tuna that is scheduled for 2012. The PBFWG currently uses a length-based age-structured SS3 model for stock assessments. SWFSC scientists met with fellow members of the PBFWG in Nanaimo, Canada, in 2010 to provide an update to the prior full assessment of the species. Subsequently, the PBFWG met in Shimizu, Japan, in January 2011 to discuss model specifications and improvements for the upcoming full assessment. During the previous assessment, the PBFWG found that the results were highly sensitive to the assumed rates of natural mortality. At the January 2011 meeting, SWFSC researchers demonstrated that this sensitivity was likely due to model misfits to eastern Pacific Ocean time series. SWFSC researchers also developed a SS3-VPA hybrid model and a SS3 model incorporating transpacific movements as research tools to help improve future assessment models. In addition, the PBFWG suggested that SWFSC scientists, in collaboration with Inter-American Tropical Tuna Commission scientists, develop an abundance index for the eastern Pacific using spotter plane data.

II. SUPPORTING PACIFIC FISHERY MANAGEMENT COUNCIL ACTIVITIES

Center scientists Stephen Stohs and Suzanne Kohin served on the Highly Migratory Species Management Team (HMSMT) of the Pacific Fishery Management Council over the past year.

Stohs has been HMSMT chair since April 2009 and was reappointed for a third term as of January 2011. The team met several times in 2010 and early 2011 to review fishery information, complete assignments from the Council and evaluate provisions of the Fishery Management Plan for U.S. West Coast Fisheries for Highly Migratory Species.

The main HMS issues facing the team and the Council over the past year have been (1) addressing requirements under revised National Standard 1 guidelines for establishing annual catch limits and status determination criteria for highly migratory species; (2) preparing analysis to support Council action on proposed changes to routine management measures for the Washington State recreational albacore fishery and for the deep-set longline tuna fishery; (3) providing recommendations to the delegations of the WCPFC and IATTC for international fishery management; (4) developing protocols for improved recreational fishery data collection from southern California shark anglers and the West Coast recreational for-hire fishery targeting albacore; and (5) preparing the 2010 Stock Assessment and Fishery Evaluation (SAFE) Report.

III. HIGHLY MIGRATORY SPECIES DATA COORDINATION

The PIFSC, PIR, Southwest Region (SWR), and SWFSC share reporting obligations for HMS fisheries in the Pacific. Each office is involved with the coordination of reporting obligations and collaborates to produce and provide HMS data summaries for these reporting obligations. Staff from each office routinely exchange information needed for various reports, data submissions and other reporting purposes such as informal data requests. Formal annual meetings of the staff members have not occurred since 2005, though ad hoc meetings and correspondence continue.

HMS staff participate in the Fisheries Information System (FIS) based at NMFS headquarters. A representative from SWFSC, SWR, PIFSC, and PIR is on the FIS Program Management Team which directs FIS-sponsored projects and activities. FIS funds numerous projects that contribute toward improving fisheries-dependent data that are collected and maintained by the agency. Staff members from SWFSC, SWR, PIFSC, and PIR are leading several of these projects to improve data collection and management systems in their respective regions.

HMS information technology specialists at the SWFSC are also improving data collection methods. Current and past electronic data collection and monitoring projects include data monitoring systems for regional observer programs, electronic calipers and handheld computers used to collect length measurements, and electronic logbook software applications. These monitoring and collection methods increase the data quality and timeliness of reporting while reducing operational costs and easing reporting burdens on fishermen.

IV. ADVANCING TUNA AND BILLFISH RESEARCH

The SWFSC research on tunas and billfishes in the Pacific Ocean has largely been focused on improving our understanding of the biology and ecology of the animals to support needs for assessing the effects of fishing and environment on the population or stock. Described below are studies that have been 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.

Monitoring the U.S. Albacore Troll and Pole-and-Line Fishery – U.S. troll and pole-and-line vessels have fished for North Pacific albacore since the early 1900s and for South Pacific albacore since 1986. North Pacific albacore fishing areas range from Vancouver Island to the coast of Baja California and from the U.S. West Coast to approximately 160°E. The fishing season begins in late April and can last into mid-November. The size of the troll fleet for a season ranges from 500 vessels to over 1,000 vessels. About 650 U.S. troll vessels fished for North Pacific albacore in 2010.

Fishing areas for South Pacific albacore extend eastward from the east coast of New Zealand to approximately 110°W and between 30°S to 45°S, overlapping the jurisdictional areas of two fishery management organizations. This fishery begins in late December and continues until early April of the following year. The international troll fleet in the South Pacific consists of 5 to 50 vessels. Factors such as increased fuel costs, lower ex-vessel prices and reduced availability of fish have contributed to a decrease in participation in the South Pacific troll fishery in recent years. Only 6 U.S. troll vessels fished for albacore in the South Pacific during the 2009-10 season; they caught 307 t of albacore, an increase from 237 t caught the previous season by 5 vessels. Bycatch species are sometimes reported in vessel logbooks and include yellowtail, dolphinfish, and skipjack, as well as yellowfin, bigeye, and bluefin tunas.

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. The cooperative research is described below.

North Pacific Albacore Biological Data Sampling Program – Since 1961, a biological data collection program, or port sampling program, has been in place for collecting size data from albacore landings made by the U.S. and Canadian troll fleets at ports along the U.S. Pacific coast. State fishery personnel collect the biological data by following sampling and data processing instructions provided by the SWFSC, where the database is maintained. In recent years, with AFRF support, fishermen have collected biological data during selected fishing trips. These data are collected to augment data collected through the port sampling program. Following procedures established by SWFSC scientists, fishermen on 5 vessels measured 2,154 albacore during the 2008 season. During 2009, 3 vessels measured 280 fish. The sample information provided by the fishermen helped to fill in gaps missed by the port sampling program. Overall, the sizes were found to be generally similar to those collected through the port sampling program.

North Pacific Albacore Archival Tagging Project – The SWFSC and AFRF initiated an archival tagging program in 2001 to study the migration patterns and stock structure of juvenile albacore in the North Pacific. Since 2001, a total of 630 archival tags and 43 dummy tags have been deployed. Two tagging charters were conducted during 2010, one off the Columbia River aboard the charter sport fishing boat *Playboy Too* during which 15 tags were deployed, and the

second off Cape Mendocino aboard F/V *Royal Dawn* during which 22 tags were deployed. SWFSC biologists John Childers and James Wraith have been participating in the tagging trips during the past few seasons. To date, 22 archival and 6 dummy tags have been recovered. Recovery rates have been low. In 2010, no tags were returned.

A manuscript summarizing the results from the first 20 archival tags recovered was published in the journal Fisheries Oceanography. The paper describes the seasonal movements, migration patterns, and vertical distribution of juvenile albacore in the northeast Pacific. Tagged albacore were at liberty from 63 to 697 days and exhibited five distinct, seasonal migratory patterns. The majority swam offshore during the fall, overwintered offshore, and then returned in the spring to the area in which they were tagged. However, many of the fish tagged in the southern region (southern California and northern Baja California, Mexico) migrated south rather than west and overwintered along the coast of Baja California. One fish migrated across the Pacific and was recaptured off Japan. Depth and temperature data revealed a broad range of vertical behaviors. In certain regions such as off Baja California, juvenile albacore make frequent dives to depths exceeding 200 m during the day and remain in the surface mixed layer at night, whereas off Oregon and Washington they remain near the surface both day and night. Water temperatures encountered ranged from 3.3 to 22.7°C. Peritoneal temperatures were significantly higher by an average of approximately 4°C. The results reveal diverse behavior that varies regionally and seasonally as albacore move among different habitats throughout the entire North Pacific.

Because of the broad range of movement patterns and behaviors recorded, a greater number of tag returns from fish that have been at liberty for several years will be needed in order to fully understand the dynamics and structure of the North Pacific albacore stock. In addition, information on the distribution and migrations of adults is needed. In 2010, the SWFSC purchased 4 mini-PAT tags to launch a pilot project to deploy tags on adult albacore that are caught near Hawaii in an artisanal handline fishery. The study is designed to determine whether there are distinct spawning populations of albacore in the central and western Pacific, and to study the movements of adult albacore. PAT tag retention on albacore has been poor in past studies, but the new generation mini-PAT is 40% smaller and we have designed two attachment methods to test. During the summer, SWFSC scientists will conduct a tagging trip in Hawaii to deploy these experimental tags. If either attachment design provides long-term records, then we will initiate a larger study to obtain information on adult albacore migrations, spawning areas, and stock structure.

Cooperative Research with Billfish Anglers – The SWFSC and the billfish angling community have been working together since 1963 to study various aspects of billfish biology and to obtain an index of angler success in the Pacific Ocean. This collaboration has resulted in one of the longest time-series available for recreational billfishing, charting trends in catch-per-unit-effort for key species. The research has also included recreational and commercial fishery monitoring, stock assessments efforts, biological research into the life history and ecology of specific billfish species, and determining the economic importance of billfish resources. Two major components of the cooperative research that were the focus in 2009 were the International Billfish Angler Survey and the Billfish Tagging Program.

International Billfish Angler Survey – In 2010, SWFSC researchers summarized the results from the 2009 Billfish Angler Survey. Initiated in 1969, the survey now provides a 41-year time series of billfish angling effort and catch in the Pacific Ocean. The time series of angler success provides a measure of relative abundance and is the only survey independent of commercial fisheries in the Pacific. CPUE, measured in number of billfish caught per angler fishing day, in the Pacific was down from previous years. In 2009, billfish catch per fishing day in the Pacific was 0.46, compared to 0.68 in 2008 and 0.72 in 2007, heavily influenced by a drop in striped marlin CPUE off Mexico. CPUE time series were also examined individually for the main species caught [Pacific blue marlin, striped marlin, Pacific sailfish (*Istiophorus platypterus*), and black marlin (*Makaira indica*)] in the main fishing areas (Tahiti, Hawaii, Baja California, southern California, Guatemala, Costa Rica, Panama, and Australia; Fig. 3). Blue marlin CPUE off Baja was relatively low in 2009 at 0.05. Conversely, anglers reported good blue marlin CPUE off Hawaii in 2009 (0.27 CPUE), continuing a very high trend from the previous year. Striped marlin CPUE off Mexico (0.38) was down from recent years but closer to the long-term average. Similarly, respondents fishing off Mexico and several Central American countries reported a drop in sailfish CPUE compared to recent years. Finally, respondents from Panama indicated a continuing upward trend in black marlin catch rates.

Recreational Billfish Tagging Program – The SWFSC's Billfish Tagging Program has provided tagging supplies to recreational billfish anglers for 48 consecutive years. Tag release and recapture data are used to determine movement and migration patterns, species distribution, and age and growth patterns. This volunteer tagging program depends on the participation and cooperation of recreational anglers, sportfishing organizations, and commercial fishers. Since its inception, over 60,000 fish of 75 different species have been tagged and released. Emphasis continues to be on the skillful tag and release of billfish. The annual total number of billfish tag releases has increased since 2007. The number of tagged billfish went up from 840 in 2007 to 866 in 2008, to 871 in 2009. This tagging effort was in thanks to the contribution of over 580 anglers and 135 captains. Table 1 shows the tagging effort for 2009 and the tag recoveries throughout the program's history. The data include releases made by SWFSC scientists during research cruises in addition to the angler releases.

Swordfish Research and SLUTH – Since 2006, NMFS has been studying swordfish in the Southern California Bight to examine migratory patterns, foraging ecology, and local stock structure. In 2008, researchers in the Fisheries Resources Division (FRD) teamed up with the Protected Resources Division (PRD) and the SWR to launch a new initiative, Swordfish and Leatherback Use of Temperate Habitat (SLUTH). The overarching objective of SLUTH is to integrate studies of swordfish and leatherback sea turtles to inform management and conservation efforts. The endangered leatherback is taken incidentally in swordfish fisheries, and concerns about leatherback populations are currently shaping the management of swordfish fisheries along the U.S. West Coast. The first step in this process was a stakeholder workshop that was conducted in May of 2008. A report detailing the content and discussions of the workshop was published as an SWFSC Administrative Report in 2009 (Benson et al. 2009, LJ-09-06).

Figure 3. CPUE as catch-per-angler-day is shown from 1969 through 2009 for A) Pacific blue marlin, B) striped marlin, C) Pacific sailfish, and D) black marlin.

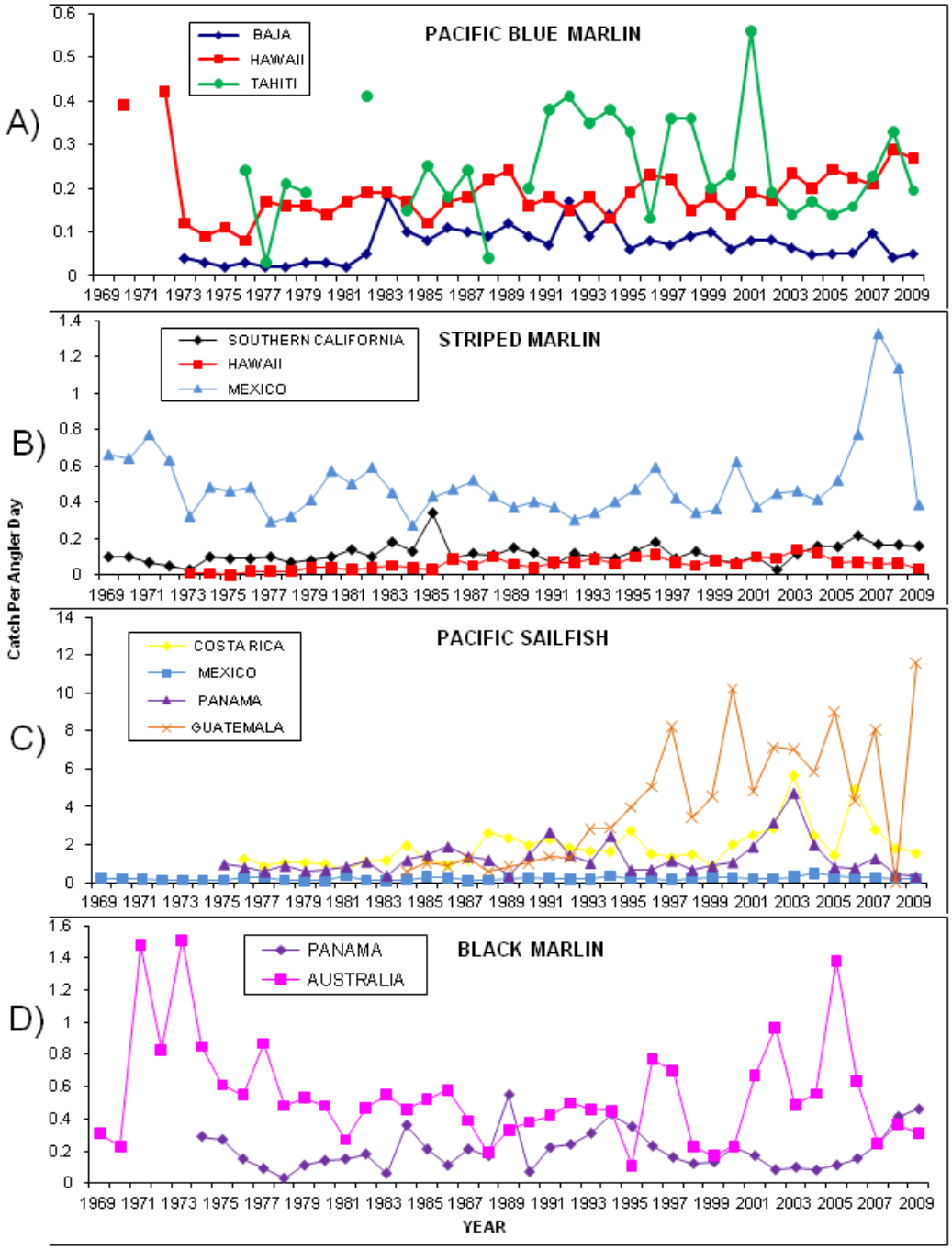

Table 1. Summary of all fish tagged through the Billfish Tagging Program in 2009 with releases and recoveries for 1963–2009, including fish tagged and released as part of the SWFSC's ongoing research efforts.

SPECIES NAME	RELEASE 2009	RELEASE TOTAL	RETURN TOTAL	RETURN RATE %
Striped Marlin	72	22,890	343	1.50
Pacific Blue Marlin	660	10,444	89	0.85
Sailfish	58	9,179	49	0.53
Billfish, unidentified	16	4,377	6	0.14
Black Marlin	1	3,385	69	2.04
Shortfin Mako Shark	206	2,247	95	4.23
Shortbill Spearfish	64	2,111	2	0.09
Blue Shark	140	1,030	69	6.70
Common Thresher Shark	203	1,056	53	5.02
Broadbill Swordfish	0	521	17	3.26
Yellowfin Tuna	0	348	25	7.18
Skipjack Tuna	0	100	2	2.00
Albacore Tuna	41	717	29	4.04
Bigeye Tuna	0	79	2	2.53
Bluefin Tuna	0	58	8	13.79
Bronze Whaler Shark	0	51	1	1.96
Hammerhead Shark	1	51	1	1.96
Atlantic Blue Marlin	0	43	0	0.00
Salmon Shark	0	33	1	3.03
Silky Shark	0	21	0	0.00
White Marlin	0	13	1	7.69
Basking Shark	0	7	0	0.00
Longbill Spearfish	0	3	0	0.00
Other Tunas	0	21	1	4.76
All Others	3	2,652	98	3.70
TOTAL	**1,401**	**61,437**	**961**	**1.56**

While a large organized initiative has yet to be established, FRD has initiated a number of research projects directed towards specific SLUTH goals. These research projects include characterizing the environmental conditions associated with fishing, swordfish and leatherback catch, assessing the rates of blue shark (*Prionace glauca*) bycatch in drift gillnet and longline fisheries, and deploying additional electronic tags to quantify the movements and habitat of swordfish.

Characterizing Target Catch and Non-target Species Catch and the Behavior of Fishermen – Part of the SLUTH initiative is to explore creative methods to reduce the bycatch of nontarget species in the California drift gillnet (CDGN) fishery. One approach is to use the fisheries data to better understand the environmental factors that affect the distribution of leatherbacks, swordfish, and the fishers themselves. Working together, researchers from the PRD and FRD are using novel statistical approaches including boosted regression trees and random forests to model the relationships between the distribution and abundance of the focal species, fishing

effort, and environmental drivers such as sea surface temperature (SST), oceanic fronts, and primary productivity. At the scale of the west coast drift gillnet fishery, the goal is to identify environmental features that separate swordfish from leatherbacks, if they exist, thereby improving fishing efficiency and reducing bycatch encounters. Preliminary results suggest that swordfish catch rate responds to both biotic (primary production, zooplankton abundance) and abiotic (SST, currents, depth) factors. If combined with data on location (i.e., latitude/longitude) and time of year (i.e., month), these factors can be used to predict swordfish catch rates with impressive accuracy (e.g., cross validated R^2 of ~ 0.7). Similar efforts are ongoing with leatherback turtles.

Though fishery-specific data are relatively complete and accurate in the fisheries managed by the NMFS, this is not the case in other parts of the Pacific. To address this challenge, researchers are exploring alternate methods for estimating cumulative fishing effort given the limited data currently available. One approach involves kriging, a method of spatial interpolation, to fill in missing data on fishing effort. By starting with a complete database for fishing effort at a fine spatial scale and selectively dropping some of the data or aggregating cells, researchers are examining the effects of missing data and spatial scale on the precision of kriged estimates. Using multiple datasets from diverse fisheries, the goal is to develop general guidelines for estimating missing data on fishing effort. A second approach involves using remotely sensed oceanographic data to predict fishing effort. Just as environmental factors can be used to predict the behavior of target and non-target catch, so too they may be useful for predicting fisher behavior. By contrasting the performance of these two approaches, researchers hope to arrive at the best method for predicting future fishing effort and thereby identifying areas of potential overlap with protected species of concern.

Improving Location Estimates from Electronic Tags – In addition to characterizing swordfish habitat using catch data, electronic tags are also being used. While the traditional pop-up satellite tags provide valuable information on vertical behavior, obtaining an accurate assessment of location is made challenging by the diel vertical migrations of swordfish. We are currently working on two approaches to get around this problem. First, in collaboration with the Commonwealth Scientific and Industrial Research Organisation in Australia, software is being developed to improve geolocation estimates. The novel approach treats the data as sequentially independent decisions instead of constructing a track. This allows us to concentrate on the analysis of covariates describing the movement instead of estimating a model describing the full path of the animal.

The second approach to improving geolocation between the tagging and pop-up locations involves testing the new towed satellite tags that capture a GPS signal when the tag breaks the surface. The post-processed GPS locations are much more accurate than those obtained either through Argos or using light-based geolocation methods. Three of these tags were deployed in 2010 and, of those, two have reported data to satellites. The datasets for the first of these has been analyzed. The tag was deployed in November and remained attached for 64 days while the swordfish moved south along the coast of the Baja California peninsula. While no data were obtained during the track, 21 GPS locations were collected and transmitted after the tag popped off in addition to the traditional information on temperature and depth. This collection of the highly accurate GPS locations provides an important proof of concept for this technology. The

ultimate goal is to deploy these towed GPS tags north of Point Conception where the overlap between swordfish and leatherbacks is the greatest. The highly accurate locations and behavioral information, when matched to environmental data, will provide data critical to mapping the preferred habitat of swordfish in this region.

Foraging Ecology – With the reauthorization of the Magnuson-Stevens Fishery Conservation and Management Act in 2006, there is a move towards ecosystem-based management. This approach requires information on ecological relationships among species, one of the most important being trophic interaction. To determine the trophic relationships of highly migratory species in the California Current, the SWFSC has been investigating the foraging ecology of a range of species since 1999.

During 2007-10, a total of 115 broadbill swordfish stomachs were collected and analyzed. Food was present in 97% of the stomachs, representing at least 34 taxa. The five top prey as determined by the geometric index of importance were all cephalopods. The most important prey was jumbo squid (*Dosidicus gigas*), which was present in 72% of stomachs, followed by the boreopacific gonate squid (*Gonatopsis borealis*) that was in 63% of stomachs. The most important teleosts were Paralepididae (barracudinas) followed by Scopelarchidae (pearleyes). The majority of the most important prey species are associated with the deep scattering layer, although epipelagic fish also occurred in their diets.

The large number of prey taxa found in the swordfish diet suggests that these vagile fish are generalists and capable of exploiting a range of prey in a variety of habitats. Generalist predators will be less susceptible to variability in the composition of the prey base that may result from natural or anthropogenic impacts. The apparent habitat overlap between swordfish and many of the non-target fish species taken in the CDGN fishery, including many of the sharks managed along the U.S. West Coast, presents a challenge to fishery managers aiming to minimize bycatch. More detailed quantitative analysis of diet studies coupled with analyses of the distribution of swordfish and vulnerable non-target species will help to identify where habitat separation exists among species and to develop appropriate management options. These efforts are currently underway.

Biological Sampling of Tunas in the Eastern Pacific Ocean – Tuna in the eastern Pacific Ocean, including the waters off the U.S. and Mexico, support substantial commercial and recreational fisheries and are also important components of the local food web. To better understand their basic biology and ecological role in the eastern Pacific Ocean, the SWFSC and the Sportfishing Association of California initiated a biological sampling program in 2007 to collect data on tuna and other HMS. While initially the program was focused in the Southern California Bight, in 2009 we expanded the program to the Northeast Pacific Ocean and are working with commercial fishermen to collect samples from albacore off Oregon and Washington. Utilizing the commercial passenger fishing vessels, commercial albacore troll/ bait fleet, and recreational anglers based out of San Diego, we collected samples from albacore, bluefin, yellowfin, skipjack, and dorado (*Coryphaena hippurus).* To date we have collected samples from 553 albacore, 231 bluefin and 253 yellowfin tuna as well as a mix of other species. This year the program will be further expanded to include Monterey Bay and San Francisco, where albacore are commonly encountered from August through December. While we are

collecting a range of tissues, the current focus is on stomach content analysis and the use of hard parts to characterize age and growth (see above section on albacore assessment research).

Analyses of stomach contents conducted to date reveal a number of interesting patterns across species and years. Preliminary analysis of stomach contents shows that tuna forage almost exclusively on juvenile fish and squid. For albacore, the average standard length of fish prey was 5.3 cm and for the squid lower rostral length was 0.34 cm. A comparison across years for albacore reveals some interesting differences. In 2007, small teleosts comprised the dominant prey category by frequency of occurrence (89%), followed by cephalopods (18%) and crustaceans (16%). In 2008, a shift in prey composition occurred with cephalopods [(*Abraliopsis felis),* California market squid *(Loligo opalescens),* and jumbo squid] playing a more important role by frequency of occurrence (86%), followed by teleosts (84%) and crustaceans (56%). While teleosts were important in both years, the species composition changed. In 2007, 80% of the stomachs contained northern anchovies (*Engraulis mordax*), whereas in 2008 this dropped to only 2%. Juvenile *Sebastes* spp., myctophids, and jack mackerel (*Trachurus symmetricus*) made up the majority of teleost prey in 2008. Samples collected during 2009 and 2010 are currently being processed. Overall, analysis shows that prey composition can vary dramatically and will likely reflect the oceanographic conditions present during those years. The appearance of tuna and other HMS in the Southern California Bight during summer and fall likely coincides with the peak in abundance of a range of juvenile fish and squid species.

In addition to studying the HMS themselves, the predators can be used as biological samplers and provide a snapshot of the forage base. Linking changes in environmental factors that influence the recruitment, fecundity, and resulting availability of forage prey types may reveal insight about habitat quality and migration patterns of HMS in the California Current. By characterizing the food web we hope to better understand how predators and prey utilize the diverse habitats found along U.S. West Coast. By sampling over multiple years we can gain insight into the impacts of changes in climate on local ecosystems and compare differences in forage base among distinct geographic regions encountered in the eastern Pacific Ocean.

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 (*Alopias vulpinus),* bigeye thresher (*A. superciliosus),* and pelagic thresher (*A. pelagicus).* Center scientists are studying the sharks' biology, distribution, movements, stock structure, population status, and potential vulnerability to fishing pressure. This information is provided to international, national, and regional fisheries conservation and management bodies having stewardship for sharks. Some of the recently completed and ongoing shark research activities being carried out at the SWFSC are discussed below.

Abundance Surveys – The blue, shortfin mako, and thresher sharks are all taken in regional commercial and recreational fisheries. Common thresher and mako sharks have the greatest commercial value and are also specifically targeted by sport fishers, especially off southern California. Although the blue shark is targeted in Mexico, it has little market importance in the

U.S. but is a leading bycatch species in the CDGN and high-seas longline fisheries. Although catches of adult blue, thresher, and shortfin mako sharks do occur, the commercial and sport catch of these species off southern California consists largely of juvenile sharks.

To track trends in the abundance of juvenile and subadult blue and shortfin mako sharks and neonate common thresher sharks, surveys are carried out in the Southern California Bight each summer. Efforts to determine abundance trends from commercial fishery data have been complicated by changes in regulations, targeted areas, and fishing methods over time. These changes have resulted in inconsistent capture rates and catch distributions that are difficult to interpret. Therefore, fishery-independent sampling was initiated, with slightly different survey strategies required for the more oceanic shortfin mako and blue sharks compared to the more coastal common thresher shark.

Offshore longline surveys from relatively large research vessels have proved most effective for sampling and estimating abundance trends of the more oceanic species (shortfin mako and blue sharks). For mako sharks, the surveys have enabled the SWFSC to obtain a valuable abundance index, which can be linked to a historical time series of logbook and landings data from a former experimental shortfin mako longline fishery in the Southern California Bight that occurred during 1988-91. Abundance trend information is also obtained for the blue shark, which is compared to that obtained by observers of the California drift gillnet and U.S. and Japanese high-seas longline fisheries.

Surveys for neonate thresher sharks are conducted using small commercial driftnet and longline vessels. Initial studies demonstrated that neonate threshers are rarely encountered in waters deeper than about 90 m. Therefore, surveys are conducted in the shallower nearshore waters between Point Conception, California, to the north and the U.S.-Mexico border to the south. The primary purpose of the surveys is to produce a relative abundance index for the west coast population by periodically sampling 0-year pups (neonates) in their nursery grounds off southern California. Once the core nursery area was defined, representative areas were identified and are now sampled annually. The resulting neonate index of abundance should mirror adult abundance because adult population and recruitment should be tightly linked in K-selected species such as sharks. This study complements the fishery-dependent data available through the nearshore small mesh net fisheries and pelagic driftnet fishery to provide measures of relative abundance of common thresher sharks for stock assessment models.

Juvenile Mako and Blue Shark Survey – In 2010, the SWFSC conducted its seventeenth juvenile shark survey for mako and blue sharks since 1994. The annual abundance survey was completed between 14 July and 12 August 2010. Working aboard F/V *Ventura II*, a team of scientists and volunteers fished a total of 5,956 hooks during 29 daytime sets inside 7 focal areas within the Southern California Bight. Survey catch totaled 13 shortfin makos, 25 blue sharks, 18 pelagic rays (*Pteroplatytrygon violacea*), 10 opah (*Lampris guttatus*), and 1 mola (ocean sunfish, *Mola mola*). The preliminary data indicate that the nominal survey catch rate was 0.057 per 100 hook-hours for shortfin mako and 0.105 per 100 hook-hours for blue sharks. The nominal CPUE for both blue and shortfin mako sharks was the lowest in survey history. There is a declining trend in nominal CPUE for both species over the time series of the survey (Fig. 4).

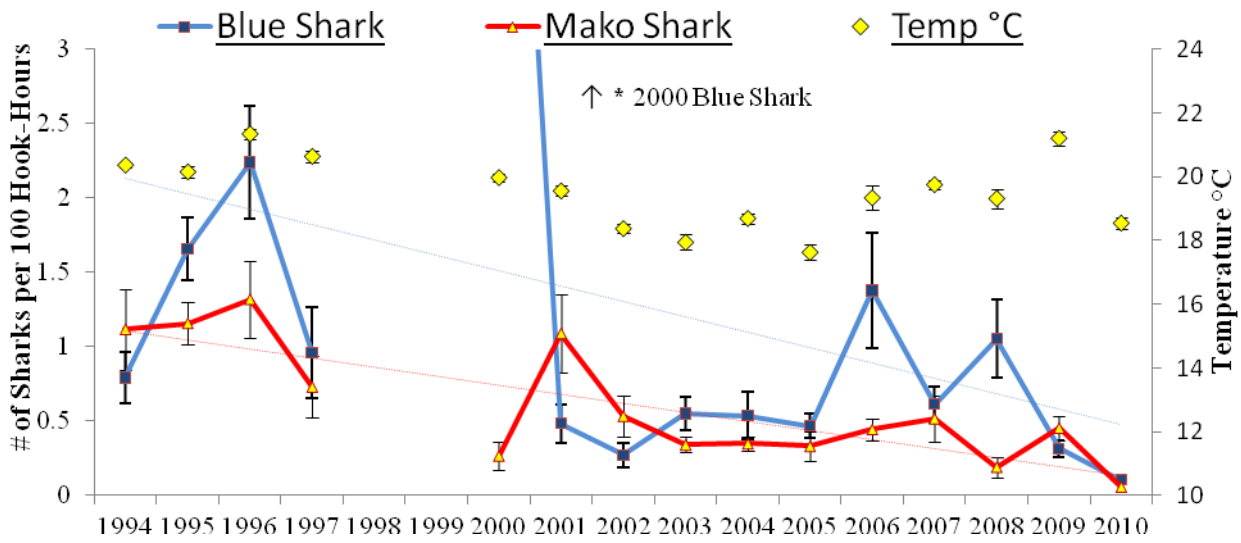

Figure 4. Average (± standard error) catch and temperature per survey set for shortfin mako and blue sharks, 1994–2010. No data were collected in 1998 and 1999. Blue shark catch per 100 hook-hours was 7.372 in 2000.

Additional research projects were also conducted during the cruise and after the shark survey was completed. An experiment directed by graduate student Melanie Hutchinson of the University of Hawaii and fishery researcher John Wang of PIFSC was continued from last year's survey to examine the potential for using rare earth metals to reduce shark bycatch. The metal was secured close to the baited hooks and catch rates on treatment and control hooks were compared. Thirteen sets were completed for the experiment during the 2010 cruise to add to the 25 sets in 2009. Preliminary results indicate that the rare earth metals did not affect the catch rate of shortfin mako or blue sharks as they were caught on the experimental hooks and control hooks in almost equal numbers. These results differ from those found on some coastal shark species where the deterrents proved effective at lowering catch rates. The data are being further examined based on size, sex, and other potential factors before drawing final conclusions.

Other objectives of the cruise were to deploy satellite and conventional tags, and to collect biological samples from sharks and swordfish. A total of 242 conventional tags were deployed on a total of 50 shortfin mako sharks and 192 blue sharks. A total of 310 DNA samples were collected including samples from 53 shortfin mako and 244 blue sharks. In a cooperative effort with TOPP (Tagging of Pacific Pelagics), 10 electronic tags were deployed on sharks to examine the habitat-use patterns in the California Current System. Four shortfin mako sharks ranging from 147 to 203 cm fork length were released with a radio position transmitting tag (SPOT). Six blue sharks ranging from 175 to 221 cm FL were also released with SPOT tags (see below for results).

Neonate Common Thresher Shark Survey – The common thresher shark pre-recruit index and nursery ground survey was initiated in 2003 to develop a fisheries-independent index of pre-

recruit abundance and has been conducted in each year since. Common thresher sharks are the most valuable sharks taken in commercial fisheries off California and are also frequently caught by recreational fishermen. In 2010, the SWFSC team worked aboard the F/V *Outer Banks*. Forty-eight longline sets were made in relatively shallow, nearshore waters and a total of 4,800 hooks were fished during the 18-day cruise. Shark catch included 295 common thresher, 5 smoothhound (*Mustelus*), 2 spiny dogfish (*Squalus acanthias*), and 1 leopard (*Triakis semifasciata*) shark. Two hundred and sixty-eight sharks were tagged with conventional tags and 280 DNA samples were collected.

The preliminary survey data indicate that the average nominal catch rate by set was 3.75 per 100 hook-hours for common thresher sharks. This is the highest catch rate since the inception of the sampling program. The distribution of common threshers is very patchy and areas of high abundance are not consistent across years. In all years, a large percentage of the catch has been neonates, which were found in all areas surveyed. In addition to providing important information on abundance and distributions, the thresher shark pre-recruit survey enhances other ongoing research at SWFSC, including age and growth, feeding, and habitat utilization studies.

Electronic Tagging Studies – Since 1999, NOAA has been using satellite technology to study the movements and behaviors primarily of blue, shortfin mako, and common thresher sharks, while other species are tagged opportunistically. In recent years, tag deployments have been carried out in collaboration with the TOPP program (www.topp.org), Mexican colleagues at CICESE (Centro de Investigación Cientifica y de Educatión Superior de Ensenada), and colleagues at the DFO (Department of Fisheries and Oceans) Pacific Biological Station in Nanaimo, British Columbia. The goals of the projects are to document and compare the movements and behaviors of these species in the California Current and to link these data to physical and biological oceanography. This approach will allow us to characterize the essential habitats of sharks and subsequently to better understand how populations might shift in response to changes in environmental conditions on short or long time scales.

In 2010, 4 shortfin mako sharks, 9 blue sharks, 1 thresher shark, and 1 basking shark were tagged with either SPOT tags or towed GPS tags. Since 1999, a total of 95 makos, 85 blue sharks, 28 common threshers, 2 hammerheads, 5 ocean sunfish, and 1 basking shark have been satellite-tagged through collaborative projects.

SPOT tags continue to provide excellent information on the movements of blue and mako sharks. Three tags deployed on blue sharks are still transmitting after periods ranging from 6 to 13 months, providing some of the longest tracks obtained to date for this species. Two tags were deployed off California, and the longest deployment is from a tag deployed off Canada in February 2010. The sharks are now dispersed from offshore of Mexico to the central Pacific Ocean north and south of Hawaii, highlighting the diversity of movements in blue sharks.

For mako sharks, 8 tags were transmitting in early 2011, 6 of which were deployed in 2009, providing well over a year's worth of data. These multiyear records provide an incredible opportunity to examine seasonal movement patters and regional fidelity. Mako sharks often undertake a seasonal migration to the Subtropical Convergence Zone in the winter or spring. Where tracks include two migratory cycles, there is a remarkable similarity in movement patters during

their southward migration. Figure 5 shows the SPOT locations for three different fish that were tracked for more than one year. While sharks ranged from the Sea of Cortez to the central Pacific, individuals return to the same region in subsequent years. Fidelity to specific areas is increasingly recognized in fish from swordfish to salmon sharks (*Lamna ditropis*) and increases the potential for regional local depletion where fisheries exist.

Age Validation Studies – Age and growth of mako, common thresher, and blue sharks are being estimated from band formation in vertebrae. SWFSC scientists are validating aging methods for these three species based on band deposition periodicity determined using oxytetracyclene (OTC). Our annual research surveys provide an opportunity to tag animals with OTC. When the shark is recaptured and the vertebrae recovered, the number of bands laid down since the known date of OTC injection can be used to determine band deposition periodicity.

Since the beginning of the program in 1997, 2,463 OTC-marked individuals have been released during juvenile shark surveys. Sharks tagged include 987 shortfin mako, 918 common thresher, 539 blue, 16 silky (*Carcharhinus falciformis*), and 3 pelagic thresher sharks. As of March 2011, recaptured OTC-marked sharks included 110 mako, 76 common thresher, 63 blue, and 2 silky sharks. Vertebrae were returned for roughly 60% of the recaptures. Time at liberty ranged from 1 to 1,938 days, and the maximum net movement for an individual shark was 3,597 nmi. An analysis of mako shark band deposition patterns is now nearly complete and a manuscript is being drafted.

Foraging Ecology of Shortfin Mako, Blue and Common Thresher Sharks – The California Current is a productive eastern boundary current that is an important nursery and foraging ground for a number of highly migratory shark species. As mentioned above, three of the most abundant juvenile sharks in the California Current are the shortfin mako, blue, and common thresher sharks. To better understand niche separation and the ecological role of these overlapping species, stomach content analyses have been ongoing at the SWFSC since 2002. Stomachs are obtained primarily from the CDGN observer program.

During 2002-10 a total of 713 shortfin mako, blue, and common thresher shark stomachs were collected and analyzed. Stomach contents were identified to the lowest possible taxonomic level. Analytical approaches to characterize prey composition and examine inter- and intra-specific patterns included both univariate and multivariate methods including the geometric index of importance (GII), Shannon and Simpson diversity, Sorensen and Morisita-Horn overlap indices, regression trees, analysis of similarity, non-metric multidimensional scaling, and bioenvironmental stepwise analysis.

Of the 330 shortfin mako shark stomachs examined (53-248 cm FL), 238 contained 43 prey taxa. Jumbo squid (GII=46.0) and Pacific saury (*Cololabis saira*, GII=25.5) were the most important prey. Of the 158 blue shark stomachs examined (76-248 cm FL), 114 contained 38 prey taxa. Jumbo (GII=33.9) and *Gonatus* spp. squids (GII=33.6) were the most important prey. Of the 225 thresher shark stomachs examined (sizes 108-228 cm FL), 157 stomachs contained 18 prey taxa. Northern anchovy, GII=68.4) and Pacific sardine (*Sardinops sagax*, GII=48.5) were the most important prey.

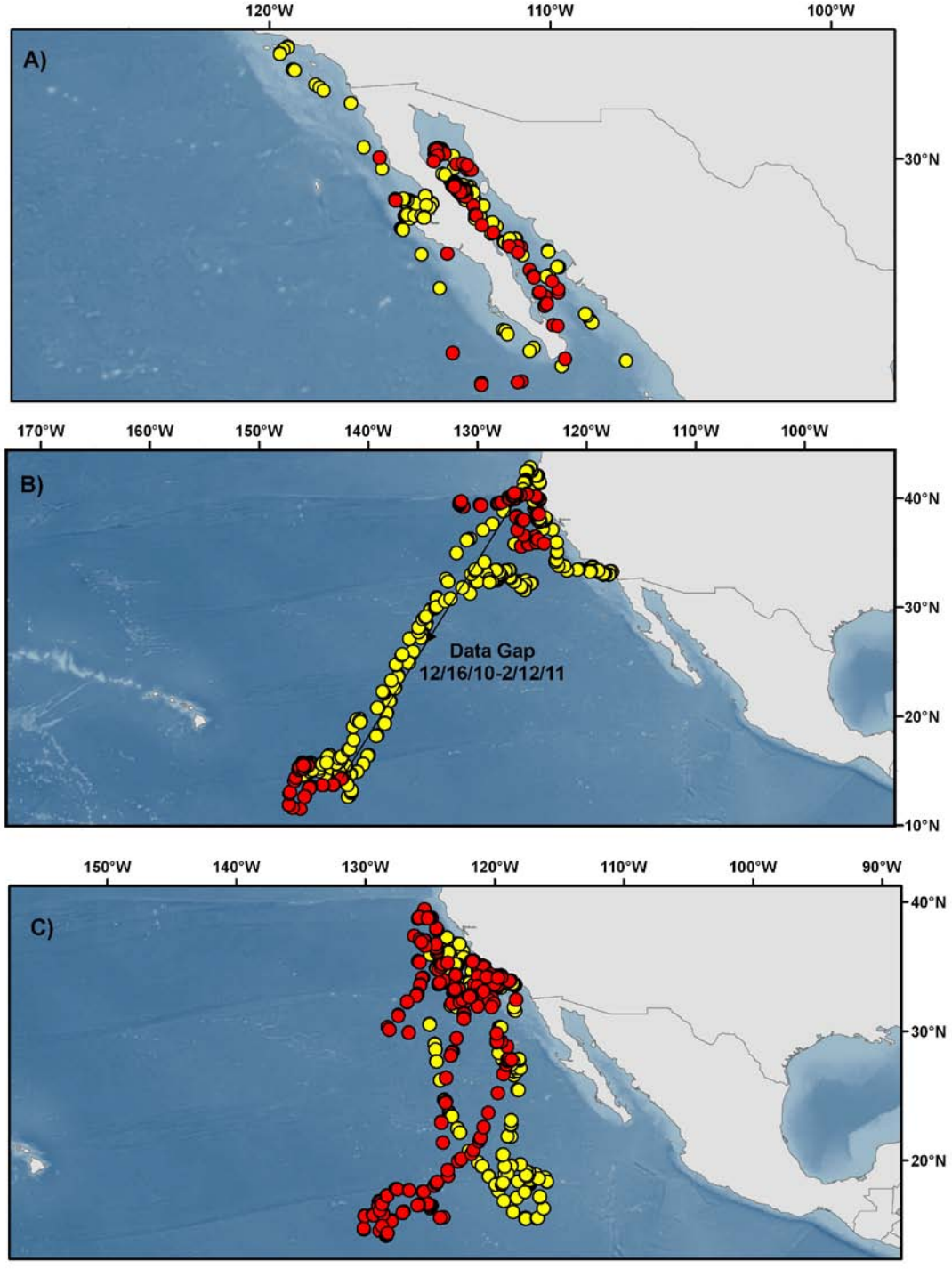

Figure 5. The three panels show the multiyear tracks for three shortfin mako sharks tagged in the Southern California Bight: A) 174 cm fork length (FL) male, B) 201 cm FL female, and C) 190 cm FL male. The first year of the track is in yellow and the second year is in red. Note the similarity in locations for individuals between years.

The Sorensen index shows that blue and mako shark diets were most similar, while dietary overlap was lowest between blue and thresher sharks as revealed by the Morisita-Horn index and regression tree analysis. Inter-annual variation in diet was greatest for blue sharks. Overall, results from the Sorensen index and multivariate analyses reveal that mako sharks have the most diverse diet, feeding on a range of teleosts and cephalopods; blue sharks generally prefer cephalopods; and thresher sharks are more specialized, feeding primarily on coastal pelagic teleosts. Despite similarities in life history characteristics and spatial and temporal overlap, diets of these three species are strongly differentiated. In 2010, the results from this research were prepared for publication in a special proceedings of the American Elasmobranch Society. The paper is currently in review.

The diet data collected for the sharks were also used to develop an indirect method of estimating foraging habitat. The method uses available data on prey distributions combined with stomach content data for predators to estimate which habitats are used for foraging. With respect to sharks in the Southern California Bight, this method confirmed conclusions of previous studies: thresher sharks foraged mostly in the epipelagic environment while makos spent relatively more time in mesopelagic and offshore habitats. Blue sharks spent the most time out of the three species foraging in offshore habitats. Results suggest that the new approach is effective and can be used for any organism in which the diet of the predator is known and the habitat distribution of prey is fairly well described.

Survival after Capture and Release – Common thresher, shortfin mako, and blue sharks are captured in both commercial and recreational fisheries in the California Current. The drift gillnet fishery is the commercial fishery which catches the greatest number of each of these species. While thresher and mako sharks are landed, almost all blue sharks are discarded. For thresher and mako sharks, regional recreational fisheries are growing in popularity. Recreational fishers are often only interested in the challenge of the fight and will frequently release their catch. The survival rate of sharks released both from the CDGN fishery and by recreational anglers is unknown. Reliable estimates of removals (i.e., mortality) are necessary in order to adequately assess the status of the stocks and determine the effects of the fisheries on their abundance.

Blue Sharks Released from the Drift Gillnet Fishery – The CDGN fishery targets swordfish in the California Current. With the exception of ocean sunfish, blue sharks are caught in greater numbers than any other finfish species taken in this fishery. Nearly all blue shark are discarded at sea due to lack of market value. A 2009 analysis of the 1990-2008 observer data reveals that 32% of blue sharks captured were released alive, and an additional 5% were discarded with their disposition unknown. The remaining 63% were discarded dead.

In 2007, the SWFSC and SWR began deploying pop-off satellite archival tags (PSATs) on sharks released from the drift gillnet fishery to assess survivorship. The tags were programmed to pop off after 30 days. The goal was to tag sharks such that the sex ratio, range of sizes, and condition at release were comparable to those released from the fishery. As a part of the study, a set of criteria was developed to document the condition of all blue sharks released: good, fair, or poor.

Since initiating the study in 2007, 11 blue sharks (100 to 200 cm FL, median 155 cm) have been tagged by fishery observers. Nine of these animals were male, and the sex of 2 animals was unknown. Three of the 11 sharks were released in "good" condition while the remaining 8 were released in "fair" condition. To date, no sharks released in "poor" condition have been tagged. Satellite tag records suggest that all animals survived the acute effects of capture in the CDGN fishery. Temperature, depth, and movement data demonstrated behavior of blue sharks that was similar to that reported in other studies. One tag appeared to have been ingested after 17 days and regurgitated 3 days later.

To meet the goal of matching the general composition of the catch, additional tag deployments are necessary. In the fishery, 29% of blue sharks released during the 2007 through 2010 seasons (the only seasons for which this information has yet been compiled) were released in poor condition. To date no sharks in poor condition have been tagged. Based on observer records, the sex ratio of blue sharks caught in this fishery is roughly 60% male and 40% female. As mentioned, when known, all sharks tagged to date were males.

Tagging efforts during the 2010-11 season were focused on smaller sharks, females, and animals released in poor condition. Tags were distributed among observers as widely as possible in an attempt to ensure deployment. However, due to the decreased effort in the fishery during the season with fewer trips observed, and the small numbers of blue sharks caught overall, particularly of the desired size and condition ranges, no blue sharks were tagged for this study during the 2010-11 drift gillnet season. The objectives for the 2011-12 season will be the same. Results to date suggest a 100% survival rate for male blue sharks released in fair or better condition.

Thresher Sharks Released from the Recreational Fishery – The SWFSC, SWR, and Pfleger Institute of Environmental Research are conducting a study to assess the post-release survival of thresher sharks caught by recreational anglers. During the first phase of the study, sharks were released after tail hooking and results demonstrated that survivorship is low for sharks greater than 185 cm FL or enduring fight times exceeding 85 minutes. Those results were published in the journal Fisheries Research in 2010. During the second phase of the study, we are testing the hypothesis that tail-hooked common thresher sharks survive the acute effects of trailing fishing gear in the southern California recreational fishery. Survivorship is being determined using PSATs deployed on subadult and adult common thresher sharks. To date, PSATs have been deployed on 5 common thresher sharks (132 to 175 cm FL) captured using fishery standard techniques and released with trailing gear. Of the 5 sharks, 3 displayed immediate mortality (within 31 hours of release), 1 shark survived the effects of trailing gear, and one of the PSATs did not report any information. The results of this study in combination with results of a published study on the survivorship of tail-hooked thresher sharks released without trailing gear will be used to estimate the survival rates of thresher sharks released from the recreational fishery. These data will be important for determining total removals by the recreational shark fishery and can be used in stock assessments for this species. Concurrent investigations on the effectiveness of degradable links and alternative fishing techniques were also performed to reduce overall post-release mortality in the recreational fishery.

Basking Shark Research Program - The eastern North Pacific basking shark population appears to have declined dramatically in the last 50 years with no evidence of a recovery. Where hundreds to thousands of individuals were observed off our coast, sighting even a few individuals is now rare. The apparent reduced abundance in the eastern North Pacific is likely linked to targeted fisheries off California in the first half of the 1900s and the eradication program established off Canada to keep basking sharks from destroying salmon nets. Due to concern about basking shark populations along the west coast of North America, the basking shark was listed as endangered in Canada and as a Species of Concern (SOC) in the U.S in 2010. Unfortunately, efforts to understand trends and develop a recovery plan are hampered by the lack of basic data on movements, the influence of environment on abundance and distribution, information on the full geographic range of the eastern North Pacific stock, and basic life-history information. Given the severe data gaps for this population, the SWFSC initiated a basking shark research program in 2010 with SOC funding to (1) mine existing data for additional biological information, (2) conduct an electronic tagging study, (3) improve international data collection, and (4) improve national sightings information by developing a sightings website and an education and outreach program centered around Monterey Bay, California. Monterey is a historic basking shark hotspot where the California fishery in the early 1900s was based.

This research program has progressed at a number of different levels. A dedicated website and hotline have been established as a part of a sightings network. This information will help with documenting patterns of occurrence and tagging efforts. A considerable amount of education and outreach has been conducted to advertise the sightings network. We also developed a tri-national team with colleagues in Canada and Mexico to coordinate research efforts. The first meeting was held in November 2010 and a second is planned for May 2011. In addition, we deployed a satellite tag on a basking shark off southern California on 6 June 2010. The tag released after 53 days off Morro Bay, California. After its release it transmitted data collected during the track, including four GPS locations, in addition to temperature, depth, and light data. No transmissions were sent by the tag before it released.

Using both the light-based and GPS locations, an estimated track between tag and release was obtained. It appears that the animal moved north-west from San Diego, shortly after being tagged, towards the Channel Islands, where it remained for some time before it moved north of Point Conception. Over the course of the deployment the shark appears to have remained over the continental shelf and slope with general focal areas being the Channel Islands and Morro Bay. Basking sharks in the Atlantic show a similar preference for nearshore regions where complex flow patterns and convergence zones act to concentrate prey, which is critical to filter feeders.

Overall, the basking shark experienced a broad range of temperatures and depths. Sea surface temperature (SST) ranged from 10.7 to 18.3^{o}C [average 12.8 ± 1.9^{o}C (SD)] and daily minimum temperatures ranged from 6 to 10.2^{o}C [average 8.9 ± 1.4^{o}C (SD)]. The maximum depth was 544 m and during most 6-h time intervals, the shark came to the surface. Depth and temperature data showed considerable variability across the track, coincident with changes in SST. At SSTs below 12 to13^{o}C, the maximum and modal depths were less than 200 m compared to depths up to 500 m in areas of higher SST. In addition, there was a significant correlation between SST and the temperature range experienced with a maximum of a 10^{o}C temperature range where SST

was 18^{o}C. The shift to shallower depths at cooler temperatures may be associated with a thermal constraint on vertical movements; however, additional information on resource distribution is necessary. Basking sharks show impressive plasticity in vertical behaviors in our study as well as in the Atlantic. They can apparently adjust their foraging strategy according to the vertical distribution of their prey. These dramatic shifts in behavior make estimating abundance based on aerial surveys and predicting overlap with fisheries challenging. Additional information on the patterns in vertical and horizontal movements is needed.

Genetic Analysis of Highly Migratory Species –

Shortfin Mako Shark – The shortfin mako is a commonly encountered shark in temperate marine fisheries but little is known about regional connectivity. Amber Michaud's recent master's thesis completed in collaboration with the University of San Diego and SWFSC provided evidence of regional stock structure within the Pacific. Her study, using mitochondrial haplotype data, showed a strong subdivision between northern and southern hemisphere populations, with additional subdivision between southeast and southwest Pacific populations; however, no subdivision was found in the North Pacific using this marker. The results of this study are being prepared for publication. As part of his Ph.D. work at University of California Davis and San Diego State University in collaboration with the SWFSC, Dovi Kacev has been developing a suite of nuclear microsatellite markers to further refine the spatial and temporal resolution of shortfin mako stocks within the Pacific. In addition to studies of stock structure, these markers will be used to develop estimates of effective population size within the California Current region. Application of these markers will commence this year.

Common Thresher Shark – Common threshers are commonly encountered in temperate coastal marine fisheries but little is known about regional connectivity. In recent years they have become part of an increasingly important recreational fishery in southern California in addition to being an important component of local gillnet fisheries. In order to better understand population connectivity, Dovi Kacev has been developing nuclear microsatellite markers for this species as well. Application of these markers will also commence this year.

Opah – The opah or moonfish is found worldwide in tropical and subtropical waters. Though caught mainly as bycatch in pelagic tuna fisheries, opah command a high price in the market and thus few are discarded. Despite being known to science for over 230 years, the existence of two morphotypes in the North Pacific was only recently discovered by PIFSC port samplers in Honolulu. The most conspicuous difference between these morphotypes is the relative size of the eye, leading to the labeling of the morphotypes as "big-eye" and "small-eye" opah. Genetic analyses performed at the SWFSC confirm that the two morphotypes are genetically distinct and in fact represent separate species. In an effort to understand the distribution of these two species, samples have been acquired from museums and observer programs worldwide. Examination of these additional samples has provided evidence for additional cryptic species and suggests there are at least five species within the opah species complex. Genetic analyses, species descriptions, and distribution maps are being prepared for publication.

Outreach – In an effort to increase international collaboration and capacity building, a genetic species identification course was taught at the III Taller Interregional de Tiburones en el Océano Pacífico Oriental in Manta, Ecuador, 6-9 July 2010. This course involved hands-on experience

using locally collected shark fins. The goals were to both genetically identify species groups that are commonly misidentified, such as the hammerhead and thresher sharks, as well as species common in this region. Some of the techniques are now being applied to studies of shark landings in Columbia and the initial results and methods are being prepared for publication.

VI. IDCPA RESEARCH

The SWFSC research conducted under the International Dolphin Conservation Program Act (IDCPA) during 2010 was focused on evaluating line transect methodology and the potential roles of the fishery and ecosystem in the apparent lack of recovery of depleted dolphin stocks in the eastern tropical Pacific Ocean (ETP). This lack of recovery follows a period of significant reductions in observed dolphin mortality in the ETP tuna purse seine fishery. Research activities included (1) analysis of data collected during the 2007 survey designed to collect fine-scale ecosystem data and assess standard methods for collecting dolphin sighting data, and (2) other data analyses, processing, and publications.

Analysis of *Stenella* Abundance Research-Line Transect and Ecosystem Survey Data – In 2007, SWFSC conducted a *Stenella* Abundance Research-Line Transect and Ecosystem (STAR-LITE) cruise to survey marine mammals and their habitat in the ETP. The primary objective of the STAR-LITE cruise was to investigate line transect methods used on surveys in the ETP and to explore fine-scale spatial and temporal variability in the ecosystem using a multidisciplinary approach.

Two different cetacean survey methodologies ("passing mode" and "closing mode") were compared using both empirical data and simulation models, and a manuscript has been published in the Journal of Cetacean Research and Management (Schwarz, L., F. I. Archer, and T. Gerrodette, *in press*) Passing survey mode—when the survey ship does not make any changes in course to approach a cetacean sighting—was compared with closing survey mode—when such course changes are made to further investigate the sighting. The results of the analysis indicated that observers are able to identify animals to species less often and that estimates of dolphin group size are lower when surveys are conducted in passing mode (no course changes are made). However, conducting surveys in closing mode results in lower encounter rates due to the stop-start nature of the survey method. Continuing to explore potential sources of bias in our methods and explicitly accounting for these in our models is critical to refining our models and ultimately improving our approaches to estimating abundance of ETP dolphins and other cetaceans.

Ecosystem data collected on this same cruise (STAR-LITE 2007) have been analyzed. Results indicate that the passage of tropical storm Kiko through the study area caused persistent changes. Wind mixing decreased surface temperature and reduced fine-scale variability. Thermocline depth and stratification both decreased. Chlorophyll in the surface layer increased, apparently due to both mixing of phytoplankton from depth and to enhanced production. These environmental changes had a variety of effects on mid-trophic and apex predator components of the ecosystem. Changes in flying fish abundance and diet, and in the abundance and community composition of both birds and cetaceans are being investigated.

This is the eleventh year of similar investigations conducted during the past 20 years, with previous cruises in 1986-1990, 1998-2000, 2003, and 2006. Using an ecosystem approach, we conducted research on physical and biological oceanography (dolphin habitat); midtrophic-level fishes and squids (dolphin prey); and seabirds, marine turtles and other cetaceans (dolphin commensals, competitors, and predators). Data and analyses resulting from STAR surveys form the basis for many international measures adopted to conserve dolphin stocks and manage the tuna purse seine fishery in the ETP. The next full STAR survey, scheduled to occur in the fall of 2009, was postponed by one year due to ship time constraints. On 6 April 2010, STAR 2010 was again postponed due to the same constraints. And in January 2010, plans for conducting STAR in the fall of 2011 were canceled indefinitely. At this time, the future of these cetacean and ecosystem assessment cruises is uncertain.

Data Analyses, Processing, and Publication – The SWFSC's investigations of dolphin stocks historically depleted by the ETP tuna purse seine fishery (spinner and pantropical spotted dolphins) are conducted with an ecosystem approach. In addition to investigating the status and trends of these dolphin stocks, auxiliary projects are conducted to improve our understanding of their surrounding environment. Data analyses, processing, and publications included (1) investigations of cetacean biodiversity hotspots; (2) assessment of relative fishery exposure for ETP dolphins; (3) variation and predictors of vessel response behaviors in ETP dolphins; (4) dolphin swimming kinematics research; (5) investigations of dolphin reproductive biology; (6) investigations of the ETP ecosystem and its change over time; and (7) metrics of ecosystem impact of the ETP purse seine fishery.

Investigations of Cetacean Biodiversity Hotspots – A paper is in preparation investigating species richness hotspots for 28 species of cetaceans in the ETP (ca. 20 million km^2) based on data collected using line transect methods aboard NOAA research vessels, August–November, in each of 10 years during a 21-year period (1986-2006). Density was calculated using species- and area-specific published values of g(0) and f(0), and interpolated throughout a 1° x 1° grid of the study area using two smoothing algorithms and two resolutions. Density was converted to presence/absence on a species-specific basis, and species richness (number of species recorded in a particular grid cell) was mapped for all years combined. Richness hotspots were defined as any grid cell that contained greater than 40% of the total species pool ($\geq$ 11 species) and were clearly evident in three distinct regions: the Equatorial Front, the Costa Rica Dome, and waters to the southwest of the Baja California peninsula. Although these hotspots encompassed areas of highest density for a few species, the correlation between richness and density for any given species was generally low (mean 0.25, range 0.03 to 0.44), as was the proportion of cells where a particular species was present and encompassed by a hotspot (mean 20%, range 4% to 56%). These results were robust to smoothing algorithm and spatial resolution.

Assessment of Relative Fishery Exposure for ETP Dolphins – For the past half century, the purse seine fishery for yellowfin tuna has been a significant factor in the lives of dolphins in the ETP. However, little is known about how frequently an individual dolphin is exposed to the fishery, and no methods are available for accurately assessing the prior exposure of dolphins encountered at sea. Archer et al. (2010) developed a method to estimate an index of exposure based on a model of dolphin movement derived from data collected from multiple tracking studies. Based on this movement model, the method weights purse seine sets given their

distance from a particular school of dolphins sighted at sea and how long ago they occurred. The method also takes into account the species composition and school size in the set. In their paper, as a demonstration, the authors use the method to examine the spatial and temporal distribution of this index over an 11-year period for which we have detailed data on purse seine sets. While the method was designed for examining exposure to the ETP purse seine fishery, it is also applicable to studies of other anthropogenic effects where there is concern about exposure rates, such as underwater sound, pollution, or ship strikes. Planned studies for this index include examining its relationship to evasive behavior, calf production as assessed from aerial photographs, and reproductive rates as measured from skin biopsies.

Variation and Predictors of Vessel Response Behaviors in ETP Dolphins – Dolphins exhibit a range of vessel response behaviors, from those that readily approach and bow ride to others that are indifferent or actively evasive. However, the factors responsible for this variation have not been examined. Archer et al. (2010) used a tree-based modeling method to investigate the influence of geography, time of day, species composition, and fishery exposure on the responses of five species of dolphins in the ETP, comprising 10 management stocks. Data were collected for 2,667 sightings during four research cruises between 1998 and 2003. The relative frequency of five responses (approaching the vessel, bow riding, running, school splitting, and low swimming) showed significant ($p < 0.0005$) variability among species, as well as stocks within the same species. Striped (*Stenella coeruleoalba*), whitebelly spinner (*S. longirostris*), and western-southern pantropical spotted dolphins (*S. attenuata attenuata*) tended to be evasive, while coastal spotted (*S. attenuata graffmani*) and common bottlenose dolphins (*Tursiops truncatus*) tended to be attracted to the vessel. There was a strong tendency of dolphins sighted offshore to be significantly more evasive than those less than about 100 nmi from the coast. The degree of evasiveness in stocks that are frequently targeted by the tuna purse seine fishery (northeastern spotted, *S. attenuata;* eastern spinner, *S. longirostris orientalis*; and short-beaked common, *Delphinus delphis*) was greater with more purse seine activity in the vicinity, while no significant relationship was found for those stocks that are rarely set on. For each stock, vessel response had a relatively unique suite of predictors, indicating an interplay of intrinsic, natural extrinsic and anthropogenic factors.

Dolphin Swimming Kinematics Research – During 2010, SWFSC completed a series of studies investigating swimming kinematics of mother and calf dolphins, as part of an effort to determine whether chase and encirclement of dolphin mother-calf pairs by tuna purse seiners in the ETP may be contributing to lack of population recovery. Two manuscripts were completed, approved by the SWFSC, and submitted to journals for review. The first manuscript, regarding the effects of infant position on swimming kinematics of dolphin calves, is now published in Marine Ecology Progress Series (Noren and Edwards 2011). This paper presents the first empirical analysis of hydrodynamic advantages afforded dolphin calves while swimming in infant position, beneath the mother dolphin's abdomen. The infant position advantage is less pronounced than the advantage enjoyed by dolphin calves swimming in echelon position (close beside the mother dolphin's midsection), but is statistically significant, allowing the dolphin calf to exert less effort to move at a specific speed when in infant position than when swimming independently. The second manuscript, still in review (Noren and Edwards, in review), presents the first empirical analysis of the hydrodynamic effects of late pregnancy on swimming kinematics of female dolphins. Morphological changes during late pregnancy, particularly the large increase in frontal

cross section, as well as the decreased amplitude of propulsive movements by the flukes, lead to significant decreases in swim performance. Results from both of these studies are being combined with earlier related studies in a hydrodynamics-based energetics model developed to investigate the potential for dolphin mother-calf separation and subsequent calf mortality due to tuna purse seine chase in the ETP.

Investigations of Dolphin Reproductive Biology – A doctoral dissertation (Kellar et al. 2008) was completed examining the pregnancy patterns of spotted dolphins in the ETP. One hypothesis for the lack of recovery of the spotted dolphin population in the ETP is that continued chase and encirclement by the tuna fishery negatively affects reproduction.

Insufficient life history sampling in this region over the last decade makes traditional estimation of population reproductive rates impossible. The current reproductive patterns of these dolphins were examined using a molecular method to assess pregnancy state from blubber progesterone concentrations in biopsy samples. Blubber progesterone was quantified in 212 biopsies from female offshore spotted dolphins sampled between 1998 and 2003 in the northeastern tropical Pacific. These concentrations were found to be sharply bimodal with no value observed between 49 ng/g and 87 ng/g, a finding consistent with the concentration gap between known pregnant and non-pregnant dolphins. Given that high blubber progesterone ($\geq$ 87 ng/g) indicates pregnancy, we found that 11.8% of the biopsied females were pregnant. This is substantially lower than an estimate of the proportion pregnant found in the fishery kill over the same region (22.3%) between 1973 and 1992. To try to ascertain the potential cause of this discrepancy, the relationship between pregnancy and fishery exposure was analyzed, and we found that pregnant females were exposed to significantly less fishery activity than non-pregnant ones ($P < 0.046$), suggesting that the fishery has an inhibitive effect on pregnancy. However, there are several caveats to this finding, and how this relationship might explain the discrepancy between these data sets is unclear. Currently, we are revisiting these results with an updated algorithm for calculating relative effort exposure and the results should be finished by May 2011. We also examined and modeled spatial patterns of reproduction and found that pregnancy was more aggregated than random ($P = 0.020$), with the highest proportion pregnant in the mouth of the Gulf of California, an area with relatively low reported fishery activity. Because this is a first attempt at applying this technique to a wild population, we are careful in the interpretation of the results. However, it appears that it is a promising tool for assessing reproductive rates in populations of free-ranging cetaceans.

In 2009, work began quantifying the levels of progesterone in spinner dolphins to replicate this study in another fishery-impacted species. To date 189 animals have been processed; hormones have been measured and pregnancy determination is complete. The next step is to analyze and add a spinner-dolphin-specific fishery exposure index to these data and assess the relationship between reproduction and exposure.

Investigations of the ETP Ecosystem and Its Change over Time – A new study of variations in thermocline depth and stratification in the eastern tropical and North Pacific is underway (Fiedler et al., in prep.). Time series from 1958-2008 were decomposed into seasonal, interannual cycle, and trend components using state-space techniques. On shorter time scales, interannual variations related to the El Niño-Southern Oscillation (ENSO) are seen, as expected in both

tropical (Wyrtki 1985) and extratropical waters (Miller et al. 1997). Long-term regional trends, either monotonic or with one or more change points resembling climate regime shifts, are observed. Such changes in upper-ocean structure, and associated ecosystem effects, are well-known in some regions. For example, Roemmich and McGowan (1995) found increasing stratification in the California Current with a concomitant decrease in zooplankton biomass. In the ETP, the pycnocline has shoaled but become more stratified. The thermocline influences nutrient input to surface waters, which limits primary productivity throughout this region. Potential ecosystem effects of the observed long-term trends will be explored. Further analysis will quantify the extent to which interannual cyclic variability observed at higher latitudes, for example in the California Current, is related to ENSO.

Vilchis and Ballance completed a retrospective study analyzing trophic level of seabirds in the eastern Pacific warm pool during the past 50 years. They set out to gauge effects of the 1976-77 regime shift of the Pacific Ocean in a tropical and pelagic community of seabirds. Using study skins of historical specimens from museum collections, they retrospectively (1960-2006) measured stable carbon (δ13C) and nitrogen (δ15N) isotopes for a suite of ecologically and phyolgenetically diverse seabirds from the eastern Pacific warm pool. In this region, seabirds generally forage by depending on subsurface predators to drive prey to the surface or by associating with oceanographic features that increase productivity or aggregate prey in space or time. They did not find community-wide changes in response to the 1976-77 regime shift. Instead, they found evidence suggesting a trophic shift and or change in foraging area for sooty terns (*Onychoprion fuscatus*) and a long-term decrease in feather δ13C for the eastern Pacific warm pool seabird community. This long-term decrease in feather δ13C can be accounted for by the Suess effect and not a decline in primary productivity of the system. Vilchis and Ballance hypothesize that a deepening trend in thermocline depth in the eastern Pacific warm pool is affecting sooty terns more so than other species in the subsurface predator-dependent guild which depend less on smaller subsurface predators like skipjack tuna. The manuscript of this study is currently in review.

Metrics of Ecosystem Impact of the ETP Purse Seine Fishery – Previous analyses in the ETP compared the relative impacts of three methods of purse seine fishing based only on numbers of individuals in the bycatch (defined here as non-target species, either retained or discarded), and found levels of discarded bycatch in floating-object sets thousands of times greater than in dolphin sets and hundreds of times greater than in unassociated tuna sets. We expanded the analysis by examining a mix of ecosystem indicators based on the type and amount of biomass of species and functional groups caught (total removals) by the fishery. Removals (landings and discards) were compared in three ways: trophic level, replacement time, and diversity. Mean trophic level was computed as the biomass-weighted mean of the trophic level of each ecological group, the mean replacement time as the biomass-weighted mean of the replacement time (1/(production/biomass ratio)) of each ecological group, and diversity of removals using the Shannon diversity index.

Total annual biomass removals averaged more than 500,000 t per year over the 16-year period from 1993 to 2008 and were dominated by the primary target species, yellowfin, skipjack, and bigeye tunas. Fishing by setting on dolphins, floating objects, and unassociated schools of tuna averaged 30%, 44%, and 26% of the biomass removed, respectively. The mean trophic levels of total removals were similar for the three fishing methods, and there was no indication of a

decline in trophic level over the 16-year period. Mean time to replace biomass varied by fishing method: lowest for dolphin sets (0.48 years), intermediate for unassociated sets (0.57 years), and highest for floating-object sets (0.74 years). Diversity of removals across the whole time period was lowest for dolphin sets (0.64), intermediate for unassociated sets (1.30), and highest for floating-object sets (1.41). Diversity declined over time for floating-object and unassociated sets and increased for dolphin sets, so that the differences among the three fishing methods were less in 2008 than in 1993. Discards (non-retained bycatch and target species), as a percentage of total removals in biomass, were 0.8% for dolphin sets, 11.0% for floating-object sets, and 2.3% for unassociated sets. The tunas were the major component (77%) of the discards. Discarded bycatch in floating-object sets was 16 times greater than in dolphin sets and 9 times greater than in unassociated sets, not thousands and hundreds of times greater, when biomass and replacement time are considered. Additional studies into the ecological impacts of ETP fisheries are planned with the aim of advancing ecosystem approaches to management in this ecosystem and more broadly. A manuscript has been submitted for publication (Gerrodette et al., in review).

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