

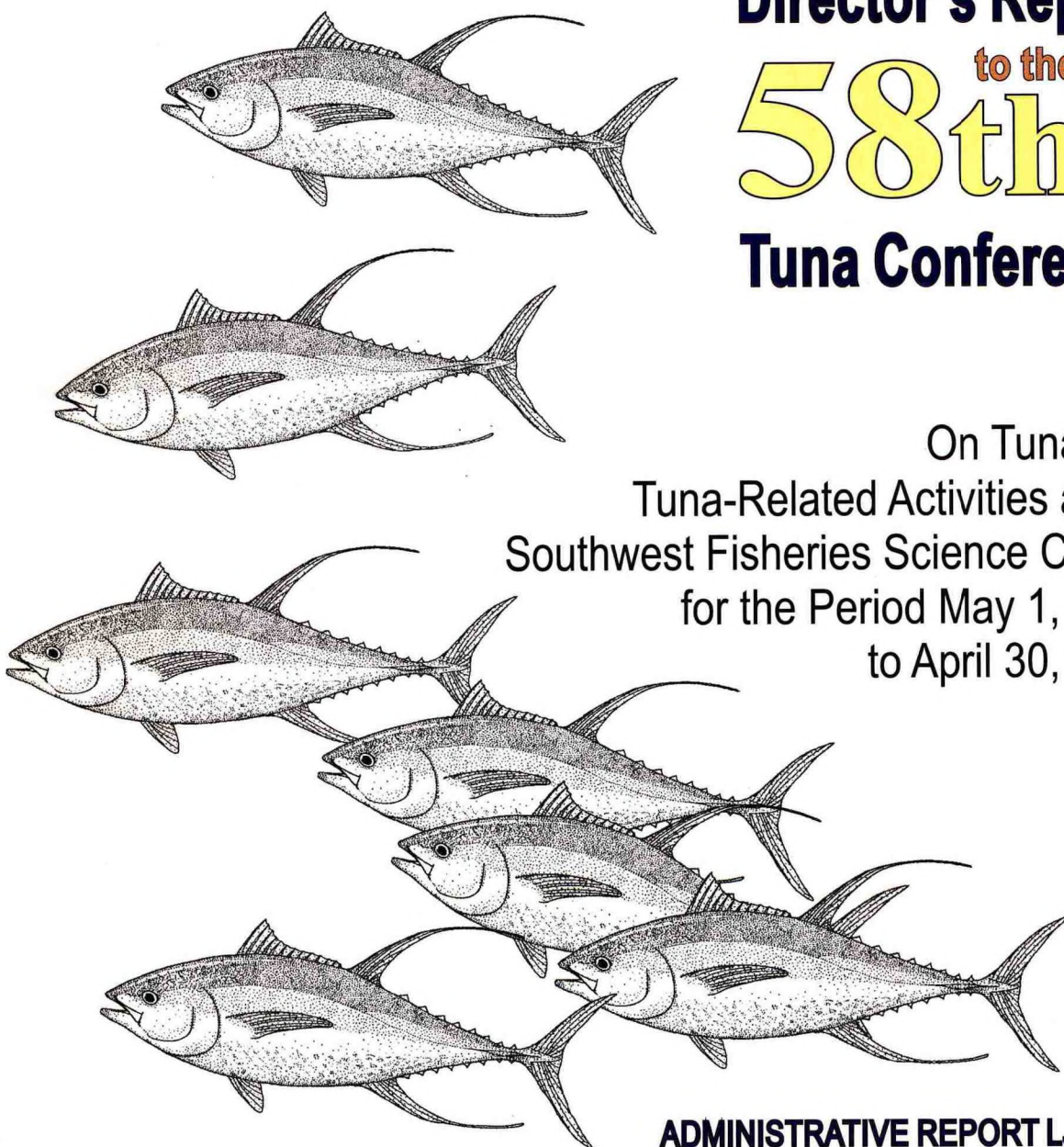
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National Marine Fisheries Service
Southwest Fisheries Science Center

Director's Report to the **58th** Tuna Conference

On Tuna and
Tuna-Related Activities at the
Southwest Fisheries Science Center
for the Period May 1, 2006
to April 30, 2007

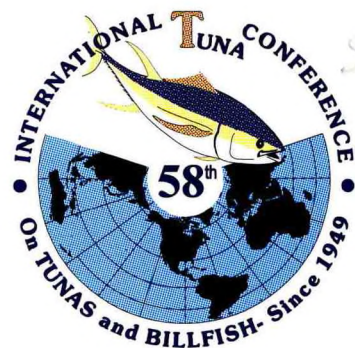


ADMINISTRATIVE REPORT LJ-07-03

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**DIRECTOR'S REPORT TO
THE 58th TUNA CONFERENCE ON
TUNA AND TUNA-RELATED ACTIVITIES
AT THE SOUTHWEST FISHERIES SCIENCE CENTER
FOR THE PERIOD MAY 1, 2006 TO APRIL 30, 2007**

**William W. Fox, Science Director
National Marine Fisheries Service, NOAA
Southwest Fisheries Science Center
8604 La Jolla Shores Drive
La Jolla, California 92037-1508**

May 2007

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ADMINISTRATIVE REPORT LJ-07-03

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Introduction

This report summarizes research conducted by the Southwest Fisheries Science Center relating to tropical tunas, albacore, billfishes, oceanic sharks and protected species associated with their fisheries for the period May 2006 through April 2007. The Center's biological, economic, and oceanographic research was focused on supporting the information needs of regional fishery management councils, international scientific working groups and committees, and the National Marine Fisheries Service. Major tuna-related activities included stock assessments, socio-economic research, research on interactions between fisheries and protected species, and mathematical modeling of fish movements and fishery interactions. The data collection and analysis were aimed at maintaining healthy U.S. and world fisheries, populations of protected marine species and fish habitat, and ensuring that the most effective fishing regulations and international treaties are carried out. In addition, Center scientists were active in tuna-related international forums such as the International Scientific Committee for Tuna and Tuna-like Species in the North Pacific Ocean and the Scientific Committee of the Western and Central Pacific Fisheries Commission.

William W. Fox Jr., Ph.D.

Science Director, Southwest Region
National Marine Fisheries Service

May 2007
La Jolla, California

I. U.S. TUNA PURSE SEINE FISHERY IN THE WESTERN-CENTRAL PACIFIC

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, as part of U.S. obligation under the South Pacific Tuna Treaty. Information from U.S. vessels licensed to fish under the treaty is collected by the NMFS Pacific Islands Regional Office in American Samoa and transmitted to the Southwest Fisheries Science Center (SWFSC) in La Jolla, California, where scientists computerize logbooks, landings, and biological data collected from the fleet.

In 2006, the size of the U.S. purse seine fleet (13 vessels) fell to the lowest level since the start of the treaty and continued a downward trend in fleet size that started in 1998. Fifteen vessels fished in 2005. Preliminary estimates of the 2006 catch (62,800 metric tons, t) also decreased 27% from the 86,100 t caught in 2005. Skipjack tuna continued to dominate the 2006 catch (84%), followed by yellowfin tuna (13%) and bigeye tuna (3%).

Sets on floating objects (logs and fish aggregation devices) in 2006 accounted for 80% of the total sets, a 43% increase from the 56% recorded in 2005. Sets on free-swimming schools of tuna accounted for 20% of the sets, a 53% decrease over 2005 (43%). The increased use of floating object sets in 2006 decreased the number of days per trip (-4%), while the number of trips per set and sets per trip remained approximately the same as those recorded in 2005. The overall catch rate decreased slightly to 27 t per day fished in 2006, compared to 28 t per day fished in 2005.

Biological samples collected from the tuna catch provided estimates of sizes of fish caught on a species-by-species basis. Length measurements were taken from 33,295 yellowfin, skipjack, and bigeye tunas, an increase of 12% from the number of fish sampled in 2005 (29,689).

II. SUPPORTING U.S. INVOLVEMENT IN INTERNATIONAL ORGANIZATIONS

SWFSC scientists are involved in research projects that are designed to support requirements of international highly migratory species (HMS) agreements of which the U.S. is a party. In collaboration with scientists from the NMFS Pacific Islands Fisheries Science Center (PIFSC) and foreign scientists, Center scientists conducted research to support U.S. involvement in the Inter-American Tropical Tuna Commission (IATTC), Western and Central Pacific Fisheries Commission (WCPFC), South Pacific Tuna Treaty, U.S.-Canada Albacore Treaty, and International Scientific Committee for Tuna and Tuna-like Species in the North Pacific Ocean (ISC). In this section, brief descriptions of some of the contributions and activities during the past year, May 2006-April 2007, are described.

Review of IATTC Stock Assessments – Under the leadership of SWSFC Director William W. Fox Jr., a team of U.S. scientists participated in IATTC's annual review of stock assessment results for 2006. The review is organized by the IATTC for the purpose of peer review by outside scientists of the IATTC staff's stock assessment analyses and conclusions prior to release to the IATTC Commission. The 2006 review focused largely on the heavily exploited yellowfin tuna (275,000 t catch in 2005) and bigeye tuna (104,000 t) stocks of the eastern Pacific Ocean. For both these stocks, the reviewers concluded that the IATTC analyses were the best available and supported the conclusion that overfishing is occurring. Furthermore, the analysis supported the conclusion that the bigeye tuna stock is overfished owing to excessive fishing over a series of years that has depressed the stock to well below that required to support maximum sustainable yield. The stocks are projected to remain in a depressed state if recent high fishing mortality is maintained in combination with average to below average annual recruitment.

Review of Stock Assessments by the Scientific Committee of the WCPFC – The Scientific Committee of the WCPFC is responsible for providing advice to that commission on the HMS fisheries and resources exploited by the international fleet in the western-central Pacific Ocean. The Committee held its second session in 2006 to review results of research on the HMS stocks of the region. Center scientists participated in the meeting as members of the U.S. delegation led by Robert Skillman of the PIFSC. The major focus was on the status of the high-yield stocks of yellowfin tuna (423,000 t in 2005), bigeye tuna (163,000 t), skipjack tuna (1,443,000 t) and South Pacific albacore (54,000 t). Participants concluded that the abundance of both yellowfin tuna and bigeye tuna has been declining and overfishing is occurring. With current levels of high fishing mortality and average recruitment levels, the stocks are projected to advance into an overfished state. For skipjack tuna, the catch is at record high and the stock is in good condition. The current high catch is sustainable provided recruitment does not persistently fall below the long-term average. For South Pacific albacore, an updated but not a full stock assessment was undertaken. The results indicated that the effects of fishing on the stock were low (10%) and greater fishing mortality and yield is possible without threat to the sustainability of the stock as a whole.

Monitoring the U.S. Tuna Purse Seine Fishery in Western-Central Pacific Ocean – U.S.-registered tuna purse seine vessels have been fishing in the western-central Pacific Ocean under a fishing access treaty arrangement, the South Pacific Tuna Treaty, since 1988. Monitoring of this fishery is performed by the NMFS Pacific Islands Regional Office with the Center staff, led by Al Coan, providing support for processing the fishery data collected from this fishery. In 2006 and 2007, the staff provided summarized fishery data for the annual consultation of parties to the treaty. The data showed a steady decline in U.S. vessels' participation, from a high of 49 vessels in 1994 to 13 vessels in 2006. The catch (62,800 t in 2006) declined by 69% over the same period. Average catch rate for the fishery was 26 t per day fished in 1994 and 27 t per day fished in 2006.

Monitoring the U.S. Albacore Troll Fishery in the North Pacific Ocean – The U.S. and Canada have a reciprocal fishing- and port-access agreement, the U.S.-Canada Albacore Treaty, for albacore in the North Pacific Ocean. The treaty allows controlled fishing access for albacore in each party's Exclusive Economic Zone (EEZ) and albacore landing privileges in designated ports. Monitoring of the fishery is performed by the NMFS Southwest Regional Office with Center staff providing support for processing the fishery data. In 2006, the staff, led by John Childers, prepared summarized data for use at the annual consultation of parties, as well as served as the agent for timely exchange of fishery data with Canadian counterparts. The summarized data showed that in 2005, 652 U.S. vessels fished for albacore and spent 25,519 days fished. This fleet caught 9,122 t of albacore at an average rate of 50 fish per day fished. The average size of fish was 70 cm fork length.

Advancing the Work of the ISC – The U.S. is a member of the ISC along with Canada, China, Chinese Taipei, Japan, Korea, Mexico, the IATTC, the North Pacific Science Organization, the Secretariat of the Pacific Community, and the Food and Agriculture Organization of the United Nations. The purpose of the ISC is to enhance scientific research and cooperation for conservation and rational utilization of the 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 six working groups—statistics, bycatch, Pacific bluefin tuna, albacore, swordfish and marlins—that report to a Plenary body. Results of the ISC are made available to participating members and HMS regional fisheries management organizations of the Pacific Ocean.

In March 2006, the SWFSC hosted the Sixth Meeting of the ISC. Results of that meeting and the Center's contributions were reported in last year's report to the 57th Tuna Conference. Since then, Center staff has made progress with ISC research assignments and participated in several meetings of the ISC working groups. Two are noteworthy. The work plan of the Albacore Working Group for 2006-07 called for major involvement by Center staff in performing a full stock assessment. The staff, led by Paul Crone, prepared for and participated in two meetings of this working group. The first meeting was to organize input data, discuss preliminary analyses of abundance indices and establish procedures for conducting the full stock assessment at the second meeting. The second meeting was held November 28-December 5, 2006. Data compilation, including expanding the data time series backward for a decade, for the stock assessment was behind schedule and had to be completed at the second meeting. Participants completed that task and performed key computer runs with the stock assessment model. Additional wrap-up runs were made after the meeting. Results (e.g., the 2005 total catch was 62,000 t, down from 86,000 t in 2004, and spawning stock biomass in 2005 is near the average level for the past two decades) are being assembled for a report to be made available in May.

Center scientists also conducted research to advance the work of the ISC Marlin Working Group. The work plan objective of the working group is to complete a full stock assessment for North Pacific striped marlin by July 2007. The scientists, led by Kevin Piner, were involved in all stages (e.g., data preparation and evaluation and assessment model development and testing) of the working group's activities required for meeting this objective. During March 19-26, 2007, the working group met to make computer runs and complete the stock assessment. The results of that assessment are being assembled for a working group report. Among the results is the finding that fishing mortality rate has increased threefold between 1970 and 2003, the catch was at a low level of 1,500 t in 2005, and that the spawning stock biomass has steadily declined over this period, recording the lowest level in 2005.

Center scientists are responsible for organizing the Seventh Meeting of the ISC Plenary, which will be held in Busan, Korea, July 25-30, 2007. Work started in June 2006 and is in collaboration with the host, National Fisheries Research and Development Institute, Busan.

Pacific Fishery Management Council Activities – Suzy Kohin and Steve Stohs currently serve on the HMS Management Team of the Pacific Fishery Management Council. The team met several times in 2006 and early 2007 in support of the recently implemented fishery management plan for U.S. West Coast HMS fisheries. The main issues facing the team and Council over the past year have been: (1) development of responses to overfishing declarations for bigeye and yellowfin tuna; (2) consideration of an exempted fishing permit to allow a limited number of vessels to fish in a currently closed area of the California/Oregon drift gillnet fishery without jeopardizing protected species; (3) consideration of an exempted fishing permit for a single vessel to conduct longline fishing for swordfish within the U.S. West Coast EEZ without jeopardizing protected species; (4) characterization of the recent U.S. albacore fishing effort; (5) modification of existing management measures, including a change in vessel marking requirements for recreational charter vessels and the implementation of bag limits for albacore and bluefin tuna fished in California waters; and (6) preparation of the 2006 Stock Assessment and Fishery Evaluation (SAFE) Report.

III. HIGHLY MIGRATORY SPECIES DATA COORDINATION

A data coordination team has been working since 2002 towards better coordination of the collection and maintenance of HMS data at the NMFS PIFSC, Pacific Islands Region, Southwest

Region, and SWFSC. The team is co-chaired by staff from the Southwest and Pacific Islands Fisheries Science Centers. During August 2006, the team met to discuss progress on resolving issues that were identified at its last meeting and to identify any new issues. Significant progress had been made on establishing a data portal (<http://swfscdata.nmfs.noaa.gov>) for sharing information and for allowing public access to summary information. The site contains an HMS data catalog with metadata descriptions and summaries of each data set maintained by the members. Meeting minutes, data submissions and guidelines, minimum suggested requirements for data collections, and data management policies are also available on the site. The site is still undergoing further development to add fisheries and enhance displaying of data. Special working groups have been organized to develop data management and collection guidelines and are continuing work on enhancing the data catalog. Significant progress was also made in establishing deadlines and protocols for submission of data to regional fishery management organizations. The next annual meeting of the HMS data coordination team is scheduled for August 2007 in San Diego, California.

The team has been also working closely with the national Fishery Information System (FIS) project at NMFS headquarters. A member of the SWFSC and PIFSC staff is on the FIS Program Management Team. The team is currently working on funding projects for 2007. The projects for 2007 have been directed to further the development of a national permits system, a one-stop shop for landings statistics for the U.S, to enhance the InPort meta data entry, and to support development of a uniform electronic reporting plan for the U.S. A pilot one-stop shop project will look at gathering landings for six major species from the Pacific Coast Fisheries Information Network (PacFIN), Alaska Fishery Information System (AKFIN), the Northeast and Southeast Regions. FIS will gather NMFS personnel involved in electronic data collections to develop a plan to move the majority of NMFS data collections to electronic means in the near future. FIS is also encouraging all NMFS Regions to continue to populate InPort with metadata on their data collections.

The SWFSC chairs a FIS Professional Specialty Group that is looking at reconciling the different types of fishery data that NMFS collects. The first step is to reconcile logbook and landings data, and future steps will look at logbooks and observer data, observer data and landings data, logbook and permits data, and landing and permits data. The SWFSC has received the beta version of an application to reconcile SWFSC collected logbook data with PacFIN landings. The application, which was developed under an FIS contract, will allow for the matching of logbook trips with landings recorded on PacFIN. The matching will enhance data quality in the two databases by enabling the correction of differences in species, gear identification and pounds landed.

HMS information technology specialists at the SWFSC are also improving data collection methods. Two sets of electronic calipers (1.6-m measuring calipers connected to Allegro handheld computers) were used by port samplers in Oregon and Washington in 2006 to collect length measurements of albacore from U.S. troll and baitboat landings. Data collected by the calipers have been entered into the HMS data system. Funding is being sought to purchase and field more calipers and to enhance the transfer of data from the calipers to the HMS data system. Specialists also developed a stand-alone electronic logbook software application that was deployed on three vessels (12 trips) in 2006. The application will be made available to the entire fleet in 2007. Vessel captains will enter data directly to the logbooks; the daily records will be stored on disk and the disk will be transferred (via e-mail or regular mail) to the SWFSC upon completion of a trip. Funding is being sought to make fishermen-suggested modifications to the application. Approval of electronic signatures by NMFS is needed before the application is truly electronic.

The SWFSC HMS team continued to process and load HMS data into the Center's new HMS database. South Pacific Tuna Treaty logbook, landings, size and species composition data for 1988 to the present have been loaded into the system and an application for Web-based data entry was completed. U.S. albacore troll logbook and size frequency data are currently being transferred to the system and a Web-based data entry application was completed. Data management forms have also been developed for the system. An application has been developed to provide data entry capability for longline and purse seine observer data into the HMS system and is being tested. The observer data will be used to interface with a national bycatch and discard data system to prepare a national bycatch and discards report. Both the HMS database system and the proposed national system are in Oracle. Harpoon, longline and gillnet fishery data and other observer data and data summary applications will be added to the HMS database in 2007.

IV. PACIFIC ALBACORE FISHERIES

U.S. troll 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 2005.

Fishing areas for South Pacific albacore extend eastward from the east coast of New Zealand to approximately 110°E and between 30°S to 45°S. This fishery begins in late December and continues until early April of the following year. The international troll fleet in the South Pacific for an albacore fishing season consists of 20 to 60 vessels. For the 2004-05 season, eight U.S. troll vessels fished for albacore in the South Pacific. Bycatch species are sometimes reported in vessel logbooks and they include yellowtail, dolphinfish, and skipjack, as well as yellowfin, bigeye and bluefin tunas.

The NMFS routinely processes the following information for use in stock assessments and for fishery monitoring: (1) landings obtained from U.S. West Coast states; (2) logbook data collected from cooperating fishermen; and (3) length-frequency data obtained through port sampling of U.S. albacore troll and baitboat vessels operating in the Pacific Ocean.

The SWR provides logbooks to fishermen, who record fishing information and return the logbooks to the SWFSC. Beginning in April 2005, logbooks have become mandatory under the requirements of a new HMS fishery management plan. Length-frequency data are collected through a Pacific States Marine Fisheries Commission contract to Washington, Oregon and California state fisheries agencies and from the NMFS office in American Samoa. Data collected during the 2005 season were analyzed by SWFSC staff and summarized in a report issued in August 2006. Highlights of the report are given below. Summary of data collected during the 2006 season will be available in August 2007.

Summary of U.S. North and South Pacific Albacore Troll Fisheries – U.S. troll vessels landed 9,122 t of North Pacific albacore in 2005, compared to 13,346 t landed in 2004. Annual catches over the last 10 years averaged 12,347 t. The most productive fishing areas in 2005 were in waters off Washington and Oregon. U.S. catches of South Pacific albacore decreased from 995 t in the 2003-04 season to 725 t in the 2004-05 season. South Pacific catches averaged 1,583 t over the past 10 years.

Catch per unit of effort (CPUE) in the North Pacific fishery decreased from 87 fish per day in 2004 to 51 fish per day in 2005. Total effort increased substantially, from 23,979 days fished in 2004 to 25,252 days fished in 2005. CPUE for the South Pacific fishery decreased from 115 fish per day in the 2003-04 season to 65 fish per day in 2004-05, while effort has remained approximately the same at 1,478 days fished in 2004-05.

A total of 21,362 albacore were measured during the 2005 North Pacific season. The average fork length (FL) of sampled albacore in 2005 is 70 cm (15.6 lb or 7.1 kg), compared to 68 cm (14 lb or 6.4 kg) in 2004. Two size-class modes are centered at 65 cm FL (3 years old) and 80 cm FL (5 years old) in the North Pacific length-frequency samples.

During the 2004-05 South Pacific season, a total of 102 albacore were measured. The average fork length of South Pacific albacore that were sampled is 72 cm (17 lb or 7.6 kg), compared to an average fork length of 66 cm (13 lb or 5.8 kg) from the 2003-04 season. Because of the low sample size, individual size-class modes were difficult to distinguish.

Preliminary estimates of 2006, North Pacific landings indicate that landings have increased 40% over those reported in 2005 to 12,600 t. South Pacific estimated 2005-06 season landings are 700 t.

Cooperative Research with the American Fishermen=s Research Foundation – SWFSC scientists are working with the American Fishermen=s Research Foundation (AFRF) 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 includes:

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 from Washington, Oregon and California following sampling and data processing instructions provided by the SWFSC, where the database is maintained. A total of 21,362 fish were sampled in 2005. In recent years, fishermen have also collected biological data during selected fishing trips and with AFRF support to augment data collected through the port sampling program. Following procedures established by SWFSC scientists, fishermen provided a randomly selected length distribution from eight trips during the 2005 season. The sample information provided by the fishermen was found to be generally similar to that collected through the port sampling program.

North Pacific Albacore Logbook Data Sampling Program – A logbook sampling program also has been in place through the AFRF since 1961, whereby albacore troll fishermen voluntarily submit their fishing records to the SWFSC. The implementation of a new HMS fishery management plan in 2005 requires the submission of a logbook from each trip that a participant in the fishery makes. These data are primarily used to develop relative indices of abundance, which subsequently provide valuable auxiliary information for fine-tuning stock assessment models. Fishing records are submitted directly to the SWFSC; in 2005, the U.S. troll fleet submitted 1,178 logbooks. A database for logbook data is also maintained at the SWFSC.

North Pacific Albacore Archival Tagging Project – The SWFSC and AFRF have been working together since 2001 to use archival tags to study movement patterns and general life history strategies of juvenile (ages 2-5) North Pacific albacore. Archival tag data provide detailed

information of North Pacific albacore migratory behavior and distribution. The original objectives of the long-term study were to deploy 500 archival tags in albacore over the period 2001-06 to obtain movement information from 50 fish.

Through October 2006, 504 archival tags have been deployed in cooperation with the commercial albacore fishing fleet. There have been 17 recoveries, most of which were at liberty for over a year and have provided over 5,000 days of data and nearly 8 million samples of water depth, water temperature, and body temperature from tagged fish. Daily location estimates from the tagged fish and the minute-by-minute depth and temperature data are providing new insights regarding their vertical and horizontal movements and feeding behavior, which were impossible to obtain without this technology. Fish ranged from the southern tip of Baja California to Vancouver Island and from the coast of North America to the central North Pacific. Most fish demonstrated a common diurnal pattern of repetitive deep diving (routinely to depths of 250 to 300 m) during the day while remaining near the surface at night. Refinements to the location estimates were made using composite sea surface temperature data from satellite imagery. Analysis of the detailed time series data reveals that albacore spend most of their time in areas where surface water temperatures are 15 to 19°C. However, their vertical movements bring them into deeper waters with temperatures as low as 9°C. During dives, internal heat is conserved with visceral temperatures averaging 3 to 4° above ambient water temperatures with apparent feeding episodes discernable as transient visceral temperature changes.

Given the lower than expected recovery rate, tagging efforts will continue in 2007. Ultimately, the data will help determine stock structure and improve CPUE standardization based on habitat-use patterns, information critical to developing sound stock assessments regarding the status of this valuable marine resource.

International Collaboration on North Pacific Albacore Research – Researchers participated in an assessment-based meeting of the ISC Albacore Working Group, which was held in November-December 2006 in Shimizu, Japan, and was attended by researchers from Japan, Taiwan, and Canada. The meeting primarily focused on assessment-related activities, including: (1) completing a formal assessment based on a backward-simulation Virtual Population Analysis (VPA) model; (2) developing a preliminary forward-simulation Stock Synthesis 2 (SS2) model; (3) continuing discussion regarding appropriate biological reference points for potential management of the stock; (4) research studies needed to improve knowledge of albacore biology; and (5) maintenance and improvement of the ISC Albacore Working Group database catalog, which contains catch, length, and catch and effort information collected from the various international fleets that harvest the stock. Scientists from the SWFSC presented various papers that addressed the meeting topics above. Assessment results indicated the population is currently being harvested at a spawning potential ratio of roughly $F_{23\%}$. Figure 1 presents the spawning stock biomass (historical, current, and projected) time series estimated from the assessment model. Finally, further fishery-related statistics and conclusions concerning the status of the stock generated from the assessment research are presented in the overall meeting report.

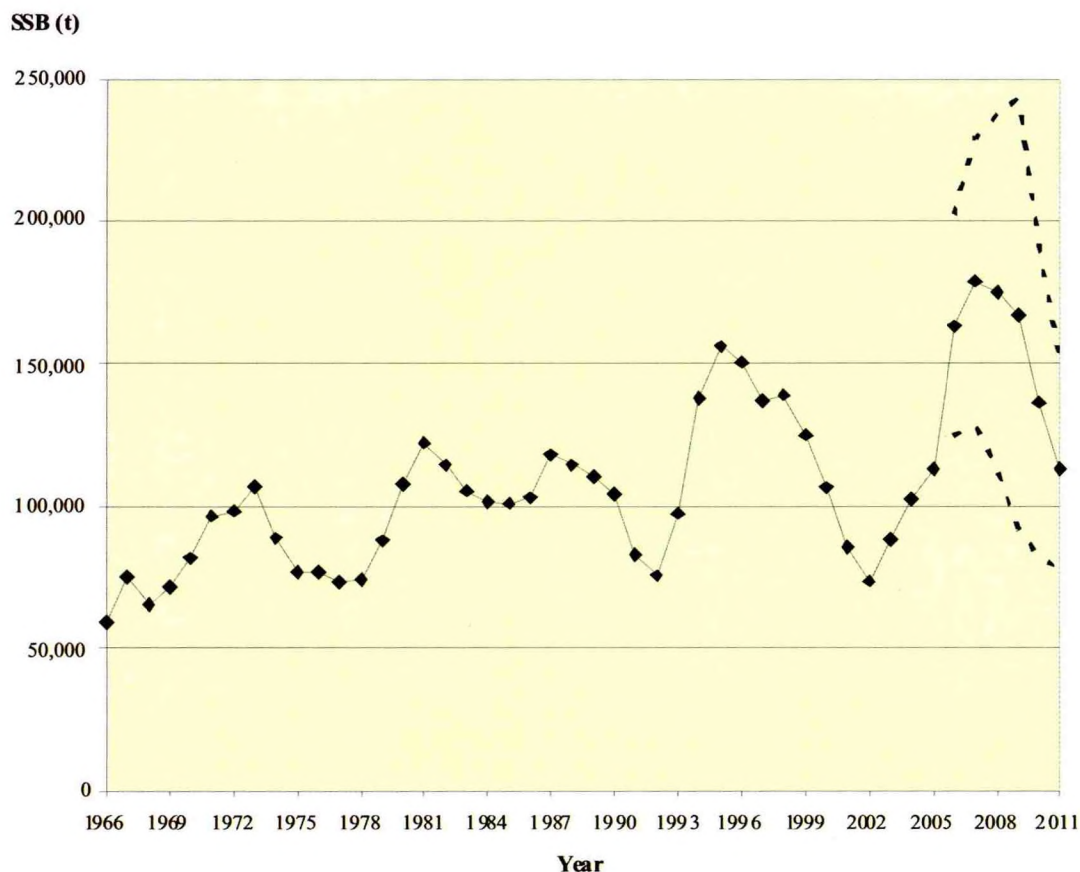


Figure 1. North Pacific albacore spawning stock biomass (SSB in t) time series estimated from the VPA-based interval assessment model conducted in 2006. Projected estimates from 2006-11 are bounded by an 80% confidence interval.

Work continues concerning population analysis efforts based on a fully integrated, length-based and age-structured modeling platform (SS2), which in the near future is expected to become the formal model for assessing the status of the albacore stock in the North Pacific Ocean; currently, a robust baseline model configuration has been developed. In this context, an intersessional meeting will be held in December 2007 that will address two assessment-related topics: (1) refinement of the SS2 model, along with (2) reevaluation of CPUE indices of abundance utilized in the current assessments of this species, including discussion regarding prioritizing/omitting particular indices, spatial/temporal characteristics of the indices, age-aggregated vs. age-specific time series, etc. Finally, the next formal assessment-related meeting of the ISC Albacore Working Group is scheduled for late 2008.

V. IDCPA RESEARCH CONDUCTED BY THE SWFSC

Research conducted under the International Dolphin Conservation Program Act (IDCPA) during 2006 was focused on evaluating 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) following a period of significant reductions in observed dolphin mortality in the ETP tuna purse

seine fishery. Research activities included: (1) an ETP ecosystem and dolphin abundance survey; (2) data analyses, processing and publication; (3) the second in a series of joint NMFS/IATTC workshops on bycatch reduction; (4) a small purse seine vessel monitoring and observer program via contract; and (5) long-term research planning.

***Stenella* Abundance Research Survey** – In 2006, SWFSC conducted a *Stenella* Abundance Research (STAR) cruise to survey marine mammals and their habitat in the ETP. The primary objective of the STAR cruise is to investigate trends in the population size of the species of dolphins most affected by the ETP tuna purse seine fishery. This is the tenth year of similar investigations conducted during the past 20 years, with previous cruises in 1986-90, 1998-2000, and 2003. Using an ecosystem approach, we conducted research on physical and biological oceanography (dolphin habitat), mid trophic-level fishes and squids (dolphin prey), 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 manage the ETP tuna purse seine fishery.

Dr. Lisa Ballance is the chief scientist for the STAR project, including STAR 2006. STAR 2006 was conducted aboard two vessels, NOAA ships *David Starr Jordan* and *McArthur II*, between July and December 2006. The ships covered almost 40,000 nm of trackline, including 18,000 nm of daytime survey effort. STAR 2006 was conducted in collaboration with Instituto Nacional de la Pesca (INP), Mexico; Instituto Nacional de Ecología (INE), Mexico; Universidad del Valle de Guatemala (Dra. Lucía Gutiérrez), Guatemala; Institut français de recherche pour l'exploitation de la mer (IFREMER), France; Ministerio de Ambiente y Energía (MINAE), Costa Rica; and Instituto del Mar del Peru (IMARPE), Peru.

Biopsy samples and photographs of cetaceans were collected on an opportunistic basis in order to perform genetic and steroid analyses. This information is expected to enhance our understanding of stock structure and allow estimation gender and pregnancy rates when appropriate (see sections on 'Genetic population structure' and 'Reproductive status of ETP dolphins' below for more details on these studies). In 2006, the aerial photogrammetry team photographed 75 cetacean schools, including 59 schools of the target species; 43 schools were photographed to calibrate observer estimates of school size. Additionally, data from all images will be used to measure cetacean length, estimate calf production for populations sampled, and back calculate birth rates to determine reproductive seasonality.

In addition, STAR 2006 included several island stops. On Clipperton Island, the scientific party conducted a masked booby nesting site survey and photo-documented vegetation growth as a result of introduced rat predation on Clipperton land crabs, which eat the vegetation providing suitable nesting habitat for masked boobies. At the request of IFREMER, STAR scientists conducted a bathymetric survey of the eastern and northern extent of Clipperton Ridge. On Malpelo Island, Colombia, scientists investigated the Nazca booby diet.

More information on STAR 2006 is available at <http://swfsc.noaa.gov/prd-star.aspx>.

Data Analyses, Processing and Publication – The SWFSC's investigations of dolphin stocks historically depleted by the ETP tuna purse seine fishery (pan-tropical spotted and spinner 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 in 2006 included: (1) direct work on depleted ETP dolphin stocks; (2) investigations of dolphin reproductive biology and energetics; and (3) research on non-depleted ETP cetaceans.

Depleted Dolphin Stocks

Life history. A comprehensive life history study is in progress to update vital parameters for eastern and whitebelly spinner dolphins. This study is improved over previous studies primarily for three reasons: (1) the sample size is much larger (~ 1,200 specimens vs. ~ 250 specimens for each subspecies); (2) ages were estimated based on a calibration study; and (3) sample preparation and handling was improved.

Two papers detailing comprehensive analyses of short-beaked common dolphin life history data were completed (Danil and Chivers, submitted) and published (Danil and Chivers, 2006). These studies are the first detailed analyses of the biological data collected from common dolphins incidentally killed in the tuna purse seine fishery between 1975 and 1993. The data set includes reproductive data for 700 female common dolphins and age estimates for 405 of these females. The availability of these data will provide additional insight about the small delphinid populations impacted by the fishery and parameter estimates for the development of population dynamics models by George Watters and colleagues.

Dolphin stock assessments. During 2006, the SWFSC continued to publish and develop stock assessment models for both depleted and non-depleted dolphin stocks in the ETP. A paper summarizing stock assessment models for northeast offshore spotted and eastern spinner dolphins that were developed in response to the IDCPA was submitted to a peer-reviewed journal and the manuscript is currently being revised. New models were developed for at least three stocks of short-beaked common dolphins (these stocks were not depleted). All of the models described here are Bayesian models that are fitted to estimates of abundance from line-transect methods and conditioned on historical estimates of mortality. The models are parameterized to consider hypotheses such as temporal changes in stock productivity and carrying capacity or under-reporting of true mortality. This type of work will continue in 2007.

Genetic population structure. The results of a genetic analysis of population structure of coastal spotted dolphins (*Stenella attenuata graffmani*) in the ETP were reported. Both mitochondrial DNA sequences and microsatellite loci indicated the presence of four distinct populations from northern Mexico south to Ecuador and Peru. Except for the northernmost population, these populations were also found to be distinct from samples of offshore spotted dolphins (*S. attenuata attenuata*). This is the first study to show evidence of subdivision in this population, suggesting that further studies are needed to identify proper stock boundaries for management.

To date, the analyses indicated significant population subdivision in coastal spotted dolphins (Escorza et al., 2005), suggesting that the historical impact of the tuna fishery might have been higher than previously thought. Subsequent work with a larger sample size revealed higher levels of structure (Rosales, 2006), indicating that further structure might be uncovered as available samples increase. Samples of coastal spotted dolphins in areas where samples had not been previously collected were added to the SWFSC tissue archive as a result of STAR 2006 survey efforts.

Reproductive status of ETP dolphins. The SWFSC Protected Resources Division has developed a method to diagnose pregnancy status from the blubber attached to most cetacean skin biopsies. With sufficient samples, this allows estimation of pregnancy rates for entire populations. The protocol detects the surge in systemic progesterone that occurs with the development of a fetus. Biopsies with as little as 100 mg of blubber tissue have yielded enough

progesterone to determine reproductive status. We have determined the relationship between progesterone levels and reproductive stages (pregnant or not pregnant) in seven species of delphinids (including *S. attenuata*, *S. longirostris* and *Delphinus delphis*) using specimens incidentally killed in eastern Pacific purse seine and gillnet fisheries. While working with these animals, for which pregnancy status is known through gross observations, we have conducted blind tests to estimate success rate of determining pregnancy using the progesterone quantification protocol alone. The method has been 100% successful in correctly identifying known pregnant dolphins (n = 56) and 99% successful in correctly identifying known non-pregnant ones (n = 149).

Currently we are using this procedure to delineate potential patterns in reproduction and ultimately using it to estimate the pregnancy rates of the ETP dolphins stocks impacted by the fishery.

Dolphin Energetics

During the period May 2006 through April 2007, several studies initiated in prior years were published. The SWFSC Dolphin Energetics Group continued to focus on investigating potential effects of tuna purse seine chase and encirclement on dolphin mothers and calves.

A review of dolphin calf behavioral and physiological development indicated that ETP dolphin calves up to at least 12 months postpartum are likely to have physiological difficulty remaining near or reuniting with their mothers during evasion of tuna purse seine sets, and that behavioral dependence on the mother is likely to persist through at least two years of age (Noren and Edwards, 2007).

An investigation of the ontogeny of swim performance (mean and maximum swim speed) and swim effort (stroke amplitude and tail beat frequency) of independently swimming bottlenose dolphins (*Tursiops truncatus*) demonstrated that swimming capabilities are extremely limited in calves. Limitations in swim speed were associated with an inability to achieve mature thrusting capabilities, as stroke amplitude and distance covered per stroke remained significantly lower than adult levels during the first year postpartum. These results indicated that other factors, such as underdeveloped physiology, act synergistically with small body size to limit independent swim performance in dolphins during ontogeny (Noren et al., 2006).

Furthermore, an investigation of size-related differences in power production and swim speed duration in northeastern spotted dolphins (*S. attenuata*) mothers and calves demonstrated that the power required by neonates to swim unassisted was 3.6 times that required of an adult to swim the same speed. Weight-specific power requirements decrease as dolphin calves increase in size, but power estimates for 2-year-old spotted dolphin calves are still about 40% higher than power estimates for adults, to maintain the same speed. Discrepancies in power production are probably ameliorated under normal circumstances by calves drafting next to their mothers, and by employing burst-coast or leap-burst-coast swimming, but the relatively high speeds associated with evasion behaviors during and after tuna sets likely diminish use of these energy-saving strategies by calves (Edwards, 2006).

The combined message from these studies is that dolphin calves, particularly during the early months, are quite likely to have difficulty maintaining proximity to their mothers during fishery evasion and are at substantial risk of unobserved fishery-related mortality if permanently separated from their mothers before two or three years of age.

Non-depleted ETP Cetaceans

Refinement of ETP common dolphin life history analyses continued in 2006. Spatial and temporal analyses of length and age data in combination with oceanographic data revealed that common dolphin stock boundaries may be fluid during significant environmental events. Specifically, northern or southern stock animals may move into the Costa Rica Dome area during El Niño events in search of more favorable habitat.

Bycatch Reduction Workshops – On October 3-4, 2006, the SWFSC, Southwest Regional Office, and the IATTC Secretariat convened a workshop in La Jolla, California, to develop alternative gear and practices for reducing bycatch of turtles, sharks, juvenile tunas and other species in the tuna purse seine fishery in the ETP. This was the second in a planned series of workshops on this topic, the first of which was held in May 2005.

During this workshop, 24 participants from the NMFS, IATTC staff, academia, environmental organizations, fishing industry and Mexican government critiqued the strengths, weaknesses, and potential conservation benefit of four research proposals. The four proposals discussed during this workshop were among 12 originally drafted for and discussed during the May 2005 workshop and were chosen for further discussion because they were thought to be most cost-effective and have the greatest conservation benefit. The proposals included: (1) time-area closures: use of historical bycatch data and simulation studies; (2) use of bait and/or deterrents to reduce incidental capture of sharks in sets on FADs; (3) modifications to the design of FADs to reduce turtle entanglement; and (4) a suite of technologies (e.g., sorting grids, vacuum pumps, etc.) requiring ship time to be tested during a single research cruise.

Following a discussion of the four proposals, workshop participants expressed general support for the proposed research and made several recommendations on priorities. These included using IATTC Captain's Workshops to utilize fishermen to design and evaluate FAD modifications and developing a list of research questions that could be answered by fisheries data in the IATTC database for consideration and potential approval by the IATTC Bycatch Working Group. In addition, workshop participants recommended several possible funding sources, as neither NMFS nor the IATTC Secretariat has identified funding for this work. Specific research priorities and funding recommendations will be detailed in the final workshop report, which will be available during the 2007 IATTC annual meeting scheduled for June.

Port Sampling and Observer Program to Monitor Small Purse Seine Vessels – The Agreement on the International Dolphin Conservation Program (AIDCP) requires observer coverage aboard 100% of the trips made by international large purse seine vessels (i.e., Class 6 vessels; those in excess of 363 t carrying capacity) in the ETP. However, approximately one quarter of all the vessels in the ETP purse seine fishery are smaller than this threshold. While all purse seine vessels are prohibited from harvesting tuna by chasing and encircling dolphins, small vessels are not required to carry observers. The absence of observer data to confirm the fishing practices of small purse seine vessels and data indicating that depleted dolphin stocks in the ETP are not recovering at the expected rate have led to concern among the AIDCP Parties. In particular, the Parties indicated there was a need for data to confirm that these vessels are fishing in accordance with the AIDCP and that small vessels are not a potential source of unobserved dolphin mortality.

To learn more about the fishing practices of these vessels, the SWFSC awarded a contract to the IATTC to expand the at-sea observer and in-port sampling programs currently

implemented in the ETP tuna purse seine fishery under the AIDCP. Port sampling under this contract began in January 2006. During 2006, the IATTC sampled 189 unloadings of Class 4 and 5 vessels in international ports. However, not all flag states with Class 4 and 5 purse seine vessels fishing in the ETP have agreed to allow their vessels to be sampled. No AIDCP Party with small purse seine vessels has agreed to the placement of at-sea observers at this time. Provided that flag states provide permission to do so, port sampling and at-sea observation onboard Class 4 and 5 purse seine vessels will continue through 2007.

SWFSC and IATTC staff are collaborating to analyze catch composition data (i.e., length-frequency and species) along with other catch characteristics collected by the IATTC during the period 2002-06 to explore the feasibility of using this type of data to identify when small purse seine vessels have harvested tuna in association with dolphins. The selected approach uses the length-frequency data of vessels with a carrying capacity greater than 363 t (Class 6 vessels; these vessels have known set type due to 100% observer coverage) to build a classification algorithm for predicting the purse seine set type of a length-frequency sample: dolphin-associated yellowfin ('dolphin' sets) versus non-dolphin-associated yellowfin ('non-dolphin' sets). The algorithm was then used to screen catch composition data from small vessels. Assuming that the fishing dynamics of size Class 6 vessels are similar to those of smaller vessels, this analysis has demonstrated an approach for identifying unusual length-frequency data of smaller vessels that could then be subject to further analysis. SWFSC and IATTC staffs are planning additional analyses of these data. Pending further refinements, this work has several potential applications, including using unusual length-frequency data from small vessels to estimate potential unobserved dolphin mortality for inclusion in stock assessments and for consideration in management. A report of this analysis is planned for later in 2007.

Long-Term Research Planning – In 2005 and 2006, SWFSC staff drafted a proposal titled "Long-term Research in the Eastern Tropical Pacific," which consists of detailed proposals for the fishery effects studies, as well as the population monitoring studies and ecosystem studies that together comprise our overall ETP work. The intent of the proposal is to guide future research. The proposal contains detailed budgets and structures in the following areas: (1) assessments of status and trends; (2) abundance and monitoring of pelagic dolphin populations; (3) cetacean stock structure in ETP pelagic waters; (4) abundance, structure and monitoring of coastal dolphin stocks; (5) ETP ecosystem studies; (6) fishery effects; (7) bycatch reduction; and (8) data management.

During 2006, the SWFSC contracted the Center for Independent Experts at the University of Miami to conduct an external review of the proposal, which has now been completed. The SWFSC is in the process of incorporating reviewers' comments and plans to circulate a revised proposal to interested entities during 2007.

VI. PELAGIC SHARK RESEARCH

The SWFSC's shark research program focuses on highly migratory pelagic sharks that occur along the U.S. Pacific Coast, including the shortfin mako (*Isurus oxyrinchus*), blue shark (*Prionace glauca*), and three species of thresher shark (common thresher, *Alopias vulpinus*; bigeye thresher, *A. superciliosus*; and pelagic thresher, *A. pelagicus*). Researchers are studying the sharks' biology, distribution, movements, stock structure and 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 and other highly migratory species. Some of the recently completed or ongoing shark research activities being carried out at the SWFSC are discussed below.

Shark Surveys – The blue, shortfin mako and thresher sharks are all taken in regional fisheries. Thresher and mako sharks are the most important commercial sharks and most popular sport species, especially in highly populous southern California. Although the blue shark is targeted in Mexico, it has little market importance in the United States but is a leading bycatch species in the U.S. West Coast drift gillnet 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 within U.S. Pacific Coast waters consists largely of juvenile sharks.

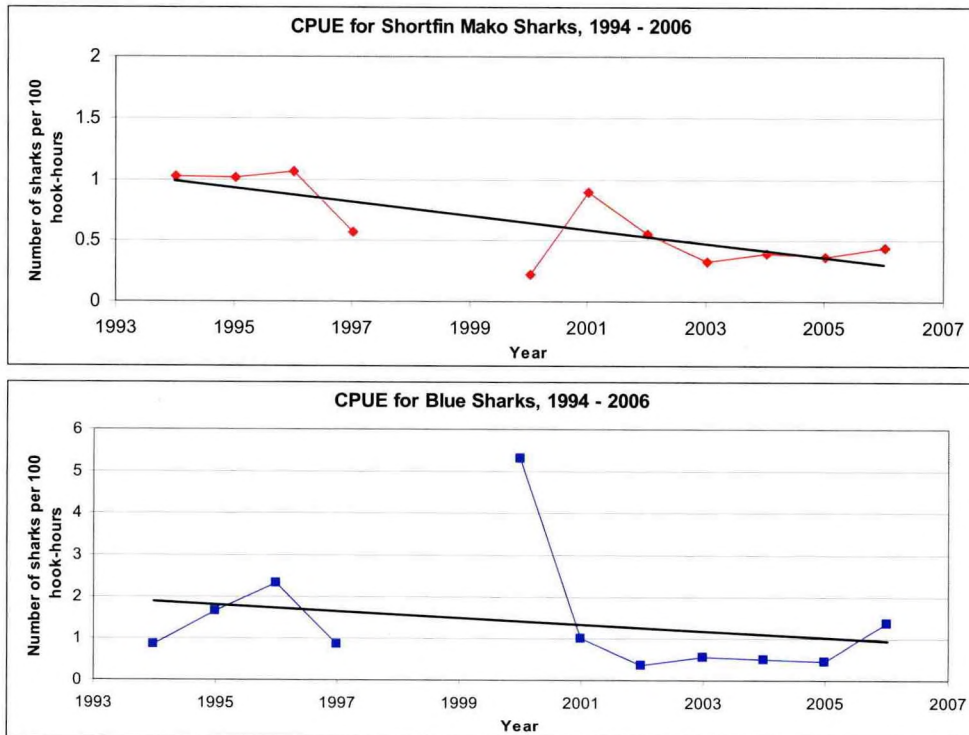
To track trends in abundance of juvenile and sub-adult blue and shortfin mako sharks and neonates of common thresher shark, surveys are carried out in the Southern California Bight each summer. Efforts to determine abundance trends from commercial fishery data have been complicated by changes in regulatory restrictions over time and in fishing methods and areas. These changes have resulted in wide swings in both catch rate and catch distributions that are difficult to interpret. Therefore, consistent, fishery-independent sampling was needed, with slightly different survey strategies required for the more oceanic shortfin mako and blue shark 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). The surveys have enabled the SWFSC to obtain a valuable abundance index for the shortfin mako, 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 in 1988-91. Abundance trend information is also obtained for the blue shark, which is compared to that obtained from observers in the California/Oregon drift gillnet and Japanese high-seas longline fisheries. The surveys are carried out cooperatively with the California Department of Fish and Game and Mexican researchers from Centro de Investigación Científica y de Educación Superior de Ensenada (CICESE) in Ensenada, Mexico. Satellite, conventional and oxytetracycline (OTC) tagging are also carried out to determine shark movements, behaviors and essential habitat and to obtain information on shark age and growth.

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 is defined, representative areas will be identified and 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 will complement the fishery-dependent data available through the nearshore set net fishery and pelagic drift net fishery to provide measures of relative and absolute abundance of common thresher shark for stock assessment models.

Juvenile Mako and Blue Shark Abundance Survey – In 2006, the SWFSC conducted its thirteenth juvenile shark survey since 1994. The team of scientists and students deployed a total of 5,733 hooks at the 28 survey sampling stations in the Southern California Bight. From catch, the index of relative abundance for juvenile sharks, defined as catch per 100 hook-hours, was calculated for the seven target survey areas. Catch for the 2006 survey included 90 mako sharks, 272 blue sharks, 2 common thresher sharks, 23 pelagic rays (*Dasyatis violacea*), 3 ocean sunfish (*Mola mola*) and 1 lancet fish (*Alepisaurus brevirostris*). The catch and effort data indicate the

overall survey catch rate was 0.445 makos per 100 hook-hours and 1.35 blue sharks per 100 hook-hours. The CPUEs for both species were somewhat higher than in 2004 and 2005; however there is a declining trend in CPUE for both species over the time series of the survey (Figures 2A and 2B). Apart from the survey sets in the seven target blocks, additional sets were made near shore targeting juvenile thresher sharks and offshore during some nights targeting swordfish. Neither juvenile threshers nor swordfish were caught during those sets, however some makos, blue sharks and pelagic rays were.



Figures 2A and 2B. Catch per 100 hook-hours for shortfin mako (top) and blue sharks (bottom), 1994-2006.

In addition to obtaining an index of relative abundance, secondary objectives of the cruise were to deploy satellite tags, continue age and growth studies and collect biological samples. Over the course of the cruise, 111 mako sharks were tagged with conventional tags and DNA sampled for analysis of movement and stock structure. Of these, 93 mako sharks were also marked with OTC for age and growth studies. In addition, two blue sharks, 12 makos and one thresher shark were tagged with satellite tags. The three *M. mola* that were caught were also tagged with pop-up satellite tags. The satellite tagging is being conducted in collaboration with the Tagging of Pacific Pelagics program (see below).

Neonate Common Thresher Shark Abundance Surveys – 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. Thresher sharks are the most valuable shark taken in commercial fisheries off California and are frequently caught by recreational fishermen. In 2006, the SWFSC team worked with the FV *Outer Banks* to sample in the California Bight from Point Conception to the Mexican border. Fifty longline sets were made in relatively shallow nearshore waters. Over the 17-day cruise, 266 thresher sharks and 2 shortfin mako sharks were caught. Roughly 60% of the threshers caught were young of the

year (<100 cm FL). Nearly all of the threshers and the two makos caught were injected with OTC for age and growth studies, tagged with conventional tags and released. In addition, pop-up satellite tags were deployed on seven thresher sharks.

While it is still too early to develop a pre-recruit index, a number of interesting patterns are apparent from efforts to date. Depth-stratified sampling revealed that over half of the neonates were caught in shallow waters of 0 to 46 m and almost all individuals are caught shallower than 90 m. The distribution of thresher sharks 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. The thresher shark pre-recruit survey provides the opportunity to enhance other ongoing studies of the SWFSC shark research group, such as age and growth, feeding, and habitat utilization studies.

Pelagic Shark Migration Studies – Since 1999, NOAA has been conducting studies using satellite technology to study the movements and behaviors of pelagic sharks. In recent years, these efforts have been made in collaboration with the Tagging of Pacific Pelagics program (www.toppccensus.org) and Mexican colleagues at CICESE to deploy satellite tags on blue, shortfin mako and common thresher sharks in the California Current. The goals of the project are to document and compare the movements and behaviors of these species and to link these data to physical and biological oceanography. This approach will allow us to both characterize the habitats sharks most frequently utilize or prefer and subsequently to better understand how populations might shift in response to changes in environmental conditions.

During the juvenile shark surveys in the summer of 2006, 12 mako, 8 thresher and 2 blue sharks were tagged with pop-off archival tags (PAT tags) and/or near real-time satellite-linked radio transmitters (SPOT tags). Since 1999, a total of 56 makos, 48 blue sharks, and 28 common threshers have been satellite tagged through these collaborative projects. From the deployments in 2006, all SPOT tags deployed on mako and blue sharks reported for at least six weeks following deployments, and four tags attached to mako sharks were still reporting after eight months. All animals remained relatively close to the coast between northern California and the tip of the Baja Peninsula, Mexico. This pattern is similar to that seen in other non-El Niño years. Data have been obtained from 9 of the 22 PAT tags, with most of the remaining tags due to report in May 2007. Four PAT tags have been recovered providing detailed depth and temperature data. Analysis of the recent mako shark data is currently being conducted by our colleagues at CICESE in Ensenada, Mexico. For the *M. mola* tagged during 2006, all tags popped off as scheduled after eight months. Similar to the sharks, the mola were all relatively close to shore off California and Baja California when the tags popped off.

The SPOT and PAT tags have provided some exciting insights into the biology of the blue, mako and thresher sharks. To date, over 200 tags have been deployed on the three species. While all species utilize the coastal waters in the Southern California Bight and regularly cross the border into Mexico, key differences among years and species are apparent. For example, over the period covered by the satellite tracks, the blue sharks tagged have traveled the farthest offshore to waters south of Hawaii. Movement patterns for mako sharks show distinct differences among years (Figure 3A). For example, sharks tagged in 2004 traveled much farther from shore over the subsequent year than those tagged in 2003 and 2005. Interestingly, during late 2004-05 El Niño conditions were present, and the shift in distribution may reflect a change in the availability of food nearshore. An examination of daily dive patterns from three sharks in particular

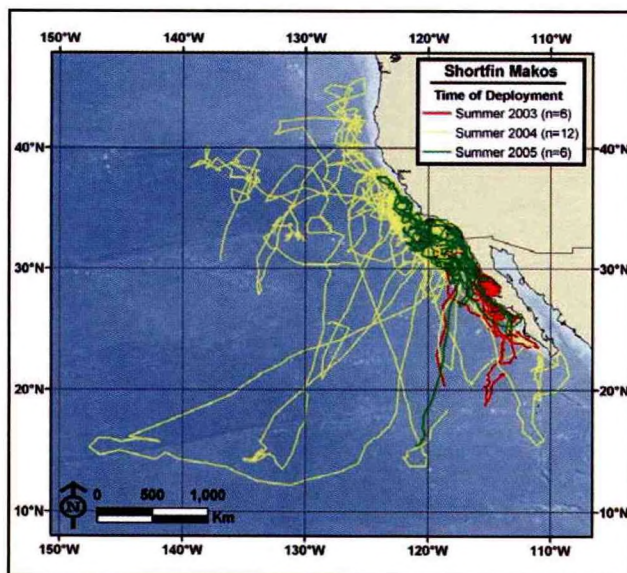


Figure 3A. The tracks of mako sharks tagged in 2003, 2004 and 2005.

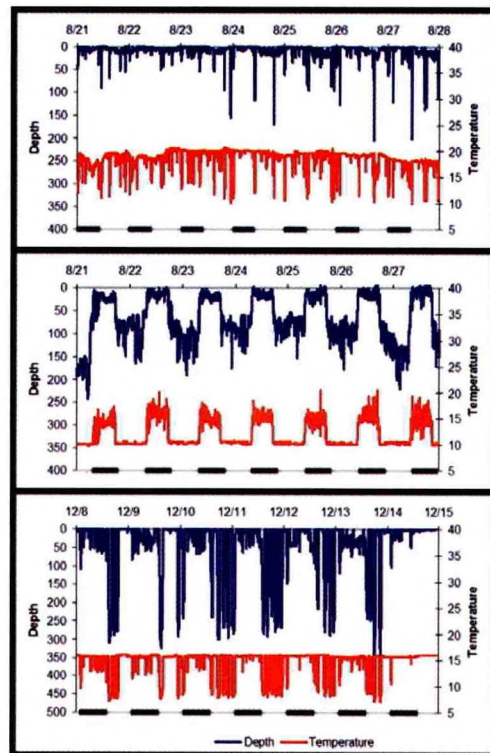


Figure 3B. The temperature (red) and depth (blue) data recorded every 2 min for mako (top), thresher (middle) and blue (bottom) sharks.

reveals distinct behaviors (Figure 3B). In comparison to the mako shark, the blue and thresher sharks showed distinct diurnal patterns. The greatest difference in day and nighttime depth distributions was apparent for the thresher shark, which spent more time at depth during the day than either of the other two sharks. We are currently analyzing records from additional recovered tags to determine whether these behavioral differences demonstrate species-specific preferences. Future efforts will focus on deploying satellite tags on larger sharks over a broader geographic range. To date, most sharks have been tagged in the Southern California Bight and are juveniles, reflecting the composition of the local fisheries.

Pelagic Shark Feeding Ecology – Since 1999, work has continued investigating the feeding ecology of the blue, shortfin mako, common thresher and bigeye thresher sharks. All are captured at various times in the drift gillnet fishery for swordfish. Distinct diet differences among the species and among years have been identified.

While the bigeye thresher is less frequently encountered than the other three species, during the August 2005-January 2006 fishing season stomachs were collected from 19 bigeye threshers. These stomachs, along with a few collected during previous years have provided new information on the feeding habits of these little known sharks. Of 25 stomachs examined, 22 contained food representing a total of 19 taxa. The six most important prey species were the barracudinas (*Paralepididae* family; GII=52.0), followed by Pacific hake (*Merluccius productus*; GII=33.8), Pacific saury (*Cololabis saira*; GII=23.1), jumbo squid (*Dosidicus gigas*; GII=21.4), Pacific mackerel (*Scomber japonicus*; GII=18.0), and northern anchovy (*Engraulis mordax*; GII=16.6). Previous studies have suggested that species of the deep scattering layer may be important in the bigeye thresher's diet; however, it appears that off California midwater and epipelagic species are important, as are some benthic species. The large number and diverse taxa suggest that the bigeye thresher is an opportunistic feeder that forages over a broad range of habitats to exploit locally abundant prey.

Mako and Thresher Shark Age, Growth and Maturity – Age and growth of mako and thresher sharks are being estimated from ring formation in vertebrae. Critical to this method is validation with OTC, which lays down a mark at the time of injection. When the shark is recaptured and the vertebrae recovered, the number of rings laid down over a known time period can be counted.

Since the beginning of the program in 1997, 948 OTC-marked individuals have been released during juvenile shark surveys. In 2006, 93 makos and 192 common thresher sharks were tagged and marked with OTC. As of January 2007, 50 mako sharks and 12 common thresher sharks have been recovered (6.2%). Of these, vertebrae were collected and returned from 28 sharks. Time at liberty ranged from 7 to 1,594 days with net movements of individual sharks as high as 2,648 nm.

Preliminary analysis of OTC-marked shortfin mako vertebrae indicate that juveniles and sub-adults lay down two bands of unequal size each year; however, as they mature and transition from a more coastal distribution to more oceanic, the calcification pattern in the vertebrae appears to change, with hyaline and calcified zones becoming narrower and more equal in relative size. This is an extremely interesting finding, since the question of whether the shortfin mako lays down one band or two bands per year has been an ongoing uncertainty, with independent labs reporting conflicting results. Tetracycline marking and release of tagged juvenile and sub-adult thresher sharks off California was initiated only recently to verify the timing of ring formation. Preliminary results from common thresher sharks indicate that they lay down one band per year.

In addition to the work with OTC-marked individuals, studies are being conducted with non-marked common thresher and shortfin mako sharks using various visualization techniques to identify bands. The purpose is to expand and refine previous ageing studies using a larger sample size with accompanying information on sex and maturity stage. Samples of both species are obtained from the California/Oregon driftnet fishery with additional mako samples coming from the Japanese longline fleet, which is widely distributed across the Pacific. The vertebrae are sectioned, X-rayed, and imaged using a Spot camera and microscope. The study will use the criteria developed in the validated (OTC-marked) ageing study for mako and thresher sharks along with the length-frequency distribution of the catches of the respective fleets.

Blue Shark Dynamics in the U.S. Pacific Coast EEZ – An examination of the factors affecting blue shark catch rates in the California/Oregon drift gillnet fishery and the California-based high-seas longline fishery for swordfish is being conducted using general additive models (GAMs). Based on Japanese fishery data, in the central North Pacific it is believed that blue sharks segregate by sex and size, with neonates and small juveniles of both sexes inhabiting higher latitudes, and adults migrating to lower latitudes to breed. Sub-adults are widely distributed in a band from 30 to 50°N latitude with males found at lower latitudes than females. Preliminary results of the GAM analyses for the drift gillnet fishery in the U.S. West Coast EEZ support the migration model developed from the Japanese fishery data. Most blue sharks taken in the fishery are small juveniles and sub-adults. Larger sub-adult males are found between latitudes 32 to 35°N with small juveniles found to the north. In contrast, larger sub-adult females are found in higher numbers at latitudes 35 to 40°N. Overall, catch rates are highest where water temperature is 14 to 18°C. A standardized CPUE for the drift gillnet fishery index is being developed based on the GAM analyses.

Bioaccumulation of Mercury in the Common Thresher and Shortfin Mako Shark – The common thresher and shortfin mako sharks are the two most valuable shark species landed for human consumption on the U.S. West Coast. As apex predators, these two species have the potential to bioaccumulate high concentrations of methyl mercury in their tissues. Despite a potential health risk, there are no comprehensive published studies of the mercury levels in these fish. The goals of this study were to describe the bioaccumulation of mercury with size for both shark species in the eastern North Pacific and determine if mercury levels in market-size fish are a cause for concern.

Over the course of this study the muscle tissue from 38 common thresher and 33 mako sharks were analyzed for methyl mercury (Hg) concentrations. For both species a relatively large size range was sampled allowing for examination of ontogenetic effects (thresher 63 to 241 cm FL; shortfin mako 75 to 330 cm FL). All of the common thresher muscle sampled in this study, regardless of size, had total Hg levels below the U.S. Food and Drug Administration and Environmental Protection Agency-established maximum limit of 1.00 ppm for human consumption (average 0.13 ppm). A similar result was found for shortfin mako sharks 160 cm FL or less, with the exception of one (mean = 0.47 ppm; sd = 0.24 ppm; n = 21). In contrast, all shortfin makos greater than 160 cm FL had muscle Hg levels exceeding this 1.00 ppm threshold (mean = 2.14 ppm; sd = 0.46 ppm; n = 13).

This study is the first to establish the ontogenetic relationship between Hg and size for both of these apex predators and the difference likely reflects differences in ecology and physiology. We conclude that there is minimal cause for concern of the human consumption of common threshers and juvenile shortfin makos of sizes predominantly taken in the U.S. West Coast drift gillnet fishery but large adult makos should be avoided.

Feeding Ecology and Trophic Status of the Common Thresher and Shortfin Mako Shark Inferred from Stable Isotope Analysis

– The common thresher and shortfin mako shark are suspected of undergoing ontogenetic diet shifts, but there is little quantitative evidence to support this. There is an ongoing SWFSC food habits study of these two shark species using stomach content analysis. Despite the high resolution of stomach content analysis it provides only a snapshot of foraging unless sampling is exhaustive in time and space and sample sizes are large. In contrast, stable isotope analysis gives an integrated view of foraging over time and provides an important complement to stomach content analysis. In brief, C^{13}/C^{12} and N^{15}/N^{14} ratios are fractionated by a particular amount at each increase in trophic level. Thus, by measuring these isotope ratios the predator's trophic level can be estimated.

To date, the isotope ratios in muscle and liver of over 30 animals of each species have been characterized over a broad ontogenetic range. The common thresher soft tissues showed a linear increase in $\delta^{15}N$ with increasing size (from 65 to 201 cm FL), suggesting a gradual trophic increase with ontogeny. The calculated range of trophic levels for thresher sharks was 3.0 to 4.3 for the larger animals. The muscle tissue $\delta^{15}N$ was always enriched relative to the liver tissue $\delta^{15}N$ from the same individual suggesting there may be seasonal shifts in diet. The low variability in the common thresher $\delta^{13}C$ suggests limited individual variability in their diet. $\delta^{13}C$ gives some insight into the source of carbon (energy flow) or food web dynamics but can be confounded by lipids and other unknown biotic factors

The results for the shortfin mako, in contrast, did not show a clear increase in $\delta^{15}N$ with increasing size. This suggests that there is not an ontogenetic shift in trophic level over a size range from 77 to 317. Trophic levels for the mako sharks ranged from 3.4 to 4.8. The muscle tissue $\delta^{15}N$ was enriched relative to the liver tissue $\delta^{15}N$ from the same individual in smaller sharks. In contrast, all females greater than 250 cm FL, the approximate size at sexual maturity, showed an inverse relationship. This could possibly be due to seasonal diet differences and could also reflect differences in the physiology of these female sharks as they reach sexual maturity. The high variability in the shortfin mako $\delta^{13}C$ suggests a more opportunistic diet with more individual variability.

To examine changes in trophic level over time, we are testing whether it is possible to profile the isotope ratios in hard parts where turnover rates are slow enough that the signature may be retained through time. In this study, vertebrae are being sampled at increasing distances from the center to examine ontogenetic changes in trophic level. These values will be compared to ratios in other tissues, muscle and liver over a range of sizes.

Population Structure of Shortfin Mako – In the Pacific Ocean, the shortfin mako is found in subtropical and temperate waters. Within their broad distribution it is unclear if and what stock structure might exist. Conventional tag returns have demonstrated that individual sharks are capable of large-scale, oceanic movement, with individuals tagged in southern California migrating as far as Hawaii, Acapulco, Mexico, and Japan; however, these data are limited by the small number of long-term tag recoveries. This study will test the hypotheses that 1) shortfin makos from the North and South Pacific are genetically distinct, and 2) female shortfin makos show reproductive site fidelity.

Population structure of shortfin mako in the Pacific Ocean is being inferred through mitochondrial DNA (mtDNA) analyses. Samples have been, and continue to be, collected throughout the Pacific Basin through cooperation with fisheries scientists in New Zealand ($n = 23$); Australia ($n = 20$); Chile ($n = 20$); and Japan ($n = 6$). Samples have also been collected from southern California ($n = 250$) and Hawaii ($n = 64$) through surveys and fishery observers. To

date, 93 samples from four of the sites have been examined. A wide diversity has been observed with 23 distinct haplotypes. Preliminary analysis reveals that genetic divergence increases with geographic distance. The locations in closest proximity—California and Hawaii, Australia and New Zealand, New Zealand and Hawaii—show no population subdivision. This is in contrast to the locations at the greatest distance where divergence is apparent. The population genetic structure of sharks from Australia is different from California and Hawaii. Sharks from New Zealand are also different from Southern California. Samples from Japan and Chile have yet to be examined.

In order to address the question of whether or not female makos display reproductive site fidelity, samples from neonates and young juvenile sharks are used whenever possible to avoid the confounding effect of sampling adults in feeding areas where distinct populations may overlap. Among shark species studied to date, it appears that many show significant genetic structure for mtDNA, in part due to reproductive behavior. Assuming that neonate makos (<70 cm FL) were born where they were caught, it is possible to show whether females return to specific nursery areas to pup. Population structure may exist if breeding and pupping sites are distinct even if the populations are mixing on feeding grounds. A better understanding of stock structure is critical to developing accurate stock assessments and improving fisheries management of this species.

VII. BILLFISH RESEARCH

The NMFS and the billfish angling community have been working together since 1963 to study various aspects of billfish biology and obtain an index of angler success in the Pacific Ocean. These efforts have created one of the longest time series available for recreational billfishing, charting trends in relative abundance for key species. The research includes recreational and commercial fishery monitoring, stock assessments, biological research into the life history and ecology of specific billfish species, and determining the economic importance of billfish resources. Two major components of that research are the International Billfish Angler Survey and the Billfish Tagging Program.

Billfish Angler Survey – In 2006, the data from the 2005 Billfish Angler Survey were analyzed and published in the Billfish Newsletter. In 2005, billfish anglers reported catching 2,471 Pacific billfish during 4,103 fishing days. The mean CPUE for all billfish in the Pacific for 2005 was 0.62, which is lower than the record set in 2003 of 0.87 but similar to the average over the last six years (0.62-0.66). This was a new high six-year average catch rate for the entire time series, which extends back to 1969. The lowest value (0.34) was reported for the late 1970s (1975-79) when billfish stocks were being impacted by large, international commercial fisheries. CPUE time series were extended for each of the main species caught (Pacific blue marlin, striped marlin, Pacific sailfish, and black marlin) in the main fishing areas (Tahiti, Hawaii, Baja California, southern California, Mexico, Guatemala, Costa Rica, Panama, and Australia). Figure 4 shows the CPUE time series by region for each species.

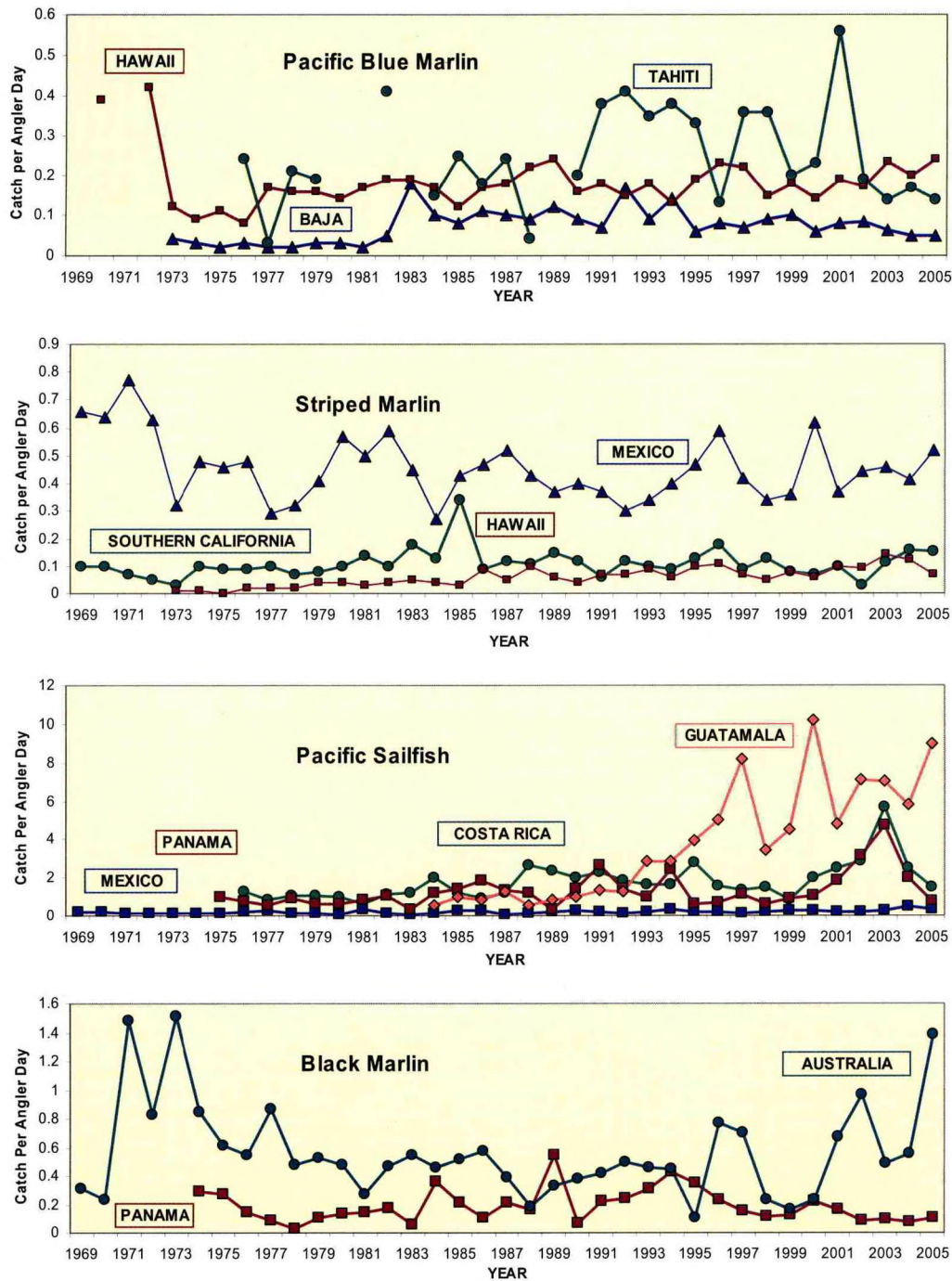


Figure 4. Catch per angler day are shown from 1969 through 2005 for Pacific blue marlin, striped marlin, Pacific sailfish, and black marlin.

Recreational Billfish Tagging Program – The SWFSC’s Billfish Tagging Program has provided tagging supplies to recreational billfish anglers for 44 continuous years. Tag release and recapture data are used to determine movement and migration patterns, species distribution, and age and growth patterns of billfish. This volunteer tagging program depends on the participation and cooperation of recreational anglers, sport fishing organizations, and commercial fishers.

Since its inception, over 54,000 fish of 75 different species have been tagged and released. Emphasis continues to be on the skillful tagging of billfish and bluefin tuna only. The tagging of other sport fish is not encouraged by this program. In 2005, 1,359 billfish and 122 other fish were tagged and released by 1,010 anglers and 173 fishing captains. In all, 728 blue marlin, 268 striped marlin, 164 sailfish, 184 spearfish, 9 black marlin and 5 unknown billfish were reported tagged and released in 2005. Table 1 shows the tagging effort for 2005 and the tag recoveries throughout the program's history.

Table 1. Summary of all fish tagged through the Billfish Tagging Program in 2005 with releases and recoveries for 1963-2005.

Species Name	Release 2005	Release Total	Return Total	Rate %
Striped Marlin	268	22,060	339	1.54
Sailfish	164	8,848	49	0.55
Pacific Blue Marlin	728	8,052	80	0.99
Marlin, unidentified	5	4,307	3	0.07
Black Marlin	9	3,365	69	2.05
Shortbill Spearfish	184	1,768	2	0.11
Shortfin Mako Shark	88	1,685	76	4.51
Broadbill Swordfish	0	520	17	3.27
Blue Shark	4	381	12	3.15
Yellowfin Tuna	1	348	24	6.90
Com. Thresher Shark	9	216	12	5.56
Skipjack Tuna	0	97	2	2.06
Albacore Tuna	0	87	1	1.15
Bluefin Tuna	1	57	8	14.04
Hammerhead Shark	1	54	2	3.70
Whitetip Shark	0	44	1	2.27
Atlantic Blue Marlin	1	42	0	0.00
Salmon Shark	6	33	1	3.03
Billfish, unidentified	0	24	2	8.33
Silky Shark	3	21	0	0.00
White Marlin	0	13	1	7.69
White Shark	0	8	0	0.00
Basking Shark	0	7	0	0.00
Whale Shark	0	4	1	25.00
Longbill Spearfish	0	3	0	0.00
Other Tunas	0	94	3	3.19
All Others	9	2,526	99	3.92
Totals	1,481	54,664	804	1.47

Adopt-a-Billfish Tagging Program – In 2002, scientists from the SWFSC and NMFS Southeast Fisheries Science Center joined forces with the Presidential Challenge billfish tournament series conducted off the coasts of Central America and Mexico to establish the Adopt-A-Billfish satellite tagging program. The focus in the Pacific Ocean has been on sailfish, the dominate billfish species caught by anglers in the eastern tropical and subtropical areas. During Phase I efforts (through 2005), 41 satellite archival tags were deployed on sailfish during tournaments in

central Mexico, Guatemala, Costa Rica and Panama. In August 2006, the program embarked on phase II to monitor sailfish in the Sea of Cortez and to study larger animals on their spawning grounds. The first research trip of Phase II was conducted August 8-10, 2006, at East Cape, Baja California Sur, Mexico, in collaboration with colleagues from two Mexican research institutes. Satellite tags were deployed on four sailfish and plankton net tows were conducted for billfish larvae. SWFSC researchers will use molecular techniques to identify billfish eggs and larvae from the net tow samples in order to determine whether billfish were spawning in the area. Although the sailfish were on the small size, averaging 40 lb or less, the tags of all four fish had reported by 120 days. Predictably, the sailfish moved to the southeast toward warmer water. Plankton samples are being analyzed to determine whether billfish were spawning in the area. Further efforts in the Sea of Cortez are planned for 2007.

International Collaboration on North Pacific Striped Marlin Research – In 2006, marlin assessment research at the SWFSC focused on meeting the ISC Marlin Working Group goal of completing a North Pacific striped marlin assessment in 2007. SWFSC scientists participated in an ISC Marlin Working Group meeting held in Shimizu, Japan. That initial meeting was held to prepare data for an assessment that should be completed in March 2007 at a meeting held in Chinese-Taipei. The SWFSC scientists were charged by the working group with producing initial assessment model runs for presentation at the March meeting in Taipei. In addition, SWFSC scientists, in conjunction with international colleagues, will use the initial modeling results to develop the final model configuration at the 2007 meeting. Results of the working group's assessment efforts will be presented at the 2007 ISC Plenary Meeting.

International Collaboration on Bluefin Tuna Research – In 2006, bluefin tuna assessment research at the SWFSC focused on completing a North Pacific bluefin tuna assessment in 2008. SWFSC scientists participated in an ISC Bluefin Tuna Working Group meeting held in Shimizu, Japan, in 2006, where an initial assessment of bluefin tuna was presented. That assessment of bluefin tuna was conducted using a Virtual Population Analysis, and several areas of uncertainty within the assessment were discovered. The SWFSC scientists are participating with international scientists in the working group to improve the reliability of the data and to develop alternative assessment modeling approaches. Results of the working group's efforts to improve the stock assessment of bluefin tuna will be presented at the 2007 ISC Plenary Meeting.

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