May 1998

INTERNATIONAL TUNA CONFERENCE
49th
On TUNAS and BILLFISH- Since 1949

Director's Report to the 49th Tuna Conference

On Tuna and
Tuna-Related Activities at the
Southwest Fisheries Science Center
for the Period May 1, 1997
to April 30, 1998

Administrative Report
LJ-98-04

National Marine Fisheries Service
Southwest Fisheries Science Center
P.O. Box 271
La Jolla, CA 92038

This report describes research at the Southwest Fisheries Southwest Fisheries Science Center (SWFSC) from May 1997 through April 1998 relating to tuna and other large pelagic fishes and to the protected resources associated with their fisheries. The work was conducted by the La Jolla Laboratory in California and the Honolulu Laboratory in Hawaii.

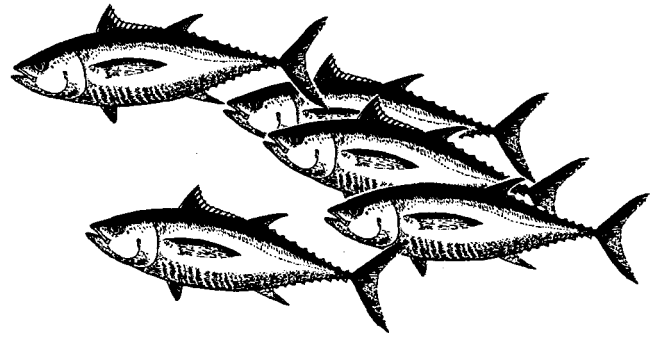
Much of the Center's research during the past year focused on supporting the information needs of the Western Pacific Regional Fishery Management Council (WPRFMC), international working groups and committees, and the National Marine Fisheries Service's (NMFS) Southwest Region and headquarters. The research included stock assessment and basic biological research to improve the scientific basis for effective fisheries management; socio-economic research for analyzing management alternatives, especially for limited-entry regimes; biological and technological research to eliminate or minimize interactions between fisheries and protected species; and mathematical modeling to improve our understanding of fishery interactions and fish movements, and to help predict some of the consequences of management actions.

The various reports that follow provide informal summaries of activities and events that have taken place at the Center since last year's Tuna Conference.

Michael F. Tillman, Ph.D.

Science Director, Southwest Region

May 1998
La Jolla, California



This Administrative Report is issued as an informal document to ensure prompt dissemination of preliminary results, interim reports and special studies. We recommend that it not be abstracted.

The Director's Report to the 49th Tuna Conference, the Tuna Newsletter, the Billfish Newsletter, and a list of other Center publications are available on the Internet at **http://swfsc.ucsd.edu.**

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SOUTH PACIFIC AND WESTERN PACIFIC TUNA FISHERIES

U.S. Tuna Fishery Annual Report—Monitoring catches in the U.S. tuna purse seine fishery in the western Pacific continued at the Center during the year. Highlights of a report on the 1997 U.S. fishery presented at the March 1998 meeting of the South Pacific Regional Tuna Treaty in Vava'u, Tonga, are given below:

During 1997, 33 U.S. vessels made total landings of 146,200 metric tons (t) of tuna from the western Pacific, down 2% from catches recorded in 1996. Landings consisted mainly of skipjack tuna (85,700 t) and yellowfin tuna (50,400 t), with lesser quantities of bigeye tuna (10,100 t). Catch rates in tons per day fished rose slightly in 1997 to 21.2 t per day fished, compared to 21.0 t per day fished in 1996. The yellowfin tuna catch rate of 8.4 t per day fished was double the rate recorded for U.S. vessels in 1996. However, the skipjack tuna catch rate of 12.8 t per day fished was well below the 1988–96 average of 18.2 t per day fished. Most fishing effort (92% of 7,400 days fished) was concentrated around Howland, Baker, Jarvis and Phoenix Islands. As in the previous year, fishing effort on drifting objects such as fish aggregation devices and logs continued to increase, and for the first time sets on tuna associated with drifting objects (59%) surpassed sets on free-swimming schools of tuna.

At the U.S. canneries in American Samoa, bigeye tuna landings were recorded as yellowfin tuna landings, and species composition samples were taken to obtain the catches by species. Species composition sampling indicated that the highest mixing of yellowfin and bigeye tunas (37%) occurred in drifting object sets on small fish (<9 kg). The average size of tropical tunas caught in 1997 was generally larger than for fish caught in 1996. Yellowfin tunas showed the largest difference in size (more than 10 cm) on average.

Forty-nine percent of the fishing trips in 1997 recorded discards of tunas and 78% recorded bycatches of other species. The catches listed above include 500 t of recorded tuna discards, the majority of which was small (<1.4 kg) skipjack tuna. Sharks comprised the largest share of bycatch species, followed by rainbow runner and mahimahi.

American Samoa Longline Fishery—The American Samoa longline fishery continued its rapid growth of the past 3 years. Most vessels in this fishery are small, 20- to 30-foot alia (open steel-hulled catamarans) setting 100-300 hooks hauled by hand cranks on 1-day trips within 25 miles of shore. During 1997, 22 longliners were active in the American Samoa fishery, making 1,536 sets. Approximately 421,000 hooks were set. The primary catch in 1997 was albacore tuna (13,103 fish) with a catch rate of 31.2 per 1,000 hooks. Yellowfin tuna was the second largest catch (947 fish), with a catch rate of 2.25 per 1,000 hooks.

WPYRG Meeting Held in June 1997—The seventh meeting of the Western Pacific Yellowfin Tuna Research Group (WPYRG) was held in Nadi, Fiji, June 18-20, 1997. G. Sakagawa, chief of the La Jolla Laboratory's Pelagic Fisheries Resources Division (PFRD), was chairperson of the group, which is composed of scientists, fishery representatives, and spokespersons from 16 countries. The meeting was attended by 38 participants, the largest number since the group was organized in 1990.

The group reviewed 23 technical papers on western Pacific yellowfin tuna fishery statistics, fishery developments, research results, and research progress. One result of the meeting was a determination that the overall declining catch, catch rate, and sizes of yellowfin tuna observed over the past few years and in several surface fisheries suggest that the stock is being exploited beyond the safe level for long-term maximum sustainable yield. The group, however, also noted that this might not be a stock abundance effect but rather a stock availability effect caused by the unfolding regime shift in the Pacific-wide oceanic environment. Analysis of catch information from the 1997 and 1998 fishing seasons, which were anticipated to occur with El Niño conditions that historically have made yellowfin tuna more available to the surface fisheries of the central-western Pacific, may help to address these questions.

The group also discussed the increasingly important issue of overfishing of bigeye tuna. Catches of bigeye have increased significantly and may be related to the expanding use of floating fish aggregating devices by purse seiners. The impact of higher catches on the bigeye stock is not clear because little is known of the biology and stock structure of this species.

The group developed a work plan for 1997-98 and will meet in 1998 to review results and progress.

INDIAN OCEAN TUNA FISHERIES

1997 First Quarter Indian Ocean Fishery Data—Data on the tuna purse seine fishery in the western Indian Ocean for the first quarter of 1997 were received from the Seychelles Fishing Authority and added to Center databases in March. The data, based on logbook returns from fishing vessels, are summarized in Lotus spreadsheets and cover the period 1983 to the present.

An average of 37 vessels (17 Spanish, 12 French, and a combined 8 Belizean, Mauritian, and Panamanian vessels) participated monthly in the tuna purse seine fishery in the western Indian Ocean during the first quarter of 1997, compared to 42 vessels recorded for the same period in 1996. The number of vessel-days fished in the first quarter of 1997 was 2,505, down 24% from the previous year. Catches of skipjack, yellowfin, and other tunas (mainly albacore and bigeye tuna) totaled 48,132 metric tons (t), down 38% from the previous year. The species composition was 54% skipjack tuna, 37% yellowfin tuna, and 9% other tunas. The catch rate for all species was 19.2 t per day fished, up 27% from the previous year. Catch rates for yellowfin and skipjack tunas were 7.2 t and 10.3 t per day fished, respectively, compared to 5.9 t and 7.0 t per day fished in 1996.

PACIFIC ALBACORE FISHERIES

1996 Albacore Fishery Data Summarized—Statistics on the U.S. North and South Pacific albacore fisheries were analyzed during the year and summarized in a report (SWFSC Admin. Rep. LJ-97-07) distributed last August. The total catch for these fisheries in 1996 was 17,800 metric tons (t) with an estimated value of $39 million. Following is a summary of the report:

North Pacific Fisheries–U.S. troll vessels completed a total of 1,200 trips during the 1996 North Pacific albacore fishery, which began in May and ended in early November. Catches of North Pacific albacore in 1996 continued to rebound from the low catches recorded in the mid-1980s and the early 1990s. Albacore landings for the 1996 fishery increased to 15,600 t from 8,200 t in 1995. Catch rates increased to 91 fish per day in 1996, compared to 47 fish per day in 1995. The average size of albacore decreased to 5.9 kg or 13 lb in 1996, compared to 6.7 kg or 15 lb in 1995.

South Pacific Albacore Fisheries–The 1995–96 South Pacific fishing season began in December 1995 and lasted through March 1996. A total of 44 trips were completed by U.S. troll vessels participating in the fishery. U.S. catches increased slightly to 2,200 t in the 1995–96 fishing season, compared to 2,000 t in 1994–95. Catch rates decreased substantially to 71 fish per day in 1995–96 season, compared to 150 fish per day in the previous season. The average size of albacore caught decreased slightly to 6.7 kg or 15 lb in 1995–96 from 7.2 kg or 16 lb in 1994–95.

Fishery Observer Data Collection—NMFS observers have accompanied U.S. troll vessels fishing in the North Pacific albacore fishery since 1990 to monitor trends in sizes of fish and areas of catch and fishing effort. During the 1997 North Pacific albacore season, an observer from the PFRD completed a 58-day trip aboard the U.S. troll vessel *Wendy Seaa* and collected size composition data from 8,866 fish. The average daily catch was 187 fish, with fish averaging 70 cm fork length (6.9 kg or 15.5 lb). The vessel unloaded 81 t of albacore caught mainly in the offshore area near 45°N latitude and 155°W longitude.

Effects of Preservation on Albacore Ovaries Examined—Results of a study on the effects of preservation on albacore ovaries by freezing and formalin indicate that largest oocyte diameters, used in maturity studies, are significantly different depending upon preservation method. Formalin-preserved samples produced larger mean oocyte diameters compared to frozen samples. Ovary weights were also significantly different depending on preservation method. On the average, formalin-preserved ovaries lost 2% of their fresh weight while frozen samples lost 6% of their fresh weight. Samples showed a large range of weight changes, including both gains and losses. The results were published in a manuscript "The effects of formalin and freezing on ovaries of albacore" by D. Ramon and N. Bartoo.

15th North Pacific Albacore Workshop Held in December—Center scientists presented eight papers at the 15th North Pacific Albacore Workshop in Nanaimo, British Columbia, December 3-5, 1997. At the workshop, 17 participants from Canada, Japan, Taiwan, and the United States reviewed working documents on North Pacific albacore and achieved several workshop objectives, including selection of biological reference points to be used for monitoring overfishing of the stock and comparing independent stock assessments of stock conditions. Stock assessment models used by the workshop indicate that the condition of the albacore stock is improving to a biomass level near maximum sus-

tainable yield, which was estimated to be in the 80,000 to 104,000 metric ton (t) range. If future catches do not increase greatly above the current level (70,000 t) and stock parameters remain at current levels, the biomass should continue to increase or remain stable.

American Fishermen's Research Foundation Activities—Also during the year, PFRD staff participated in a meeting of the board of directors of the American Fishermen's Research Foundation, to discuss proposed research, the 1997–98 South Pacific albacore fishery, and provide technical advice on projects funded by the board for the coming year. In one project, the board conducted an exploratory fishing effort for albacore off Chile in South America during a 30-day period in December and January. Oceanographic information, including measurements of currents, temperature, and salinity, also was collected during the trip. The effort will be repeated during the same period in 1998–99 and the results compared with results from the previous year, during which El Niño conditions prevailed.

HAWAII LARGE PELAGIC FISHERIES

Developments in the Hawaii Longline Fishery—Preliminary information for the Hawaii-based domestic longline fishery shows that it was a record year in terms of pounds landed (whole weight) and ex-vessel revenue. Total longline landings were 27 million pounds (worth $58 million). The total number of fishing vessels was relatively stable at 105 vessels in 1997, compared to 103 vessels in 1996, but remains approximately 25% below the peak years of the early 1990s. The largest change has been the shift in targeting from swordfish to tuna, with only 26 vessels taking swordfish-directed trips in 1997. In addition, a number of longline vessels targeting swordfish off-loaded and operated out of ports in California for at least part of the year. However, by year's end a number of East Coast swordfish longliners had returned to Hawaii.

Other changes in fishing effort include a substantial decrease in use of light sticks per hook on swordfish trips (to 0.35 per hook in 1997 from 0.75 per hook in 1991) and an increase in hooks per set on tuna trips (1,600 hooks per set). In addition, with the increased tuna trips, more fishing is occurring within the Exclusive Economic Zone (EEZ) of the main Hawaiian Islands (671 trips and 32.5% of all hooks set).

In terms of catch, bigeye and albacore were the leading fish retained, while blue shark continued to be caught in the largest number. In 1997, almost 60% of sharks were retained, usually for the dried fin market. There was a dramatic decline in swordfish landings in 1997 as targeted trips dipped substantially. The catch rate on these trips rose in 1997, but given the small number of trips, this is probably not an indication of stock abundance. The catch of blue sharks was also down in 1997 to 79,978 fish, compared to 96,224 fish in 1996, again because of the decrease in swordfish trips. Bigeye tuna had the highest landings in 1997, with catch rates on tuna target trips at 5.63 per 1,000 hooks.

Albacore tuna continued its dramatic rise since the early 1990s, with 71,079 fish caught in 1997, compared to 57,329 in 1996 and only 14,051 in 1991. Catch rates on mixed target trips in 1997 were at 2.77 per 1,000 hooks and on tuna target trips at 5.10 per 1,000 hooks. Yellowfin tuna appeared to be an important "target" on mixed target trips, with a catch rate of 3.30 per 1,000 hooks.

Particularly noticeable is the rise in the value of shark landings (from the dried fins) and albacore. Albacore landings (whole weight) have increased more than their value because of their relatively low price ($1.28 per pound, round weight) in 1996. The fisheries yielded an estimated ex-vessel revenue of $1.25 million for shark and $4.6 million for albacore in 1997, compared to $1.06 million and $3.32 million in 1996 and $144,000 and $924,000 in 1991.

Incidental Catch of Blue Shark by the Hawaii Longline Fishery—There is no U.S.-directed shark fishery in the central and western Pacific. However, relatively large incidental catches of shark are taken in the Hawaii domestic longline fishery. The number, species, and disposition of sharks caught are reported in federal logbooks. The number of sharks caught by the fishery has ranged from about 70,000 to 155,000, and in the recent four years has been between roughly 85,000 to 115,000. Approximately 95% of the sharks caught are blue sharks, with mako, bigeye thresher, and an array of species comprising the balance. During 1991 through 1994, most of the shark catch (ca. 55-70%) was taken during fishing operations targeting primarily swordfish. However, since 1995, the proportion of sharks caught by swordfish fishing operations has dropped significantly to 14% in 1997, while the proportion of sharks caught during tuna and mixed fishing operations has increased. In the early 1990s, most sharks caught were released by fishermen (about 90-97%) and based on observer records, 80% were alive at the time of release. Since 1995, there has been a large increase in the proportion of sharks

kept for processing; for example, in 1997, nearly 58% of the sharks caught were retained for processing. Essentially all of the blue sharks that are retained by fishermen are processed for fins. Varying amounts of the other shark species that are kept are processed for flesh and fins or fins.

The Hawaii longline fishery expends about 12-15 million hooks annually and catches an estimated 2,000 metric tons (t) of blue sharks. This is less than 1.5% of the total estimated annual catch of blue sharks taken by other longline fisheries in the Pacific Ocean, which annually set roughly 710 million hooks and catch an estimated 148,000 t of blue sharks.

To gather more information about the status of shark resources in the central-western Pacific, research is underway at the Honolulu Laboratory to estimate the catch of sharks by the Hawaii longline fishery, evaluate the performance of logbook records for assessing shark catch, gather biological data for blue shark stock assessment, and evaluate impacts of the longline fishery on Pacific blue shark populations.

Archival Tagging Project—To understand harvest impacts and interactions among fisheries for tuna and billfish across the Pacific, information is needed on migration patterns and on how environmental factors influence distribution and catchability. The recent development of archival tags provides a new tool for studying fish movement and habitat over long periods. Decades of conventional tagging and ultrasonic tracking research have not provided the important insights into long-term cyclical movement patterns produced by archival tags. The new technology is being used in an archival tagging project on bigeye tuna and swordfish that the Honolulu Laboratory is conducting in collaboration with the Joint Institute of Marine and Atmospheric Research's Pelagic Fisheries Research Program (JIMAR PFRP, University of Hawaii) and the Commonwealth Scientific and Industrial Research Organization (CSIRO) in Australia.

Originally, the archival tagging project was intended to deploy new pop-up, satellite-transmitting archival tags (PSTATs) on swordfish. For species such as the swordfish, marlins, and perhaps sharks, in which recapture rates are likely to be very low, the high cost of using conventional archival tags is a major deterrent. The PSTAT tags are designed to be released from fish at predetermined times, pop up to the surface of the ocean, and transmit a record of movements and habitat use to researchers via satellite. Some early versions of such tags which do not yet archive geopositions have been deployed by other researchers. Pop-up tags which will archive geoposition have been promised by several commercial electronics manufacturers but are not yet in production. Rapid external attachment of PSTATs will be achieved by harpooning an intramuscular tag anchor into the fish which then trails the tag on a tether. Early on, the project designed tag anchors which were successfully tested using dummy PSTATs on southern bluefin tuna in Australia.

In 1997, the project contracted for the design of a hydrodynamic pop-up tag container, incorporating a rapid "fail-safe" release mechanism to prevent its crushing if the fish descends below specified depths. The completed design has a round ogival nose, ducted tail fins, and a trailing antenna. A pyrotechnic detachment mechanism forces the nose cone, to which the tether is attached, forward out of the tag body, leaving the PSTAT positively buoyant and simultaneously deploying a pendant counterweight to improve vertical antenna stability. Improved geolocation software for use on archival tag and PSTAT time-depth recorders is under development by CSIRO, which will incorporate these improvements in PSTATs now being built to their specifications for delivery in September 1998.

Meanwhile, because of PSTAT production delays, 80 conventional archival tags were purchased from two vendors in 1997 for investigations involving bigeye tuna, a species with much higher recapture rates. Testing of tags from both sources revealed serious malfunctions, which were corrected by the vendors. Some tags are again undergoing tests, but in April 1998 the project began deploying fully tested tags on a longline research cruise underway at the time of this report. In the first 10 days of fishing, 13 tags were deployed on bigeye tuna off Kona, Hawaii.

Longline Research on NOAA Ship *Townsend Cromwell*—In addition to the archival tag deployments in April, a longline research cruise aboard R/V *Townsend Cromwell* was conducted in late August and September 1997 in the equatorial current region south of the Hawaiian Islands. This area was found to be productive for swordfish tagging at a time of year when fishing areas north of the Hawaii-based fishery are unproductive or beset by bad weather. The main objective of this cruise, and swordfish longline cruises since 1996, was to develop methods to increase live swordfish capture rates and viability for tag and release. Longline-caught swordfish are frequently dead or moribund

by the time the line is hauled. Swordfish often swallow the bait and become hooked in the gut, and if they are not retrieved before daylight they may die fighting to dive. Different hook types and shorter fishing intervals are being tested in an effort to reduce capture mortality.

A host of other objectives were also served by the research cruises, including the collection of oceanographic data on the fishing grounds, and the collection of samples used in studies of swordfish age, growth, sex, reproduction, parasitology, and physiology. Catches of other species, such as sharks and sea turtles, are also studied, and viable animals are tagged and released. The 1997 cruise was a collaboration between the Honolulu Laboratory and Inter-American Tropical Tuna Commission (IATTC) researcher M. Hinton, who used the opportunity to collect morphometric and reproductive activity data from istiophorid billfishes and genetic data from bigeye tuna for ongoing and cooperative investigations of the IATTC.

Townsend Cromwell provides an excellent platform for longline research. Research fishing gear is more cumbersome than commercial gear, but research gear provides information that complements logbook and observer data relative to factors affecting catch rates for the various pelagic species. For example, depth of fishing and time of day are major influences on catch per unit effort (CPUE). Logbook data include a target fishing depth and hook per float information related to fishing depth but lack capture time data. Observers collect more details regarding commercial gear configuration and are often able to note hook positions and haul times for individual fish. On *Townsend Cromwell*, the longline gear is fitted with both time-depth recorders to measure true gear depth and hook timers that record when fish actually bite. When fish are retrieved alive, the timers measure hooked longevity, which indicates differences in relative viability among capture modes.

The cruise encountered concentrations of swordfish and silky shark in the north edge of the north equatorial counter current. Generally, 450 to 500 hooks were used on each set of the longline. The line was set each evening using frozen squid for bait and a light stick attached to each ganglion. Retrieval of the longline was initiated each morning at about 0400 h and was completed by about 1000 h. Thirty-one swordfish were obtained for sampling during 17 days of fishing. In addition, tissue or data (or both) were collected from 22 bigeye tuna, 7 blue marlin, and 4 striped marlin. Swordfish CPUE averaged 5.0 per 1,000 hooks, and fish weighed between 31 and 547 lb (mean = 150 lb, round weight). The locations and relative speeds of the various equatorial currents were clearly indicated by an analysis conducted at the Honolulu Laboratory based on satellite altimetry data received from the ship every 10 days. Current locations were confirmed by shipboard acoustic and electronic instruments and by longline drift. Successful sets ranged from about 40 m to 80 m deep. Four hook types were compared to see if some types had a lower incidence of gut hooking. Preliminary results suggest that viable live captures were more numerous but not because of the novel hook types or shorter fishing intervals: more fish were jaw hooked and viable for release, and more gut-hooked fish were still alive. It is hypothesized that feeding behavior was different because the swordfish mouthed the bait more before swallowing it. Also, the oxycline was much shallower than in the northern fishing grounds, dropping below 1 mg/l at 100 m. Perhaps with so little oxygen at depth, swordfish did not fight so hard to dive. In any case, the area looks promising for future swordfish tagging efforts.

Pelagic Ecosystem Modeling—J. Kitchell (University of Wisconsin) visited the Honolulu Laboratory during January 1998 to work with C. Boggs on a model of the central North Pacific fishery ecosystem. Beginning in September 1998, this work will be funded for four years by a $540,000 National Science Foundation grant to Dr. Kitchell. Much of this work will be done in collaboration with the Honolulu Laboratory. Building upon preparatory work conducted throughout 1997, Boggs and Kitchell used the Ecopath modeling approach originally developed by J. Polovina and new Ecosim software developed by C. Walters to conduct various simulations. One example illustrated the effects of reducing fishing mortality to circa 1950 levels (before distant-water longline fisheries spread across the Pacific). When fishing mortality alone was considered, the abundance of most exploited species was much higher circa 1950. For the slowest growing (k-select) groups such as sharks, billfishes, and bigeye tuna, the abundances circa 1950 were even greater when food web interactions were included. In contrast, the model predicted that the abundance of some very fast growing (*r*-select) exploited groups such as mahimahi and small tuna, as well as many forage species, was lower circa 1950 than now.

Another simulation examined the effect of a 50% pulse in primary productivity. Fast growing, short-lived animals such as mahimahi, squids, flying fish,

small billfishes, and small tuna respond quickly to the increased productivity, increasing in biomass by 50% within a year after the productivity pulse. For these animals the biomass increase is short lived (1-4 years), whereas large tunas and juvenile sharks showed more moderate biomass increases (25-15%) that were sustained for longer periods. Adult billfishes and sharks showed very little response to the pulse.

Habitat and Physiology of Bigeye Tuna—The physiological capabilities of bigeye tuna which determine their habitat and capture depth are the subject of a University of Hawaii JIMAR PFRP project led by R. Brill in collaboration with the Honolulu Laboratory. Studies of habitat depth have important influences on catchability and have played an important role in improving stock assessment models. Data from ultrasonic telemetry studies conducted near the main Hawaiian Islands clearly show that bigeye tuna have significantly greater vertical mobility than yellowfin tuna. In other words, bigeye tuna appear more tolerant than yellowfin of the rapid ambient temperature change experienced during descents through the thermocline. Both longline capture-depth data and whole animal physiology studies strongly suggest that bigeye tuna are able to exploit more of the water column because they are also more tolerant of low ambient oxygen than are yellowfin or skipjack tunas.

Fishes that tolerate low ambient oxygen often have blood with a high oxygen affinity, but usually they are also sluggish, low-energy-demand species. This is because blood with an enhanced oxygen affinity does not readily release oxygen (in the muscles) in a manner necessary to support high rates of aerobic metabolism. It thus seems incongruous that bigeye tuna (a high-energy-demand species) could also be tolerant of low ambient oxygen. This study was undertaken to better understand the physiological basis for bigeye tuna's apparent enhanced tolerance. The ultimate goal is to provide data from which the depth distribution of bigeye tuna (and other tuna species) can be modeled or predicted based on temperature and oxygen stratigraphy. These types of models/predictions are critical for correcting abundance estimates based on CPUE data (i.e., for differentiating changes in abundance from changes in gear vulnerability).

Using standard in vitro techniques, this study found bigeye tuna blood to have an unusually high oxygen affinity. When equilibrated with 0.5% CO_2, the P_{50} (the partial pressure of oxygen needed to achieve a blood oxygen content that is 50% of the maxim theoretical oxygen content based on measured hemoglobin concentration) was only 12-15 mm Hg in bigeye tuna blood, compared with 21-23 mm Hg in skipjack and yellowfin tuna blood. These data support the conclusion that bigeye tuna are better adapted for taking up oxygen from the water under conditions of low ambient oxygen than are yellowfin or skipjack tunas. This study also found the oxygen affinity of bigeye tuna blood to be essentially temperature-independent when subjected to a 10°C open-system temperature change, as is the blood of all other tuna species studied to date. (Subjecting blood to open-system temperature changes in vitro mimics temperature changes occurring in vivo as blood passes through the gills of tunas moving up and down through the thermocline). Surprisingly, however, it was also found that bigeye tuna blood has an enhanced temperature sensitivity when subjected to a 10°C closed-system temperature change. (Closed system temperature changes in vitro mimic temperature changes occurring when blood passes through tunas' vascular countercurrent heat exchangers). To use the physiologist's shorthand, unlike the blood of other tuna species studied to date, bigeye tuna blood has a significantly enhanced Bohr effect (i.e., $\Delta \log P_{50}/\Delta pH$) when subjected to the increases in PCO_2 and decreases in plasma pH that inevitably accompany closed-system temperature shifts.

Taken together, these data show how a high-energy-demand species like bigeye tuna can also be tolerant of low ambient oxygen. In the gills, bigeye tuna blood can readily take up oxygen even under low ambient oxygen conditions because of its high oxygen affinity. When the blood reaches the warm muscles, however, the elevated Bohr effect and resultant large increase in P_{50} ensure adequate rates of oxygen off-loading in the tissues of this high-energy-demand teleost.

Workshop to Review Sea Turtle and Seabird Takes in Longline Fisheries—During April, a workshop will be convened by the Honolulu Laboratory to 1) review the statistical methods used to estimate incidental takes of sea turtles and seabirds in longline fisheries, 2) identify theoretical and practical considerations for development of take estimation strategies, and 3) recommend steps to improve take estimation methods.

In the United States and other countries, incidental takes of sea turtles and seabirds have become a significant management issue in longline fisheries. Consequently, in a growing number of fisheries,

programs have been established to monitor fishery interactions with turtles and seabirds and to estimate the magnitude of takes and related mortality. In some fisheries, ancillary research has been undertaken to assess impacts of the mortality on the status and recovery of affected populations and to develop effective take mitigation measures.

Take estimation involves a number of difficult statistical issues. These include the rarity and patchiness of take events for many species, low coverage (sampling rate) in the observer programs used to collect take data, and complex relationships between the frequency of take events and a range of biological, technological, and other factors. Various methods have been used to derive estimates of turtle and seabird takes in longline fisheries and assign levels of statistical reliability to them.

The workshop will begin with presentation and discussion of four "case studies," including the Hawaii longline fishery for swordfish and tuna. These will describe a range of fishery situations and statistical methodologies currently applied to them. Drawing in part on the case study descriptions, workshop participants will discuss theoretical and practical statistical issues arising in take estimation, design of take monitoring surveys, and related topics. The group will develop a set of recommendations for ways to improve take estimation methods or surveys. Workshop proceedings will be compiled and published as a NOAA Technical Memorandum.

Post-hooking Survival and Movements of Sea Turtles Studied—At the Honolulu Laboratory, researchers have begun using satellite telemetry to measure the survivorship of sea turtles incidentally hooked and released alive in the Hawaii-based longline fishery. In a feasibility study conducted during the year, commercially available satellite transmitters were attached to the carapaces of hard-shelled turtles by trained NMFS observers aboard commercial fishing vessels, using techniques perfected by the Honolulu Laboratory. Satellite data on the locations and movements of the turtles were relayed daily to the Honolulu Laboratory for processing, analysis, and mapping.

The researchers successfully tracked post-release movements of 9 pelagic loggerhead and 4 pelagic olive ridley turtles across the North Pacific for up to six months over distances from 160 to 6,950 km. In addition, three other loggerheads and a green turtle were recently equipped with transmitters and released after being hooked. Data for these four turtles are currently being processed. The hooking status of the tracked turtles ranged from "lightly hooked" (hook easily removed from the beak or flipper) to "deeply ingested" (hook deep in the esophagus and impossible to safely remove). Six turtles (two ridleys, four loggerheads) were lightly hooked and seven (two ridleys, five loggerheads) were deeply ingested. Preliminary results demonstrate that at least some of the turtles with deeply ingested hooks were capable of swimming considerable distances against prevailing currents, presumably in a normal fashion.

The next phase of this research project will incorporate the use of several satellite-linked dive recording transmitters to collect information on turtle diving patterns and surface intervals. In addition, a number of transmitters with about one-third more battery reserve will be deployed to provide better insight into transmitter life.

This project has benefited substantially from a teamwork approach in collaboration with other researchers at the Honolulu Laboratory. Satellite tracking of all turtles is being analyzed in relation to geostrophic current and other oceanographic environmental data supplied by satellites. Results will ultimately provide new and important information that will benefit longline fisheries and increase knowledge of the pelagic life histories of sea turtles.

Satellite Data Used in Swordfish Research—In February, at the Ocean Sciences Meeting held in San Diego, California, Honolulu Laboratory researchers presented two posters on new applications of satellite altimetry to swordfish research. One presentation, "Diagnosis of the variability of swordfish catches north of Hawaii" by G. Mitchum and J. Polovina, used TOPEX/Poseidon (T/P) satellite altimetry data to construct an index of the strength of the subtropical front, showing that this index was highly correlated with swordfish CPUE in the Hawaii-based longline fishery. Thus, variation in fishery CPUE to date largely reflects changes in the strength of the subtropical front. Other satellite information currently is being used to examine the spatial and temporal dynamics of chlorophyll (a measurement of productivity) at the subtropical front and to ultimately describe swordfish forage habitat.

The second presentation, "Use of near real-time TOPEX/Poseidon altimetry to guide fisheries oceanography field studies in the central North Pacific" by M. Seki, D. Kobayashi, J. Polovina, and G. Mitchum, described results from 1997 shipboard oceanographic surveys of the North Pacific sub-

tropical front region. This research, which continues with another survey scheduled during April-May 1998, uses the satellite altimeter data to elucidate the position and mesoscale variability of the subtropical front, which corresponds closely with areas of greatest swordfish fishing activity and highest catch rates, particularly early in the fishing season (for example, March). Hydrographic transect lines through the front and selected mesoscale features identified from altimetry are subsequently conducted to collect information on the distribution and interplay of physical, chemical, and biological properties through the water column.

Swordfish Size at Sexual Maturity and Sex Composition of Catches Estimated —Sex-specific body size at sexual maturity of swordfish caught by the Hawaii-based longline fishery was estimated in a paper (DeMartini et al., submitted to Fish. Bull.), which also described temporal and spatial patterns in the size and sex composition of catches. This study is significant because the dynamic nature of catch and effort statistics for Pacific swordfish requires an age-structured approach to stock assessment. Age at sexual maturity, derived from size-at-age and size-at-maturity estimates, constitutes a fundamental part of any age-structured model. Temporal and spatial patterns in size and sex composition data can help stratify catch and effort data and reduce the overall variance of catch statistics.

Body size at 50% sexual maturity was estimated separately for male and female swordfish. More than 1,300 gonad tissue specimens, collected at sea by NMFS Southwest Region observers over a 40-month period (March 1994–June 1997), were evaluated using histological criteria to determine state of maturation. Estimated size at maturity was 143 ± 3 cm eye-to-fork length (EFL) for more than 800 females, and 102 cm ± 2 EFL for about 500 males. Females and males predominated at body lengths 150 cm and 140 cm EFL, respectively. Sex ratios (females/total) were consistently 0.9 at lengths 215 cm EFL, indistinguishable from 0.5 at lengths 100 cm, and a positive function of length between 100 and 215 cm EFL.

The size and sex compositions of swordfish catches were both temporally and spatially dynamic. More male swordfish were caught south of 27°N latitude, whereas females predominated north of the same latitude. The largest fish (both sexes, but mostly female) were caught above 35°N latitude during late summer-early winter. Reproductively active fish of both sexes dominated catches near the Hawaiian Archipelago during early spring-early summer. Small-bodied fish of both sexes prevailed below 22°N latitude.

Estimates of swordfish body size at sexual maturity provide a key element for the age-structured stock assessment models that are under development. The described patterns of size and sex composition should help identify important temporal and spatial strata for reducing the variance of swordfish catch and effort statistics.

Swordfish Size-at-Age Studies Continued—Age and growth studies of swordfish continued with complementary analyses using otoliths and anal fin rays. Counts of presumed "daily" microincrements were completed for a cumulative total of 27 young-of-year (YOY) and yearling swordfish ranging from 19 to 135 cm EFL and an estimated 31 to 616 days old. Length at age 365 days was estimated as 106 cm EFL (95% CI = 84-129 cm EFL). Preliminary analyses further suggest that the age of young swordfish can be predicted from length of counting path (otolith rostrum), implying that rostrum length might provide a cost-effective proxy for age based on microincrement counts.

Preparation and analyses of anal fin rays continued for swordfish spanning the entire range of exploited sizes from about 70 to 230 cm EFL. Preliminary ageing and fin ray measurements were completed for a cumulative total of more than 1,000 fish (550 females and 450 males). An ongoing focus has been to match size at age 1 year from fin ray cross-sections with size at age 365 days from otolith microincrement counts. Limited (n = 3) recaptures of tagged yearling fish at liberty for 1, 2, and 4 years indicate that a preliminary characterization of length-at-age is reasonable.

A von Bertalanffy growth function utilizing comprehensive data for YOY through large adult fish would provide more accurate estimates of instantaneous growth rates. Estimates of growth as well as age-at-maturity distributions are essential elements of pending age-specific stock assessments for swordfish in the Pacific.

Oracle Database for Pelagic Fisheries—As reported last year, the Honolulu Laboratory is converting from a long established flat file archival system to a modern on-line, relational database for pelagic fisheries using Oracle database software. The goal is to improve access to data and database summaries not only for laboratory researchers but also for the WPRFMC and other users. Project accomplishments during the past year included

1) implementation of a database model which acknowledges the existing data management program; 2) loading of two day sets of pelagic data: the western Pacific longline logbook data set and the western Pacific longline observer database; 3) development of forms for on-line viewing of the data as well as extracting and downloading selected data fields to ASCII files; 4) development of on-line, dynamic reports based on longline logbook and observer data; and 5) testing the setup of a server to provide Web access to the Oracle database forms and reports. Several problems with the current database model and future development directions also were identified.

1997 Pelagic Economic Research—The Hawaii Fishing Industry and Vessel Economics Project (HI-FIVE) of the JIMAR PFRP is the primary locus for economic research at the Honolulu Laboratory. Research completed in 1997 included a cost-earnings study of the small-boat commercial and recreational fishery in Hawaii and the initiation of a similar study of charter boats. A study of charter boat patrons will be initiated in 1998. Results from these studies will be reported by JIMAR cooperative researcher M. Hamilton at the 1998 Tuna Conference in Lake Arrowhead, California.

EASTERN TROPICAL PACIFIC TUNA FISHERIES

Dolphin-Safe Research Program Activities—The Marine Mammal Division's Dolphin-Safe Research Program at the La Jolla Laboratory continued to focus on the development of acoustic and optical detection devices to replace dolphins as sighting cues for locating large yellowfin tuna in the eastern tropical Pacific Ocean (ETP). By concentrating on large yellowfin tuna not associated with dolphin, program staff hope to eliminate the need for the practice of "dolphin fishing" in the ETP, during which dolphins are located, chased, and encircled with nets in order to capture the large yellowfin tuna which frequently associate with dolphins in this part of the Pacific.

Again this year, the researchers focused on completing the original program objective of obtaining a detailed design for an acoustic tuna detection system that could be used specifically in the eastern Pacific, and they continued or initiated investigation of a number of other aspects of dolphin-safe fishing in the ETP. Rather than limiting the focus to recommendations from a single research group about the optimal design for an ETP tuna acoustics system, the Dolphin-Safe Program researchers were able to achieve completion of two separate design studies, one funded through the Dolphin-Safe Program and the other through the Saltonstall-Kennedy Grant Program. Both research groups recommended very similar systems with respect to hardware and deployment: a high decibel sound source and a separate receiving array, both to be towed behind the seiner. The primary differences in system design entailed methods of return signal data processing and analysis. With the completion of these design projects, the acoustic design and recommendation phase of the Dolphin-Safe Program has been completed. Further work will involve building and testing prototype systems, an endeavor which is presently beyond the financial resources of the program.

Other projects completed or in progress during the past year included continuation of work on potential use of lidar for tuna location and identification, an extensive review of the potential impacts of acoustic devices on marine mammal hearing, and the first direct measurements of swim bladder volume in larger yellowfin tuna from the ETP.

New Dolphin Research Mandated by IDCPA—Several new research activities were initiated at the La Jolla Laboratory during the year in response to the August 1997 enactment of the International Dolphin Conservation Program Act (IDCPA). This new U.S. legislation would implement provisions of the Panama Declaration and mandated new research on the effects of encirclement by purse seine nets on dolphins. The research will be used by the Secretary of Commerce to support a preliminary finding by March 1999 on whether or not encirclement has a significant adverse impact on depleted dolphin stocks in the ETP, and a final finding by December 2002 on whether or not to permit a change in the current U.S. definition of "dolphin-safe" tuna (i.e., no tuna was taken in association with dolphins).

As a first step in this process, the Center convened an expert consultation in January, including representatives from the Marine Mammal Commission and IATTC, to review plans for undertaking three dolphin abundance surveys to be conducted during August–December in 1998, 1999, and the year 2000. Planning also was undertaken at the Center for dolphin stress studies, which will include a literature review of mammalian stress research, a necropsy sampling program aboard commercial seiners, a review of historical data, and a chase and recapture experiment. Currently, the literature re-

view is in progress, and the other projects are in the planning or implementation stages.

SHARK RESEARCH

1997 Shark Abundance Survey Completed—A three-part shark abundance survey was conducted in 1997 by the Center to define juvenile shark abundance and nursery areas off southern California and northern Baja California, Mexico. Cooperating agencies included the California Department of Fish and Game, the National Fisheries Institute (INP) of Mexico, and CICESE, Ensenada, Mexico.

Annual Shark Abundance Survey—This survey intended to index juvenile shark abundance and define shark nursery areas within the southern California Bight was conducted July 23 to August 12, 1997, aboard the chartered research vessel *Yellowfin*. Two regularly scheduled survey sampling sets were conducted during daylight hours throughout the survey period, and night sets were conducted on selected nights to evaluate bycatch in longline fisheries.

In all, 36 sampling sets employing stainless steel longline fishing gear were conducted during the 18 days of sampling. Each of the 30 daytime sets consisted of 129 to 194 baited hooks attached to a 2.8 km longline. Six sets were conducted at night using monofilament leaders. A total of 5,528 hooks were deployed yielding a total of 195 blue sharks captured of which 171 were tagged and released for population and movement studies. There were also 70 of 107 shortfin mako tagged and released. The catch rate for blue sharks was 3.5 per 100 hooks while the catch rate for shortfin mako was 1.9 per 100 hooks.

Cooperative Shark Assessment Cruise—PFRD and Mexican scientists completed a 12-day cooperative shark assessment cruise in July off northern Baja California. A total of 24 sets (2,945 hooks deployed) were made with shark longline gear during the cruise. The shark catch was 415 blue, 13 mako, 1 soupfin, and 1 thresher. Eighty-three percent of the sharks were tagged and released. The catch rate for blue sharks was 13.4 per 100 hooks, a higher rate than seen on prior surveys off southern California. The catch rate for shortfin mako was very low at 0.42 per 100 hooks. The cause for these large differences in catch rate is not known but could be due to the exceptionally warm water in the survey area.

Juvenile Shark Abundance Survey—In October, SWFSC scientists completed a survey to determine abundance of juvenile sharks in waters off northern Baja California, Mexico. The survey was conducted during a Monterey Bay Aquarium fish collecting cruise aboard a chartered fishing vessel in an area from Monterey, California, to Cabo Colonet, Mexico, to San Clemente Island off southern California. During the cruise, a total of 8 longline sets were completed using monofilament nylon leaders; nearly 400 hooks baited with market squid and sardine were deployed. Total catch was 20 blue sharks, 5 pelagic sting rays and 1 dorado (mahimahi). One shortfin mako shark caught by rod-and-reel was tagged and released for movement studies, and 12 small juvenile yellowtail also were collected for display at the aquarium.

New Procedure For Estimating Productivity of Sharks Developed—Center scientists have developed a new demographic method for estimating a population's intrinsic rate of increase that depends on the level of total mortality. The method uses age at female maturity, maximum reproductive age, and average fecundity, and incorporates concepts of density dependence. This procedure is shown to be capable of providing intrinsic rates of increase for shark species which compare favorably with results obtained by other methods. This method has the feature of requiring significantly less parameter estimates than other methods and should prove useful for assessing the status of shark populations for which few data exist. The results are detailed in a manuscript "A demographic method with population density compensation for estimating productivity and yield per recruit of the leopard shark" by D. Au and S. Smith.

Transboundary Shark Research Discussed at Symposium in Monterey, California —Eleven papers on the biology of and fisheries for transboundary sharks in the Mexico-U.S. Pacific and adjacent areas of the eastern Pacific were presented in August at a symposium held concurrently with meetings of MEXUS-Pacífico and the American Fisheries Society. At the MEXUS-Pacífico annual meeting, which was convened by Science Director M. Tillman, the group agreed to continue U.S.-Mexico cooperative research on swordfish, sharks, sperm whales, and sea turtles. The MEXUS-Pacífico program was created in 1989 to plan research and exchange information on Pacific Coast transboundary stocks of mutual concern to both countries.

BILLFISH INVESTIGATIONS

The goal of the Center's billfish research program is to provide information for the conservation and rational management of Pacific and Indian Ocean

billfish resources. Two components of the billfish investigations are the International Billfish Angling Survey, which tracks changes in recreational angling catch and effort, and the Cooperative Billfish Tagging Program, which provides information on the distribution, migratory patterns, and growth rates of Pacific and Indian Ocean billfishes. The results of billfish research conducted by the Center are published annually in the Billfish Newsletter.

Results of 1996 and 1997 Billfish Angler Surveys—The Center has collected angler catch and effort data through the Billfish Angler Survey annually since 1969. These data are collected from individual anglers, sportfishing clubs, and cooperating international and national agencies. Trends in angler catch rates at major billfishing areas throughout the Pacific and Indian Oceans aid in understanding the impact of commercial fisheries on billfish resources. Long-term trends are used to identify emerging issues resulting from fishery, environmental, economic, and other causes. Results from the 1996 and 1997 fishing seasons are reported here.

Angers responding to the International Billfish Angler Surveys reported catching 3,712 billfish during 6,642 fishing days in 1996 and 4,698 billfish during 10,973 fishing days in 1997. The overall success rate was 0.56 in 1996 and 0.43 billfish per angler-day in 1997. The current average catch per unit of effort of 0.48 for 1996 and 1997 is consistent with the preceding 5-year average (1991 to 1995) of 0.46 and nearly the same as the pre-preceding 5-year period (1985 to 1989) of 0.54. The highest reported catch rate (0.57) was from 1969 to 1971 and the lowest (0.38) occurred in the mid-1970s.

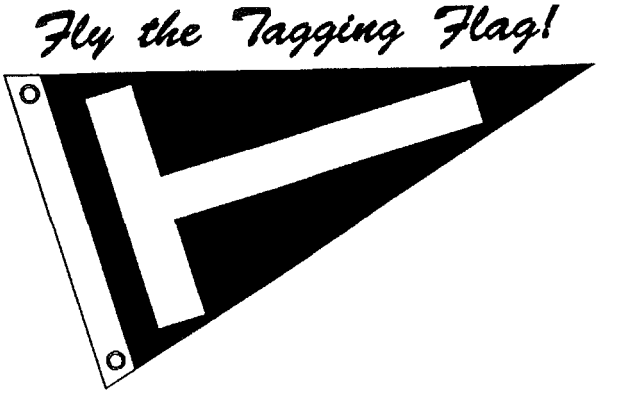
The principal value of these data is in long-term trend analysis compared with other events such as regional commercial fisheries, weather patterns, and local economic changes. Many fishing nations throughout the Pacific and Indian Oceans are expanding their pelagic fisheries beyond traditional waters. The trend analysis from this survey assists in monitoring the impact of this expansion and highlights the importance of recreational fishing for billfish and the economic contribution to local communities.

1997 Cooperative Marine Game Fish Tagging Program Results—The Center's angler-based Billfish Tagging Program began in 1963. The program encourages the participation and cooperation of recreational anglers, commercial fishers, and affiliated research agencies. The specific goal of the program is to determine migration, distribution, and growth patterns of billfish utilizing tag recapture data.

Figures from Billfish Tagging Report cards received by the Center in 1997 indicate a total of 849 billfish were tagged and released by 554 anglers and 219 fishing captains. This is 29% fewer tag releases than reported in 1996. Fewer billfish of all species were tagged last year. There were 6 striped marlin, 6 blue marlin, 1 sailfish, 2 swordfish, and 1 shortfin mako shark recaptured in 1997. Long-term recapture rates are: striped marlin, 1.63%; blue marlin, 0.86%; black marlin, 2.07%; sailfish, 0.38%; and swordfish, 2.36%. Twenty-eight percent of recaptures occurred within the first month after release and 77% within the first year. Only 1% of recaptured billfish were at liberty three years or longer.

Recapture data indicate billfish are both robust and resilient to the stress of post-tagging trauma, travel long distances, and have established migratory patterns. Billfish routinely make trans-Pacific and equatorial crossings which expose them to numerous international commercial and recreational fisheries. While most of the fishery-related impacts occur on the high seas, significant fishery interactions also occur within the EEZs of the various countries throughout the Pacific region. Clearly, international monitoring of the Pacific billfish resource is needed to understand the extent of billfish/fishery interactions.

In other tagging program activities during the year, the Center and The Billfish Foundation began a joint analysis of their sets of billfish tagging data for the Pacific Ocean. The Center also furnished tagging supplies to tournament anglers and reported results of tagging in the Pacific area.



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