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U.S. Fisheries and Research on Tuna and Tuna-like Species in the North Pacific Ocean[1]

NOAA, National Marine Fisheries Service

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Executive Summary

U.S. fisheries harvest tuna and tuna-like species in the North Pacific from coastal waters of North America to the archipelagoes of Hawaii, Guam and the Commonwealth of the Northern Mariana Islands (CNMI) in the central and western Pacific Ocean. The small-scale gill net, harpoon, pole-and-line, tropical troll and handline fisheries operate primarily in coastal waters, whereas the large-scale purse seine, albacore troll, and longline fisheries that account for most of the catch operate both within U.S. Exclusive Economic Zones and on the high seas. Skipjack tuna (*Katsuwonus pelamis*) landings in the North Pacific Ocean decreased from 66,529 t in 2009 to 30,221 t in 2010, mostly due to a decrease in the purse-seine catches of this species. Total U.S. purse-seine landings declined from 74,144 in 2009 to 34,280 in 2010. The thousands of trollers and handliners operating in the tropical Pacific Islands represent by far the largest number of vessels but contribute a small fraction of the catch.

The National Oceanic and Atmospheric Administration (NOAA) Fisheries conducted research on Pacific tuna and associated species at its Southwest and Pacific Islands Fisheries Science Centers and in collaboration with scientists from other organizations. Fishery monitoring and socio-cultural research was conducted on tunas, billfishes, and animals caught as bycatch in Pacific coastal and high seas fisheries. In 2010, catch and angler effort information, shark catch in the Hawaii longline fishery was analyzed, albacore catch and effort in the albacore troll fishery was analyzed, and economic indicators in the Hawaii longline and small boat fisheries were assessed.

Stock assessment research was conducted almost entirely in collaboration with member scientists of the International Scientific Committee for Tuna and Tuna-Like Species in the North Pacific Ocean (ISC) and other international Regional Fisheries Management Organizations.

NOAA Fisheries biological and oceanographic research on tunas, billfishes, and sharks addressed fish movements, habitat preferences, post-release survival, feeding habits, and age and growth. Significant results include analyses of albacore age and growth and population structure. Billfish research includes migration and life-history studies. Several studies on sharks focused on their survival after capture and release. Shark tagging studies continued, and provide an increasing body of migration data. Several studies on sea turtles and sharks focused on bycatch mitigation.

I. Introduction

Various U.S. fisheries harvest tuna and tuna-like species in the North Pacific Ocean. Large-scale purse seine, albacore (*Thunnus alalunga*) troll, and longline fisheries operate both in coastal waters and on the high seas. Small-scale gill net, harpoon, handline and pole-and-line fisheries as well as commercial and recreational troll and hook and line fisheries usually operate in coastal waters. Overall, the range of U.S. fisheries in the North Pacific Ocean is extensive, from coastal waters of North America to Guam and the Commonwealth of the Northern Mariana Islands (CNMI) in the western Pacific Ocean and from the equatorial region to the upper reaches of the North Pacific Transition Zone.

In U.S. Pacific fisheries for tunas and billfishes, fishery monitoring responsibilities are shared by the National Oceanic and Atmospheric Administration's National Marine Fisheries Service (NOAA Fisheries or federal agency) and by partner fisheries agencies in the states of California, Oregon, Washington, Hawaii, and territories of American Samoa, Guam, and the CNMI. On the federal side, monitoring is conducted by the Southwest Regional Office (SWRO) and the Southwest Fisheries Science Center (SWFSC) in California, and the Pacific Islands Regional Office (PIRO) and the Pacific Islands Fisheries Science Center (PIFSC) in Hawaii. NOAA Fisheries fishery monitoring activities include collection of landings and sales records at markets and ports of landing, federally-mandated logbook statistics on fishing effort and catch, observer data, and biological sampling data. In California, Washington, and Oregon, landings receipts are collected by state agencies and placed in the Pacific Fisheries Information Network (PacFIN) system. Some state agencies also collect logbook and size-composition data. In the central and western Pacific Ocean, monitoring by partner agencies also involves market sampling and surveys of fishing activity and catch and is coordinated by the Western Pacific Fishery Information Network (WPacFIN), a federally funded program managed by the PIFSC. The management of data on U.S. Pacific fisheries for tuna and tuna-like species is coordinated among the SWFSC, SWRO, PIFSC, and PIRO.

This report provides information on the number of active vessels by fleet and their catches of tunas and billfishes in the North Pacific Ocean based on the data available through 15 March 2011. Data for 2010, however, are considered preliminary and are subject to change. Although the report is focused on tunas and billfishes, many of the fisheries include catch of other pelagic fish important to the fishing fleets and local economies; catch data for these species are not included.

NOAA Fisheries also conducts scientific research programs in support of marine resource conservation and management both domestically and internationally. These studies include stock assessments, biological and oceanographic studies, socio-economic analysis, and more. This report includes summaries of recent and ongoing scientific work by NOAA Fisheries of relevance to the ISC.

II. Fisheries

A. Purse Seine

The U.S. purse seine fishery consists of two separate components, one that operates in the western-central Pacific Ocean (WCPO), and another that operates in the eastern tropical Pacific Ocean (ETP). The ETP purse seine fishery started in the mid-1900s and most catch came from there until 1993 when vessels moved to the WCPO in response to dolphin conservation measures in the ETP. Vessels also moved to the WCPO because fishing access was granted by the South Pacific Tuna Treaty. The WCPO fishery operates mainly in areas between 10°N and 10°S latitude and 130°E and 150°W longitude. The ETP fishery operates off the coast of Southern California and outside the EEZ of Mexico off Baja, California. The number of U.S. vessels participating in the U.S. purse seine fishery and fishing north of the equator decreased from a high of 110 in 1985 to 10 in 2006 (Table 1) increasing to 49 in 2009. In 2010, there were 36 vessels participating. Before 1995 the fleet fished mainly on free-swimming schools of tunas in the WCPO and on schools associated with dolphins in the ETP. Since 1995 most catches have been made on fish aggregation devices (FADs) and other floating objects.

U.S. purse seine catches of tunas north of the equator are shown in Table 2. Catches in the North Pacific Ocean, over the past five years (most of the catch is south of the equator), have been primarily skipjack tuna (*Katsuwonus pelamis*) (79%) and yellowfin tuna (*Thunnus albacares*) (14%). Skipjack tuna catches peaked in 1988 at 78,250 t (metric tons) then decreased to 4,002 t in 2002. In 2009, 65,767 t and in 2010 29,677 t of skipjack tuna were caught by U.S. purse seiners in the North Pacific. Yellowfin tuna catches generally decreased from a high of 123,044 t in 1987 to 1,112 t in 2006. In 2009, 5,523 and in 2010 4,010 t of yellowfin tuna were caught by U.S. purse seiners in the North Pacific. Figure 1 shows the spatial distribution of reported fishing effort in 2010 by the U.S. purse seine fleet in the Western-Central Pacific Ocean.

U.S. purse seine vessels fishing in the WCPO have been monitored by NOAA Fisheries under the South Pacific Regional Tuna Treaty since 1988. Logbook and landings data are submitted as a requirement of the Treaty (coverage 100%). Landings are sampled for species and size composition as vessels land their catches in American Samoa by NOAA Fisheries personnel and by samplers in other ports (coverage approximately 1-2% of landings). Species composition samples are used to separate bigeye tuna (*Thunnus obesus*) from yellowfin tuna in the reported landings. The Forum Fisheries Agency (Treaty Manager) places observers on 100% of the vessel trips.

The Inter-American Tropical Tuna Commission (IATTC) monitors U.S. purse seine vessels fishing in the ETP by large-scale U.S. purse-seine vessels. Logbooks (coverage 100%) are submitted by vessel operators to NOAA Fisheries or the IATTC, and landings (coverage 100%) are obtained from each vessel, canneries or fish buyers. IATTC observers are placed on all large purse seine vessels.

B. Longline

The U.S. longline fishery targeting tuna and tuna-like species in the North Pacific Ocean is made up of two components, the Hawaii-based fishery and the California-based fishery. Vessels transited between the two regimes freely until 2000 when domestic regulations placed restrictions on moving between the two domestic management regimes. The Hawaii-based component of the U.S. longline fishery currently comprises a majority of the vessels, fishing effort, and catch. Regulatory restrictions, due to interactions with endangered sea turtles, curtailed Hawaii-based longline swordfish (*Xiphias gladius*) directed effort in 2000 and 2001 followed by a prohibition altogether in 2002 and 2003, after which the Hawaii-based longline fishery targeted tunas exclusively. The Hawaii-based fishery for swordfish (shallow-set longline) was reopened in April 2004 under a new set of regulations to reduce sea turtle interactions. 2005 was the first complete year in which the Hawaii-based longline fishery was allowed to target swordfish. In the following year, the shallow-set longline fishery reached the annual interaction limit of 17 loggerhead sea turtles (*Caretta caretta)* and the fishery was closed 20 March 2006. The vessels that targeted swordfish converted to deep-set longline and targeted tunas for the remainder of the year. The Hawaii-based shallow-set longline fishery has stayed below the annual sea turtle interaction limit and remained open throughout the entire year since 2007.

The number of vessels in the California-based fishery was relatively low and was composed mainly of vessels that targeted swordfish. Most vessels also participated in the Hawaii-based fishery. The California-based longline fishery for swordfish was closed in 2004 and resulted in relocation of most of those vessels back to Hawaii. Only one vessel fished exclusively in the California longline fishery between 2005 and 2010 targeting tunas.

The longline fishery extended from outside the U.S. West Coast 200-mile Exclusive Economic Zone (EEZ) to 175°W longitude and from the equator to 35°N latitude in 2010 (Figure 2). The number of vessels participating in the longline fishery increased from 36 in 1985 to a high of 141 vessels in 1991 (Table 1). Since then, the number of vessels has remained relatively stable. Approximately125 vessels participated in 2010. In Hawaii and California, swordfish are generally landed dressed (headed, tailed, and gutted). Tunas and large marlins are landed gilled and gutted while other bony fishes are usually landed whole. Sharks are landed headed and gutted. In Hawaii, the landed catch is weighed at the fish auction. Dressed weights are converted to whole weight for reporting of total catches.

Catch levels and catch-species composition in the U.S. longline fishery have changed considerably over the past years in response to fishery and regulatory changes. The majority of the catch now consists of tunas and billfishes and exceeded 10,000 t in 1993, 1999, 2000 and 2008 (Table 2). Bigeye tuna dominates the tuna catch with landings over 4,000 t in the past seven years. The 2010 bigeye tuna catch was 5,242 t. Swordfish has been the dominant component of the billfish catch from 1990 and reached a peak of 5,936 t in 1993 before decreasing to 1,185 t in 2004. The 2010 swordfish catch was 1,654 t.

The Hawaii-based longline fishery is monitored by NOAA Fisheries and the State of Hawaii's Division of Aquatic Resources (DAR). Longline fishers are required to complete federal longline logbooks for each fishing operation. The logbook data include information on effort, area fished, catch, and other details of operation. Logbook coverage for the Hawaii-based longline fishery is estimated at 100%. DAR also requires fish dealers to submit landings data, and coverage for the longline fishery is very close to 100%. Observers contracted by NOAA Fisheries are placed on longline vessels to monitor protected species interactions, vessel operations, and catches. The observers are required aboard Hawaii-based longline vessels at a rate of coverage of no less than 20% for deep-set (tuna-target) vessels and 100% for shallow-set (swordfish-target) vessels. Sizes of fish caught in the Hawaii-based longline fishery are shown in Figures 3 through 5. In general, smaller fish are captured more in the shallow-set longline fishery.

The California-based longline fishery is monitored by NOAA Fisheries and the California Department of Fish and Game (CDFG). Longline landings data are collected from 100% of the fleet by the CDFG landing receipt program. Logbooks, developed by the fishing industry (similar to the federal logbooks used in Hawaii), were submitted voluntarily to NOAA Fisheries until 1994. Landed swordfish were measured for cleithrum to fork length by CDFG port samplers until 1999. NOAA Fisheries currently places observers on all California-based longline trips. The observers collect data on protected species interactions, fish catch and measure the sizes of fish caught (retained and discarded).

C. Albacore troll

The U.S. albacore troll fishery in the North Pacific Ocean started in the early 1900s. The fishery operates in waters between the U.S. west coast and 160°E longitude. Fishing usually starts in May or June and ends in October or November. The number of vessels participating in the fishery ranged from a low of 172 in 1991 to a high of 1172 in 1997 (Table 1). In 2010, 653 vessels participated in the fishery. Figure 6 shows the spatial distribution of the albacore troll fishery in 2010.

The troll fishery catches mainly albacore with minor incidental catches of skipjack, yellowfin and bluefin tunas (*Thunnus orientalis*), eastern Pacific bonito (*Sarda chiliensis lineolata*), yellowtail (*Seriola lalandi)*, and mahi mahi (*Coryphaena hippurus*). Since 1985, the albacore catch has ranged from a low of 1,845 t in 1991 to a high of 16,938 t in 1996 (Table 2). In 2010, 10,130 t were caught. Figure 7 shows the size distribution of albacore caught.

U.S. troll vessels voluntarily submitted logbook records to NOAA Fisheries until 1995 when those vessels fishing on the high-seas were required to submit logbooks. Starting in 2005, all vessels must submit logbooks under a Highly Migratory Species Fishery Management Plan (HMS FMP). Landings are monitored by NOAA Fisheries and various state fisheries agencies through landing receipts and coverage is 100% of the fleet. Landings are also sampled for fork length by state agency port samplers along the U.S. West Coast and by NOAA Fisheries personnel in American Samoa. Since 1961, the port sampling program has been in place for collecting size data from albacore landings along the U.S. Pacific coast. State fishery personnel collect the size data according to sampling instructions provided by the SWFSC, where the database is maintained. In recent years, cooperative fishermen have also collected size data randomly selected fishing trips. These data are collected to augment data collected through the port sampling program. Following procedures established by SWFSC scientists, fishermen on five vessels measured 752 albacore during the 2009 season. During 2010, five vessels measured

1,010 albacore. The sample information provided by the fishermen helped to fill in gaps missed by the port sampling program.

D. Pole-and-line

There are two components of the pole-and-line fishery, one that operates around the Hawaiian Islands, targeting tropical tunas and another that operates in waters along the U.S. West Coast, targeting albacore. The number of vessels participating ranged from a low of 7 in 2000 to a high of 96 in 2009. In 2010 there were 87 vessels participating. Skipjack tuna is usually the largest component of the catch by Hawaii pole-and-line vessels. The highest skipjack tuna catch for this fishery was 3,450 t in 1988 (Table 2). The highest yellowfin tuna catch for the pole-and-line fishery was 2,636 t, recorded in 1993. Preliminary pole-and-line catches of albacore tunas were 1,874 t in 2010. Less than three vessels participated in the Hawaii pole-and-line fishery in 2010.

NOAA Fisheries collects west coast pole-and-line logbook data. Logbook submissions since 2005 are mandatory under the HMS FMP. Albacore fork-length data are collected by NOAA Fisheries through a contract with state agencies of Oregon, Washington, and California. Coverage rates for length data are less than 1% of the landings. Landings data are collected by state agencies (coverage 100%).

Hawaii DAR monitors the Hawaii pole-and-line fishery using Commercial Fish Catch reports submitted by fishers and Commercial Marine Dealer reports submitted by fish dealers.

E. Tropical Troll and Handline

Troll fisheries operate in Hawaii, Guam, and the CNMI. Handline fisheries also operate in Hawaii. These fisheries catch tuna and tuna-like fish in the North Pacific Ocean. The vessels in these fisheries are relatively small (typically around 8 m in length) and make mainly day long trips fishing in coastal waters. The number of vessels ranged from 1,878 in 1988 to 2,502 in 1999; there were 2,117 vessels in 2010 (Table 1). The operations range from recreational, subsistence, and part-time commercial to full-time commercial. Their catches generally are landed fresh and whole, although some catches are gilled and gutted. Weights of individual fish are obtained when fish are landed. Figure 8 shows the size distributions of skipjack and yellowfin tuna caught in this fishery in 2010.

The total catch from these tropical troll and handline fisheries ranged from 1,163 t in 1992 to 2,199 t in 2001 (Table 1). Total tropical troll and handline catch was 1,730 t in 2010. Yellowfin tuna made up 38% of the troll and handline catch in 2010. The next largest components were bigeye tuna, skipjack tuna, and blue marlin (*Makaira nigricans*). The Hawaii tropical troll and handline fisheries accounted for 84% of the total U.S. tropical troll and handline landings in 2010.

The Guam Division of Aquatic and Wildlife Resources (DAWR) monitors the troll fishery using a statistically designed creel survey. The Guam DAWR, with the assistance of NOAA Fisheries, extrapolates the creel survey data to produce total catch, fishing effort, and participation estimates. The Hawaii tropical troll and handline fishery catch and effort summaries are compiled from Hawaii DAR Commercial Fish Catch reports and Commercial Marine Dealer reports. The CNMI monitors the tropical troll fishery using their Commercial Purchase database.

F. Gill Net

The U.S. drift and set gill net fisheries operate in areas within the 200-mile EEZ of California and sometimes off Oregon. Tuna and tuna-like fishes are caught mainly by pelagic drift gill nets, with minor quantities caught incidentally in set gill nets. The number of vessels participating in the pelagic drift gill net fishery decreased from a high of 220 in 1986 to 33 in 2004 and was 38 in 2010. Swordfish catches are the major portion of the catch and peaked in 1985 at 2,990 t. Since then, swordfish catches have fluctuated while decreasing to 182 t in 2004 before rebounding slightly to 478 t in 2007 (Table 2). The preliminary estimate of swordfish caught n the drift gill net fishery for 2010 is 48 t.

Gill net fishery landings data (100% coverage) are collected by state agencies in California and Oregon (only minor amounts of tuna and tuna-like fishes are landed in Oregon). Logbook data for gill net fisheries are collected from 100% of the fleet by the CDFG. CDFG also collected length data for swordfish landings until 1999 from less than 1% of the landings. NOAA Fisheries observers on gill net vessels also collect length data.

G. Harpoon

The harpoon fishery operates in areas within the 200-mile EEZ of California between 32°N and 34°N latitude. The number of vessels participating in the fishery generally decreased from 113 in 1986 to 23 in 2001 (Table 1). Twenty-five vessels fished in 2010. Swordfish is targeted and trends in catches generally decreased from 305 t in 1985 to 20 t in 1991 (Table 2). Fifty t were landed in 2009 and 31 in 2010.

Landings and logbook data for the harpoon fishery are collected by the CDFG and coverage is 100% of the fleet. Length measurements were taken until 1999, covering less than 1% of swordfish landings.

III. RESEARCH

A. Fishery Monitoring, Management, and Socio-Economic Research

Shark Catch from the Hawaii Pelagic Longline Fishery -- Standardization of catch-per-unit-effort (CPUE=sharks/1,000 hooks) for blue shark (*Prionace glauca*) in the Hawaii pelagic longline fishery is in progress, using data gathered by the Pacific Islands Regional Observer Program in 1995–2010. These analyses are intended to clarify the catch trends for this species, which is the predominant shark caught in the Hawaii longline fishery, after adjusting for the effects of extrinsic factors (e.g., geographic position, sea surface temperature, gear configuration). The standardized CPUE time series (1995–2010) should be suitable for use as background information or input to a stock assessment for this species.

Catch and catch rate data for oceanic whitetip shark (*Carcharhinus longimanus*) and silky shark (*C. falciformis*) in the Hawaii pelagic longline fishery are also being analyzed using fishery observer data from 1995–2010. This work is important because these species are taken in large but unknown numbers, primarily as bycatch, in many Pacific Ocean fisheries. Standardized CPUE time series will be produced for oceanic whitetip shark (1995–2010) and silky shark (2000–2010).

Hawaii Pelagic Longline Economics – In 2004 NOAA Fisheries started a project to assess the change of important economic indicators of the Hawaii-based pelagic longline fisheries that target tuna and swordfish. Data on fishing costs and other economic information were collected by fishery observers for over 1,900 longline fishing trips. Over the Period 2004-2009, the average trip cost in the Hawaii longline fishery for tuna target trip increased by about 60%, from $13,900 per trip in 2004 to $22,100 per trip in 2009. Fuel cost made up about 52% of the total trip cost in 2009. However, the trip expenditure in 2009 went down compared to that in 2008, mainly because the fuel price in 2009 went down from the peak in 2008 (Pan, 2010). Based on the data, regulatory impact analysis of the 2010 WCPO bigeye closure was conducted and results indicated that bigeye closure resulted in bigeye landings in December 2010 that were 2.5% lower than the average for the period 2004-2009 (Pan and Arita, 2011). The economics data collection program is continuing with the Hawaii longline fishery and will be extended to other fisheries and areas in Guam, American Samoa, and the Commonwealth of the Northern Mariana Islands.

Hawaii Pelagic Small Boat Economics – NOAA Fisheries conducted an economic survey to assess economic and social characteristics of the Hawaii small boat pelagic fishery. A total of 343 intercept surveys on fishing trip costs were conducted at boat ramps across the state of Hawaii from April 2007 – April 2008. Results suggest that fuel is the primary cost fishers must incur on a fishing trip. For an average trolling trip in 2007, fuel accounted for 70% of total trip costs, and the increasing price of fuel may challenge the future economic viability of small boat pelagic fishing in Hawaii which may have implications for nearshore fishery resources (Hospital et al., 2011).

Retail Seafood Monitoring Project – Beginning in late 2006 a retail monitoring project has been in place allowing researchers to develop a time-series of consumer levels prices for the Hawaii seafood retail market. These data provide information on the economic contribution of fisheries and the market impacts of regulations by exploring how price changes travel through the fish 'value chain' from the fisherman to the consumer. The database includes weekly retail-level prices for all pelagic species and product forms prevalent in Hawaii's seafood market. Additionally, our database includes information on country of origin to allow an understanding of market demand and price premiums for locally caught seafood. A manuscript summarizing four years of data will be the first published source of consumer-levels prices for Hawaii seafood (Hospital and Beavers, in press).

Marine Debris -- In 2006, a partnership project was initiated among various NOAA offices in Hawaii to study and quantify rates of interaction and the subsequent economic impact of marine debris within Hawaii's longline fishery. In the North Pacific Ocean, derelict fishing gear (mainly lost or discarded nets from other fishing fleets) is often found drifting within areas heavily fished by the Hawaii longline fleet. Derelict fishing gear (DFG) impacts the longline fishery through active gear entanglement, vessel interactions, and catch interaction. The debris poses a safety hazard for crew to disentangle the vessel and impacts the fishery economically by the occurrence of immobilized or slowed fishing operations and may induce behavioral responses within the fishery. The main objectives of this partnership project were to gain a better understanding of the overall impacts of DFG and to quantify the economic impact of marine debris to the Hawaii-based longline fishing industry (Hospital and Morishige, 2011).

Albacore fishery dynamics - To prepare for the ISC albacore stock assessment, a paper was recently completed that describes changes in the distribution of catch and effort of the U.S. albacore troll fishery from 1960 to 2008 (Teo et al., 2010). One of the interesting changes has been the intense concentration of effort in the waters off Oregon and Washington over the past decade. From the 1970s to 1990s, a large proportion of the catch effort occurred along the transition zone of the North Pacific. However, from 2000 to 2008, ~75% of the catch and effort was concentrated in a 5° x 10° area off the Oregon and Washington coasts. The CPUE and length-composition time series in 4 subareas (dividing lines at 40°N and 130°W) were also investigated. The range of lengths caught by the albacore troll fishery was similar in all areas (corresponding to approximately age-2, -3, and -4 year classes). Length compositions in all areas were multimodal, with the strongest mode at age-3 (~65 cm FL). However, areas south of 40°N showed a relatively higher proportion of age-4 fish, which helps explain the higher mean lengths reported by previous studies. The areas south of 40°N also showed a relatively higher variability in the relative proportions of age-3 and -4 cohorts as compared with the areas north of 40°N, which has age-3 fish dominating the catch for most years. While the CPUE indices for the area south of 40°N were unreliable due to a lack of data, the CPUE indices for the other areas were relatively similar and highly correlated with each other (r ranged from 0.57 to 0.96, $p \ll 0.001$ for all correlations).

B. Stock Assessment Research

NOAA Fisheries continues to support stock assessment modeling efforts in the Pacific Ocean as part of several international fora including the International Scientific Committee for Tuna and Tuna-Like Species in the North Pacific Ocean (ISC) and the Western and Central Pacific Fisheries Commission (WCPFC). In particular, NOAA Fisheries analysts have been involved in model development for population analysis on albacore, Pacific bluefin tuna, bigeye tuna, striped marlin, swordfish, and blue shark (*Prionace glauca*).

Stock assessment research generally involves collaborative development of population models, which provide stock status determinations and form the basis for management advice to regional fisheries management organizations (RFMOs). As this work is conducted as international collaborations and reported directly to the RFMOs, it is not further described here.

C. Biological and Oceanographic Research

Otolith Collections to Support Stock Assessments

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

Age and growth – Age and growth of North Pacific albacore were assessed by examining annual growth increments in sagittal otoliths from 338 fish collected throughout the North Pacific Ocean. A wide size range of albacore (53-128 cm fork length, FL) was collected in the western, central, and eastern Pacific Ocean in an attempt to incorporate size-at-age information over juvenile, sub-adult, and adult life history stages. Overall, ages ranged from 1 to 15 years with the majority of fish between 2 to 4 years of age. Growth models fit otolith-based size-at-age well, and a bias-corrected form of Akaike's Information Criterion indicated that the specialized von Bertalanffy (VB) model provided the best fit (Fig. 1). Biological parameters of the specialized VB model included L_∞=120.0, K=0.184, and t_0=-1.945. Several albacore otoliths were processed for daily increments and confirmed our results using the annual method. In addition to otolith-based techniques, dorsal fin spines and length frequency (LF) analysis were used to generate estimates of size-at-age. In general, fin-spine ages matched otolith-derived ages (85% of samples). These new otolith data provide improved, updated growth information and they were used in the 2011 albacore stock assessment.

Population structure – NOAA Fisheries initiated a study using otolith chemistry to investigate population structure of the North Pacific albacore, which appears to be more complex than the current single stock hypothesis. The purpose of this study is to examine otolith stable isotopes of carbon ($\delta^{13}C$) and oxygen ($\delta^{18}O$) in addition to several trace elements in whole otoliths of albacore collected in two regions of the eastern Pacific Ocean that have shown limited mixing: northern region (offshore Oregon and Washington, > 40°N) and southern region (offshore southern California and northern Baja California, Mexico, < 40°N). Samples from three age classes (ages 2-4) were collected from each region through recreational and commercial fishing vessels from July to October of 2010. Significant differences existed in otolith chemistry from fish collected between the two regions ($P < 0.05$), and overall cross-validated classification success to respective collection region was 100% with age-specific comparisons exceeding 90% success. Otolith $\delta^{18}O$ was significantly enriched in the southern region relative to the northern region, similar to reported seawater $\delta^{18}O$ differences. In addition, significantly higher concentrations of sodium and magnesium, combined with lower phosphorus in otoliths from fish collected in the southern region, is consistent with regional physicochemical conditions (i.e., salinity, temperature, phosphate). Our preliminary findings support previous studies that have shown limited regional mixing of albacore in the eastern Pacific Ocean and provide life history information useful for sustainable management of North Pacific albacore.

North Pacific Albacore Archival Tagging Project – NOAA Fisheries and the American Fishermen's Research Foundation (AFRF) initiated an archival tagging program in 2001 to study the migration patterns and stock structure of juvenile albacore in the North Pacific. Since 2001, a total of 630 archival tags and 43 dummy tags have been deployed. To date, 22 archival and 6 dummy tags have been recovered. Recovery rates have been low. In 2010, no tags were returned.

A manuscript summarizing the results from the first 20 archival tags recovered was published in the journal *Fisheries Oceanography* (Childers et al. 2011). The paper describes the seasonal movements, migration patterns, and vertical distribution of juvenile albacore in the northeast Pacific.

Central Pacific Bigeye Tuna Tagging -- The spatiotemporal variability in bigeye tuna dive behavior in the central North Pacific Ocean was investigated based on data from 29 pop-up archival transmission (PAT) tags deployed on commercial size tuna (mean fork length 122.2 +/- 7.8 cm SD) in the central North Pacific Ocean from 4ºN - 32ºN. Results published in Howell et al. 2010 indicate that during the day, bigeye tuna generally spent time in the 0 – 50 m and 300 – 400 m depth ranges, with spatial and temporal variability in the deep mode; at night, bigeye tuna generally inhabited the 0 – 100 m depth range. More shallow and intermediate dive type behavior was found in the first half of the year, and at latitudes between 14ºN and 16ºN and north of 28º N. More detailed results can be found in Howell et al., 2010.

Billfish Life History Studies – NOAA Fisheries is collaborating with Charles Sturt University, Australia to conduct an age and growth study of striped marlin harvested in the Hawaii-based longline fishery. NOAA Fisheries is providing dorsal fin rays and otoliths collected at sea by observers onboard Hawaii-based longline vessels to Charles Sturt University for age determination. Gonad sub-samples are concurrently collected for determination of gender and sex-specific length at 50% reproductive maturity. Observers also continue to collect small (<110 cm eye-fork length) whole juvenile specimens; billfish of this size are rarely available.

Target vs. Non-target Catch in the Swordfish Fishery– As part of the Swordfish and Leatherback Use of Temperate Habitat (SLUTH) initiative begun in 2008, which aims to integrate studies of swordfish and leatherback sea turtles to inform management and conservation efforts, a study was conducted to identify environmental features that separate swordfish from leatherbacks, if they exist, thereby improving fishing efficiency and reducing bycatch encounters in the west coast drift gill net fishery. Preliminary results suggest that swordfish catch rates are correlated with both biotic (primary production, zooplankton abundance) and abiotic (SST, currents, depth) factors. If combined with data on location (i.e., latitude/longitude) and time of year (i.e., month), these factors can be used to predict swordfish catch rates with impressive accuracy (e.g., cross validated R^2 of ~ 0.7). Similar efforts are ongoing with leatherback turtles.

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

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

Additional research projects were also conducted during the cruise. An experiment begun in 2009 was continued to examine the potential for using a composite of rare earth metals to reduce shark bycatch. Preliminary results indicate that the rare earth metals did not affect the catch rate of shortfin mako or blue sharks as they were caught on the experimental hooks and control hooks in almost equal numbers. These results differ from those found on some coastal shark species where the deterrents proved effective at lowering catch rates. The data are being further examined based on size, sex, and other potential factors before drawing final conclusions.

Electronic Tagging Studies – Since 1999, NOAA Fisheries has been using satellite technology to study the movements and behaviors primarily of blue, shortfin mako, and common thresher sharks in the California Current and link these data to physical and biological oceanography. In recent years, tag deployments have been carried out in collaboration with the TOPP Program (http://www.topp.org), Mexican colleagues at CICESE (Centro de Investigación Cientifica y de Educatión Superior de Ensenada), and colleagues at the DFO (Department of Fisheries and Oceans) Pacific Biological Station in Nanaimo, British Columbia. This approach will allow us to characterize the essential habitats of sharks and subsequently to better understand how populations might shift in response to changes in environmental conditions on short or long time scales. Since 1999, a total of 95 shortfin mako, 85 blue and 28 common threshers have been satellite tagged thought this collaborative effort. NOAA Fisheries' scientists contributed to a recent paper describing the broader TOPP Program (Block et al., 2011) that highlighted the shark tagging studies as well as other NOAA studies on leatherback turtle and albacore tagging.

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

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

In 2007, the NOAA Fisheries began deploying pop-off satellite archival tags (PSATs) on sharks released alive from the drift gillnet fishery to assess survivorship. To date, 11 blue sharks (100 to 200 cm FL) have been tagged by fishery observers. Nine of these animals were male, and the sex of 2 animals was unknown. Three of the 11 sharks were released in "good" condition while the remaining 8 were released in "fair" condition. No sharks released in "poor" condition have yet been tagged. Satellite tag records suggest that all animals survived the acute effects of capture in the CDGN fishery. Temperature, depth, and movement data demonstrated behavior of blue sharks that was similar to that reported in other studies. One tag appeared to have been ingested after 17 days and regurgitated 3 days later. No confirmed female sharks or sharks in poor condition have yet been tagged, and future efforts will focus on tagging sharks that more broadly represent the catch, but the results show 100% survival rate for male blue sharks released in fair or better condition.

Survival of Thresher Sharks Released from the Recreational Fishery – NOAA Fisheries with the Pfleger Institute of Environmental Research is conducting a study to assess the post-release survival of thresher sharks caught by recreational anglers. During the first phase of the study, sharks were released after tail hooking and results demonstrated that survivorship is low for sharks greater than 185 cm FL or enduring fight times exceeding 85 minutes. Those results were published in the journal *Fisheries Research* in 2010 (Heberer et al., 2010). During the second phase of the study, the hypothesis that tail-hooked common thresher sharks survive the acute effects of trailing fishing gear in the southern California recreational fishery is being tested. Survivorship is being determined using PSATs deployed on subadult and adult common thresher sharks. In phase II, PSATs have been deployed on 5 common thresher sharks (132 to 175 cm FL) captured using fishery standard techniques and released with trailing gear. Of the 5 sharks, 3 displayed immediate mortality (within 31 hours of release), 1 shark survived the effects of trailing gear, and one of the PSATs did not report any information. The results of this study in combination with results of a published study on the survivorship of tail-hooked thresher sharks released without trailing gear will be used to estimate the survival rates of thresher sharks released from the recreational fishery.

Pelagic Shark Movement and Post-Release Survival -- Knowledge of species-specific horizontal and vertical movement patterns of pelagic sharks could allow targeting of longline gear to create mismatches between hook depth and the sharks' habitat (i.e., minimize vulnerability of the species to be avoided). NOAA Fisheries in collaboration with the Secretariat of the Pacific Community conducted a study (Beverly et al. 2009) where specially weighted longlines, with the shallowest hook being > 100 m, caught significantly fewer epipelagic species and had an improved catch rate of target species. Thus, certain bycatch species can be avoided by sinking hooks beneath the mixed layer but this strategy will not work for all pelagic species. It is also necessary to have accurate estimates of both at-vessel and post-release mortality rates so that mitigation strategies can be optimized by concentrating on species with high rates of post-release mortality.

NOAA Fisheries deployed 71 pop-up satellite archival tags (PSATs) on the five most commonly caught species of pelagic shark in the Hawaii-based commercial longline fishery (blue shark; shortfin mako, *Isurus oxyrinchus*; silky shark, *Carcharhinus falciformes*; oceanic whitetip, *C. longimanus*; and bigeye thresher, *Alopias superciliosus*) to determine species-specific horizontal and vertical movement patterns and survival after release from longline fishing gear. Meta-analysis on blue shark mortality from published and ongoing research indicated the summary effect for post-release mortality from longline gear was 15%. Favorable rates of post-release survival suggest catch-and-release in longline fisheries can be a viable management tool to protect parental biomass in shark populations, although fishery related factors (hook type, soak time, handling of catch during release) can influence survival rates (Musyl et al., in press).

Pop-up Satellite Archival Tag Performance – NOAA is analyzing the performance of pop-up satellite archival transmitting (PSAT) tags deployed on a wide array of highly migratory species to help improve attachment methodologies, selection of target species, and experimental designs, particularly with respect to post-release survival studies. While PSATs have been used as research tools to chronicle or 'archive' the habitat preferences, horizontal and vertical movements, fishery interaction, and post-release mortality rates of a variety of pelagic animals, there still remains operational problems with lower-than-expected reporting rates, early detachment, and incomplete data returns. These issues were quantified by analysis of data from 731 PSAT deployments on 19 pelagic species provided by collaborators and from 1433 PSAT deployments on 24 pelagic species taken from 53 published articles.Shark species in the database include bigeye thresher, blue, shortfin mako, silky, oceanic whitetip, great white, and basking sharks. Other pelagic species include: black, blue, and striped marlins; broadbill swordfish; bigeye, yellowfin, and bluefin tunas; tarpon; and green, loggerhead, and olive ridley turtles.

Based on the combined data from 1433 tags described in the literature and 731 tags provided by collaborators, there is a 77% overall reporting rate. Of the tags that recorded data, 106 (18 percent) hit their programmed pop-off date and 471 tags popped off earlier than their program date. The 154 (21 percent) non-reporting tags are not assumed to reflect fish mortality. Logistic regression models showed that reporting rates have improved significantly over time and are lower in species undertaking large vertical excursions. Of all the PSATs attached to sharks, 80% reported and 65% detached before the programmed pop-up date. Shark PSAT reporting rates were highest in species such as oceanic whitetip (81%) which were epipelagic and remained near the ocean surface. Reporting rates were lowest in species undertaking large (~1000 m) vertical excursions, such as bigeye thresher (37%) and shortfin mako (40%). Tag retention for the three sharks species averaged 155 days for oceanic whitetip, 220 days for bigeye thresher and 164 days for shortfin mako. Species-specific reporting rates were used to make recommendations for future PSAT sampling designs for fisheries researchers. Information derived from this study should allow an unprecedented and critical appraisal of the overall efficacy of the technology (Musyl et al., in press).

D. Bycatch and Fishing Technology Research

False Killer Whale Bycatch in the Central North Pacific – NOAA Fisheries has examined Hawaii-based deep-set longline observer data collected between 1994 and 2009, with emphasis on 2003–2009, to identify patterns of cetacean bycatch and depredation in relation to area, time, vessel, habitat variables, fishing gear, and set characteristics. The objectives of these analyses were to identify relationships amongst fishery interaction rates and variables that could provide opportunities to reduce depredation by cetaceans, especially false killer whales (*Pseudorca crassidens*), reduce the likelihood of incidentally catching a cetacean when present, or reduce the severity of injuries to cetaceans if caught. No correlates were identified that could markedly reduce depredation rates, but a slight (16%) reduction in repeat depredation within a fishing trip was evident when vessels moved at least 100 km following a depredaton event. The most practical option for reducing bycatch of false killer whales was determined to be the use of small (14/0–16/0) circle hooks, which could result in an estimated 6% reduction in bycatch and a greater likelihood of releasing animals with non-serious injuries. Additional research is needed to address unresolved questions relating to processes involved in depredation events and hookings or entanglements of false killer whales (Forney et al., 2011; Oleson et al., 2010).

Gear Modification to Reduce Bycatch -- NOAA Fisheries is contracting or otherwise assisting in longline and gill net fishing trials to test the efficacy of sea turtle bycatch mitigation methods in Brazil, Uruguay, Spain, Vietnam, Peru, Mexico, and Italy. The trials are designed to test the effects of gear modifications (e.g., use of large circle hooks, hook rings, net illumination) on the rates of hooking and entanglement of sea turtles in longline and gill net fisheries. These trials are also aimed to determine catch rates of target species as well in order to understand the potential viability of this modification in a commercial fishery.

Research from the previous few years indicate that relatively large circle hooks effectively reduce the bycatch of both loggerhead and leatherback sea turtles in longline fishing gear (Sales et al. 2010; Swimmer et al., 2010, 2011). These hooks also show acceptable catch rates of tuna species, but slightly reduced catch rates of targeted swordfish. In addition, use of circle hooks has been found to reduce the rates of capture of pelagic stingrays (*Pteroplatytrygon violacea*), motivating some fishermen, particularly in Italy, to convert to circle hooks (Piovano et al., 2009). Technical assistance was provided to numerous programs, both governmental and non-governmental, as experimental longline tests expand worldwide.

NOAA Fisheries also continues to investigate the post-release survival of sea turtles after their release from fishing gear. Methods involve use of pop-up satellite archival tags (PSATs) and platform terminal transmitters (PTTs) to estimate post-release survival of loggerhead turtles caught on longline fishing gear in the North Pacific Ocean, South Atlantic Ocean and

Mediterranean Sea. Preliminary results of tracking studies indicate no differences in duration of transmissions as a function of turtles 'severity' of injury, specifically deep or shallow hookings, and that most sea turtles were tracked for the duration of the tags' battery life.

Dive Behavior of Juvenile Loggerhead Turtles - Satellite telemetry data from 17 juvenile loggerhead turtles (43.5–66.5 cm straight carapace length) were used in conjunction with oceanographic data to analyze the influence of regional and seasonal oceanography on dive behavior of loggerhead turtles in the North Pacific Ocean. Combined dive behavior for all individuals showed that turtles spent more than 80% of their time at depths less than 5 m, and more than 90% of their time at depths less than 15 m. Multivariate classifications of dive data revealed four major dive types, three representing deeper, longer dives, and one representing shallower dives shorter in duration. Turtles exhibited variability in these dive types across oceanographic regions, with deeper, longer dives in the Hawaii longline swordfish fishing grounds during the first quarter of the year, as well as in the Kuroshio Extension Bifurcation Region and the region near the Baja California Peninsula, Mexico. Turtles in the Kuroshio Extension Bifurcation Region also exhibited dive variability associated with mesoscale eddy features, with turtles making deeper, longer dives while associated with the strongest total kinetic energy. Turtles in the central North Pacific exhibited seasonality in dive behavior that appeared to reflect synchronous latitudinal movements with the North Pacific Subtropical Front and the associated seasonal, large-scale oceanography. Turtles made deeper, longer dives during the first quarter of the year within this region, the reported time and area where the highest loggerhead bycatch occurs by the longline fishery (Howell et al., 2010).

Research on Escape Solutions in Japan Pound Nets – A new NOAA collaborative effort provided technical information and expertise to the Sea Turtle Association of Japan (STAJ), Tokyo University of Marine Science and Technology, and ProPeninsula to help develop methods to identify mitigation measures useful in reducing loggerhead sea turtle bycatch in mid-water pound net fisheries in Japan. In the initial phase of this project, the researchers designed and constructed a 50% scale model of the cod end of a pound net (4.5m x 4.5m x 3m). The scale model was used to test turtle escape solutions in a controlled tank environment to simulate the conditions experienced by sea turtles inside actual pound net gear. A system of panels was designed that allowed researchers to change out different prototype pound net escape devices (PEDs) during testing. Six PED designs were developed based on observations of gear in pound net and other fisheries. By testing these designs, a protocol was established for handling turtles and characterizing turtle escape behavior, and one promising PED prototype was identified.

Phase II of this project was conducted at Suma Aqualife Park in Kobe, Japan from 24 September to 4 October 2010. Using lessons learned from Phase I the trap of the pound net was redesigned to allow for better and more controlled testing of the PED. Successful PED designs will need to deliver: a) turtle encounter of PED; b) turtle escape via PED; and c) fish retention. During Phase II of the project we tested viability of turtle escape. Fishers from Japan and Mexico, as well as gear manufacturers were invited to join and participate in PED brainstorming of ideas, designing, developing, and testing. We ran a total of 34 trials of 11 variations of 3 PED designs at Suma Aqualife Park. In doing so, we refined a detailed research protocol, tested several PEDs, gained a better understanding of PED design pitfalls, and identified several promising PED designs. Of the 11 PEDs tested, all allowed turtles to escape (Ishihara et al., in press).

Longline Hook Effects on Shark Bycatch -- A NOAA study using fishery observers was conducted to compare bycatch rates under different operational factors (e.g., hook type, branch line material, bait type, the presence of light sticks, soak time, etc.) in the Hawaii-based longline fishery that might reduce shark bycatch. Sixteen contracted vessels within the deep-set Hawaii-based tuna fleet with fishery observers were used to test catch efficacy of large (size 18/0) circle hooks versus traditional Japanese style tuna hooks (size 3.6 sun) in controlled comparisons (Curran and Bigelow, 2010 and 2011). Fishery observers monitored a total of 1,182 sets comparing circle hooks versus tuna hooks, and also tested for fish size selectivity and survival upon longline retrieval.

The eighteen most caught species were analyzed representing 97.6% of the total catch by number. Catch rates on large 18/0 circle hooks were significantly reduced by 17% for blue shark, 27% for bigeye thresher shark and 69% for pelagic stingray. Bycatch rates for other incidental species such as billfish, opah (Lampris guttatus), and mahi mahi were also reduced compared to traditional tuna hooks. There was no significant difference in the catch rate of the target species, bigeye tuna, by hook type. In contrast to tuna hooks, large circle hooks have conservation potential for use in the world’s pelagic tuna longline fleets for some highly migratory species based on demonstrated catch rate reductions.

Electromagnetic Deterrents to Shark Bycatch -- NOAA Fisheries have been investigating the use of electropositive metals (lanthanide series) to selectively repel sharks from longline hooks. Electropositive metals generate large oxidation potentials when placed in seawater, and may perturb the electrosensory system in sharks and rays, causing the animals to exhibit aversion behaviors. Since commercially targeted pelagic teleosts do not have an electrosensory sense, they would not be affected by the perturbed electrical field around baited hooks associated with electropositive metal objects.

Feeding behavior experiments conducted with Galapagos sharks (*Carcharhinus galapagensis*), sandbar sharks (*Carcharhinus plumbeus*), and scalloped hammerhead (*Sphyrna lewini*) on Oahu indicated that sharks significantly reduced their biting of bait in proximity to electropositive metal objects, and exhibited significantly more aversion behaviors. Other experiments off Oahu were conducted to test the effects of Nd/Pr (Neodymiun/Praseodymium) alloy on the catch rates of sharks on bottom set longline gear using metal branchlines and control branchlines. Analysis showed a significant reduction in CPUE on hooks with the control treatment (Wang et al., 2010; Hutchinson et al., in press).

Further colloaborative studies involved conducting longline trials off the coast of Southern California and Ecuador. Branchlines with lead weight were alternated with branchlines with Nd/Pr metal weight. However, analysis of catch data indicated no difference in the catch rates of blue sharks, mako sharks, thresher sharks, silky sharks, and scalloped hammerhead sharks between control branchlines and branchlines with Nd/Pr metal.

IV. NOAA FISHERIES LITERURATURE FROM THE PAST YEAR

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Table 1. Number of vessels fishing in the North Pacific Ocean in U.S. HMS fisheries. Data for 2010 are preliminary.[1]

Year	Purse Seine [2]	Longline	Albacore Troll [3]	Pole-and-Line [4]	Tropical Troll & Handline	Gill Net	Harpoon
1985	110	36	792	27		210	99
1986	85	39	419	19		220	113
1987	85	37	486	18	1,899	210	98
1988	87	50	531	17	1,878	192	83
1989	84	88	338	18	2,002	158	44
1990	85	138	368	12	2,042	146	49
1991	65	141	172	12	2,117	123	32
1992	62	124	602	11	2,160	113	48
1993	62	122	608	13	2,132	105	44
1994	62	127	721	11	2,210	112	49
1995	55	116	471	11	2,387	127	39
1996	40	114	676	9	2,411	100	30
1997	38	117	1,172	9	2,400	104	31
1998	37	122	841	9	2,370	87	26
1999	25	140	776	9	2,502	78	30
2000	27	130	645	7	2,229	77	26
2001	29	125	860	9	2,208	64	23
2002	27	123	644	13	2,045	45	29
2003	29	128	729	14	1,960	37	34
2004	19	126	695	11	2,012	33	29
2005	23	126	541	10	1,917	37	24
2006	10	128	601	11	1,924	45	24
2007	20	130	628	59	1,888	49	28
2008	44	130	543	57	2,076	51	32
2009	49	128	710	102	2,184	54	28
2010	36	125	653	89	2,117	38	25

1 - Estimations of west coast vessels targeting ISC species are currently under revision.
2 - Includes both ETP and WCPO purse seine vessels that operated in the North Pacific.
3 - Number of albacore troll vessels prior to 2008 include some pole-and-line vessels.
4 - Includes albacore pole-and-line vessels and tropical pole-and-line vessels.

Table 2. U.S. catches (metric tons) of tunas and tuna-like species (FAO codes) by fishery in the North Pacific Ocean, north of the equator. Data for 2010 are preliminary. Species codes: ALB = albacore, YFT = yellowfin tuna, SKJ = skipjack tuna, BET = bigeye tuna, PBF = Pacific bluefin tuna, BKJ = black skipjack, BEP = bonito, SWO = swordfish, BUM = blue marlin, MLS = striped marlin.

Gear / Year	ALB	YFT	SKJ	BET	PBF	BKJ	BEP	SWO	BUM	MLS	UNSPEC. BILLFISH	UNSPEC. TUNA	TOTAL
Purse Seine [1]													
1985	26	92,623	47,634	1,751	3,320	0	3,360	32	0	0	0	0	148,746
1986	47	102,736	52,817	264	4,851	5	171	87	0	0	0	132	161,109
1987	1	123,044	48,667	222	861	1	3,093	2	0	0	0	56	175,947
1988	17	88,302	78,250	1,120	923	34	3,416	4	0	0	0	9	172,075
1989	1	77,744	35,671	516	1,046	85	795	6	0	0	0	70	115,934
1990	71	63,722	53,213	674	1,380	260	3,687	0	0	0	0	39	123,046
1991	0	26,789	50,107	415	410	2	218	2	0	0	0	7	77,950
1992	0	29,668	74,234	3,709	1,928	2	770	13	0	0	0	0	110,324
1993	0	23,805	60,485	3,035	580	0	186	17	0	0	0	0	88,108
1994	0	10,516	30,183	2,472	906	30	75	0	0	0	0	8	44,191
1995	0	16,934	60,036	5,803	657	9	20	0	0	0	0	0	83,459
1996	11	6,653	20,646	6,884	4,639	39	202	0	0	0	0	0	39,075
1997	2	20,866	37,525	8,702	2,240	0	115	2	0	0	0	7	69,459
1998	33	20,831	25,258	3,645	1,771	34	418	1	0	0	0	0	51,991
1999	48	4,989	18,710	3,236	184	62	18	0	0	0	0	0	27,248
2000	4	1,670	5,508	454	693	0	32	0	0	0	0	0	8,361
2001	51	5,362	17,794	1,122	292	13	0	0	0	0	0	0	24,634
2002	4	6,612	4,002	580	50	37	0	1	0	0	0	0	11,286
2003	44	3,562	21,212	3,528	22	70	0	0	0	0	0	0	28,439
2004	1	3,810	6,860	1,437	0	78	0	0	0	0	0	0	12,186
2005	0	6,792	19,171	3,992	201	0	0	0	0	0	0	0	30,157
2006	0	1,112	5,075	1,492	0	0	0	0	0	0	0	0	7,678
2007	0	2,725	11,045	555	42	0	0	0	0	0	0	0	14,367
2008	0	3,694	14,378	512	0	0	0	0	0	0	0	0	18,584
2009	39	5,523	65,767	264	410	0	2,132	0	4	1	0	4	74,144
2010	18	4,010	29,677	573	0	0	0	0	2	0	0	0	34,280
Pole and Line [2]													
1985	1,498	472	1,328	0	3	0	0	68	0	0	0	0	3,369
1986	432	554	1,367	0	1	0	0	9	0	0	0	1	2,364
1987	158	1,861	2,087	0	0	0	1	22	0	0	0	0	4,129
1988	598	1,140	3,450	5	5	0	26	40	0	0	0	0	5,264
1989	54	1,318	2,456	0	9	0	1	26	0	0	0	3	3,867
1990	115	154	553	0	61	0	0	21	0	0	0	2	906
1991	0	942	1,840	0	0	0	0	22	0	0	0	0	2,804
1992	0	1,928	1,744	0	2	0	0	33	0	0	0	2	3,709
1993	0	2,636	2,850	0	5	0	0	139	0	0	0	5	5,635
1994	0	1,844	2,422	0	1	0	187	19	0	0	0	18	4,491
1995	80	394	2,393	0	1	0	0	21	0	0	0	0	2,889
1996	24	696	1,331	0	0	0	0	9	0	0	0	1	2,061
1997	73	468	1,755	0	1	0	0	1	0	0	0	0	2,298
1998	79	2,206	1,067	0	4	0	6	5	0	0	0	0	3,367
1999	60	57	601	4	2	0	0	17	0	0	0	0	741
2000	69	3	320	1	12	0	0	24	0	0	0	0	429
2001	139	4	448	0	1	0	0	14	0	0	0	0	606
2002	381	2	420	0	2	0	0	0	0	0	0	2	807
2003	59	35	587	0	3	0	1	1	0	0	0	4	690
2004	127	18	279	0	0	0	1	37	0	0	1	0	463
2005	66	68	353	0	0	0	0	0	0	0	0	1	488
2006	23	3	294	0	0	0	0	0	0	0	0	3	323
2007	21	23	272	0	0	0	0	0	0	0	0	1	317
2008	1,472	23	293	0	0	0	0	0	0	0	0	4	1,792
2009	2,218	17	214	0	0	0	0	0	0	0	0	1	2,450
2010	1,874	0	0	0	0	0	0	0	0	0	0	0	1,874

Table 2. Continued.

Gear

Year	ALB	YFT	SKJ	BET	PBF	BKJ	BEP	SWO	BUM	MLS	UNSPEC. BILLFISH	UNSPEC. TUNA	TOTAL
Albacore Troll													
1985	6,415	5	0	0	0	0	0	0	0	0	0	0	6,420
1986	4,708	1	0	0	0	0	0	0	0	0	0	0	4,709
1987	2,766	76	0	0	0	0	33	0	0	0	0	0	2,875
1988	4,212	7	0	0	0	0	0	2	0	0	0	0	4,221
1989	1,860	1	0	0	0	0	0	0	0	0	0	0	1,861
1990	2,603	0	0	0	0	0	55	0	0	0	0	0	2,658
1991	1,845	0	0	0	0	0	0	0	0	0	0	0	1,845
1992	4,572	0	0	0	0	0	0	0	0	0	0	0	4,572
1993	6,254	137	62	0	0	0	0	1	0	0	0	1	6,455
1994	10,978	769	352	0	0	0	0	0	0	0	0	0	12,099
1995	8,045	211	1,157	0	0	0	0	1	0	0	0	0	9,414
1996	16,938	606	393	0	2	0	0	1	0	0	0	0	17,940
1997	14,252	4	2	0	1	0	0	1	0	0	0	0	14,260
1998	14,410	1,246	2	0	128	0	10	6	0	0	0	0	15,802
1999	10,060	52	16	0	20	0	0	1	0	0	0	0	10,149
2000	9,645	3	4	0	1	0	0	8	0	0	0	1	9,662
2001	11,210	1	1	0	6	0	0	0	0	0	0	0	11,218
2002	10,387	0	0	0	1	0	0	2	0	0	0	0	10,390
2003	14,102	0	2	0	0	0	0	0	0	0	0	0	14,104
2004	13,346	1	0	0	0	0	0	0	0	0	0	0	13,347
2005	8,413	0	0	0	0	0	0	0	0	0	0	0	8,413
2006	12,524	0	0	0	0	0	0	0	0	0	0	0	12,524
2007	11,887	0	0	0	0	0	0	0	0	0	0	0	11,887
2008	10,289	0	0	0	0	0	0	0	0	0	0	0	10,289
2009	10,575	5	1	0	0	0	0	0	0	0	0	0	10,581
2010	10,130	0	0	0	0	0	0	0	0	0	0	0	10,130
Longline													
1985	0	0	0	0	0	0	0	2	0	0	0	0	2
1986	0	0	0	0	0	0	0	2	0	0	0	0	2
1987	150	261	1	815	0	0	0	24	51	272	45	0	1,619
1988	307	594	4	1,239	0	0	0	24	102	503	68	0	2,842
1989	248	986	10	1,442	0	0	0	281	356	612	132	0	4,067
1990	177	1,098	5	1,514	0	0	0	2,437	378	538	58	0	6,205
1991	312	733	30	1,555	2	0	0	4,535	297	663	69	0	8,196
1992	334	346	22	1,486	38	0	0	5,762	347	459	142	0	8,936
1993	438	633	36	2,124	42	0	0	5,936	339	471	100	0	10,120
1994	544	610	53	1,827	30	0	0	3,807	362	326	99	5	7,663
1995	882	984	101	2,099	29	0	1	2,981	570	543	182	0	8,372
1996	1,185	634	41	1,846	25	0	0	2,848	467	419	115	2	7,581
1997	1,653	1,143	106	2,526	26	0	0	3,393	487	352	143	2	9,830
1998	1,120	724	76	3,274	54	0	0	3,681	395	378	172	9	9,883
1999	1,542	477	99	2,820	54	0	0	4,329	357	364	242	10	10,294
2000	940	1,137	93	2,708	19	0	0	4,834	314	200	152	0	10,397
2001	1,295	1,029	211	2,418	6	0	0	1,969	399	352	136	0	7,815
2002	525	572	127	4,396	2	0	0	1,524	264	226	160	0	7,796
2003	524	809	207	3,618	1	0	0	1,958	363	538	248	0	8,266
2004	361	715	142	4,339	1	0	0	1,185	283	376	200	9	7,611
2005	296	712	91	4,999	1	0	0	1,622	337	511	216	0	8,785
2006	270	958	94	4,466	1	0	0	1,211	409	611	174	0	8,194
2007	250	844	93	5,798	0	0	0	1,735	262	276	160	0	9,418
2008	353	869	121	5,927	0	0	0	1,980	348	426	239	0	10,263
2009	201	524	136	4,560	1	0	0	1,813	357	256	121	0	7,969
2010	409	544	149	5,242	0	0	0	1,654	293	158	125	0	8,574

Table 2. Continued.

Gear Year	ALB	YFT	SKJ	BET	PBF	BKJ	BEP	SWO	BUM	MLS	UNSPEC. BILLFISH	UNSPEC. TUNA	TOTAL
Gill Net													
1985	2	12	0	2	8	0	289	2,990	0	0	0	0	3,303
1986	3	14	0	3	16	0	58	2,069	0	0	0	4	2,167
1987	5	3	0	6	2	0	95	1,529	0	0	0	5	1,645
1988	15	7	0	5	4	0	33	1,376	0	0	0	2	1,442
1989	4	1	5	0	3	0	12	1,243	0	0	0	3	1,271
1990	29	1	1	1	11	0	35	1,131	0	0	0	2	1,211
1991	17	1	3	3	4	0	14	944	0	0	0	3	989
1992	0	4	1	1	9	0	7	1,356	0	0	0	6	1,384
1993	0	7	2	0	32	0	8	1,412	0	0	0	9	1,470
1994	38	0	0	0	28	0	1	792	0	0	0	2	861
1995	52	2	70	1	20	0	2	771	0	0	0	1	919
1996	83	2	2	0	43	0	2	761	0	0	0	0	893
1997	60	3	2	5	58	0	6	708	0	0	0	0	842
1998	80	2	3	4	40	0	4	931	0	0	0	2	1,066
1999	149	0	0	2	22	0	1	606	0	0	0	1	781
2000	55	1	0	2	30	0	1	649	0	0	0	0	738
2001	94	5	1	0	35	0	0	375	0	0	0	0	510
2002	30	1	0	0	7	0	1	302	0	0	0	0	341
2003	16	0	9	6	14	0	1	216	0	0	0	0	262
2004	12	1	0	0	10	0	2	182	0	0	0	0	207
2005	20	2	0	0	5	0	0	220	0	0	0	0	247
2006	3	1	2	0	1	0	0	443	0	0	0	1	451
2007	4	0	0	0	2	0	0	478	0	0	0	0	484
2008	1	0	0	0	0	0	0	280	0	0	0	0	281
2009	3	1	0	0	3	0	0	249	0	0	0	0	256
2010	3	0	0	0	0	0	0	48	0	0	0	0	51
Harpoon													
1985	0	0	0	0	0	0	0	305	0	0	0	0	305
1986	0	0	0	0	0	0	0	291	0	0	0	0	291
1987	0	0	0	0	0	0	0	235	0	0	0	0	235
1988	0	0	0	0	0	0	0	198	0	0	0	0	198
1989	0	0	0	0	0	0	0	62	0	0	0	0	62
1990	0	0	0	0	0	0	0	64	0	0	0	0	64
1991	0	0	0	0	0	0	0	20	0	0	0	0	20
1992	0	0	0	0	0	0	0	75	0	0	0	0	75
1993	0	0	0	0	0	0	0	168	0	0	0	0	168
1994	0	0	0	0	0	0	0	157	0	0	0	0	157
1995	0	0	0	0	0	0	0	97	0	0	0	0	97
1996	0	0	0	0	0	0	0	81	0	0	0	0	81
1997	0	0	0	0	0	0	0	84	0	0	0	0	84
1998	0	0	0	0	0	0	0	48	0	0	0	0	48
1999	0	0	0	0	0	0	0	81	0	0	0	0	81
2000	0	0	0	0	0	0	0	90	0	0	0	0	90
2001	0	0	0	0	0	0	0	52	0	0	0	0	52
2002	0	0	0	0	0	0	0	90	0	0	0	0	90
2003	0	0	0	0	0	0	0	107	0	0	0	0	107
2004	0	0	0	0	0	0	0	69	0	0	0	0	69
2005	0	0	0	0	0	0	0	77	0	0	0	0	77
2006	0	0	0	0	0	0	0	71	0	0	0	0	71
2007	0	0	0	0	0	0	0	59	0	0	0	0	59
2008	0	0	0	0	0	0	0	33	0	0	0	0	33
2009	0	0	0	0	0	0	0	50	0	0	0	0	50
2010	0	0	0	0	0	0	0	31	0	0	0	0	31

Table 2. Continued.

Gear

Year	ALB	YFT	SKJ	BET	PBF	BKJ	BEP	SWO	BUM	MLS	UNSPEC. BILLFISH	UNSPEC. TUNA	TOTAL
Sport and Other													
1985	1,176	58	5	1	107	0	426	100	0	42	0	468	2,383
1986	196	227	0	6	52	0	28	105	0	19	0	6	639
1987	74	2,159	633	1	52	0	266	27	0	28	0	67	3,307
1988	74	936	372	1	48	0	335	58	0	30	0	2	1,856
1989	183	849	103	0	121	0	137	49	0	52	0	0	1,494
1990	28	508	147	0	85	0	227	38	0	23	0	1	1,057
1991	77	235	137	0	92	0	69	38	0	12	0	0	660
1992	74	1,119	1,014	0	123	0	78	46	0	25	0	2	2,481
1993	25	2,031	2,279	0	322	0	140	157	0	11	0	0	4,965
1994	319	3	0	0	89	0	12	20	0	17	0	0	460
1995	103	5	263	0	258	0	0	23	0	14	0	0	666
1996	88	0	0	4	40	0	0	10	0	20	0	0	162
1997	1,019	0	83	0	203	0	0	4	0	21	0	0	1,330
1998	1,210	43	0	0	467	0	0	12	0	23	0	1	1,756
1999	3,622	0	0	0	528	0	0	18	0	12	0	0	4,180
2000	1,801	1	0	0	342	0	0	33	0	10	0	0	2,186
2001	1,635	0	0	0	356	0	0	19	0	0	0	0	2,010
2002	2,357	27	1	0	654	0	0	3	1	0	0	1	3,044
2003	2,214	8	2	3	394	0	0	1	0	0	0	0	2,622
2004	1,506	27	2	132	49	0	0	37	5	0	0	0	1,758
2005	1,719	0	0	0	79	0	2	0	0	0	0	0	1,800
2006	385	349	12	0	96	0	0	1	0	0	0	0	844
2007	1,225	0	0	0	14	0	0	12	0	0	0	0	1,251
2008	415	0	0	0	93	0	0	34	0	0	0	0	542
2009	678	7	1	0	177	0	1	1	0	0	0	0	865
2010	689	0	1	0	117	0	0	5	0	0	0	0	812
Tropical Troll and Handline													
1985	7	967	101	8	0	0	0	4	145	18	12	2	1,264
1986	5	1493	120	5	0	0	0	4	220	19	14	4	1,884
1987	6	1616	137	8	0	0	0	4	261	31	20	11	2,094
1988	9	941	172	17	0	0	0	6	266	54	20	11	1,496
1989	36	828	153	14	0	0	0	7	326	24	23	11	1,422
1990	15	891	138	25	0	0	0	5	295	27	17	11	1,424
1991	72	802	237	25	0	0	0	6	346	41	25	9	1,563
1992	54	602	167	13	0	0	0	1	260	39	17	10	1,163
1993	71	861	157	3	0	0	0	4	311	69	20	6	1,502
1994	90	870	138	7	0	0	0	4	298	35	22	8	1,472
1995	177	978	152	20	0	0	0	6	315	52	29	7	1,736
1996	188	934	224	7	0	0	0	5	409	55	18	5	1,845
1997	133	770	196	26	0	0	0	7	378	39	17	4	1,570
1998	88	766	143	9	0	0	0	7	242	26	19	6	1,306
1999	331	1019	181	24	0	0	0	9	293	29	33	4	1,923
2000	120	1080	415	207	0	0	0	0	235	14	20	15	2,106
2001	194	878	523	226	0	0	0	0	291	42	32	13	2,199
2002	235	632	355	586	0	0	0	0	225	29	13	6	2,081
2003	85	735	268	213	0	0	0	10	210	29	18	25	1,593
2004	157	746	251	381	0	0	0	7	188	35	23	45	1,833
2005	175	679	259	295	0	0	0	5	187	20	15	14	1,649
2006	95	508	296	303	0	0	0	4	160	21	14	12	1,413
2007	98	759	272	386	0	0	0	5	128	13	12	9	1,682
2008	29	680	384	222	0	0	0	6	181	14	13	8	1,537
2009	100	788	410	195	0	0	0	5	181	10	8	15	1,712
2010	25	650	395	465	0	0	0	0	144	5	12	34	1,730

1 - Purse Seine catches include catches from WCPO and ETP fisheries

2 - Most albacore Pole-and-Line catches prior to 2008 are included with albacore troll catches. Pole-and-Line catches of YFT, SKJ, and TUN after 2005 are from the Hawaii Pole-and-Line fishery

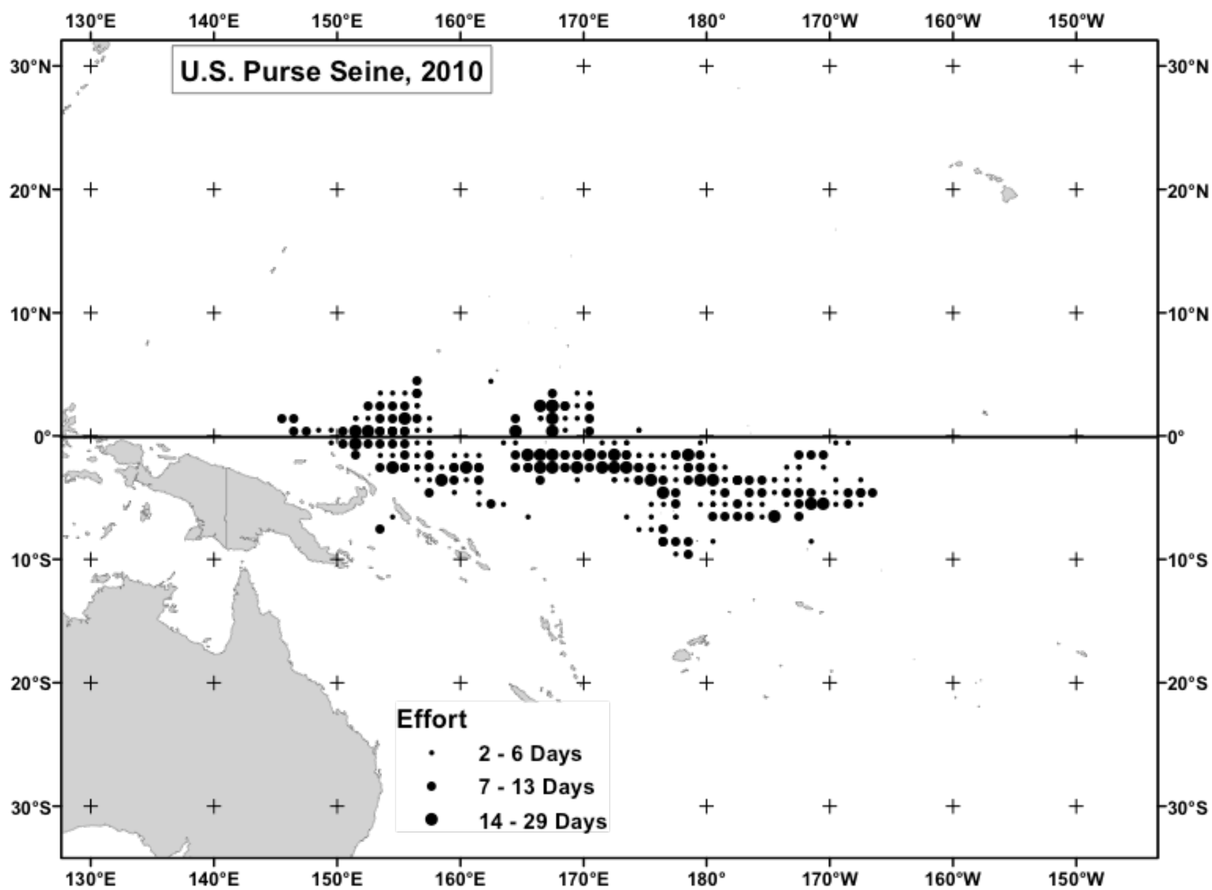

Figure 1. Spatial distribution of reported fishing effort in 2010 by the U.S. purse seine fleet in the Western-Central Pacific Ocean (provisional data). Area of circles is proportional to effort. Effort in some areas is not shown in order to preserve data confidentiality. Effort in the South Pacific is shown to represent the entire fishery, but the data reported herein are for the North Pacific only.

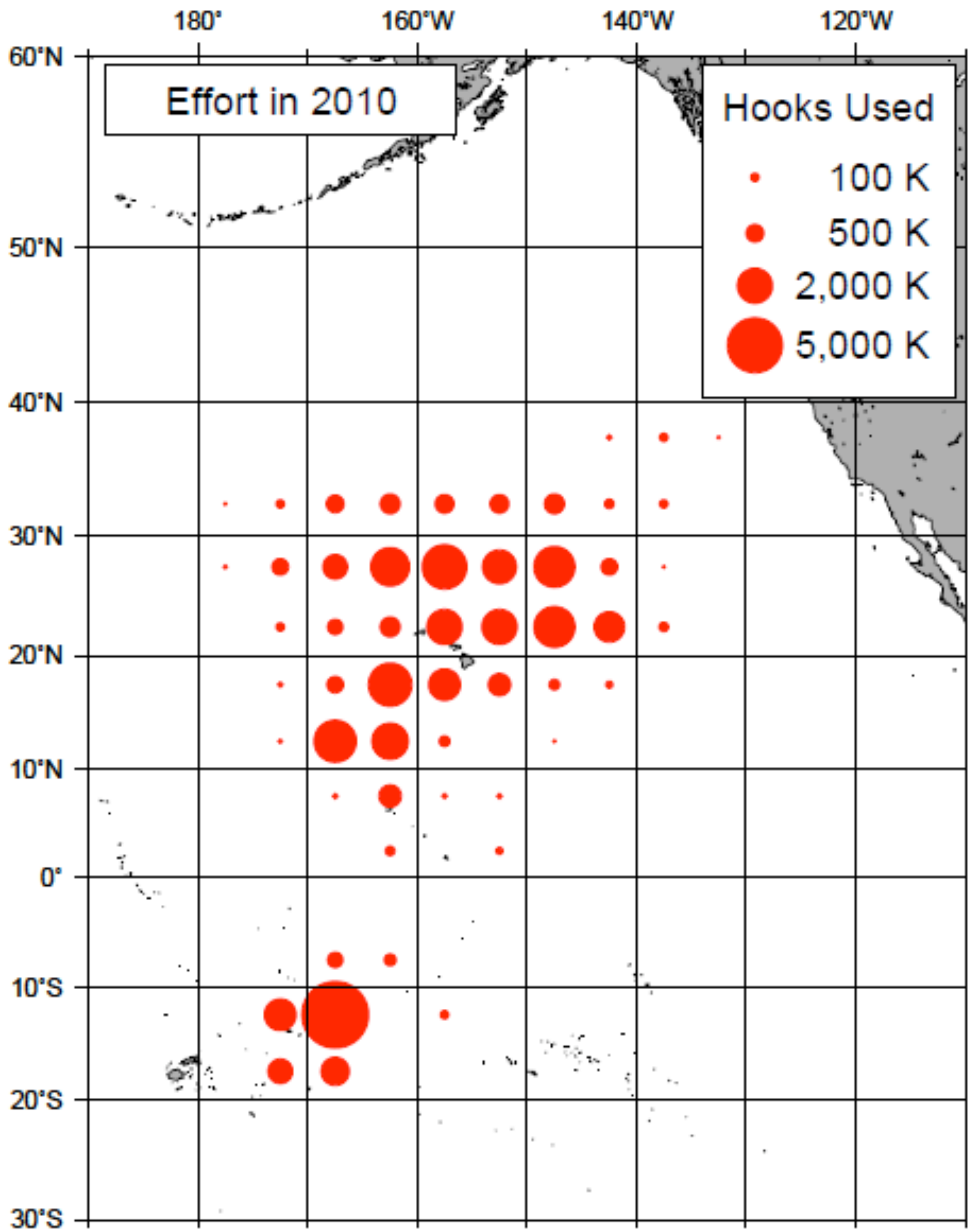

Figure 2. Spatial distribution of reported fishing effort by the U.S. longline fleet, in 1,000s of hooks in 2010 (provisional data). Area of circles is proportional to effort. Effort in some areas is not shown in order to preserve data confidentiality. Effort in the South Pacific is shown to represent the entire fishery, but the data reported herein are for the North Pacific only.

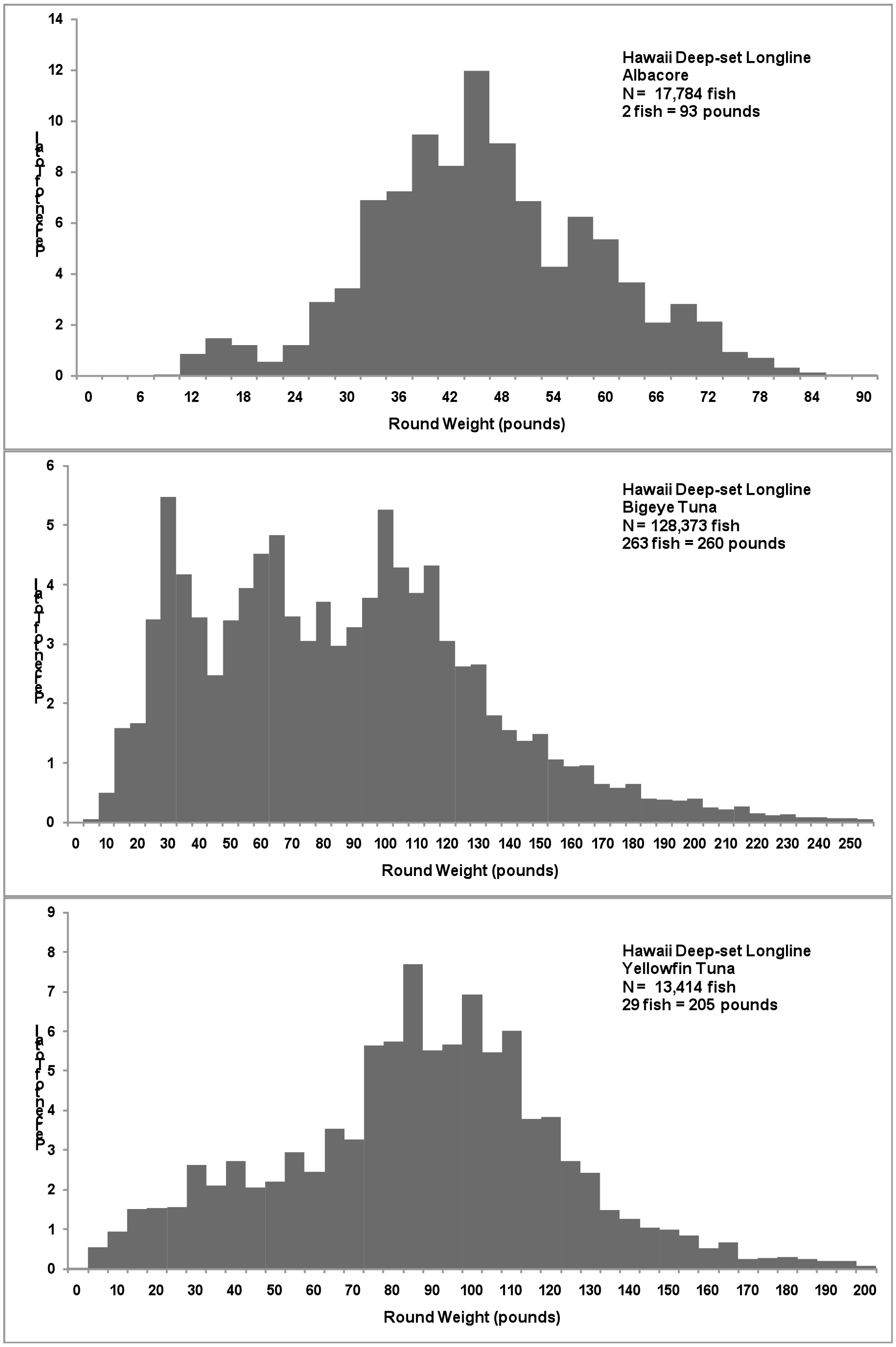

Figure 3. Size distribution of (A) albacore (*Thunnus alalunga*), (B) bigeye tuna (*Thunnus obesus*), and (C) yellowfin tuna (*Thunnus albacares*) catch by the Hawaii-based, deep-set longline fishery in the North Pacific Ocean, 2010.

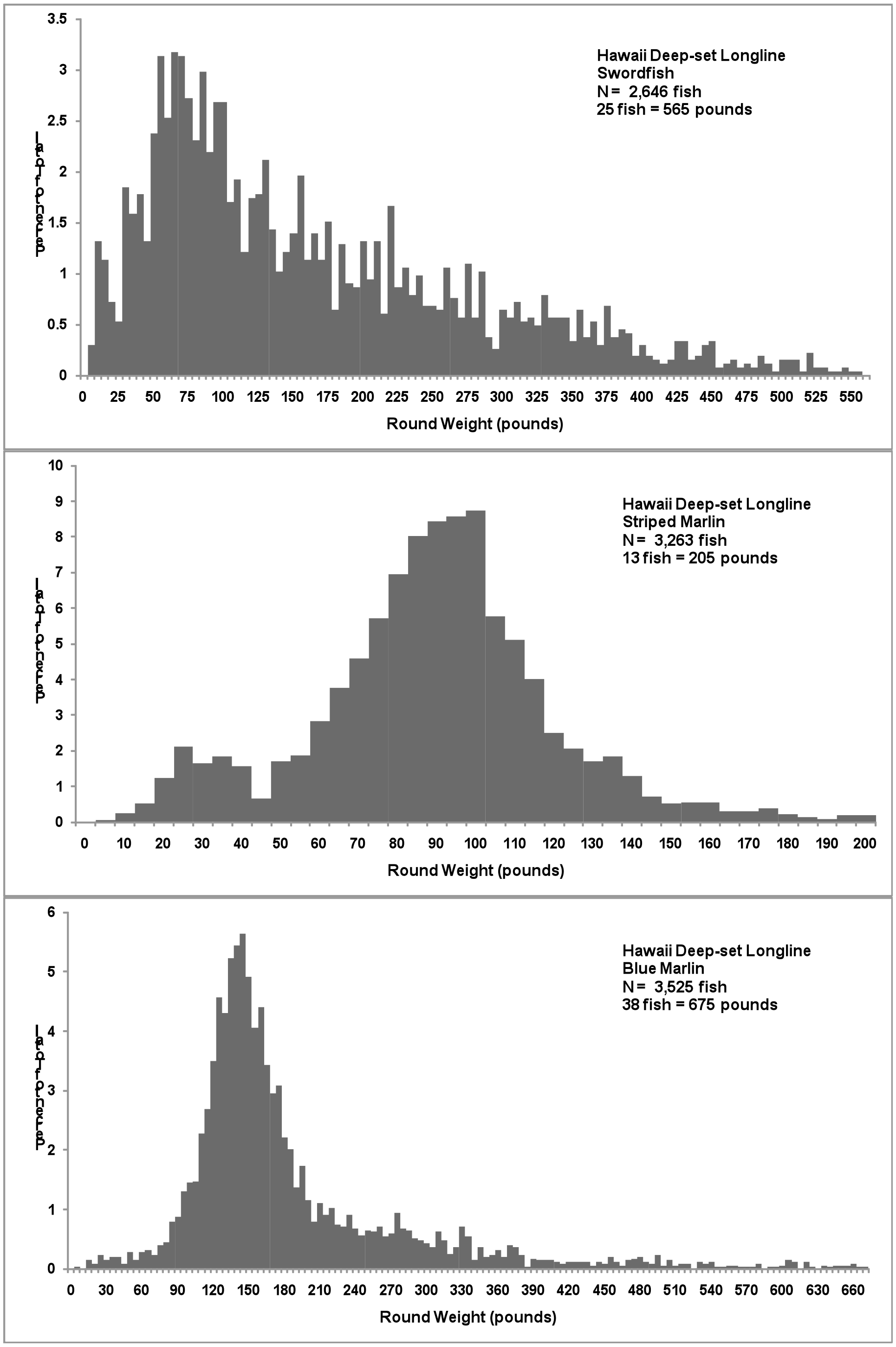

Figure 4. Size distribution of (A) swordfish (*Xiphias gladius*), (B) striped marlin (*Tetrapturus audax*), and (C) blue marlin (*Makaira mazara*) catch by the Hawaii-based deep-set longline fishery in the North Pacific Ocean, 2010.

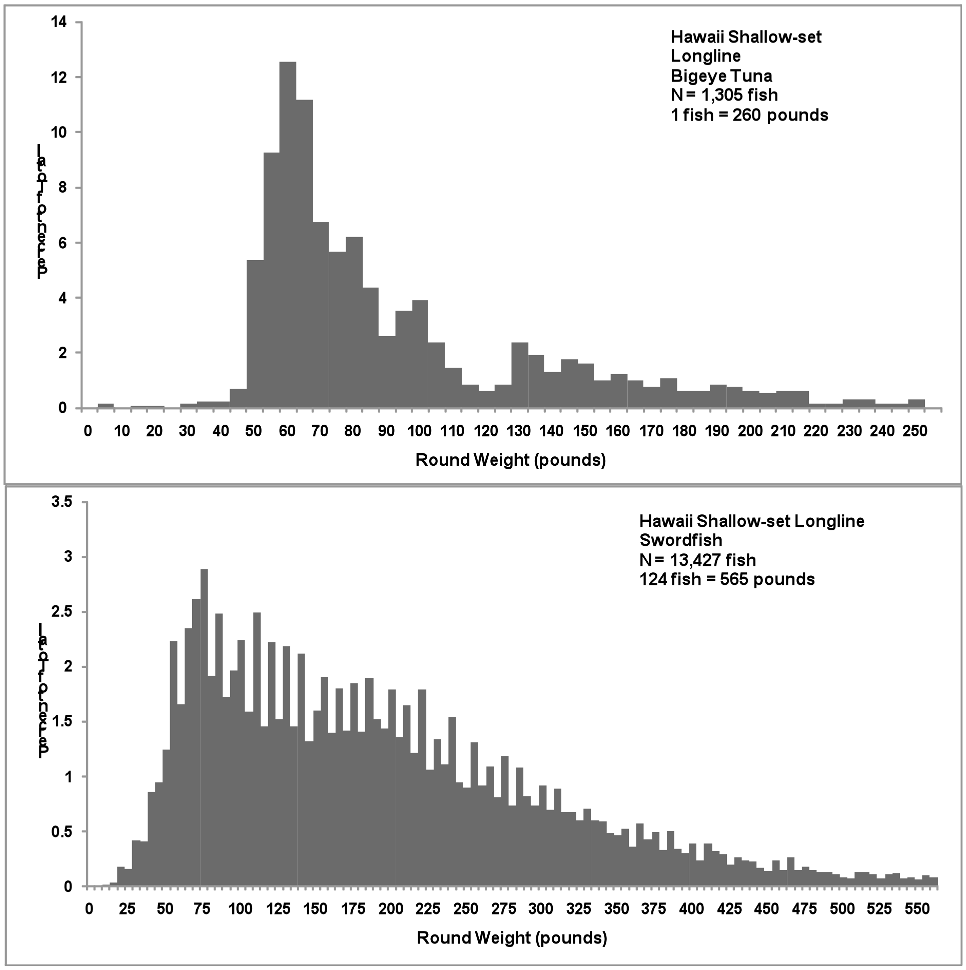

Figure 5. Size distribution of (A) bigeye tuna (*Thunnus obesus*) and (B) swordfish (*Xiphias gladius*) catch by the Hawaii-based, shallow-set longline fishery in the North Pacific Ocean, 2010.

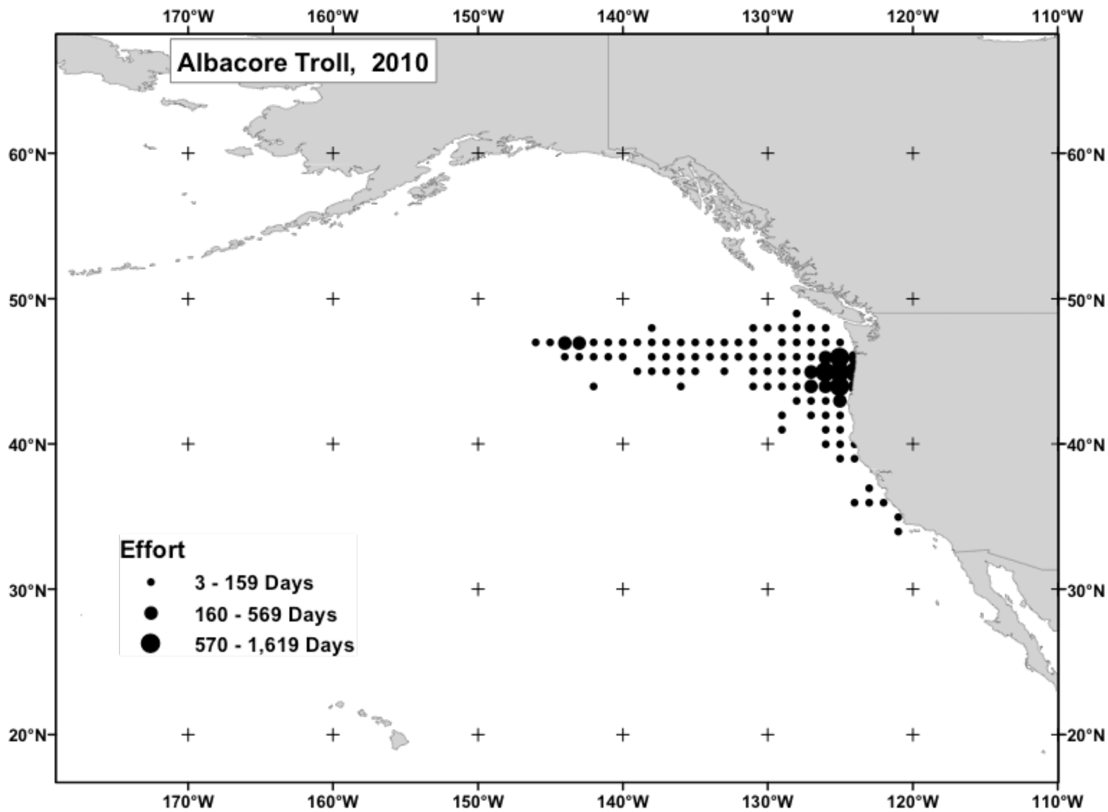

Figure 6. Spatial distribution of reported fishing effort by the U.S. albacore (*Thunnus alalunga*) troll fleet, in days fished in 2010 (provisional data). Area of circles is proportional to effort. Effort in some areas is not shown in order to preserve data confidentiality.

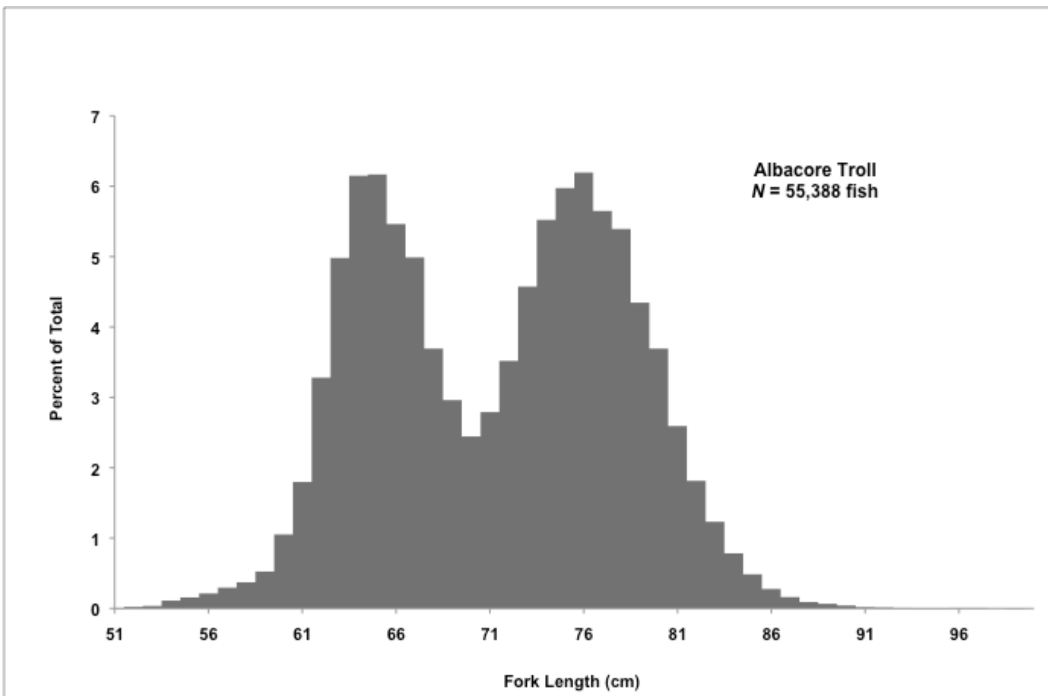

Figure 7. Size distribution of albacore catch by the U.S. albacore (*Thunnus alalunga*) troll fishery in 2010.

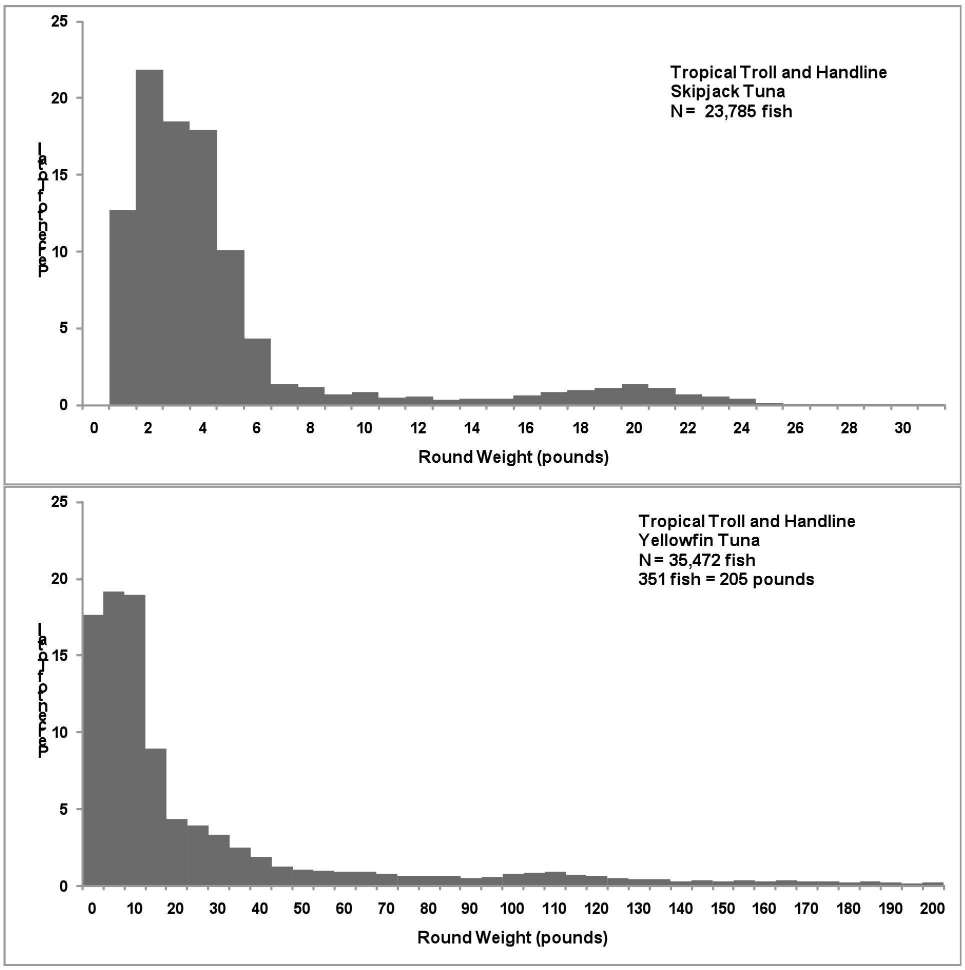

Figure 8. Size distribution of (A) skipjack tuna (*Katsuwonus pelamis*) and (B) yellowfin tuna (*Thunnus albacares*) catch by the Hawaii troll-and-handline fishery, 2010.