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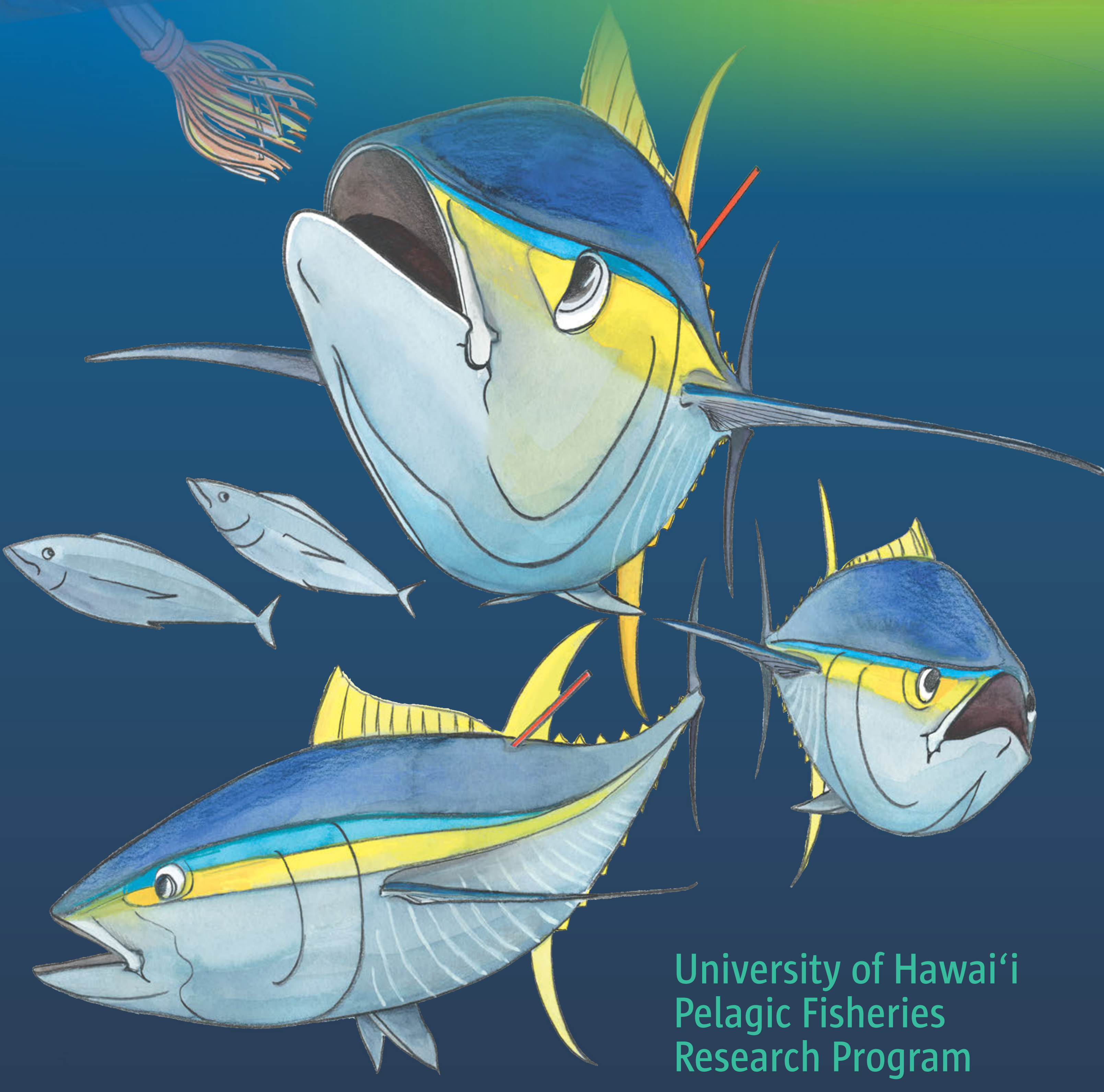

University of Hawai‘i Pelagic Fisheries Research Program

By Paul Dalzell

About the Author

Paul Dalzell is a Fellow of the Royal Geographic Society and the former senior scientist and pelagic fisheries coordinator for the Western Pacific Regional Fishery Management Council, a position he held for more than two decades. Prior to joining the Council, he worked at the South Pacific Commission (now the Pacific Community)

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List of Acronyms

AMO	Atlantic multi-decadal oscillation
BPUE	bycatch per unit effort
CLIOTOP	Climate Impacts on Oceanic Top Predators
cm	centimeter
CNMI	Commonwealth of the Northern Mariana Islands
CPUE	catch per unit effort
EEZ	exclusive economic zone
ENSO	El Niño–Southern Oscillation
EPO	Eastern Pacific Ocean
FAD	Fish aggregating device
FCMA	Fishery Conservation and Management Act
FEP	Fishery Ecosystem Plan
FFA	Forum Fisheries Agency
FL	fork length
GLM	generalized linear models
HTTP	Hawai‘i Tuna Tagging Project
IATTC	Inter-American Tropical Tuna Commission
ISC	International Scientific Committee for Tuna and Tuna-Like Species
JIMAR	Joint Institute for Marine and Atmospheric Research
kg	kilogram
km	kilometer
LJFL	lower jaw fork length
m	meter
MHLC	Multilateral High-Level Conference
mm	millimeter
MLE	maximum likelihood estimation
MSA	Magnuson-Stevens Fishery Conservation and Management Act
MSY	maximum sustainable yield
mt	metric ton
mtDNA	mitochondrial DNA
nm	nautical mile
NMFS	National Marine Fisheries Service
PI	principal investigator
PICES	North Pacific Marine Science Organization
PIFSC	Pacific Islands Fisheries Science Center
PFRP	Pelagic Fisheries Research Program
PRIAs	Pacific Remote Islands Areas
PSAT	Pop-up Satellite Archival Tag
RFP	request for proposal
SCTB	Standing Committee on Tuna and Billfish
SEAPODYM	Spatial Ecosystem and Population Dynamics Model
SEC	South Equatorial Current
SECC	South Equatorial Counter Current
SOEST	School of Ocean and Earth Science and Technology
SPC	Secretariat of the Pacific Community
SST	sea surface temperature
UH	University of Hawai‘i
UNCLOS	United Nations Convention on the Law of the Sea
WCPFC	Western and Central Pacific Fisheries Commission
WCPO	Western and Central Pacific Ocean
WPRFMC	Western Pacific Regional Fishery Management Council
WTP	Western tropical Pacific
ZINB	zero-inflated negative binomial

1. Introduction

This monograph is a history of a grant awarding program, the Pelagic Fisheries Research Program (PFRP), which was conducted through the University of Hawaiʻi (UH) from 1992 to 2012. The focus of the funding was research on tuna and tuna-like species in the Pacific Ocean, the largest single feature on Earth, extending over 65 million square miles (fig. 1). This vast area of water is surrounded by Australasia and East and Southeast Asia in the west and the various nations along the West coast of the American continent.

The importance of the Pacific can be illustrated by the tuna catch histories for the Eastern Pacific Ocean (EPO) and Western and Central Pacific Ocean (WCPO) (figs. 2a and 2b). The time series for the WCPO shows a more or less monotonous increase driven primarily by skipjack, caught predominantly by purse seines.

There are numerous islands across the Pacific, primarily within the tropical belt and settled by Melanesians, Micronesians and Polynesians (fig. 3). This area, termed Oceania comprises more than 10,000 islands, with a total land area (excluding Australia, but including Papua New Guinea and New Zealand) of approximately 317,700 square miles, or 822,800 square kilometers (km).

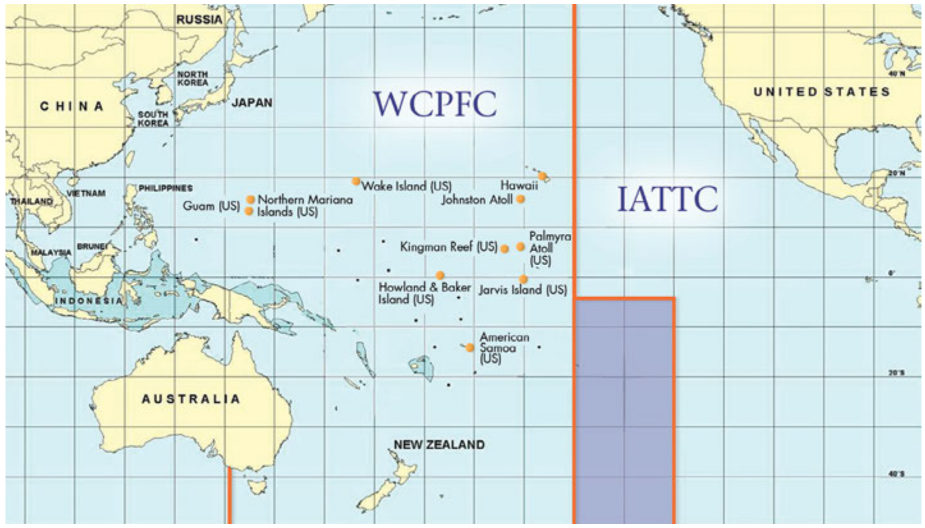
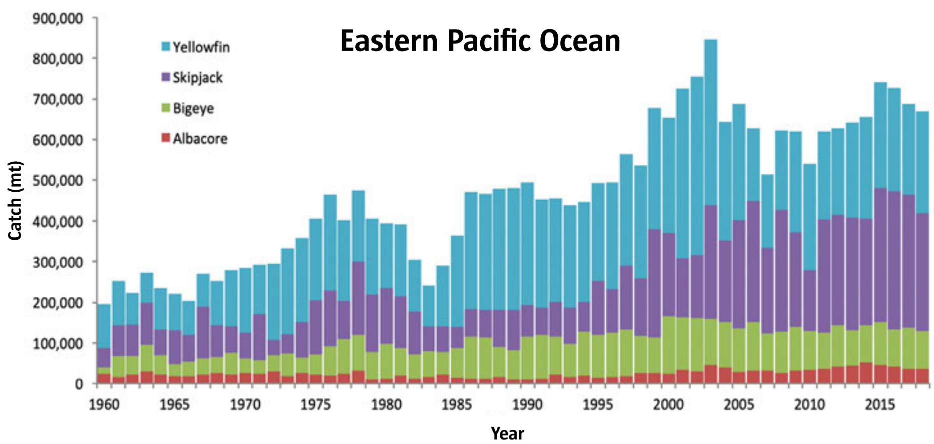
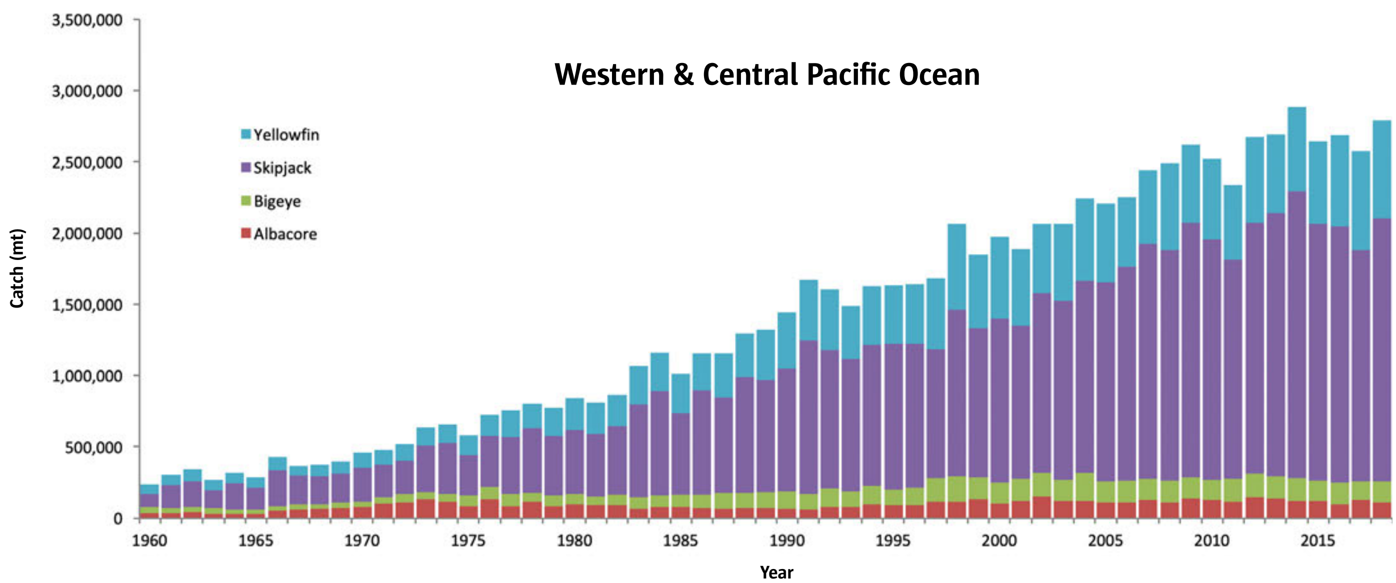


Fig. 1. Internationally, pelagic fishery resources of the Eastern Pacific Ocean are managed by the Inter-American Tropical Tuna Commission (IATTC) while those in the Western and Central Pacific are subject to conservation and management measures developed by the Western and Central Pacific Fisheries Commission (WCPFC). The blue box indicates an area of overlapping jurisdiction. Source: WPRFMC.





Figs. 2a and 2b. Catches of yellowfin, skipjack, bigeye and albacore in the EPO and WCPO between 1960 and 2018. Source: WCPFC.

1.1 Traditional Marine Resource Management in Oceania

While there is evidence that the regions that make up Oceania had different processes of cultural diversification owing in part to environmental settings and the differential size of the islands, many communities throughout the tropical Pacific share a similar knowledge of basic resource conservation principles that are the result of centuries of continuing experimentation and innovation. Localized adaptive management was based on customary knowledge and practices and was responsive to changes in local environmental and social conditions.

Long before Western societies recognized the limits of ocean resources, the people of Oceania developed methods to safeguard against the collapse of these invaluable resources. Their long history of conservation was motivated by scarcity, limited resources and climate variability. Some species were referred to as "famine foods," suggesting that food needs were not always met. Some Pacific Island cultures learned that their resources were limited and introduced appropriate conservation measures, while others exceeded those limits, which ultimately led them to overshoot their carrying capacity.

Localized adaptive management was based on customary knowledge and practices and was responsive to changes in local environmental and social conditions. A part of the conservation ethic, particularly in Micronesia and Polynesia, had to do with ocean voyaging and learning to prepare special voyaging foods and rationing.

The people of Oceania relied on the sea for much of their protein, as well as other essential nutrients and minerals that were lacking in the poor-quality soils of many atolls and small islands. In addition, other important resources such as building materials, fishing gear, jewelry, medicines and household tools were obtained from the sea. These included extremely important items for tools, like pearl shells for lures and hooks. Marine resource management was often in the hands of the local resource users who were knowledgeable of the natural rhythms and processes that controlled resource abundance. Fishermen were often held in high regard within the community, and master fishermen held extensive knowledge that was passed down from generation to generation

Species of importance often have multiple names, depending on various life history characteristics (e.g., size, sex, color). In Rapa Nui, the rudderfish *Kyphosus sandwicensis*, locally known as *nanue*, is one of the most important nearshore fisheries species and has seven secondary names based on size and five secondary names based on color pattern. Names were also associated with various life history phases, which often connoted an understanding of the ecology of the species.

Pacific Islanders developed an encyclopedic knowledge of their marine resources, especially as they related to seasonal movements, feeding behavior, and spawning seasons and locations. Approaches to harvest management were often based on identifying the specific times and places that fishing could occur so as not to disrupt basic processes and habitats of important food resources Many natural processes affect the distribution of these resources, but some of the most important are related to seasons and moon phases. This knowledge helped to inform lunar calendars, which were mental models based on a holistic understanding of marine and terrestrial environments and emphasized certain repetitive ecological processes (e.g., spawning, aggregations, feeding habits) that function at different time scales (e.g., seasonal, monthly and daily), which were adapted to fishermen's own observations for specific locations

The most important marine conservation measure in Oceania was local marine tenure, where the right to fish in a location was controlled by a clan, chief or family. Spatial closures within these tenure systems were employed throughout Oceania for various purposes. These closures were often imposed to ensure large catches for special events or as a cache for when resources in the commonly accessed fishing grounds ran low. Temporal closures were widely used to reduce intensive harvest of spawning fishes or other predictable aggregations. These collective practices were developed through much trial and error and fostered sustainability under highly variable and scare resource conditions.

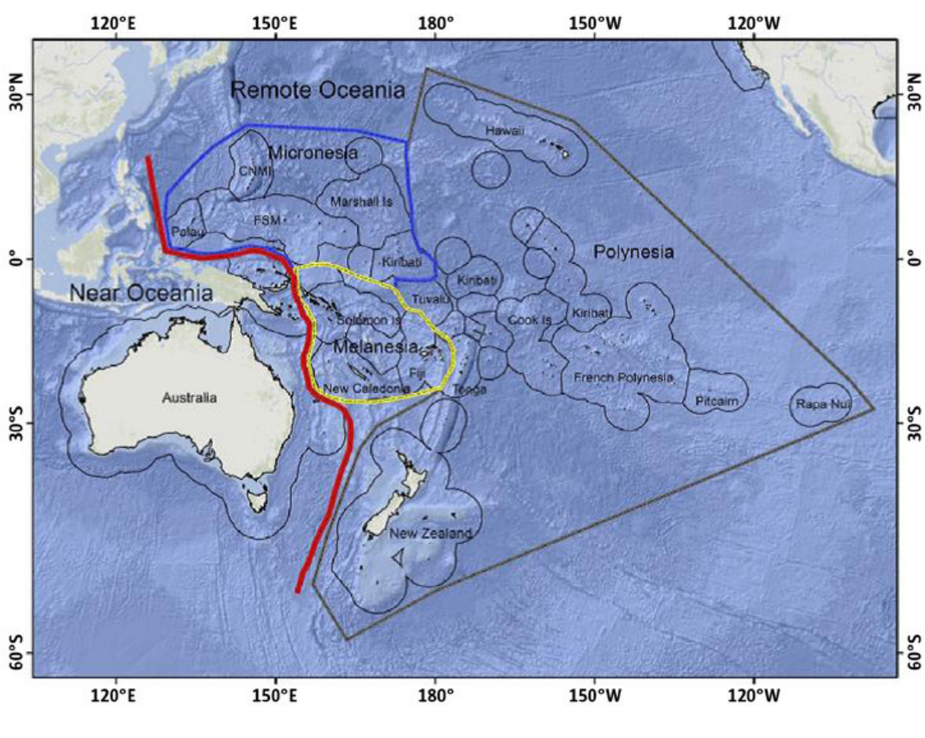


Fig. 3. Near and remote Oceania showing extent of Polynesia, Melanesia and Micronesia. Source: Friedlander 2018.

1.2 Contemporary Marine Resource Management of Pacific Pelagic Species

People have been drawing imaginary lines on the Pacific Ocean since it first began to be extensively navigated by the ancestors of the Southeast Asian and Pacific Island cultures. Maps, known as "stick charts," were used by Micronesian navigators on long ocean voyages. Further lines on the ocean were drawn by Europeans during the advent of exploration and expansion in the later 15th century. One of the first major divisions occurred in 1493 when Pope Alexander VI formally approved the division of the unexplored world between Spain and Portugal, through the *Treaty of Tordesillas*, which Spain and Portugal signed one year later. Through the 18th, 19th and 20th centuries, various imperial and colonial administrations divided up the various archipelagos in the Pacific, demarcating more lines on the ocean in terms of boundaries, in some cases separating clearly related peoples such as dividing the islands of Samoa, or separating the people of Guam and the Commonwealth of the Northern Mariana Islands (CNMI).

The development of the United Nations Convention on the Law of the Sea (UNCLOS) led to the implementation globally of the concept of exclusive economic zones (EEZs). These areas of coastal water and seabed commonly spanned 200 nautical miles (nm) from shore of a country's coastline, to which the country claims exclusive rights for fishing, drilling, and other economic activities.

In the United States, the Fishery Conservation and Management Act (later known as the Magnuson-Stevens Act or MSA) was passed by Congress in 1976 as the primary law governing marine fisheries management in the U.S. EEZ. The MSA fosters long-term biological and economic sustainability of the nation's marine fisheries. Key objectives are to prevent overfishing, rebuild overfished stocks, increase long-term economic and social benefits, and ensure a safe and sustainable supply of seafood. Under the MSA, eight regional fishery management councils were established to develop policy for federal fishery management. They are the New England, Mid-Atlantic, South Atlantic, Gulf of Mexico, Caribbean, North Pacific (Alaska), Pacific (West Coast and Idaho) and the Western Pacific Regional Fishery Management Councils.

The Western Pacific Council (WPRFMC or Council) has authority over the management of fisheries seaward of the state waters (i.e., in general beyond 3 nm) of Hawai'i, American Samoa, Guam, the CNMI and seaward from the short of the U.S. Pacific remote island areas (PRIAs[1]). Together referred to as the Western Pacific Region, these islands are surrounded by 1.5 million square miles of U.S. EEZ waters, nearly half of the nation's entire EEZ (fig. 4).

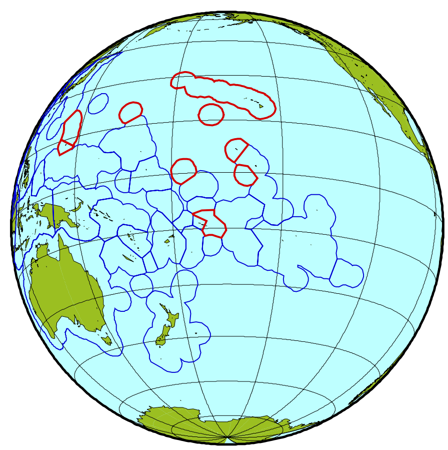


Fig. 4. The U.S. EEZ (red lines) in Oceania within which the authority for federal fisheries management is the responsibility of the Western Pacific Regional Fishery Management Council. Source: PFRP.

Under the MSA, U.S. fisheries management is a transparent and public process of science, management, innovation and collaboration with fishing communities. As a result, the United States is ending and preventing overfishing, actively rebuilding stocks and providing fishing opportunities and economic benefits for both commercial and recreational fishermen, as well as shore-side businesses that support fishing and use fish products.

1.3 Oceanographic Environment[2]

The Hawai'i Archipelago and the Mariana Archipelago, which includes Guam and CNMI, lie in the North Pacific subtropical gyre while American Samoa lies in the South Pacific subtropical gyre. These subtropical gyres rotate clockwise in the Northern Hemisphere and counter clockwise in the Southern Hemisphere in response to trade wind and westerly wind forcing. Hence the main Hawaiian Islands, Guam, CNMI and American Samoa experience weak mean currents flowing from east to west, while the northern portion of the Hawai'i Archipelago experiences a weak mean current flowing from west to east. Imbedded in this mean flow are an abundance of mesoscale eddies created from wind and current interactions with bathymetry. These eddies, which can rotate either clockwise or counter clockwise, have important biological impacts. Eddies create vertical fluxes, with regions of divergence (upwelling) where the thermocline shoals and deep nutrients are pumped into surface waters enhancing phytoplankton production, and also regions of convergence (downwelling) where the thermocline deepens.

North and south of the islands are frontal zones that also provide important habitat for pelagic fish and thus are targeted by fishers. To the north of the Hawai'i and Mariana Archipelagoes and also to the south of American Samoa lie the subtropical frontal zones consisting of several convergent fronts located along latitudes 25° to 40° N and S, often referred to as the Transition Zones. To the south of the Hawai'i and Mariana Archipelagoes and to the north of American Samoa, lies the equatorial current system spanning latitudes 15° N to 15° S and consisting of alternating east and west zonal flows with adjacent fronts.

A significant source of interannual physical and biological variation is the El Niño and La Niña events. During an El Niño the normal easterly trade winds weaken, resulting in a weakening of the westward equatorial surface current and a deepening of the thermocline

[1] The U.S. Pacific remote islands are comprised of Johnston, Midway, Palmyra and Wake Atolls; Baker, Howland and Jarvis Islands; and Kingman Reef.

[2] This summary of the oceanography of the tropical and sub-tropical Pacific Ocean is taken from a Final Environmental Impact Statement for the Fishery Management Plan for the Pelagic Fisheries of the Western Pacific Region published by the NMFS in 2001, which is believed to be a complete and accurate account of that ecosystem.

in the Central and Eastern equatorial Pacific. Water in the Central and Eastern equatorial Pacific becomes warmer and more vertically stratified with a substantial drop in surface chlorophyll. A La Niña event exhibits the opposite conditions. During an El Niño the purse-seine fishery for skipjack tuna shifts over 1,000 km from the western to the central equatorial Pacific in response to physical and biological impacts (Lehodey et al. 1997).

Physical and biological oceanographic changes have also been observed on decadal time scales. These low frequency changes, termed regime shifts, can impact the entire ocean basin. Recent regime shifts in the North Pacific have occurred in 1976 and 1989, with both physical and biological (including fishery) impacts (Polovina 1996; Polovina et al. 1995).

Oceanic pelagic fish such as skipjack and yellowfin tuna and blue marlin prefer warm surface layers, where the water is well mixed by surface winds and is relatively uniform in temperature and salinity. Other fish (such as albacore, bigeye tuna, striped marlin and swordfish) prefer cooler, more temperate waters, often meaning higher latitudes or greater depths. Preferred water temperature often varies with the size and maturity of pelagic fish, and adults usually have a wider temperature tolerance than sub-adults. Thus, during spawning, adults of many pelagic species usually move to warmer waters, the preferred habitat of their larval and juvenile stages.

Large-scale oceanographic events (such as El Niño) change the characteristics of water temperature and productivity across the Pacific, and these events have a significant effect on the habitat range and movements of pelagic species. Tuna are commonly most concentrated near islands and seamounts that create divergences and convergences which concentrate forage species, also near upwelling zones along ocean current boundaries and along gradients in temperature, oxygen and salinity. Swordfish and numerous other pelagic species tend to concentrate along food-rich temperature fronts between cold upwelled water and warmer oceanic water masses.

2. Pelagic Fisheries Research Program Overview

When the nation's regional fishery management councils were first established, the MSA excluded tuna as a federally managed species. Spearheaded by the Western Pacific Council, a campaign to include tuna in MSA was waged as tuna was an important fish targeted by fishermen and prized by U.S. seafood consumers, especially in the Western Pacific Region. This campaign culminated in 1990 with enactment of amendments that repealed the tuna exclusion provisions of the MSA and subjected tuna to exclusive U.S. management in the U.S. EEZ. See Appendix 1 for more details on the inclusion of tuna.

The PFRP was established in 1992 after the MSA was amended to include "highly migratory fish" under the purview of the Councils. The PFRP was to provide scientific information on pelagic fisheries to the WPRFMC for use in development of fisheries management policies. The term "pelagic" generally refers to fish that live in the near-surface waters of the ocean, often far from shore, such as tuna and billfish. Detailed information on these species can be found in Appendix 2.

The PFRP was funded by Congress through earmarks requested by U.S. Sen. Daniel K. Inouye (D-Hawai'i). The program was administered by the Joint Institute for Marine and Atmospheric Research (JIMAR), under the UH School of Ocean and Earth Science and Technology (SOEST). The program manager was a researcher at the UH. The general management of the PFRP was supervised by a Steering Committee composed of representatives of the UH, the NOAA Pacific Islands Fishery Sci ence Center (PIFSC) and the WPRFMC (fig. 5).

In order for the Council to determine "optimum use" of the valuable pelagic fishery resources in the region, information was required from a broad spectrum of research disciplines, e.g., biology, genetics,

Fig. 5. The PFRP Steering Committee (circa 1996): (l-r) Michael Laurs, director, NMFS Honolulu Laboratory; John Sibert, program manager, PFRP; Barry Raleigh, dean, SOEST; Kitty M. Simonds, executive director, WPRFMC; Gary Sakagawa, coordinator of Pelagics Research, NMFS Southwest Fishery Science Center; Mike Tillman, director, SW Fisheries Science Center, La Jolla; and Tom Schroeder, acting director, JIMAR. Sibert and Tillman attended the meeting as guests. Committee member Paul Callaghan, chair, WPRFMC Scientific and Statistical Committee (not pictured) participated via telephone from Guam. PFRP photo.

statistics, sociocultural and economics. The original PFRP research priorities were the product of a 1992 workshop. Corresponding projects were developed and approved by late 1993. Work on these projects began in 1994.

Most of the topics identified during the workshop were addressed in the first few years of PFRP operations. However, during those years, management concerns, governance arrangements and the fisheries themselves changed drastically. The ecosystem approach to fisheries became the dominant paradigm for 21st century fisheries management. Ecosystem-based fisheries management is a holistic way of managing fisheries and marine resources by taking into account the entire ecosystem of the species being managed.

A second workshop was held at the UH Imin Conference Center in November 2005 to identify new research priorities for future requests for proposals (RFPs). Some of the high ranking topics of concern to those attending included a) economic modeling to explore management policy choices and their impacts on the fishing industry and on target and non-target species abundance; b) ecosystem impact of reduction of the abundance of specific tuna species and movement on all scales through support of local, regional and basin-scale tagging; and c) analysis of sources, distribution and cultural value of fish in fishing communities.

The PFRP solicited for new research proposals every one to two years as federal funding permitted. RFPs were posted on the PFRP web site, on selected email list servers and circulated to fishery research offices in academic and commercial fishery programs. In consultation with the PFRP Steering Committee, the RFPs focused on particular research themes such as, oceanographic environment on pelagic fisheries, economic factors influencing fishing industries, ecosystems management approaches and fishery bycatch topics. Submitted research proposals went through an external review process before submission to the PFRP Steering Committee for a final decision.

Members of the steering committee and the program manager were eligible to apply for PFRP funds as principal or co-principal investigators (PI). In such instances, they had to recuse themselves from deliberations and decisions on proposals on which they were named. Most project investigators were affiliated with regional research institutes, such as the National Marine Fisheries Service (NMFS) and the Secretariat of the Pacific Community (SPC, New Caledonia). Funds were also awarded to private consulting firms and to U.S. and foreign universities.

Table 1. Project areas of the PFRP and number of projects funded under each research topic.

Project Area	Number of Projects
Biology	41
Statistical and Modeling	21
Economics	18
Socioculture	13
Oceanography	9
Protected Species	7
Trophodynamics	5
Genetics	4

In total, the PFRP funded 118 research projects. The dominant projects were biological (41) followed by statistical and modeling (21), economics (18) and sociocultural (13). The complete breakdown of project by topic areas is shown in Table 1. A few projects from each area are highlighted below. The complete list of all projects can be found in Appendix 3.

Projects selected for funding were required to submit annual progress reports and make presentations at PFRP PI meetings, which were held in Honolulu and at the Lake Arrowhead Tuna Conference in California. (See Appendix 4 and fig. 28.)

The projects were also highlighted in the PFRP's quarterly newsletter. The PFRP newsletter provided a platform for the PIs and collaborators to give a summary of their findings to a broader audience. These articles would be later drafted for a SOEST JIMAR report and/or publication in a peer-reviewed journal. A list of the PFRP newsletter issues and articles can be found in Appendix 5 as well as online at www.soest.hawaii.edu/PFRP/pub_list_newsletter.html. The SOEST-JIMAR reports and journal and other publications can be found at www.soest.hawaii.edu/PFRP/allpub.html.

In 2012, the program quit accepting RFPs due to discontinuation of program funding from the federal government. Further information about the PFRP is available on the PFRP website (www.soest.hawaii.edu/PFRP/), maintained by the UH.

Fig. 6. About to release a bigeye tuna carrying an electronic data-logging and tracking tag in the equatorial Pacific. David Itano photo.

3. SELECT BIOLOGY PROJECTS

3.1 Reproductive Biology of Yellowfin Tuna, *Thunnus albacares*, in Hawaiian Waters and the Western Tropical Pacific Ocean.

David Itano and Richard Shomura

The reproductive biology of yellowfin tuna *(Thunnus albacares)* was examined in relation to seasonality, their vulnerability to capture and fisheries interaction in the WCPO. Results from this study confirmed the high reproductive potential of yellowfin tuna in areas where sea surface temperatures (SST) remain above 24°C to 25°C. However, spawning activity was noted to decrease or temporarily cease in some areas where SST remained high, suggesting that trends in local water temperatures, forage availability or localized productivity may be important to maintain spawning activity.

The study examined peak spawning areas and seasons by school and by capture gear type, noting a positive relationship between high reproductive rates, localized areas of forage abundance and heightened vulnerability to surface fisheries. Length at 50% maturity for equatorial samples was estimated at 104.6 centimeters (cm) with no significant difference in length at maturity estimates between samples taken by surface and sub-surface gears. However, spawning frequency estimates varied according to school and harvest gear type. Reproductively active fish are vulnerable to troll, shallow handline, shallow-set longline and purse-seine gear. Mature but reproductively inactive fish are predominant in the catches of deep-set longline gear.

Histological evidence suggests alternating periods of near daily spawning interspersed with non-spawning periods as female yellowfin tuna cycle in and out of active spawning periods, characterized by near daily spawning periodicity and high fecundity. Higher latitude regions, such as around Hawai‘i, have well defined seasonal patterns of yellowfin spawning at which time these fish become vulnerable to surface fisheries.

Seasonal peaks in spawning may also be evident in equatorial areas subject to strongly reversing monsoon weather patterns that dictate upwelling and localized productivity. In the equatorial region of the WCPO purse-seine fishery, consistently high SSTs and a relatively stable oceanographic environment suggest tropical tunas can reproduce independently of season. However, areas and times of elevated spawning activity appear to exist and vary spatially and temporally between years.

Fig. 7. Ripe ova of a reproductively active yellowfin tuna in active spawning mode. David Itano photo.

Fig. 8. Female yellowfin in Hawai‘i with mature gonads. Catch rates for surface trollers increase during the spring-summer spawning season. David Itano photo.

Fig. 9. Beach landing of mature yellowfin tuna taken by a handline fishery. David Itano photo.

Fig. 10. A purse-seine vessel advancing on a large school of tuna actively feeding on the ocean anchovy *Encrasicholina punctifer*. These actively feeding schools are often in a near daily spawning rhythm. Their surface-feeding activity makes them vulnerable to purse-seine gear. David Itano photo.

Fig. 11. NOAA researcher attaching pop-up archival tag on an albacore tuna on a longline vessel in waters off American Samoa. NMFS PIFSC photo.

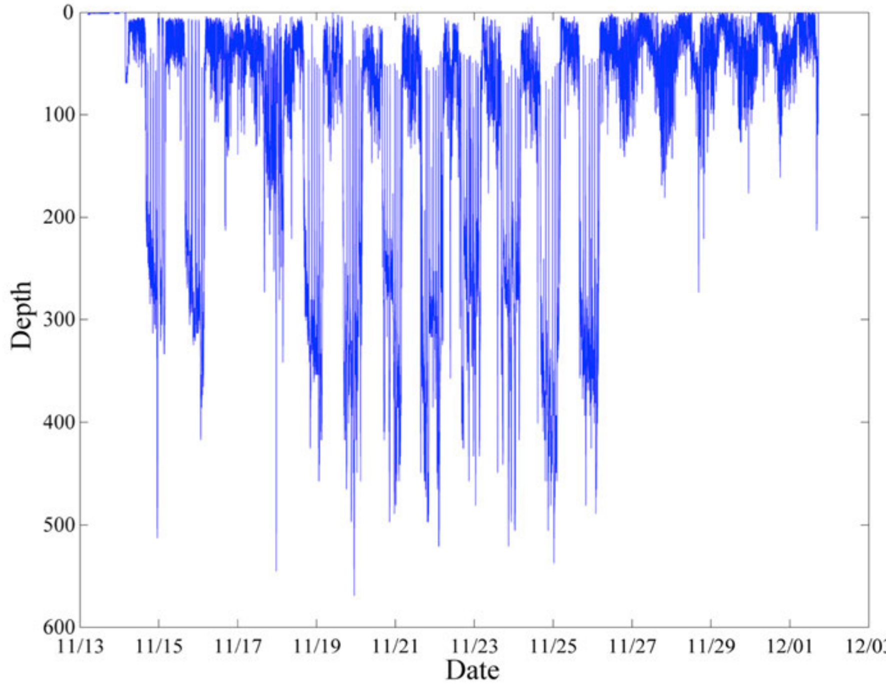


Fig. 12. Bigeye tuna high-resolution archival data from a successfully recovered pop-up archival tag for the period Nov. 14–Dec. 2, 2002. The tuna occupied shallow depths (<100 m) during the night and deep (200 m to 400 m) foraging dives during the day between Nov.17 and 27 and generally remained in depths less than 200 m during the day between Nov. 28 and Dec. 2. Source: Howell et al. 2010.

The study found a positive relationship between intense feeding activity on the ocean anchovy *Encrasicholina punctifer* and high reproductive rates for yellowfin. It is suggested that discrete areas of elevated forage abundance that vary in time and space and between years could help to explain differences in proposed spawning areas and "seasons" in this equatorial region.

In Hawai'i, fisheries targeting large yellowfin appear to be based on an inshore spawning run during the spring, summer and early fall, when vulnerability to surface gear and the potential for gear conflict and interaction between fisheries increases. Inshore longline area closures have been implemented to mitigate gear conflict issues between large and small gear types.

An unintended consequence of these measures is that reproductively active yellowfin close to the main Hawaiian Islands are exposed to reduced fishing pressure. However, the significance of this will require more information on the role of immigration, residence times, spawning site fidelity and recruitment of yellowfin to Hawaiian fisheries.

3.2 Describing the Vertical Habitat of Bigeye and Albacore Tunas and Post-Release Survival for Marlins in the Central Pacific Longline Fisheries with Pop-Up Archival Transmitting Tags

Jeffrey Polovina and Michael Seki

Data from 29 pop-up archival transmission tags deployed on commercial-size bigeye tuna *(Thunnus obesus)* in the central North Pacific Ocean from 4° N to 32° N were analyzed to describe variability in their dive behavior across space and time. During the day, bigeye tuna generally spent time in the 0 to 50 meter (m) and 300 to 400 m depth ranges, with spatial and temporal variability in the deep mode. At night, bigeye tuna generally inhabited the 0 to 100 m depth range. Three daily dive types were defined based on the percentage of time tuna spent in specific depth layers during the day. These three types were defined as shallow, intermediate and deep and represented 24.4%, 18.8% and 56.8% of the total number of days in the study, respectively.

Data from 11 pop-up archival transmitting tags attached to opah (*Lampris guttatus*, family Lampridae) in the central North Pacific between November 2003 and March 2005 were used to describe their vertical movement and habitat. In the subtropical gyre northwest of the Hawaiian Islands, opah generally inhabited a 50 to 400 m depth range and 8° to 22° C temperatures. They were frequently found in depths of 50 to 150 m at night and in greater depths (100 to 400 m) during the day but were constantly moving vertically within this broad range.

Two publications resulted from this project: Howell et al. 2010 and Polovina et al. 2008. This project also contributed to tagging of several albacore tunas in American Samoa, and those results are presented along with oceanographic data from a research cruise in Domokos et al. 2007.

3.3 Age and Growth of Striped Marlin, *Kajikia audax*, in the Hawai'i-based Longline Fishery

R. Keller Kopf and Robert Humphreys Jr.

Striped marlin is the most widely distributed species of Istiophorid billfish (marlin, sailfish and spearfish). Currently it is believed that there five semi-independent stocks in the Pacific Ocean. Striped marlin is the most valuable species of Istiophorid billfish caught in the Pacific, with 4,000 metric tons (mt) harvested per year in the WCPO. However, the biomass of striped in the North Pacific has declined to approximately 6% to 16% of 1952 levels.

The project found that the first yearly annulus typically formed at about 301 days after hatching. The observed spine radius of the first annulus was 5.35 ± 0.62

millimeters (mm). The mean marginal increment showed that a new annulus forms annually each spring. Striped marlin growth averaged 4.5 mm per day during the first 12 months of life. Growth was rapid in terms of length (not mass). A striped marlin caught on the April 15, 2008, had an estimated hatch date of Oct. 28, 2007. This fish was six months old, with a lower jaw fork length (LJFL) of 1,220 mm.

Growth in the Southwest Pacific Ocean was validated. This striped marlin stock exhibited rapid early growth with 70% to 75% of maximum body length (L∞=2722 ♀, 2581 mm LJFL ♂) during the first two years of life. Ages ranged from 130 estimated days in a 4-kg whole weight (1,120 mm LJFL) male to eight estimated years in a 168-kg (2,871 mm LJFL) female.

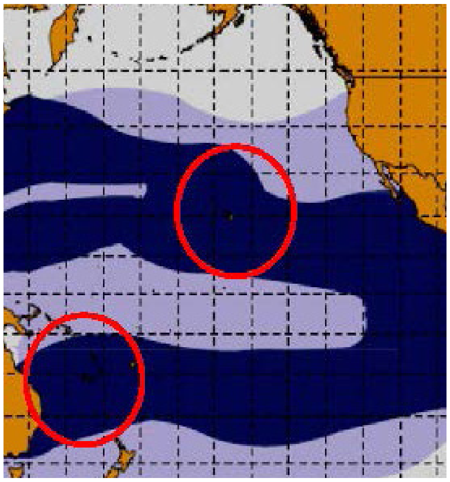


Fig. 13. North and South Pacific striped marlin primary distribution (dark blue), occasional distribution (light blue) and study regions (red circles). Source: Kopf and Humphreys 2012.

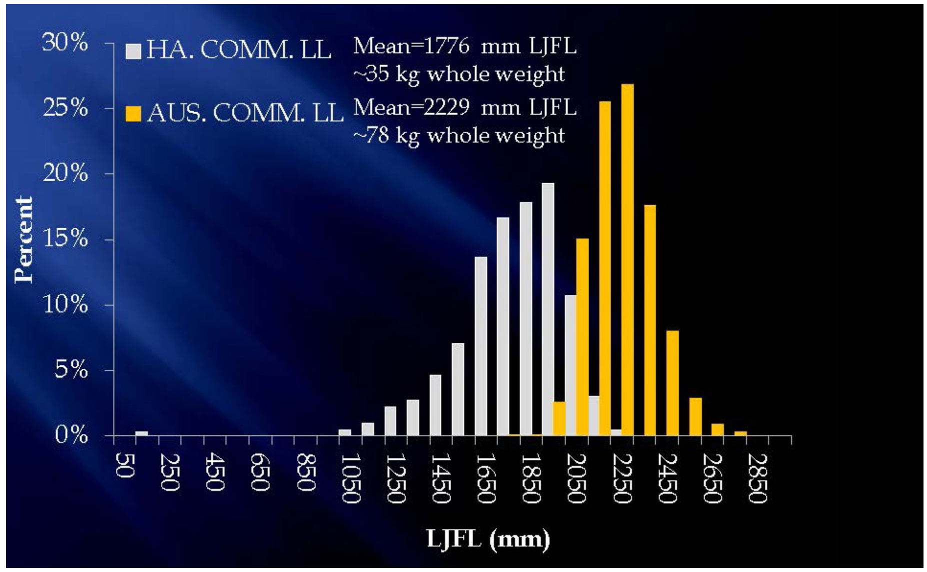


Fig. 14. Growth rates of Pacific striped marlin in the Hawai'i and Australia commercial longline fleets as measured by the lower jaw fork length. Source: Kopf and Humphreys 2012.

4. SELECT STATISTICAL AND MODELING PROJECT

4.1 Incorporating Oceanographic Data in Stock Assessments of Blue Sharks and Other Species Incidentally Caught in the Hawai'i-Based Longline Fishery

Pierre Kleiber and Hideki Nakano

A stock assessment of the blue shark (*Prionace glauca*) population in the North Pacific was conducted using catch and effort data from commercial longline and large mesh driftnet fisheries from the years 1971 through 2002 as well as small mesh driftnet fisheries operating primarily in the 1980s. Because reporting of shark catch has not been required in these fisheries, which target primarily tunas, a system for identifying the more reliable longline catch reports was utilized.

Two different assessment models were utilized, a surplus production model, and an integrated age and spatial structured model tested with a variety of structural assumptions. The two models were found to be in general agreement. The trends in abundance in the production model and all alternate runs of the integrated model show the same pattern of decline in the 1980s followed by recovery to above the level at the start of the time series. The integrated model analyses indicated some probability (around 30%) that biomass at the end of the time series was less than BMSY (overfished) and that there was a lesser probability at that time that fishing mortality was greater than FMSY (overfishing occurring).

There was an increasing trend in total effort expended by longline fisheries toward the end of the time series, and this trend may have continued thereafter. It would be prudent to assume that the

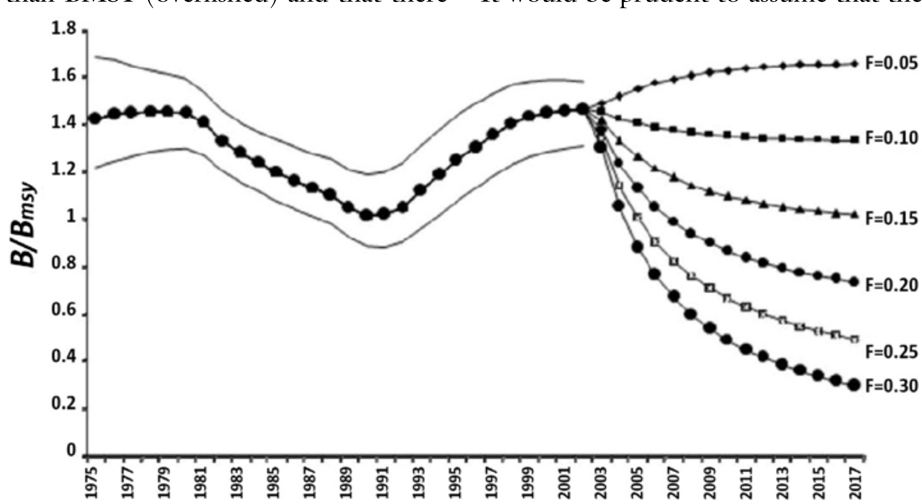


Fig. 15. Median values of blue shark stock size relative to stock size at MSY. Thin lines show 90% probability intervals, B/Bmsy. Projections based on various levels of fishing mortality, F. Source: Kleiber et al. 2009.

population is at least close to maximum sustainable yield (MSY) level and fishing mortality may be approaching to the MSY level in the future.

4.2 Analyses of Catch Data for Blue and Striped Marlins (Istiophoridae)

William A. Walsh and Jon Brodziak

Catch per unit effort (CPUE) standardizations and model selection procedures were conducted for four billfish species (Family Istiophoridae) caught as incidental catch in the Hawai‘i-based pelagic longline fishery during 1995–2011: Blue marlin *(Makaira nigricans)*, striped marlin *(Kajikia audax)*, shortbill spearfish *(Tetrapturus angustirostris)* and sailfish *(Istiophorus platypterus)*. The first three species were analyzed on a fishery-wide basis. For sailfish, the fishery data came exclusively from tuna-targeted longline sets in the deep-set sector of the Hawai‘i-based fishery. Fishery observer data from the NOAA Fisheries Pacific Islands Regional Observer Program was used to fit the CPUE standardization models.

In this context, the objective was to investigate the quality of model fit for five types of generalized linear models (GLMs): Poisson, negative binomial, zero-inflated Poisson, zero-inflated negative binomial (ZINB) and delta-Gamma. Each of these models represented a different hypothesis about the capture process for a bycatch species for which the catch data primarily consisted of zero catch observations. The five GLMs were fitted by forward entry variable selection, and the best fitting GLM for each species was selected on the basis of Akaike Information Criterion values and calculated Akaike weights.

The best-fitting model selected for each species was a ZINB GLM. The ZINB model was comprised of a negative binomial counts model for expected zero catch sets and a positive catch per set distribution along with a binomial inflation model to account for excess zeros. For each species, the important explanatory variables for standardizing CPUE were fishing year, fishing (i.e., calendar) quarter and fishing region. The best fitting models indicated that standardized CPUE for striped and blue marlins decreased significantly during the study period. It is suggested that longline CPUE for incidentally caught billfishes is best represented as a process characterized by zero inflation and over dispersion in the positive catches and expected zero catches, because the ZINB model was selected as the best fitting model for all species. It was recommended that ZINB models be considered as an a priori model for CPUE standardizations of billfishes and other bycatch species in longline fisheries.

4.3 Pacific-Wide Analysis of Bigeye Tuna *(Thunnus obesus)* Using a Length-Based, Age Structured Modeling Framework (MULTIFAN-CL)

John Hampton, Richard Deriso and Naozumi Miyabe

(This summary is based on the abstract from Bigelow et al. 2002.)

A new habitat-based model was developed to improve estimates of relative abundance of Pacific bigeye tuna *(Thunnus obesus)*. The model provides estimates of "effective" longline effort and therefore better estimates of catch-per-unit-of-effort (CPUE) by incorporating information on the variation in longline fishing depth and depth of bigeye tuna preferred habitat. The essential elements in the model are as follows:

1. Estimation of the depth distribution of the longline gear, using information on gear configuration and ocean currents;
2. Estimation of the depth distribution of bigeye tuna, based on habitat preference and oceanographic data;
3. Estimation of effective longline effort, using fine-scale Japanese longline fishery data; and
4. Aggregation of catch and effective effort over appropriate spatial zones to produce revised time series of CPUE.

Model results indicated that effective effort has increased in both the WCPO and EPO. In the WCPO, effective effort increased by 43% from the late 1960s to the late 1980s due primarily to the increased effectiveness of effort (deeper longline sets) rather than to increased nominal effort. Over the same period, effective effort increased 250% in the EPO due primarily to increased nominal effort. Nominal and standardized CPUE indices in the EPO show similar trends: a decline during the 1960s, a period of stability in the 1970s, high values during 1985–1986 and a decline thereafter.

In the WCPO, nominal CPUE is stable over the time-series; however, standardized CPUE has declined by 50%. If estimates of standardized CPUE accurately reflect relative abundance, then substantial reductions of bigeye tuna abundance for some regions in the Pacific Ocean has been documented. A decline in standardized CPUE in the subtropical gyres concurrent with stability in equatorial areas may represent a contraction in the range of the population resulting from a decline in population abundance. The sensitivity of the results to the habitat (temperature and oxygen) assumptions were tested using Monte Carlo simulations.

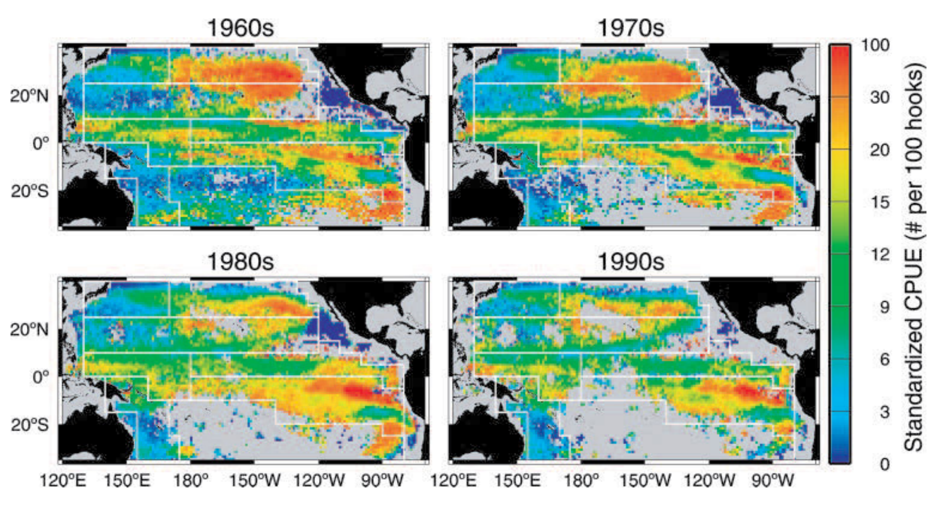


Fig. 16. Spatial comparison of bigeye standardized CPUE in the Japanese longline fishery during the last four decades. Source: Bigelow et al. 2002.

5. SELECT ECONOMIC PROJECTS

5.1 The Role of Social Networks on Fishermen Economic Performance in Hawai'i's Longline Fishery

PingSun Leung, Shawn Arita and Stewart Allen

(This summary is based on the abstract from Barnes-Mauthe et al. 2013.)

Social networks have recently been identified as key features in facilitating or constraining collaborative arrangements that can enhance resource governance and adaptability in complex social-ecological systems. Nonetheless, the effect of ethnicity on social network structure in an ethnically diverse common-pool resource system is virtually unknown. The entire social network of Hawai'i's longline fishery is characterized as an ethnically diverse competitive pelagic fishery. This study investigated the network homophily, network structure and cross-scale linkages.

Results showed that ethnicity significantly influences social network structure and is responsible for a homophily effect, which can create challenges for stakeholder collaboration across groups. The analysis also suggested that ethnicity influences the formation of diverse network structures and can affect the level of linkages to outside industry leaders, government or management officials, and members of the scientific community.

This study provided the first empirical examination of the impact of ethnic diversity on resource user's social networks in the common-pool resource literature, having important implications for collaborative resource management.

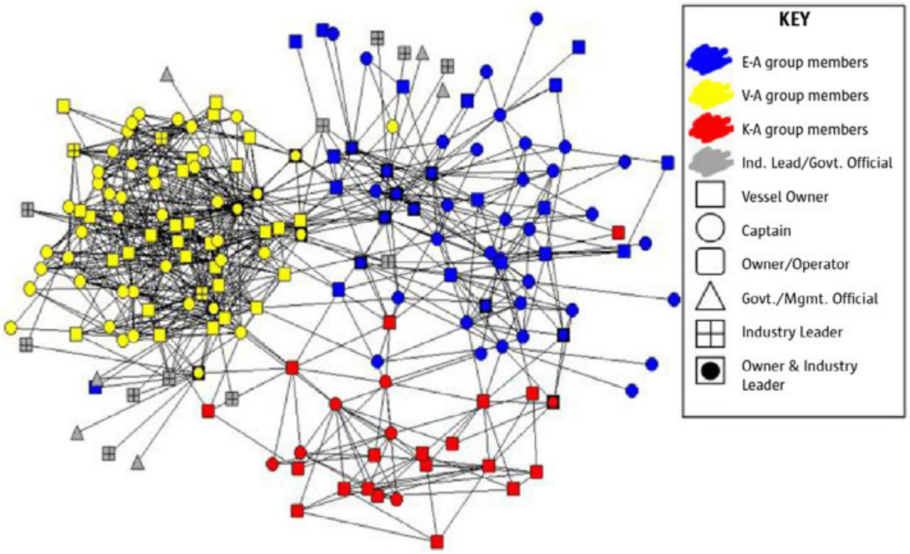


Fig. 17. Network configuration of all relations identified by Hawai'i's longline fishermen, referred to as the entire HLF network. Nodes (representing actors) with the smallest path lengths to each other are placed closest together in the graph by an algorithm that uses iterative fitting. E-A = Euro American, V-A = Vietnamese-American, K-A = Korean-American. Source: Barnes-Mauthe et al. 2013.

5.2. Factors Affecting Price Determination and Market Competition for Fresh Pelagic Fish

John Kaneko and Paul Bartram

This study examined the highly differentiated market for fresh tuna products and the relationship between quality characteristics and market value. Fresh tuna are individually graded, and each fish is directed to the most appropriate (and profitable) market and end use. The range of acceptable quality within each market niche and consumer application defines the grade and, ultimately the price, of fresh tuna. By contrast, marketing options are greatly reduced for conventionally frozen tuna, most of which is sold for canning without individual grading of fish. The influence of quality gradations on fresh tuna pricing in the Hawai'i market was assessed quantitatively by analyzing over 8,000 individual tuna transactions during the summers of 1994 and 1995.

Hawai'i grading standards were compared and "calibrated" with those in major U.S. and Japanese fresh tuna markets. Market connectedness is demonstrated by comparing tuna prices in Hawai'i with prices of equivalently graded fish in export markets. Fresh marlin, which is the largest bycatch of tuna fisheries and enters the same markets as fresh tuna, is a secondary focus of the research. Tuna quality grading is a highly subjective process. Graders can easily observe fish body appearance, but they can directly sample only a small section of the fish muscle. There are usually only a few seconds to evaluate and assign a grade for each tuna during purchasing or export processing.

Grading criteria were not always applied uniformly, but a common understanding of quality standards evolves over time between fresh tuna sellers and buyers in each market. Research results will enable Pacific island resource managers to value pelagic fisheries under varied marketing scenarios. The findings also suggest some strategies that could enhance the economic viability of island-based tuna fisheries.

5.3 Incidental Catch of Non-target Fish Species and Sea Turtles: Comparing Hawai'i's Longline Fisheries with Others

John Kaneko and Paul Bartram

The quantity and species composition of longline targeted and incidental catch are strongly influenced by gear configurations, especially the depth of hooks. The ecological impacts of pelagic longline fisheries vary with when, where and how the mainline and hooks are set.

Hawai'i pelagic longline fisheries are sometimes characterized as having "high bycatch." To assess this statement quantitatively, the present study examined diverse longline fisheries, including those in Hawai'i, that supply or have the potential to supply the same pelagic fishery products to U.S. markets. Incidental catch rates of sea turtles and finfish bycatch were estimated for the fisheries where data were available. The term "bycatch" is defined as fish released at sea dead or with a poor chance of survival.

Indices of bycatch per unit effort (BPUE) and CPUE were calculated from reported target catch, effort and incidental catch data for these fisheries. Catch to bycatch ratios (C/B ratio) were calculated by dividing CPUE by BPUE. C/B ratios provide a standardized index that allows 1) scaling of pelagic longline bycatch rates from low to high and 2) comparison of Hawai'i's pelagic longline fisheries with others on this quantitative scale.

The major finding of this research is that Hawai'i's tuna longline fishery has a lower C/B ratio of sea turtles and finfish waste (except for longnose lancetfish) compared to most competing pelagic longline fisheries studied. Claims of high rates of incidental catch of sea turtles and finfish bycatch (waste) associated with Hawai'i tuna longline fishing are, therefore, incorrect. The extraordinary amount of regulation and monitoring of Hawai'i longline fisheries and the rich source of data they provide for resource assessment and technological solutions to bycatch issues qualify them as a model for fisheries management.

The positive attributes of the Hawai'i fishery can be considered a "value-added" component of Hawai'i longline products to "brand" and differentiate them from non-Hawai'i longline products that have significantly higher associated bycatch.

6. SELECT SOCIOCULTURAL PROJECTS

6.1 Local Fishery Knowledge: Its Application to the Management and Development of Small Scale Tuna Fisheries in the U.S. Pacific Islands

John Kaneko and Paul Bartram

Effective natural resource management requires the best available knowledge about the biological, social, cultural, economic and political factors that comprise a management system. Fishery managers base decision making on expert input from scientists and the concerns of various stakeholders. Defining expert or stakeholder consensus views on fishery resources is critical to understanding how each group arrives at its particular assessments and opinions about management options.

Cultural consensus analysis was evaluated as a quantitative means of eliciting and analyzing the consensus views on pelagic fisheries resources held by expert and stakeholder groups. The method is capable of determining if a group shares a consensus view on a set of resource questions. The method generates the consensus view (the answer key) through individual interviews without the need to convene the expert group and without knowing the answers ahead of time.

Using this method, a group's consensus view was determined without the politics inherent in a group consensus building process. The study investigated the use of cultural consensus analysis to determine the local resource knowledge held by fishermen. Information relevant to the management of Hawai'i's yellowfin handline fishery was elicited on Hawai'i's bigeye longline fishery, Guam's blue marlin troll fishery, and the management and development of Samoa's (Western and American) albacore alia longline fishery.

The management and industry development implications of these consensus views were discussed. Cultural consensus analysis was recommended to fisheries managers as a potential management tool for use in resource issue scoping, problem assessment, formulation of research agenda and management options, conflict resolution and selection of management policy.

6.2 Sociological Baseline of Hawai'i-Based Longline Fishery: Extension and Expansion of Scope

Sam Pooley and Stewart Allen

The Hawai'i based longline fishing industry has been heavily regulated with little analysis of the resulting social and cultural effects. In 2003–04, NOAA PIFSC studied fishermen in the Hawai'i-based longline fleet to develop a comprehensive sociocultural profile of industry participants.

One focus of the study was the Filipino crew members, who comprised about three-quarters of the longline crew population working at the time. One researcher, with the assistance of a Filipino interpreter-community liaison, developed oral histories of 145 crew members. Consistent with ethnographic approaches, the oral histories were developed over time, with individuals and small groups, until each crew member's story was fully documented.

Much data were collected through participant-observation, as the researcher and interpreter became regular fixtures on the docks for nearly two years. Many of the Filipinos had backgrounds in fishing and had substantial levels of related training, such as marine engineering.

Their main incentives for working in the Hawai'i longline industry were the economic benefits and status provided by overseas employment, although most appreciated the fishing lifestyle. Job satisfaction was relatively high; salary levels were acceptable, and there was potential to earn additional income. Despite being confined to the immediate pier area because of their visa status,

Filipino crew members derived benefits from several types of social networks and exhibited many characteristics common to communities.

6.3 An Analysis of Archaeological and Historical Data on Fisheries for Pelagic Species in Guam and Northern Mariana Islands

Judith Amesbury and Rosalind Hunter-Anderson

The first people to arrive in the Mariana Archipelago at least 3,500 years ago were skilled fishermen. Their ability to reach the Marianas over a long distance of open ocean was accompanied by the ability to fish for open-ocean species. Analysis of fish bones from archaeological sites shows that the Chamorro fished for pelagic species, especially mahimahi and marlin, throughout the long Prehistoric Period (at least 1500 BC to AD 1521). A comparison of ten sites with pelagic species and MNI analysis indicates that approximately sixteen percent of the fishes caught were pelagic species. It is noted that archaeological sites in Southern Taiwan and the Northern Philippines also have yielded bones of mahimahi and marlin from deposits which date to approximately the same time period as the Pre-Latte Phase in the Marianas.

Pelagic fishing continued into the Spanish Period with the addition of iron for fishhooks. The writers of the early Spanish Period described fishing for flying fish, mahimahi, and billfish. By all accounts the Chamorro were exceptionally skilled sailors and fishermen. However, when hostilities broke out soon after Spanish colonization in 1668, the Chamorro people and culture were drastically affected.

As a result of the 25-year long Spanish-Chamorro Wars and the Spanish policy of requiring nearly everyone in the Marianas to move to Guam, the flying proa was no longer built by about 1750, and the Chamorro people did not participate in pelagic fishing for the next 200 years. Refaluwasch people from the Caroline Islands moved into the Marianas and took over inter-island travel during the second half of the 1700s and the 1800s. Both Chamorro and Carolinian people engaged in reef fishing.

The next major development in pelagic fishing was the pole-and-line fishery operated by the Japanese in Saipan in the 1920s and 30s, which was the first commercial fishery in the Marianas. The labor was mostly Japanese and Okinawan; and the fish were exported to Japan. Extraordinarily large amounts of skipjack were caught. The Japanese fishery ended with the American takeover of Saipan in 1944. For a few years after the war, a cooperative of Carolinian fishermen tried to resume the pole-and-line fishery, but it did so with less success than the Japanese had. Meanwhile in pre-war Guam, the U.S. Navy decided to teach Chamorro men how to fish for pelagic species. A lack

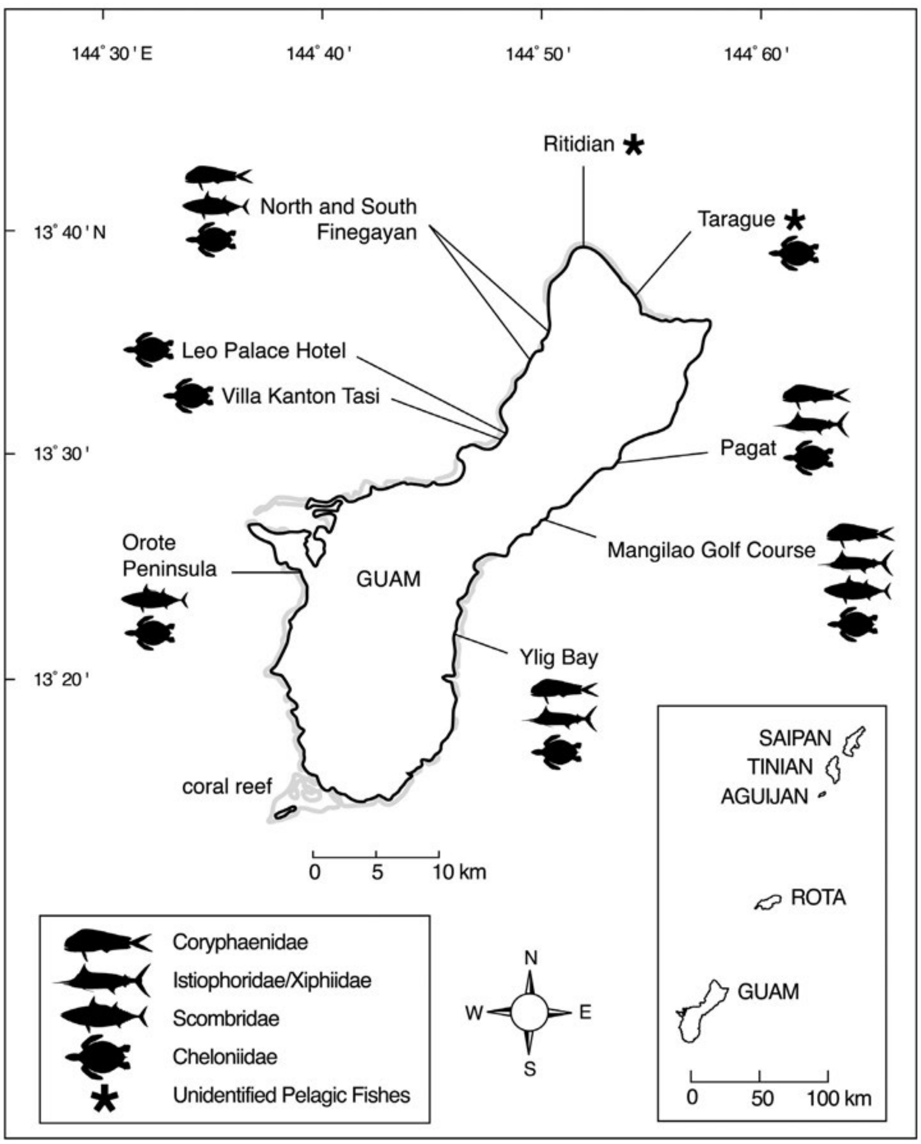


Fig. 18. Guam, showing archaeological sites with pelagic fish and turtle remains. Courtesy of Robert Amesbury.

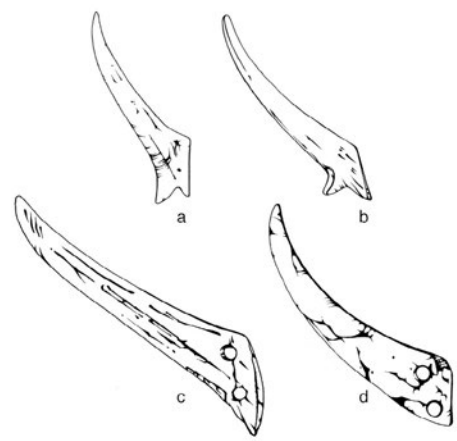


Fig. 19. Points of composite fishhooks from archaeological sites in Guam. a = human bone point from Tarague. Courtesy of Robert Amesbury.

Fig. 20. Human bone point of composite fishhook from Ylig Bay, Guam.
Rick Schaefer photo.

of boats prevented that idea from getting off the ground. Boats became available in the 1950s and 60s as the economy improved after the war.

Pelagic fishing had begun by 1956 according to the post-war Guam governors' reports. By the mid-1960s there were only a few boats on Tinian and Rota, but more on Guam and Saipan. Good fishery data from the 1980s on show that the small boat fishermen of the Marianas now land hundreds of thousands of pounds of pelagic fish annually. Five species (mahimahi, skipjack, wahoo, yellowfin and marlin) make up about 95% of the catch. The Chamorro fishermen have reclaimed their heritage as great pelagic fishermen.

7. SELECT OCEANOGRAPHY PROJECTS

7.1 Oceanographic Characterization of the American Samoa Longline Fishing Grounds for Albacore, *Thunnus alalunga*

Michael Seki, Jeffrey Polovina and Reka Domokos

The South Equatorial Counter Current (SECC) strongly influences the EEZ surrounding American Samoa and changes strength on a seasonal and El Niño–Southern Oscillation (ENSO) cycle. A strong SECC is associated with a predominantly anticyclonic eddy field as well as increased micronekton biomass and CPUE for albacore tuna, the economically important target species of the local longline fishery.

A strong SECC carries chlorophyll-a rich waters from upwelling regions at the North coast of New Guinea towards the EEZ, most likely resulting in the observed increase in micronekton biomass, forage for albacore. Relatively stable anticyclonic eddies show a further increase in micronekton biomass, apparently advected from neighboring SECC waters. The presence of forage presumably concentrates albacore, thus resulting in the observed increase in CPUE.

High shear regions of neither anticyclonic nor cyclonic eddies correlate with increased micronekton biomass. Areas characterized by South Equatorial Current (SEC) waters correspond to areas with the lowest micronekton biomass and the highest number of aggregative structures, which are most likely small pelagic fish shoals. Micronekton composition in SEC waters differs from that in the SECC.

During El Niños, the seasonal signals at the North shore of New Guinea and in the SECC are exceptionally strong and correspond to higher albacore CPUE in the EEZ. The results suggest that the strength of upwelling and the resulting increase in chlorophyll a at New Guinea, as well as the Southern Oscillation Index, could be used to predict the performance of the local longline fishery for albacore tuna in the EEZ surrounding American Samoa.

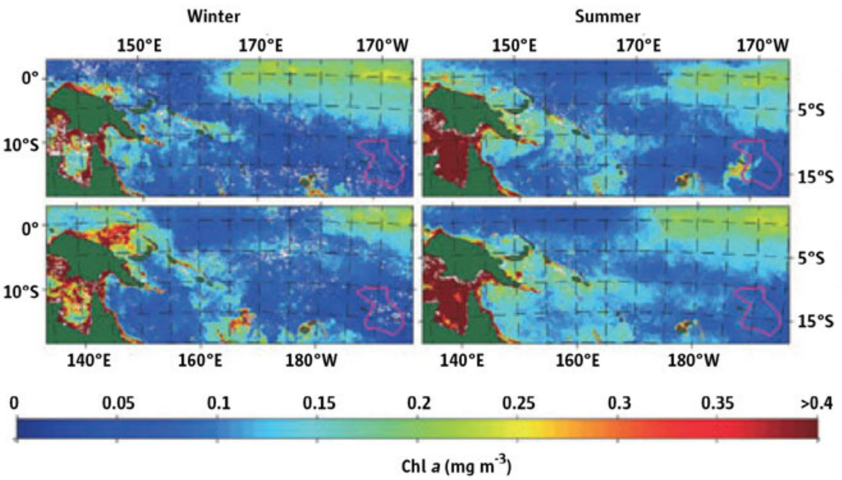


Fig. 21. Representative monthly sea surface Chl a concentrations over the Southwestern Pacific in winter (left) and summer (right) during non–El Nino (top) and El Nino (bottom) conditions. The EEZ borders around American Samoa are shown in the lower right in magenta. Source: Domokos 2009.

The borders of the EEZ around American Samoa are shown at the lower right in magenta. Source: Domokos 2009.

7.2 Regime Shifts in the Western and Central Pacific Ocean Tuna Fisheries

David Kirby, Patrick Lehodey, Valerie Allain and Adam Langley

This analysis aimed to establish whether the "regime shifts" documented for the North Pacific Ocean are seen in the WCPO and are relevant to recruitment variation for tropical tunas. Quantitative indicators of oceanographic state were derived by multivariate analysis of physical and biological variables output from an ocean general circulation and biogeochemical model. Tests were applied to determine the existence of statistically significant regime shifts in time series of both ecosystem indicators and tuna recruitment estimates.

Shifts were found at times that are broadly consistent with other studies for the North Pacific (1976, 1989, 1998) although earlier shifts (ca. 1964) appear to be just as significant. The methods were sound for the purposes of oceanographic monitoring and analysis but were inadequate to build causal or predictive relationships between the ocean environment and tuna recruitment. Other statistical models have proved useful in that regard and the best single indicator for monitoring the effect of long-term environmental variability on yellowfin tuna recruitment appears to be the area of the western Pacific warm pool.

Parallel research by other workers suggests that the Atlantic Ocean acts as a key pacemaker for the western Pacific decadal climate variability.

Observational analysis suggests that the western tropical Pacific (WTP) SST shows predominant variability over multi-decadal time scales, which is unlikely to be explained by the interdecadal Pacific oscillation. This variability is largely explained by the remote Atlantic multi-decadal oscillation (AMO). A suite of experiments successfully reproduces the WTP multi-decadal variability and the AMO–WTP SST connection.

The AMO warm SST anomaly generates an atmospheric teleconnection to the North Pacific, which weakens the Aleutian low and subtropical North Pacific westerlies. The wind changes induce a subtropical North Pacific SST warming through wind-evaporation-SST effect. In response to this warming, the surface winds converge towards the subtropical North Pacific from the tropics, leading to anomalous cyclonic circulation and low pressure over the WTP region. The warm SST anomaly further develops due to the SST–sea level pressure–cloud–longwave radiation positive feedback.

For more details of the project, see Kirby DS et al. 2004, Kirby et al. 2007, Lehodey et al. 2006, Lehodey et al. 2020, Sun et al. 2017 and Bertrand A et al. 2020.

7.3 The Role of Oceanography on Bigeye Tuna Aggregation and Vulnerability in the Hawai'i Longline Fishery from Satellite, Moored and Shipboard Time Series

Russell Brainard, Jeff Polovina, Michael Seki, Bo Qiu and Pierre Flament

Bigeye tuna *(Thunnus obesus)* is the principal deep-water target species of the longline fishery in the Pacific Ocean yielding total annual catches exceeding 150,000 tons. In the Hawai'i-based longline fishery, bigeye tuna have consistently been one of the dominant species in terms of landings and ex-vessel revenue.

Although stock assessment of bigeye tuna has been conducted using indices of abundance, non-equilibrium production models and yield-per-recruit analysis, each of these methods requires the use of longline fishery CPUE as an index of bigeye abundance. Unfortunately, fishery-dependent CPUE does not necessarily represent the abundance of the stock but rather the catchability of the stock. Catchability, in turn, is dependent to a considerable extent upon variable oceanographic conditions. Oceanographic variability can significantly affect the depth of the thermocline and the most likely depth of occurrence of bigeye tunas. The preferred foraging habitat of bigeye tunas is the 8°–15° C water at or near the base of the thermocline.

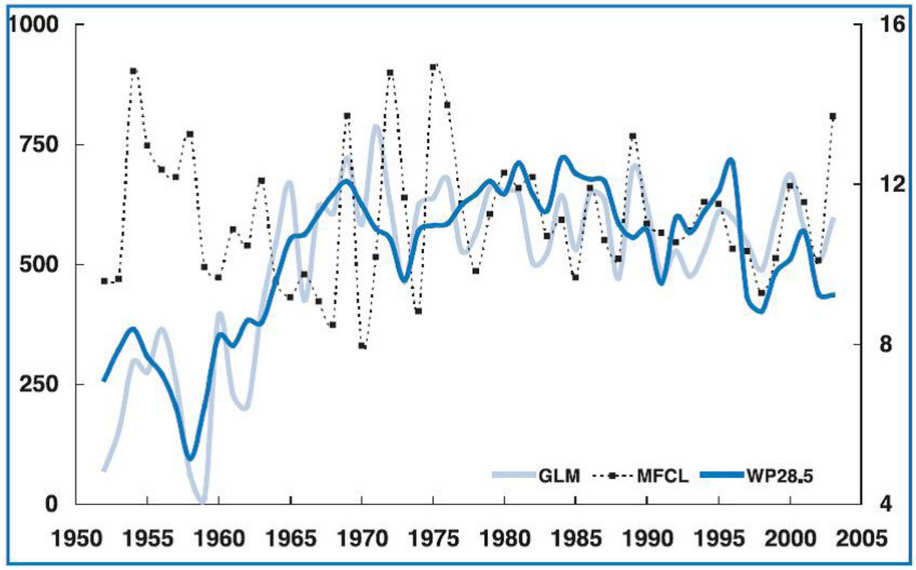


Fig. 22. Yellowfin tuna recruitment estimates (first y-axis; units: millions of fish) from the stock assessment model MULTIFAN-CL and the GLM plotted with annual average warm pool area (WP28.5, second y-axis; units: millions of square kilometers). Source: Kirby et al. 2007

Evidence from a recently recovered NMFS archival tag from a bigeye tuna in Hawaiian waters revealed a repetitive pattern of remaining in the upper 10 m–90 m at night and diving to 350 m–500 m (8°–10° C) each day. During the day, the tuna remained at depth, apparently foraging, until its body temperature dropped to about 17° C (typically at depth for about 45 minutes). The fish then briefly migrated to warmer waters (50 m–150 m) before returning to depth. This behavior suggests that at times when the thermal structure is depressed, bigeye tunas may be generally deeper and less aggregated due to their extended vertical migrations. Although the stock abundance may be unchanged, catchability and CPUE are reduced. Conversely, when the thermal structure is elevated, the habitat is generally shallower and bigeye tunas may be more aggregated, resulting in increased catchability and CPUE.

By modifying the depth of penetration and performance of longline, the velocity shear of the ocean currents also has a profound effect on catchability and CPUE. It is important to note that both vertical and horizontal velocity shears affect the performance of longline gear. Although strong current shears generally tend to lift longline gear and prevent it from penetrating to the depth of the bigeye habitat, convergent flows can also result in deepening of the longline.

As these cases have demonstrated, CPUE does not necessarily reflect stock abundance. Oceanographic features which affect the depth of the 8°–15° C layer or result in regions of high vertical or horizontal velocity shear could impact CPUE of bigeye tuna. These features undoubtedly include cyclonic and anticyclonic mesoscale eddies, westward-propagating Rossby waves, shear instability waves and large-scale inter-annual and decadal shifts in the positions and strengths of the North Pacific gyre. These features have significant variability over time scales from diurnal to decadal around the Hawai'i Archipelago. Likewise, the overall CPUE for bigeye tunas in the Hawai'i-based longline fishery shows significant variability over these time scales. For purposes of stock assessment and management, it is necessary to have an index of the bigeye local abundance that is less biased by changes in fish aggregation or catchability of the gear associated with these oceanographic features.

8. SELECT PROTECTED SPECIES PROJECTS

8.1 Comparing Sea Turtle Distributions and Fisheries Interactions in the Atlantic and Pacific

Molly Lutcavage and Selina Heppell

Loss of megafauna, termed trophic downgrading, has been found to affect biotic interactions, disturbance regimes, species invasions and nutrient cycling. One recognized cause in air-breathing marine megafauna is incidental capture or bycatch by fisheries. Characterizing megafauna-bycatch patterns across large ocean regions is limited by data availability but essential to direct conservation and management resources. Empirical data were used to identify the global distribution and magnitude of seabird, marine mammal and sea turtle bycatch in three widely used fishing gears. Taxa-specific hotspots were identified and found evidence of cumulative impacts. This analysis provides an unprecedented global assessment of the distribution and magnitude of air-breathing megafauna-bycatch, highlighting its cumulative nature and the urgent need to build on existing mitigation successes.

Recent research on ocean health has found large predator abundance to be a key element of ocean condition. Fisheries can impact large predator abundance directly through targeted capture and indirectly through incidental capture of non-target species or bycatch. However, measures of the global nature of bycatch are lacking for air-breathing megafauna. This study fills this knowledge gap and presents a synoptic global assessment of the distribution and intensity of bycatch of seabirds, marine mammals and sea turtles based on empirical data from the three most commonly used types of fishing gears worldwide.

The study identifies taxa-specific hotspots of bycatch intensity and finds evidence of cumulative impacts across fishing fleets and gears. This global map of bycatch illustrates where data are particularly scarce—in coastal and small-scale fisheries and ocean regions that support developed industrial fisheries and millions of small-scale fishers—and identifies fishing areas where, given the evidence of cumulative hotspots across gear and taxa, traditional species or gear-specific bycatch management and mitigation efforts may be necessary but not sufficient. Given the global distribution of bycatch and the mitigation success achieved by some fleets, the reduction of air-breathing megafauna-bycatch is both an urgent and achievable conservation priority.

8.2 Direct Tests of the Efficacy of Bait and Gear Modifications for Reducing Interactions of Sea Turtles with Longline Fishing Gear in Costa Rica

Yonat Swimmer

Reducing bycatch of sea turtles in pelagic longline fisheries, in concert with activities to reduce other anthropogenic sources of mortality, may contribute to the recovery of marine turtle populations. Due to the state of management regimes in most longline fisheries, strategies to reduce turtle interactions must not only be effective but also must be commercially viable. Most research has been initiated only recently, and many results are not yet peer-reviewed, published or readily accessible.

Moreover, most experiments have small sample sizes and have been conducted over only a few seasons in a small number of fisheries; many study designs preclude drawing conclusions about the independent effect of single factors on turtle bycatch and target catch rates; and few studies consider effects on other bycatch species. In the U.S. North Atlantic longline swordfish fishery, 4.9-cm wide circle hooks with fish bait significantly reduced sea turtle bycatch rates and the proportion of hard-shell turtles that swallowed hooks vs. being hooked in the mouth compared to 4.0-cm wide J hooks with squid bait without compromising commercial viability for some target species. But these large circle hooks might not be effective or economically viable in other longline fisheries.

The effectiveness and commercial viability of a turtle avoidance strategy may be fishery-specific, depending on the size and species of turtles and target fish and other differences between fleets. Testing of turtle avoidance methods in individual fleets may, therefore, be necessary. It is a

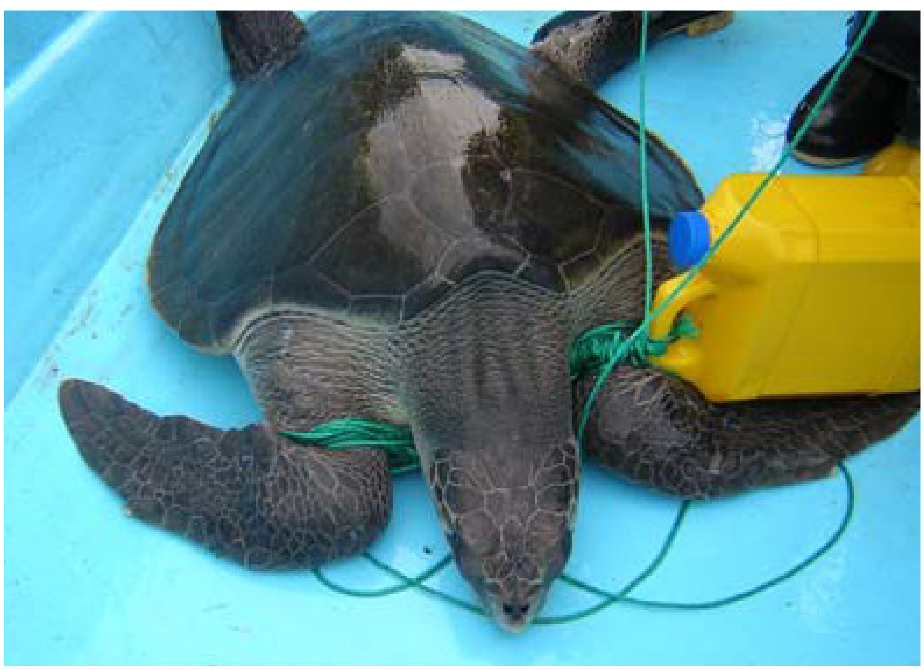


Fig. 23. Olive ridley sea turtle entangled in a polypropylene multifilament line next to a float (plastic jug). This gear is typical of that used in artisanal longline fisheries in Latin America. Yonat Swimmer photo.

priority to conduct trials in longline fleets that set gear shallow, those overlapping the most threatened turtle populations and those overlapping high densities of turtles such as those fishing near breeding colonies. In addition to trials using large 4.9-cm wide circle hooks in place of smaller J and Japan tuna hooks, other fishing strategies are under assessment. These include the following:

a. Using small circle hooks (≤ 4.6-cm narrowest width) in place of smaller J and Japan tuna hooks;
b. Setting gear below turtle-abundant depths;
c. Single hooking fish bait vs. multiple hook threading;
d. Reducing gear soak time and retrieval during daytime; and
e. Avoiding bycatch hotspots through fleet communication programs and area and seasonal closures.

For more recent work, see Boggs and Swimmer 2007 and Swimmer et al. 2009.

8.3 A General Bayesian Integrated Population Dynamics Model for Protected Species

Mark Maunder

Managing wildlife-human interactions demands reliable information about the likely consequences of management actions. This requirement is a general one, whatever the taxonomic group. A method was developed for estimating population dynamics and decision analysis that is generally applicable, extremely flexible, uses data efficiently and gives answers in a useful format.

The case study involved bycatch of a protected species, the Northeastern offshore spotted dolphin *(Stenella attenuata)*, in the tuna fishery of the EPO. Informed decision-making requires quantitative analyses considering all relevant information, assessing how bycatch affects these species and how regulations affect the fisheries, and describing the uncertainty in analyses.

Bayesian analysis is an ideal framework for delivering information on uncertainty to the decision-making process. It also allows information from other populations or species or expert judgment to be included in the analysis, if appropriate. Integrated analysis attempts to include all relevant data for a population into one analysis by combining analyses, sharing parameters and simultaneously estimating all parameters, using a combined objective function. It ensured that model assumptions and parameter estimates were consistent throughout the analysis, that uncertainty was propagated through the analysis and that the correlations among parameters were preserved.

Perhaps the most important aspect of integrated analysis is the way it both enables and forces consideration of the system as a whole so inconsistencies can be observed and resolved

9. SELECT TROPHODYNAMICS PROJECTS

9.1 Integrating Conventional and Electronic Tagging Data into the Spatial Ecosystem and Population Model SEAPODYM

Inna Senina, Patrick Lehodey and Francois Royer

Spatial Ecosystem and Population Dynamics Model (SEAPODYM) is a model that was developed for investigating spatiotemporal dynamics of fish populations under the influence of both fishing and the environment. The model simulated age-structured population dynamics using advection-diffusion-reaction equations describing movement, recruitment, and natural and fishing mortality.

The dynamic processes are constrained by environmental data and distributions of prey species. Model parameter estimation using fishing data was implemented initially, based on a maximum likelihood estimation (MLE) approach and adjoint technique. Further work described the integration of tagging data into the existing MLE approach with application to skipjack tuna *(Katsuwonus pelamis)* in the Pacific Ocean.

Tagging data improved estimates of species habitat parameters and movement rates and, hence, allowed better representation of spatial dynamics of fish population. Due to estimated lower diffusion and higher advection rates, the model predicted less non-observed "cryptic" biomass, which leads to the stock sizes being closer to those estimated by stock assessment models commonly used by tuna commissions.

9.2 Assessment of the Impacts of Mesoscale Oceanographic Features on the Forage Base for Oceanic Predators

Jeffrey Drazen and Reka Domokos

In the pelagic food-web, micronekton at the mid-trophic level are one of the lesser known components of the ocean ecosystem despite being a major driver of the spatial dynamics of their predators, of which many are exploited species (e.g., tunas).The oceanic mesoscale includes dynamic features such as eddies that are ubiquitous features of ocean circulation and shallow seamounts that can alter local circulation patterns. These features can contribute significantly to patterning in pelagic ecosystems affecting organismal abundance, distribution, productivity and trophic structure, including patterns in large fishes such as tuna and cetaceans. Trawl and bioacoustics sampling have been used to evaluate the effect of mesoscale eddies in American Samoa and Cross Seamount off Hawai‘i on micronekton communities.

The American Samoa region acoustics showed that micronekton biomass increased inside anticyclonic eddies and within SECC waters, the water mass from which anticyclonic eddies formed. In addition, micronekton composition in SECC waters differed from those in the surrounding SEC that flows in the opposite direction. Data indicated that the enhanced biomass with distinct composition in the SECC was the results of seasonal upwelling and chlorophyll bloom at the North shore of New Guinea that were transported east with the SECC, likely providing forage for micronekton that are carried in the EEZ from the west. Off Cross Seamount, acoustics indicated enhanced biomass and a change in community composition over the seamount. However, trawls illustrated that there was significantly less large micronekton over the seamount than in the nearby open ocean.

While predation might be partly the cause, the taxa absent from the summit all have daytime depths that are deeper than the depth of the summit, indicating avoidance may be a major reason for the low abundance. The seamount community was dominated by smaller taxa such as juvenile fishes and stomatopod larvae, which may be the drivers of the enhanced acoustic backscatter. Additional results from off the lee of Hawai'i showed an enhanced micronekton abundance and biomass, but this may have related more to the moon phase at the time of sampling.

Micronekton migrated close to the surface during a new moon and were more susceptible to capture at this time. The results help understanding of how oceanographic mesoscale features altered micronekton distributions, resulting in enhanced foraging opportunities for oceanic top predators. SEAPODYM is one modelling approach that includes a representation of the spatial dynamics of several epi- and mesopelagic mid-trophic-level functional groups. The dynamics of these groups are driven by physical (temperature and currents) and biogeochemical (primary production, euphotic depth) variables.

A key issue is the parameterization of the energy transfer from the primary production to these functional groups. A method used in situ acoustic data to estimate the parameters with a maximum likelihood estimation approach. A series of twin experiments was conducted to test the behavior of the model. This suggested that in the ideal case, that is, with an environmental forcing perfectly simulated and biomass estimates directly correlated with the acoustic signal, a minimum of 200 observations over several time steps at the resolution of the model is needed to estimate the parameter values with a minimum error. A transect of acoustic backscatter at 38 kHz collected during scientific cruises

Fig. 24. Representative mesopelagic micronekton: A) *Myctophum lychnobium* (Myctophidae); B) *Oplophorus gradlarostris* (Oplophoridae); C) *Vindguerria nimbaria* (Gonostomatidae); D) *Pyroteuthis addolux* (Pyroteuthidae); E) *Janicella spinacauda* (Oplophoridae); F) *Sternoptyx sp.* (Sternoptychidae); G) *Hyalateuthis pelagica* (Ommastrephfidae); and H) Stomatopod larvae. Source: Drazen and De Forest 2008.

north of Hawai'i allowed a first illustration of the approach with actual data. Finally, there are various sources of uncertainties associated with the use of acoustic data in micronekton biomass.

For more details of this project see De Forest and Drazen 2009; Drazen and De Forest 2008; and Drazen, De Forest and Domokos 2011.

9.3 Intra-Guild Predation and Cannibalism in Pelagic Predators: Implications for the Dynamics, Assessment and Management of Pacific Tuna Populations

Tim Essington, Mark Maunder, Robert Olson, James Kitchell and Enric Cortes

The ecological consequences of widespread fisheries-induced reductions of large pelagic predators are not fully understood. Tropical tunas are considered a main component of apex predator guilds that include sharks and billfishes and thus may seem unsusceptible to secondary effects of fishing top predators. However, intra-guild predation can occur because of size-structured interactions. The study compiled existing data of apex predator diets to evaluate whether skipjack tuna *(Katsuwonus pelamis)* and yellowfin tuna *(Thunnus albacares)* might be vulnerable to top-down control by large pelagic predators in the Eastern tropical Pacific Ocean.

The study identified potentially important predators of tunas by the frequency, quantity, size and age of tunas in their diets and considered the degree that predated tunas could have potentially contributed to the reproductive output of the population. The results indicated that the proportion of predator diets consisting of skipjack and yellowfin tunas was high for sharks and billfishes. These predators also consumed a wide size range of tunas, including sub-adults of the size capable of making a notable contribution to the reproductive output of tuna populations.

The study suggested that in the Eastern tropical Pacific Ocean, tropical tunas act as meso-predators more so than apex predators. Sharks and billfishes have the potential to play an important role in regulating these tuna populations. This study will inform future research that might ascertain whether diminished levels of large predators have enhanced the production of tuna stocks and whether the trophic interactions of skipjack and yellowfin tunas should be explicitly accounted for when their population dynamics are assessed.

For more information, see Hoyle and Maunder 2004; Maunder 2004; McCarthy et al. 2004; and Hunsicker et al. 2012.

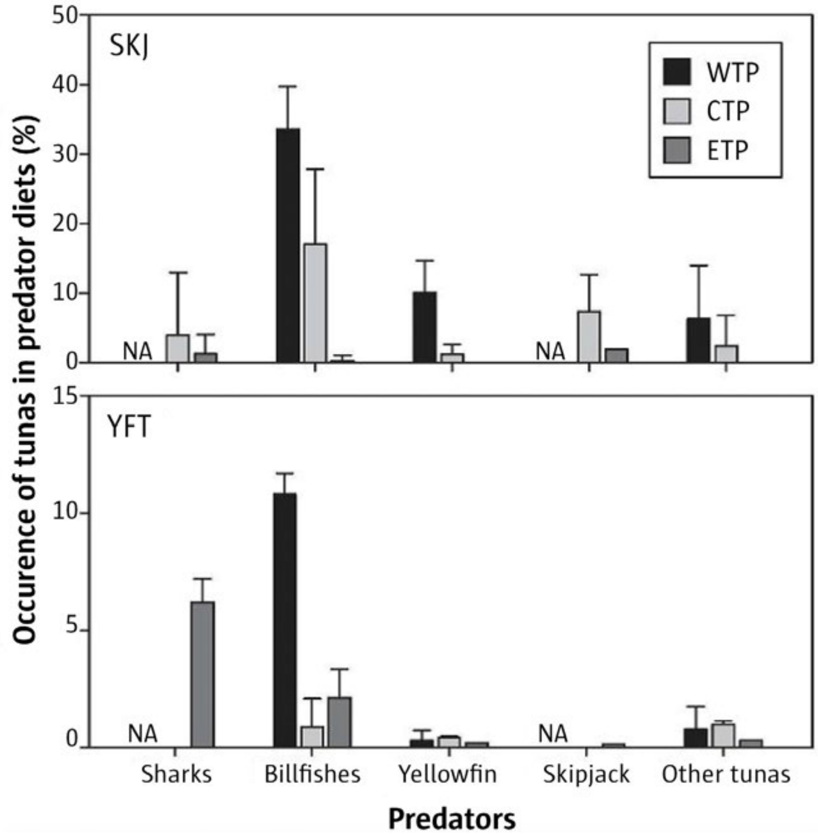


Fig. 25. Mean (+SD) percent frequency of occurrence of skipjack tuna (SKJ) and yellowfin tuna (YFT) in the diets of apex predators in the Eastern (ETP), Central (CTP) and Western (WTP) tropical Pacific Ocean. Estimates are based on summarized data sources. "Other tunas" category includes albacore, bigeye and Pacific bluefin tunas. NA: data not available. Source: Hunsicker et a1. 2012.

10. SELECT GENETICS PROJECTS

10.1 Analysis of Pacific Blue Marlin and Swordfish Population Structure Using Mitochondrial and Nuclear DNA Technologies

John Graves and Barbara Block

According to tag-and-release studies, marlin and swordfish are capable of large-scale movements that cover thousands of kilometers. For example, a swordfish tagged northeast of the Hawaiian Islands was recaptured off the coast of California, a straight-line distance of approximately 3,000 km. Do such long-distance recaptures mean that all swordfish belong to a single, worldwide stock or to particular basin-wide stocks, e.g., Pacific, Atlantic and Mediterranean? And if the species is distributed into more than one stock, what are the distribution limits of each stock? And what is the amount, if any, of genetic-mixing between the stocks? Answering questions such as these is essential if effective fishery management policies are to be developed. If the populations of a fishery are highly structured, that is, there is little mixing of the populations, then management directives aimed at a broad geographic area would be inappropriate and could lead to the irrevocable loss of regional populations, decreasing the genetic diversity and evolutionary potential of the species. On the other hand, management efforts divided on too fine a scale may be overly restrictive.

Genetic material from more than 60 individual blue marlin from the Atlantic and Pacific Oceans was analyzed. The preliminary results indicate that blue marlin in the Pacific and Atlantic Oceans represent genetically distinct populations of a single species. These stocks were isolated at times in the past, but there is evidence of recent or current gene flow between them. With regard to swordfish, genetic material from more than 125 individuals has been analyzed. The preliminary conclusions contrast sharply with those for blue marlin. There appear to be several genetic stocks in the Pacific Ocean alone.

It is necessary to manage billfish populations that fishing pressure does not exceed a population's ability to sustain it. Several recent scientific management panels agreed that identification of billfish stock structure was a primary need. Research into a species' population stock structure provides managers with an understanding of the ranges and composition of fishery management units.

10.2 Population Structure and Dynamics in Mahimahi as Inferred through Analysis of Mitochondrial DNA

Carol Reeb

Dolphinfish, or mahimahi (*Coryphaena hippurus*), are an important component of local fisheries in many Western Pacific areas. However, to date, little is known about their stock structure, and no estimate of sustainable yield is available. Genetic analysis of several pelagic fish populations indicated a period of instability about 18,000 years ago during the Pleistocene period (characterized by the spreading and recession of continental ice sheets).

A study of mitochondrial DNA (mtDNA) indicated that dolphinfish were no exception. The genetic composition of 55 dolphinfish from a collection of 200 samples, collected from 11 sites worldwide, found 13 genetic types. One of these types was found to be very common and distributed worldwide while the remaining 12 were quite rare. While the data to date has not been useful in discerning population subdivisions, it does suggest that dolphinfish had faced one of three scenarios:

1. A catastrophic near extinction;
2. Demographic parameters favoring males; or
3. Recurrent extinction and recolonization of populations.

This research located a faster-evolving part of the mtDNA, which may provide a better study of the population structure of mahimahi. Mahimahi possess a very large mtDNA region that appears to be similar to a rapidly evolving microsatellite sequence. The study devised a novel and quick method to screen this molecular marker for use in future studies.

10.3 An Assessment of Bigeye Tuna *(Thunnus obesus)* Population Structure in the Pacific Ocean based on Mitochondrial DNA and Microsatellite Variation.

Barbara Block and Carol Reeb

Nine collections of bigeye tuna from different regions of the Pacific Ocean, with individual sample sizes ranging from 69 to 105 specimens, were examined for genetic variation in mtDNA and microsatellite loci. Eight microsatellite loci were examined in approximately 70 fish from the two geographically most-separated collections, Ecuador and the Philippines. None of these loci showed evidence of significant allele frequency differentiation after Bonferroni correction.

Four microsatellite loci were examined in 664–806 fish from the nine collections; again, none showed evidence of significant allele frequency differentiation after Bonferroni correction. The two geographically most-separated collections (Ecuador and the Philippines) showed some evidence of differentiation for one microsatellite locus following Bonferroni correction. The mtDNA data showed some indications of significant differentiation among the collections, but this became non-significant if the mtDNA analyses are considered as one of the several genetic tests of differentiation.

It is concluded that there is some evidence for restricted gene-flow between Ecuador and the Philippines but that, otherwise, the data fail to allow the null hypothesis of a single panmictic Pacific-wide population of bigeye tuna to be rejected. Tagging data generally supports this conclusion.

For additional information, see Reeb et al. 2000 and Reeb et al. 2003.

11. Conclusion

It is clear from the foregoing that a large volume of scientific investigation was begun and completed by the PFRP Research. (See Appendix 3 or go to https://www.soest.hawaii.edu/PFRP/allpub.html.)

The Western Pacific Council has had and will continue to have a need for high quality novel research covering the spectrum embraced by the topics above. Moreover, the landscape for Pacific pelagic fisheries research is very different to that identified in 1992. The 1992 workshop was to some extent dealing with a tabula rasa. Only two multinational organizations dealt with Pacific pelagic fisheries, the SPC Oceanic Fisheries Program covering the WCPO and the Inter-American Tropical Tuna Commission covering the EPO. Scientific work on pelagic species was limited to a relatively small group of individuals from a few metropolitan countries that comprised the primary resource of harvesters and processors.

In the second decade of the new century, the networks and patterns of the 1992 era have fallen by the wayside. New players espousing new priorities have emerged with the establishment of the Western and Central Pacific Fisheries Commission (WCPFC), the Forum Fisheries Agency (FFA), Parties to the Nauru Agreement and the International Scientific Committee for Tuna and Tuna-Like Species (ISC). There are now more intergovernmental bodies dedicated to advancing Pacific fishery science and more and diverse resources being devoted to the study and management of Pacific pelagic resources. Further, the non-tuna fish and squid have been the focus of other such relative newcomers like South Pacific Regional Fisheries Management Organization and the North Pacific Fisheries Commission.

Each organization has its own priorities which may overlap and mesh with those of the other agencies. However, the objective of the Conventions is to ensure the long-term conservation and sustainable use of fisheries resources while protecting the marine ecosystems of the Pacific Ocean in which these resources occur. Moreover, there are existing science organization such as the North Pacific Marine Science Organization (PICES), which conducts fishery and ecosystem research.

It is argued here that the roles and priorities of all of the foregoing are very likely to leave gaps and holes in the scientific knowledge base that should be addressed by a program like the PFRP. Moreover, academia has a key role in pelagic fisheries and ecological research in and of itself, which applies to Pacific.

It is a big task. Finding and filling these gaps and holes in scientific knowledge is a difficult but beneficial undertaking. The defunding of PFRP in 2012 eliminated a significant contribution to the effort. Good fishery science depends upon public-private cooperation and coordination.

Based on these criteria, the PFRP has been partially successful. Projects which elucidate the biology and population dynamics of target and non-target species have been used extensively in the amendment documents drafted by the Western Pacific Regional Fishery Management Council for its Pelagic

Fishery Management Plan, which has been restructured into the Pacific Pelagic Fishery Ecosystem Plan (FEP). The same is true to a similar extent of the oceanography and trophodynamics projects and the projects that cast light on the sociocultural dynamics of the Western Pacific fishing industries.

The inescapable facts, however, are that Council's Pelagic FEP amendments and associate environmental impact studies would be more speculative without the outputs of the PFRP.

Finally, the State of Hawai'i and the UH does not have a fisheries school. Nor do the University of Guam and community colleges in American Samoa. This is unusual, given that all coastal states and some inland states, especially around the Great Lakes, have universities and colleges that have fisheries programs. Some of these fisheries schools are recognized centers of excellence across the spectrum of the ecological, sociocultural and economic dynamics of marine and freshwater fisheries. This includes the University of Miami's Rosenstiel School of Marine and Atmospheric Science and University of Washington's School of Marine and Environmental Affairs.

This absence is problematic in a number of ways.

First, a fisheries school/program adds to the personnel and funds dedicated to fisheries research.

Second, the absence of fisheries school/program undermines institutional strengthening by turning out graduates and post-graduates from Hawai'i who would stay to pursue a career in Hawai'i and in other parts of the Western Pacific Region.

Third, fisheries management in the Western Pacific is forced to develop fisheries policy in an information vacuum for many types fishing activity and the stocks captured thereby.

Fourth, the social, cultural and economic importance of fish and fishing remains poorly understood and thus fisheries policy may have unforeseen impacts on an occupation that contributes to social cohesion.

Fifth, graduate students pursuing a higher degree are an importance resource and a relatively inexpensive pool of technical and scientific personnel to tackle gaps in fisheries knowledge

The PFRP recognized the problems posed by the absence of a regional fisheries school and, in 2004, funded a contractor to work on developing a graduate academic program in coastal and marine resources. The proposal would have had the School of Ocean and Earth Science and Technology at the UH at Manoa establish a complementary academic program, in collaboration with the College of Tropical Agriculture and Human Resources, the College of Social Sciences and the School of Law at the UH at Manoa and with the College of Agriculture, Forestry and Natural Resource Management at the UH at Hilo. Unfortunately, the collective wisdom of the administration was that, without funding for permanent faculty positions, the University could not increase positions or funding dedicated to fisheries research.

It is obvious that there is a huge gulf between science and policy. In the current time, faced with a changing climate and the public health crisis of COVID-19, this gulf is only exaggerated. If there is an eventual resurrection of the PFRP or something like it, closing the gulf between science and policy should be explicitly mentioned as an objective.

Appendix 1: Tuna Inclusion in the Magnuson-Stevens Act

(The following summary is freely adapted from Carr 2004.)

By the mid-1980s, momentum was building for tuna inclusion into the Fishery Conservation and Management Act (FCMA, now known as the Magnuson-Stevens Act) as the regional management councils were frustrated in their efforts to regulate billfish. The movement for tuna inclusion would be given additional impetus in 1985 and 1986 as the Western Pacific Council, threatened with elimination, asserted it would play an essential role in the management of tuna. At the same time, however, the economic importance and political clout of the California-based U. S. distant water tuna industry was eroding. This confluence of circumstance set the stage for enactment of amendments to the FCMA in 1990 bringing tuna comprehensively under U.S. management jurisdiction.

In 1985, a draft report of the Office of the Inspector General of the Department of Commerce recommended elimination of the Western Pacific Council and the transfer of its responsibility to the Pacific Council on the ground that there were not meaningful fishery resources to be managed in the Western Pacific Region. The Western Pacific Council responded that most of the catch from fisheries in the region occurred in federal waters, regulated by the Council, and that substantial tuna fishing within the fishery conservation zones of the U.S. Flag Pacific islands, which the Council claimed had impelled it to advocate tuna inclusion from its inception, had to be taken into account. Shortly thereafter, in 1986, a blue ribbon study of fishery management commissioned by NOAA recommended tuna inclusion.

However, the same study recommended elimination of the Western Pacific and Caribbean Fishery Management Councils on the ground that most fisheries within their regions were conducted within state, commonwealth and territorial boundaries, rendering those councils largely purposeless. To say that the Inspector General's report and NOAA fishery management study "activated" the Western Pacific Council to press for tuna inclusion is an understatement. In response to the NOAA study, the Western Pacific Council argued that its recommendation to subject tuna to U.S. fishery management jurisdiction required the existence of the Council to carry out such management.

The Council's response resulted in the publication of an Addendum to the study, which receded from the earlier recommendation to eliminate the Western Pacific and Caribbean Councils. With tuna management identified, if not as its reason for existence, then as one of its essential functions, the Western Pacific Council would orchestrate the campaign of the fishery management councils for tuna inclusion. This campaign would culminate in 1990 with enactment of amendments repealing the tuna exclusion provisions of the FCMA and subjecting tuna to exclusive U.S. management in the EEZ.

One of the main arguments of tuna inclusion supporters was that, while the U.S. domestic fishery for tuna inside the U.S. 200-mile zone had increased dramatically since enactment of the FCMA in 1976, this economically valuable fishery could not be managed by U.S. authorities and was subjected to virtually unlimited foreign fishing. A further argument put forward in support of tuna inclusion was that studies showed that tuna, and particularly commercially important skipjack and yellowfin species, were not, in fact, highly migratory so as to require international management for their effective regulation. Supporters of tuna inclusion also asserted that the 1987 Tuna Treaty had affected de facto recognition of coastal state jurisdiction over tuna and that elimination of the FCMA's tuna exclusion provisions and the U.S. juridical position would improve U.S. foreign relations in the Pacific. Finally, supporters of tuna inclusion emphasized difficulties in billfish management posed by the FCMA's tuna exclusion provisions.

Tuna inclusion was opposed, as it had been for years, by U.S. distant-water tuna interests and the Department of State. In their views, the negotiating "leverage" afforded by the U.S. juridical position had made possible the conclusion of the 1987 Tuna Treaty and, moreover, that Treaty did not recognize coastal state jurisdiction over tuna. Opponents of tuna inclusion also challenged the claim that tuna are not really highly migratory species, meriting international management. They further argued that there was relatively little foreign fishing for tuna in the U.S. EEZ and so no need to regulate or exclude such vessels. They also rejected the argument that the FCMA's tuna exclusion provisions had negatively impacted billfish management in the U.S. EEZ.

Finally, a number of tuna inclusion opponents characterized the push for it as an effort by recreational fishermen to restrict commercial fishing in the U.S. EEZ for tuna. However, by the mid-1980s the U.S. distant-water tuna industry no longer enjoyed the substantial political and economic clout that it had exercised in the past. Between 1980 and 1985, U.S. tuna canneries relocated from the U.S. mainland to overseas sites. As a result, by the end of 1985, only one small cannery was left operating in the mainland United States. Cannery-based jobs and incomes declined by close to 95% during 1980–1985. Moreover, the negative economic impacts of the restructuring were not limited to canneries and their employees. As one commentator put it, "When an industry that produces $1.5 billion in food products moves out of the U.S. and attracts support industries to offshore sites, the indirect and induced economic losses spread to many sectors of the U.S. economy." It was from this greatly weakened position that the industry opposition to tuna inclusion was mounted. The debate on these issues culminated in the enactment of amendments bringing tuna under the FCMA in late 1990.

The amendments delayed the effective date for the assertion of U.S. jurisdiction over tuna until 1992. Nonetheless, the repeal of the FCMA's tuna exclusion provisions very clearly signaled the waning of the U.S. distant water tuna industry's political power, which had strongly influenced U.S. fisheries policy for much of the post-World War II era. While it is also widely understood to have signaled the demise of the juridical position, in truth one component of the juridical position would continue to persist as an important element of U.S. fisheries diplomacy: the insistence that tuna be managed through international cooperation as called for by Article 64 of UNCLOS.

All of the developments canvassed above culminated in the conclusion in September 2000 of the Convention on the Conservation and Management of Highly Migratory Fish Stocks in the Western and Central Pacific Ocean (hereinafter "Western Pacific Tuna Convention" or "Honolulu Convention"). This Convention resulted from negotiations among the Pacific island countries and fishing nations in the Multilateral High-Level Conference (MHLC) process that had begun in December 1994.

The chairman of the MHLC, Satya Nandan of Fiji, underscored in his closing remarks that, when the FFA was established in the late 1970s, "it was not opportune to negotiate" an Article 64 type body "mainly because some distant water fishing nations did not recognize the jurisdiction of coastal states over highly migratory species in their exclusive economic zones." The Honolulu Convention opened for signature on Sept. 4, 2000.

However, the Honolulu Convention, itself, definitively resolves neither the long-standing differences in view as to the meaning and requirements of Article 64 nor how the compatibility requirement of Article 7 of the U.N. Fish Stocks Agreement is to be implemented. As Nandan noted, throughout the negotiations the island countries and fishing nations were "keenly aware that they had differing views of Article 64's duty to cooperate and the compatibility requirement of Article 7 of the U.N. Fish Stocks Agreement" and they "did not try to directly persuade each other of their views." Instead, the parties agreed upon a formulation, consisting of several articles, "that in important ways reconciles their differing interests."

The most important of these articles concerns application of regulatory measures developed by the Commission to areas of national jurisdiction. As had been the case in the negotiations concerning the highly migratory species article at UNCLOS, the parties to the MHLC could not reach agreement on whether or not coastal states would be required to apply regulations developed by regional organizations in their EEZs. The Honolulu Convention assigns the Commission the responsibility and authority to develop conservation and management measures for both high seas and areas of national jurisdiction. Although the text of the Convention leaves it to the Commission to decide how a particular measure is to be implemented, according to a U.S. negotiator, "[a] major assumption in the Convention is that coastal states will be willing to vote on a case-by-case basis (but not as a general requirement built into a treaty) to apply Commission measures within waters under their national jurisdiction." At the same time, in light of the Convention's failure to specify that certain measures developed by the Commission must be applied in EEZs, one Pacific island country commentator has observed that "it is not clear what role the Commission will play in regulating EEZ areas." Anticipating an area of likely controversy in the future, this same commentator believes "the Convention is not so clear as to whether the powers of the Commission also include adoption of measures for areas under national jurisdiction."

By leaving it to the Commission to decide what measures, if any, to apply in areas of national jurisdiction, the MHLC parties took an approach similar to that spelled out in the Evensen Group's draft article on highly migratory species at the 1975 Geneva Session of the Law of the Sea Conference. That draft article had assigned to the regional organization the responsibility and authority to develop conservation and management measures and also to decide which of those measures would be "standards" that coastal states were obliged to implement in their EEZs. Of course, these provisions of the draft article were not incorporated in Article 64, which also left unresolved the related issue of the compatibility of measures for the high seas and zones of national jurisdiction.

The Honolulu Convention mandates the Commission to adopt a variety of conservation and management measures and requires coastal states to apply in areas under their national jurisdiction those measures determined applicable to such areas by the Commission. The Convention further seeks to insure compatibility of measures in high seas and areas of national jurisdiction by requiring measures adopted by the Commission to be compatible with coastal state measures and by enjoining coastal states to insure that measures they adopt and apply in areas under their jurisdiction do not undermine the effectiveness of measures adopted by the Commission.

As to the decision-making procedures established by the Convention, again the influence of the Evensen Group's draft article, affording coastal states significant protections, is evident. The Evensen Group's draft article provided for the organization to adopt binding "standards" and non-binding "recommendations" by consensus or, in its absence, "a two-thirds majority, including the votes of all coastal States of the region present and voting." This effectively gave each coastal state in the organization a veto. The Honolulu Convention specifies that only decisions of the Commission concerning the allocation of the total allowable catch or the total level of fishing effort, including decisions related to the exclusion of vessel types, must be taken by consensus. All other decisions regarding conservation and management measures may be decided by a three-fourths majority, if consensus cannot be reached. However, the three-fourths majority vote must be supported by the votes of three-fourths of each of two "chambers," composed of FFA member countries and non-FFA member countries, respectively. The Convention also specifies that "in no circumstances shall a proposal be defeated by two or fewer votes in either chamber."

"This key proviso," according to one commentator, "prevents a very small minority within one chamber from vetoing proposed measures." In this respect, the Convention, as a formal matter, provides somewhat less protection to coastal states than the Evensen text would have. However, as a practical matter, the Commission will be unable to impose measures in areas of national jurisdiction unless the great majority of the island countries agree to such measures. At the same time, the two-chamber voting system provides protection to the fishing nations, which the Evensen text would not have.

Hence, although the Honolulu Convention may indeed be the "final chapter" in the relations between the Pacific island countries and distant water fishing nations, it is a chapter that remains to be completed. The Convention does not itself definitively resolve the "inside-outside" problem with respect to management of highly migratory species. But the Convention specifies principles and procedures according to which states party, through the Commission it establishes, are to implement Article 64's duty to cooperate and related injunction to ensure the conservation of highly migratory species both within and beyond exclusive economic zones. Whether the Commission will serve as a laboratory for further elaboration of Article 64's requirements remains to be seen.

Appendix 2: Targeted and Non-targeted Pelagic Species Caught in the Western Pacific Region

A summary of the status of WCPO tuna, billfish and shark stocks is given in Table 2. Illustrations courtesy of NMFS.

1. Tuna

Albacore

Albacore is a highly migratory, epipelagic and mesopelagic oceanic species that is abundant in surface waters of 15.6° C to 19.4° C. Deeper swimming, large albacore are found in waters of 13° C to 25.2° C. Temperatures as low as 9° C may be tolerated for short periods. Vertical behavior differs substantially between tropical and temperate latitudes. At tropical latitudes, albacore show a distinct diel pattern in vertical habitat use, occupying shallower warmer waters above the mixed layer at night and deeper cooler waters below the mixed layer during the day. In contrast, there is little evidence of a diel pattern of vertical behavior in albacore at temperate latitudes, with fish limited to shallow waters above the mixed layer almost all of the time.

Immature albacore recruit into surface fisheries in the Western and Eastern Pacific and before maturing, gradually move near their spawning grounds in the WCPO, where they are vulnerable to more deeply set longline gear. Details of migration in the Eastern North Pacific remain unclear, but juvenile fish (2- to 5-year-olds) are believed to move into the EPO in the spring and early summer and return to the WCPO perhaps annually, in the late fall and winter, where they tend to remain as they mature.

In the South Pacific the length at 50% maturity is about 87 cm fork length (FL) at an estimated age of 4.5 years. Spawning occurs over seven months, March to September, in tropical oceanic waters off Taiwan and the Philippines. Like other tunas, albacore are batch spawners with asynchronous egg development and indeterminate annual fecundity. Albacore spawn in the South Pacific every 1.3 days during peak spawning from October to December. Generation length is not well known for albacore but is conservatively estimated to be eight to 10 years.

Bigeye Tuna

Bigeye tuna are pelagic and oceanodromous and occur in surface waters with temperatures ranging from 13°–17° C, with an optimum is between 17° C and 22° C. This coincides with the temperature range of the permanent thermocline. Variation in occurrence is closely related to seasonal and climatic changes in surface temperature and thermocline. Juveniles and small adults school within the upper 50 m in monospecific groups or mixed with other tunas of similar size and may be associated with floating objects. Adults occupy warm surface waters to depths of 50–100 m during the night but typically make repeated dives to cooler waters at depths of up to 500 m or more during the day to exploit the deep scattering layer. Some dives exceeded 1,000 m where temperatures were less than 3° C. Such dives expose adults to a wide range of temperatures and, in certain areas, waters of low oxygen concentrations. Bigeye tuna can rapidly alter their body thermal conductivity.

Bigeye tuna are a highly migratory species. Conventional tag data demonstrate that individuals can undertake movements in excess of 7,000 km; however, the vast majority of tag returns are for much smaller distances. In the EPO, greater than 95% of conventional tag recoveries occurred within 1,894 km of the release location, and similar frequencies of long-distance movements have been observed in other ocean basins.

Bigeye tuna spawning has been recorded between 10° N and 10° S in the EPO. Sexual maturity for bigeye tuna is reached at 100- to 130-cm FL at an age of about 3 years. However, minimum length at first maturity for females can be 80- to 102-cm FL and predicted length at 50% maturity is 102- to 135-cm FL. Spawning peaks from April through September in the Northern Hemisphere and between January and March in the Southern Hemisphere. Although spawning apparently occurs widely across the equatorial Pacific Ocean, the greatest reproductive potential appears to be in the Eastern Pacific, based on maturation, size frequencies and CPUE.

Bigeye tuna are opportunistic feeders, eating fish, squids and invertebrates.

Pacific Bluefin Tuna

Pacific bluefin tuna are known to spawn in only two areas of the Western North Pacific: from the Philippine Islands north to the Ryuku Islands from April to June and further north in the Sea of Japan from June to August. The distribution of sizes of fish on the two spawning grounds differs, with larger fish (modal size 220-cm FL) on the Southern grounds and with smaller fish (modal size 150 cm FL) spawning in Sea of Japan. The difference in size distributions results in a difference in estimated age at 50% maturity: age 11 for the Southern grounds and age 4 for the Northern grounds.

The fraction of females in spawning condition increases steadily on the spawning grounds through the spawning season, as females leave the area immediately after spawning ceases. The sex ratio is about 1:1. Females are batch spawners and can spawn almost every day, with an average batch fecundity of 6.4 million oocytes. Batch fecundity increases with length, from about 5 million eggs at 190-cm FL to about 25 million eggs at 240-cm FL. The life cycle of the Pacific bluefin tuna has been completed under aquaculture conditions, the first for a large species of tuna.

Scientists consider Pacific bluefin tuna as a single North Pacific-wide stock. The U.S. longline fleet rarely catches Pacific bluefin tuna.

Skipjack Tuna

Skipjack tuna are pelagic and oceanodromous in offshore waters to depths of 330 m, with one record down to 596 m. Skipjack tuna exhibit a strong tendency to school in surface waters, often in association with floating objects, sharks and whales. They often form mixed schools with small yellowfin and bigeye tuna when associated with floating objects.

Skipjack maintain elevated body temperatures, 4° to 10° C above the temperature of the water around them. Lacking a swim bladder, skipjack rely on lift from their pectoral fins to help keep them up in the water, constantly swimming at about 69 cm/sec, or 1.6 body lengths/sec. Their lower temperature limit appears to be about 15°–18° C, but the upper temperature limit apparently varies with size, from 30° C or more for small fish to 25° C for the largest fish. Skipjack are also limited to water with unusually high concentrations of dissolved oxygen, at least 3.0–3.5 ml/1 (4–5 ppm) for long-term survival.

Yellowfin Tuna

Yellowfin tuna are epipelagic and oceanic, occupying surface waters ranging from 18° to 31° C. They spend most of their time in the mixed layer above the thermocline but adults routinely make repetitive bounce dives during the day into cooler waters at depths of 200–300 m to forage on deep scattering–layer prey organisms. Electronic archival tag data indicate that yellowfin tuna can dive to depths of at least 1,602 m.

Vertical distribution and time at depth is restricted by the yellowfin tuna's physiological tolerance to oxygen and temperature. There is a close correlation among the vulnerability of the fish to purse-seine capture, the depth of the mixed layer and the strength of the temperature gradient within the thermocline. Yellowfin tuna are confined to the upper 100 m of the water column in areas with marked oxyclines (upwelling zones) and are not usually caught below 250 m in the tropics.

Spawning is widespread spatially and temporally throughout the world's oceans at SSTs of 24° C or higher, with the majority of spawning occurring at temperatures greater than 26° C. Spawning seasonality occurs in the Northern and Southern summer months in subtropical regions. Spawning occurs almost entirely at night between 2200 and 0600 hours. Length at 50% maturity in the EPO was 69 cm for males and 92 cm for females, corresponding to an age of about 2.1 years for females.

2. Billfish

North Pacific Swordfish

Swordfish are oceanic but are sometimes found in coastal waters, generally above the thermocline, preferring temperatures of 18°–22° C. They migrate toward temperate or cold waters for feeding in the summer and back to warm waters in the fall for spawning and overwintering. Swordfish typically forage in deep waters during the day and stay in the mixed layer to feed at night, and there is a tendency to remain closer to the surface with lower lunar light levels. Based on records of forage organisms taken by swordfish, depth distribution in the Western North Pacific normally ranges from the surface to a depth of about 550 m, but there are depth records down to 2,878 m. The maximum depth of swordfish tagged in the Eastern South Pacific was 1,136 m, and five of six swordfish dove deeper than 900 m. Temperature and depth ranges for tagged fish in the Central North Pacific were 3.2°–28.8° C and 0–1,227 m; five fish dove as deep as 1,200 m.

Swordfish are reported to spawn in the upper layers of the water column, from the surface to a depth of 75 m. The distribution of larval swordfish indicates that spawning occurs in waters with a temperature of 24° C or more and salinity of 33.8 to 37.4 ppt. Spawning appears to occur in all seasons in equatorial waters but is restricted to spring and summer at higher latitudes. Pairing of solitary males and females is thought to occur when spawning. Estimates of egg numbers vary considerably, from 1 million to 16 million in a 168 kg female and 29 million in a 272 kg female. Pelagic eggs measure 1.6–1.8 mm, and the newly hatched larvae is 4 mm long.

Genetic heterogeneity has been reported among swordfish from various locations in the Pacific, and evidence is consistent with four separate Pacific sub-stocks: northwest, northeast, southwest and southeast.

Pacific Blue Marlin

Blue marlin are deep cobalt blue on top and silvery white on the bottom. They have a pronounced dorsal fin and a long, spear-shaped upper jaw (bill). Blue marlin live throughout tropical and subtropical waters of the Indian, Pacific and Atlantic Oceans. They may grow to be more than 12 feet long and may weigh up to 2,000 pounds. Female blue marlin grow larger than males and may live 20 years. Male blue marlin reach 7 feet in length and may live up to 10 years. Males mature around 2 years old, and females mature between 3 and 4 years old. Blue marlin spawn between May and September. They eat mostly tuna and other open-water fishes.

Blue marlin are typically solitary but may form small aggregations for feeding or possibly mating. Acoustic and electronic tagging of blue marlin have provided considerable information on habitat utilization. The fish spend the majority of their time in the upper 10 m but are capable of making dives below 500 m.

In the Pacific, size at first maturity of males is thought to range from 130- to 140-cm eye-FL (86.8% to 87.8% of body length), with age at maturity estimated as two years. Blue marlin spawning probably takes place year-round in equatorial waters to 10° latitude and during summer periods in both hemispheres to 30° N/ S, in all oceans. Based on the capture of gravid females or early life history stages. In the Pacific Ocean, concentrations of spawning fish occur around French Polynesia, and gravid females, eggs and larvae have been collected off Hawai'i.

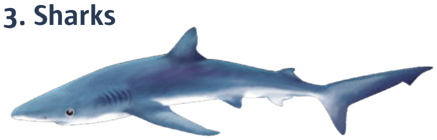
Striped Marlin

Striped marlin are widely distributed, pelagic and oceanodromous, usually found above the thermocline and shallower than 120 m, although they have been known to occur as deep as 532 m. They generally inhabit cooler water than either black or blue marlin. Abundance increases with distance from the continental shelf; they are usually seen close to shore only where deep drop-offs occur. Striped marlin are mostly solitary but form small schools by size during the spawning season and are also known to feed cooperatively on schooling prey. They are usually dispersed at considerably wide distances.

Pop-up satellite archival tag deployments throughout the Pacific Ocean demonstrate that striped marlin spend more than 50% of their time in the upper 10 m of the water column and tend to be at shallower depths at night than during the day. Striped marlin occur over a wide range of surface temperatures (15°–31° C), spending almost all of their time in waters within 8° C of the SST.

Striped marlin spawning is known to occur in several areas within the Pacific, evidenced by the seasonal occurrence of mature females and early life history stages. Larvae are most abundant in the respective local early summers. The lower temperature limit for the distribution of larvae is approximately 24° C in the Pacific Ocean. Spawning sites are between 10° S and 30° S in the Southwest Pacific. A central Pacific spawning ground was documented by Hyde et al. 2006, based on identification of seven larvae from Hawaiian waters. Spawning activity in the Southern Coral Sea, off the coasts of Fiji, and south of French Polynesia was confirmed by Kopf et al. 2011. Spawning occurs in concentrated aggregations across a broad longitudinal band. An average 109 kg female may produce an annual reproductive output of 90–281 million hydrated oocytes spread across 27–90 spawning events per season. Age at 50% maturity is 2.5 years. Length at 50% maturity was 160 cm LJFL for males and 210 cm LJFL for females.

3. Sharks

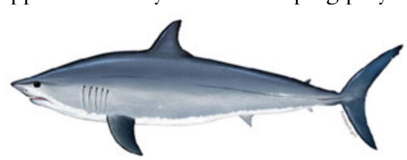


North Pacific Blue Shark

The blue shark is an oceanic and epipelagic shark found worldwide in deep temperate and tropical waters from the surface to about 350 m. It lives as far north as Norway and as far south as Chile. Blue sharks are found off the coasts of every continent, except Antarctica. Its greatest Pacific concentrations occur between 20° and 50° N but with strong seasonal fluctuations. In the tropics, it spreads evenly between 20° N and 20° S. It prefers water temperatures between 12° and 20° C but can be seen in water ranging from 7° to 25° C.

Blue sharks are viviparous, with a yolk-sac placenta, delivering four to 135 pups per litter. The gestation period is between nine and 12 months. Females mature at 5 to 6 years of age, and males at 4 to 5.

Sharks have been observed and documented working together as a "pack" to herd prey into a concentrated group from which they can easily feed. Blue sharks may eat tuna, which have been observed taking advantage of the herding behavior to opportunistically feed on escaping prey.



North Pacific Shortfin Mako Shark

The shortfin mako inhabits offshore temperate and tropical seas worldwide. It is a pelagic species that can be found from the surface to depths of 150 m, normally far from land, though occasionally closer to shore, around islands or inlets. One of the very few known endothermic sharks, it is seldom found in waters colder than 16° C.

Shortfin mako sharks travel long distances to seek prey or mates. In December 1998, a female tagged off California was captured in the Central Pacific by a Japanese research vessel, meaning this fish traveled more than 2,776 km (1,725 miles). Another specimen swam (2,128 km (1,322 miles) in 37 days, averaging 58 km (36 miles) a day.

Shortfin mako sharks over 3 m have interior teeth considerably wider and flatter than smaller mako, which enables them to prey effectively upon dolphins, swordfish and other sharks. Mako also tend to scavenge long-lined and netted fish. Its endothermic constitution partly accounts for its relatively great speed. Like other lamnid sharks, the shortfin mako shark has a heat-exchange circulatory system that allows the shark to be 4°–7° C warmer than the surrounding water.

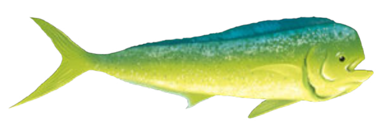
Silky Shark

Silky sharks have a restricted habitat range compared to the other highly migratory species, but, within this range, they are most common in longline and purse seine catches (Rice and Harley 2013).

The silky shark is one of the three most common pelagic sharks along with the blue and oceanic whitetip sharks. It counts among the most numerous large oceanic animals in the world with a population of at least tens of millions. Compared to the other two species, it is less strictly pelagic with the greatest numbers found in offshore waters associated with land, where food is more readily obtained than farther out in the truly open ocean. This shark is often found around floating objects such as logs or tethered naval buoys.

Silky sharks in most parts of the world are thought to reproduce year-round. However, in some cases, the presence of reproductive seasonality may have been obscured by biases in data collection. Females give birth after a gestation period of 12 months, either every year or every other year. The litter size ranges from one to 16 and increases with female size, with six to 12 being typical. The pups are born in reef nursery areas on the outer continental shelf, where there are ample food supplies and protection from large pelagic sharks. The risk of predation has selected for fast growth in young sharks, which add 25–30 cm to their length within their first year of life. After a few months, the now-sub-adult sharks migrate out from the nursery into the open ocean.

4. Other Pelagic Species



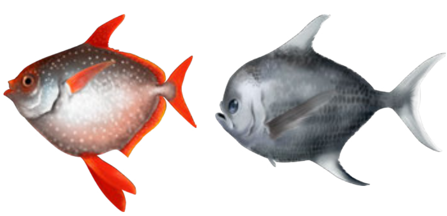
Mahimahi

Mahimahi, or dolphinfish, has a wide distribution throughout the tropical and subtropical waters of the world's oceans and is mostly found in the surface water. It is one of the most important species caught in the artisanal fisheries of the coastal nations of the EPO, ranging from Chile in the south to Mexico in the north. Their flesh is soft and oily, similar to sardines. The body is slightly slender and long, making them fast swimmers; they can swim as fast as 50 knots (92.6 km/hour). Available fisheries statistics indicate that the EPO is the dominant region in global production of this species.

Mahimahi can live for up to five years, although they seldom exceed four. Females are usually smaller than males. Catches typically are 7 to 13 kg and a meter in length. They rarely exceed 15 kg, and mahimahi over 18 kg are exceptional. Mahimahi are among the fastest-growing of fish.

Males and females are sexually mature in their first year, usually by the age of four to five months. Spawning can occur at body lengths of 20 cm. Females may spawn two to three times per year and produce between 80,000 and 1,000,000 eggs per event. Mahimahi spawn in warm ocean currents throughout much of the year, with greater numbers of larvae detected in spring and fall. In waters at 28 °C, mahimahi larvae are found year-round.

Mahimahi has been thought of as highly resilient to overfishing due to its high productivity in all the oceans of the world. However, stock assessments are needed to obtain a better picture of the stock status of the species and develop reference points for management.



Opah and Monchong

Opah (moonfish) and monchong (pomfret) are two pelagic species incidentally caught by Hawai'i-based longliners targeting bigeye tuna in the North Pacific. Opah exhibit sexual dimorphism that enables the determination of a fish's gender without cutting into the peritoneal cavity to examine the gonads for the determination of sex. In general, smaller individuals are taken at higher latitudes ranging from 30 to 107 cm with a mean of 64 cm. The monchong harvested in Hawai'i-based fisheries are composed principally of two species: the sickle pomfret *(Taractichthys steindachneri)* and the lustrous pomfret *(Eumegistus illustris)*.

Particularly valued by the restaurant trade in Hawai'i, these exotic, deep-water fishes are generally harvested in small, but nevertheless significant, quantities. Since neither are targeted species, these fishes have historically been poorly studied and as a result available information pertaining to the biology and ecology are virtually nonexistent.

Wahoo

Wahoo (known as ono in Hawai'i) is an oceanic, epipelagic species frequently found solitarily or forming small, loose aggregations rather than compact schools. The global stock structure of wahoo is uncertain. The species is reputed to exist as a single panmictic population worldwide (Theisen et al. 2008). It spends the vast majority of its time both day and night above the thermocline, at least around topographic features, but occasionally dives to at least 340 m. The probability of occurrence of wahoo in the EPO has been predicted to be the highest when SSTs are 20°–25° C and chlorophyll-a concentrations are less than 2 mg per cubic meter of seawater.

Previous studies have reported a skewed sex ratio in wahoo populations, ranging from 1.3 to 3.4 females to every male. Wahoo exhibit early sexual maturity. They live for at least five to six years, and some may live as long as 10 years. Generation length is estimated to be between three and five years. Off eastern Australia, 50% of females reach maturity by 104.6 cm and approximately 7 months of age. Wahoo have an extended spawning season during warmer months in both the Northern and Southern Hemispheres.

Off the Pacific coast of Australia, female wahoo spawn October to February. Females are multiple batch spawners and are highly fecund. Mean spawning frequency has been reported as two to nine days during a spawning season. Predicted mean weight at length in Hawai'i was highest at the beginning of the spawning season in June and lowest after the spawning season in September. Fish in different maturity stages are frequently caught at the same time. Batch fecundity is positively correlated with fish size in eastern Australia, ranging between 0.65 and 5.12 million oocytes. Relative fecundity was estimated at 122 oocytes per gram of ovary-free body weight.

Fig. 26. About to release a striped marlin marked with a popup satellite tag. David Itano photo.

Table 2. Overview of stock status of interest to the Western and Central Pacific Fishery Commission (as of Oct. 31, 2019).

(*The determination of overfished and overfishing is not a firm statement but one of likelihood. Percentages provided indicate probability. SC=Science Committee of the WCPFC.)

Stock	Latest Assessment	Overfished*	Overfishing*	Next Assessment
WCPO Tuna				
Bigeye tuna *(Thunnus obesus)*	Update 2018 (SC14)	No (100%)	No (94%)	2020
Yellowfin tuna *(T. albacares)*	2017 (SC13)	No (92%)	No (96%)	2020
Skipjack tuna *(Katsuwonus pelamis)*	2019 (SC15)	No	No	2022
South Pacific albacore tuna *(T. alalunga)*	2018 (SC14)	No	No	2021
Northern Stocks				
North Pacific albacore *(T. alalunga)*	2017 (SC13)	No	No	2020
Pacific bluefin tuna *(T. orientalis)*	UPDATE 2018 (SC14)	Yes	Yes	2020
North Pacific swordfish *(Xiphias gladius)*	2018 (SC14)	No	No	2022
WCPO Billfish				
Southwest Pacific swordfish *(X. gladius)*	2017 (SC13)	No (100%)	No (68%)	2021
Southwest Pacific striped marlin *(Kajikia audax)*	2019 (SC15)	Likely (50%)	No (56%)	2023
North Pacific striped marlin *(K. audax)*	2019 (SC15)	Yes	Yes	2024
Pacific blue marlin *(Makaira nigricans)*	2016 (SC12)	No	No	TBD
WCPO Sharks				
Oceanic whitetip shark *(Carcharhinus longimanus)*	2019 (SC15)	Yes	Yes	TBD
Silky shark *(C. falciformis)*	2018 (SC14)	No (indicative)	Yes (indicative)	2023
South Pacific blue shark *(Prionace glauca)*	2016 (SC12)	N/A	N/A	2021
North Pacific blue shark *(P. glauca)*	2017 (SC13)	No	No	2022
North Pacific shortfin mako *(Isurus oxyrinchus)*	2018 (SC14)	No (>50%)	No (50%)	2023
Pacific bigeye thresher shark *(Alopias superciliosus)*	2017 (SC13)	N/A	N/A	2022
Southern Hemisphere Porbeagle shark *(Lamna nasus)*	2017 (SC13)	N/A	Very low	2022
Whale Shark *(Rhincodon typus)*	Productivity Susceptibility Analysis 2018 (SC14)	N/A	N/A	TBD

Appendix 3: List of PFRP Projects and Principal Investigators

Additional information on the projects, including progress reports, can be accessed at https://www.soest.hawaii.edu/PFRP/allprojects.html.

Biology Projects

1. Age and Growth of Striped Marlin, *Kajikia audax*, in the Hawai'i-based Longline Fishery. *R. Keller Kopf and Robert Humphreys Jr.*
2. Analyses of Catch Data for Mahimahi *(Coryphaena hippurus)* and Wahoo *(Acanthocybium solandri)* from the Hawai'i-Based Longline Fishery and Other Pacific Fisheries. *William A. Walsh*
3. Aspects of the Ecology of the Red Squid *(Ommastrephes bartramii)*, a Potential Target for a Major Hawaiian Fishery. *Richard Young*
4. Assimilating in situ Bio-acoustic Data in Mid-Trophic Level Model and its Impact on Predicted Albacore Feeding Habitat in the American Samoa Waters. *Reka Domokos and Patrick Lehodey*
5. Associative Dynamics of Tropical Tuna to a Large-Scale Anchored FAD Array. *Kim Holland, David Itano and John Hampton*
6. Automated Monitoring of Yellowfin Tuna at Hawaiian FADs and Relationship to Water Mass Dynamics based upon Satellite Imagery. *Peter Klimley and Charles Holloway*
7. Biology and Habitat Use of Monchong *(Eumegistis illustris)* at Cross Seamount, Hawai'i. *Kevin Weng*
8. Biotelemetry Tag Retention in Pelagic Tunas. *T. Todd Jones, John Wang and Michael Musyl*
9. Describing the Vertical Habitat of Bigeye and Albacore Tunas and Post-Release Survival for Marlins in the Central Pacific Longline Fisheries with Pop-Up Archival Transmitting Tags. *Jeffrey Polovina and Michael Seki*
10. Design of Tag-Recapture Experiments for Estimating Yellowfin Tuna Stock Dynamics, Movements and Fishery Interactions. *John Sibert and Peter Bills*
11. Developing Biochemical and Physiological Predictors of Long Term Survival in Released Blue Shark. *Christopher Moyes, Richard Brill and Michael Musyl*
12. Developing Tools to Assess Sex and Maturational Stage of Bigeye Tuna *(Thunnus obesus)* and Swordfish *(Xiphias gladius). Malia Chow and E. Gordon Grau*
13. Development of "Business Card" Tags: Inter-individual Data Transfer. *Laurent Dagorn and Kim Holland*
14. Distributions, Histories, and Recent Catch Trends with Six Fish Taxa Taken as Incidental Catch by the Hawai'i-Based Commercial Longline Fishery. *William A. Walsh*
15. Early Life Stage Dispersal of Yellowfin Tuna *(Thunnus albacares)* in the Central North Pacific. *Kelvin Richards and Claire Paris*
16. Ecological Characterization of American Samoa's Small-Scale Alia Albacore Longline Fishery. *John Kaneko, Paul Bartram and Elvin Mokoma*
17. Evaluating Biochemical and Physiological Predictors of Long Term Survival in Released Pacific Blue Marlin Tagged with Pop-Up Satellite Archival Transmitters (PSATs). *Michael Musyl, Chris Moyes and Richard Brill*
18. Examining Pelagic Food Webs using Multiple Chemical Tracers. *Jeffrey Drazen and Brian Popp*
19. Feasibility of Airborne Laser Devices for Pelagic Fish Surveys. *John Sibert and Chris Schoen*
20. Fishery Dynamics in the Samoan Archipelago. *Keith Bigelow, Adam Langley and John Hampton*
21. Hawai'i Regional Tuna Tagging Project. *Kim Holland and David Itano*
22. Hawai'i Tuna Tagging Project 2. *Kim Holland, David Itano and Kevin Weng*
23. Impacts of Fishing on Vulnerable Non-target Species at Seamounts. *Kevin Weng*
24. Instrumented Buoys as Autonomous Observatories of Pelagic Ecosystems. *Kim Holland and Laurent Dagorn*
25. Investigating the Life History and Ecology of Opah and Monchong. *Michael Seki*
26. Investigation of Pacific Broadbill Swordfish Migration Patterns and Habitat Characteristics using Electronic Archival Tag Technology. *Chris Boggs and John Gunn*
27. Investigation of Aggregation Behavior of FAD-associated Small Yellowfin Tuna and Size Project status. *Kim Holland, Laurent Dagorn, David Itano and Dean Grubbs*
28. Laboratory and Field Research to Enhance Understanding of Tuna Movements and Distribution, and to Improve Stock Assessment Model. *Richard Brill*
29. Long-Term Deployment of Satellite Tags using the California Harpoon Fleet. *Heidi Dewar and Jeffrey Polovina*
30. Modeling the Eco-physiology of Pelagic Fishes and Sharks with Archival and Pop-up Satellite Archival Tags (PSATs). *Michael Musyl, Hans Malte and Richard Brill*
31. Nursery Origin of Yellowfin Tuna *(Thunnus albacares)* in the Hawaiian Islands. *Jay Rooker and David Itano. Kim Holland, David Itano and John Hampton*
32. Pop-Off Satellite Archival Tags to Chronicle the Survival and Movements of Blue Shark Following Release from Longline Gear. *Michael Musyl and Richard Brill*
33. Population Biology of Pacific Oceanic Sharks. *Chris Boggs*
34. Reproductive Biology of Yellowfin Tuna, *Thunnus albacares*, in Hawaiian Waters and the Western Tropical Pacific Ocean. *David Itano and Richard Shomura*
35. Scaling Up: Linking FAD-associated Local Behavior of Tuna to Regional Scale Movements and Distribution. *Kim Holland and Laurent Dagorn*
36. Survivorship, Migrations, and Diving Patterns of Sea Turtles Released from Commercial Longline Fishing Gear, Determined with Pop-Up Satellite Archival Transmitters. *Richard Brill, Yonat Swimmer, George Antonelis, George Balazs and Jeffrey Polovina*
37. Synchronous Assessment of Bigeye Tuna *(Thunnus obesus)* and Micronekton Biomass, Distribution, and Movement Patterns at Cross Seamount, and the Effects of the Seamount Environment. *Reka Domokos, Kim Holland and Jeffrey Polovina*
38. A Tag and Release Program for the Hawai'i Seamount Yellowfin and Bigeye Tuna. *Kim Holland*
39. Three-Dimensional Laser Confocal Microscopy as a Tool to Age Fish Otoliths by Optical Sections: Validation of Daily Micro-increments by both Injected Dyes and Theoretical Otolith Growth Models. *Robert Gauldie*
40. Trophic Ecology and Structure-Associated Aggregation Behavior in Bigeye and Yellowfin Tuna in Hawaiian Waters. *Kim Holland, Richard Young, Richard Brill and Laurent Dagorn*
41. Workshop on How to Improve Studies on the Collective Behavior of Pelagic Fish. *Laurent Dagorn and Kim Holland*

Oceanography Projects

1. Development of Oceanographic Atlases for Pelagic and Insular Fisheries and Resource Management of the Pacific Basin. *Russell Brainard, John Sibert and David Foley*
2. Evaluation of Remote Sensing Technologies for the Identification of Oceanographic Features Critical to

Pelagic Fish Distribution around the Hawaiian Archipelago. *Gary Mitchum and Jeffrey Polovina*

3. A Numerical Investigation of Ocean Circulation and Pelagic Fisheries around the Hawaiian Islands. *Bo Qiu and Pierre Flament*
4. Ocean Acidification Impacts on Tropical Tuna Populations. *Simon Nicol, Dan Margulies and Vernon Scholey*
5. Oceanographic Characterization of the American Samoa Longline Fishing Grounds for Albacore, *Thunnus alalunga*. *Michael Seki, Jeffrey Polovina and Reka Domokos*
6. Physical Characteristics of the Environment influencing Pelagic Fishes. Pierre Flament
7. Regime Shifts in the Western and Central Pacific Ocean Tuna Fisheries. *David Kirby, Patrick Lehodey, Valerie Allain and Adam Langley*
8. The Role of Oceanography on Bigeye Tuna Aggregation and Vulnerability in the Hawai‘i Longline Fishery from Satellite, Moored and Shipboard Time Series. *Russell Brainard, Jeff Polovina, Michael Seki, Bo Qiu and Pierre Flament*
9. Trophic Structure and Tuna Movement in the Cold Tongue-Warm Pool Pelagic Ecosystem of the Equatorial Pacific. *Valerie Allain, Robert Olson, Felipe Galvan Magana and Brian Popp*

Statistical and Modeling Projects

1. Addition of Multi-species Capability, Sex Structure and other Enhancements to the Length-Based, Age-Structured Modeling Software MULTIFAN-CL. *John Hampton, Pierre Kleiber and John Sibert*
2. Analyses of Catch Data for Blue and Striped Marlins (Istiophoridae). *William A. Walsh and Jon Brodziak*
3. Biological, Economic, and Management Drivers of Fishery Performance: A Global Meta-Analysis of Tuna and Billfish Stocks. *Trevor Branch, Ray Hilborn and Olaf Jensen*
4. Causes of Rapid Declines in World Billfish Catch Rates. *Ransom Myers and Peter Ward*
5. Combining Individual and Population Based Estimation of Migration Patterns. *Anders Nielsen and John Sibert*
6. Comparisons of Catch Rates for Target and Incidentally Taken Fishes in Widely Separated Areas of the Pacific Ocean. *William A. Walsh*
7. Development of Assessment Model for Yellowfin Tuna. *John Sibert*
8. Estimation of Bycatch and Discards of Sharks and Other Species by the Hawai‘i Longline Fishery. *Pierre Kleiber, Chris Boggs and William Walsh*
9. Evaluation of Data Quality for Catches of Several Pelagic Management Unit Species by Hawai‘i-Based Longline Vessels and Exploratory Analyses of Historical Catch Records from Japanese Longline Vessels. *William A. Walsh and Keith Bigelow*
10. Improved Effectiveness of WCPFC through Better Informed Fishery Decision Makers. *Simon Hoyle, Shelton Harley and Fabrice Bouye*
11. Incorporating Oceanographic Data in Stock Assessments of Blue Sharks and Other Species Incidentally Caught in the Hawai‘i-based Longline Fishery. *Pierre Kleiber and Hideki Nakano*
12. Integration of Hawai‘i Longline Fishery Performance Models with Environmental Information. *Chris Boggs*
13. Integrative Modeling in Support of the Pelagic Fisheries Research Program: Spatially Disaggregated Population Dynamics Models for Pelagic Fisheries. *John Sibert, Peter Bills and Kevin Weng*
14. Integrating Electronic and Conventional Tagging Data into Modern Stock Assessment Models. *Simon Nicol, Mark Maunder and Pierre Kleiber*
15. Investigation of Shark Bycatch in the Hawai‘i-Based Longline Fishery, and an Extension of Analyses of Catch Data from Widely Separated Areas in the Pacific Ocean. *Keith Bigelow, Mark Maunder, Adam Langley and Pascal Bach*
16. Local Pelagic Catch and Effort Data Analysis and Integrated Modeling to Quantify the Effects of Local Fisheries on Fish Availability. *Chris Boggs*
17. Mixed-Resolution Models for Investigating Individual to Population Scale Spatial Dynamics. *Patrick Lehodey, Jeffrey Polovina, David Kirby and Raghu Murtugudde*
18. Pacific-Wide Analysis of Bigeye Tuna *(Thunnus obesus)* using a Length-Based, Age Structured Modeling Framework (MULTIFAN-CL). *John Hampton, Richard Deriso and Naozumi Miyabe*
19. Performance of Longline Catchability Models in Assessments of Pacific Highly Migratory Species. *Keith Bigelow, Mark Maunder, Adam Langley and Pascal Bach*
20. Rescue, Compilation, and Statistical Characterization of Historic Longline Data, Pacific Ocean Fisheries Investigation 1951–73. Performance of Longline Catchability Models in Assessments of Pacific Highly Migratory Species. *Bert Kikkawa*
21. Stock and Fishery Dynamics of Yellowfin Tuna, *Thunnus albacares*, in the Western and Central Pacific Ocean: Development of an Integrated Model Incorporating Size and Spatial Structure. *John Hampton and David Fournier*

Genetics Projects

1. Analysis of Pacific Blue Marlin and Swordfish Population Structure using Mitochondrial and Nuclear DNA Technologies. *John Graves and Barbara Block*
2. An Assessment of Bigeye Tuna *(Thunnus obesus)* Population Structure in the Pacific Ocean based on Mitochondrial DNA and Microsatellite Variation. *John Hampton and Peter Grewe*
3. Genetic Analysis of Population Structure in Pacific Swordfish *(Xiphias gladius)* using Microsatellite DNA Techniques. *Barbara Block and Carol Reeb*
4. Population Structure and Dynamics in Mahimahi as Inferred through Analysis of Mitochondrial DNA. *Carol Reeb*

Economics Projects

1. Analysis of Alternatives for Participation in International Management of Pelagic Fisheries. *Sam Pooley*
2. Analyzing the Technical and Economic Structure of Hawai‘i’s Pelagic Fishery. *PingSun Leung*
3. Contributions of Tuna Fishing and Transshipment Operations to Local Economies. *Michael Hamnett and Sam Pintz*
4. A Dynamic Model to Evaluate the Effect of Regulation on the Hawai‘i Commercial Fisheries. *Ujjayant Chakravorty*
5. Economic Contributions of Hawai‘i’s Fisheries. *PingSun Leung, Stuart Nakamoto and Sam Pooley*
6. Economic Fieldwork on Pelagic Fisheries in Hawai‘i. Minling Pan and Sam Pooley
7. Economic Interactions between U.S. Longline Fisheries. *Michael Travis*
8. The Economics of Recreational Fishing for Pelagics in Hawai‘i. *K. Ted McConnell*
9. Evaluating Closed-Area Management Regimes in the Gulf of Mexico, Northwest Atlantic, and Central Pacific Highly Migratory Species Longline Fisheries. *David Kerstetter and John Graves*
10. Factors Affecting Price Determinations and Market Competition for Fresh Pacific Pelagic Fish, Phase I: Tuna and Marlin. *John Kaneko and Paul Bartram*
11. Hawai‘i Pelagic Fishing Vessel Economics. *Sam Pooley*
12. Incidental Catch of Non-Target Fish Species and Sea Turtles: Comparing Hawai‘i’s Pelagic Longline Fishery Against Others. *John Kaneko and Paul Bartram*
13. Modeling Longline Effort Dynamics and Protected Species Interaction. *PingSun Leung, Naresh Pradhan and Sam Pooley*
14. A Multilevel and Multiobjective Programming Model of Hawai‘i

Commercial Fisheries. *PingSun Leung and Stuart Nakamoto*

15. Regulatory Impact Analysis Framework for Hawai'i Pelagic Fishery Management. *Minling Pan and Keiichi Nemoto*
16. Recreational Fisheries Meta Data - Preliminary Steps. *Paul Dalzell and Sam Pooley*
17. The Role of Social Networks on Fishermen Economic Performance in Hawai'i's Longline Fishery. *PingSun Leung, Shawn Arita and Stewart Allen*
18. Spatial Modeling of the Tradeoff between Sea Turtle Take Reduction and Economic Returns to the Hawai'i Longline Fishery. *Minling Pan, Shichao Li and Michael Parke*

Sociocultural Projects

1. An Analysis of Archaeological and Historical Data on Fisheries for Pelagic Species in Guam and Northern Mariana Islands. *Judith Amesbury and Rosalind Hunter-Anderson*
2. Coordinated Sociocultural Investigation of Pelagic Fishermen in American Samoa and the Commonwealth of the Northern Mariana Islands. *Michael Hamnett, Robert Franco and Craig Severance*
3. Descriptive Assessment of Small-Scale and Traditional Fisheries in the Western Pacific. *Ed Glazier and John Petterson*
4. Distribution and Use of Seafood in the Context of the Community: A Case Study of the Main Hawaiian Islands. *Ed Glazier and Stewart Allen*
5. Human Dimensions Analysis of Hawai'i's Ika-Shibi Fishery. *Ed Glazier and John Petterson*
6. Integrated Information System for Pelagic Fishery Research and Management. *Robert Skillman*
7. Local Fishery Knowledge: Its Application to the Management and Development of Small-scale Tuna Fisheries in the U.S. Pacific Islands. *John Kaneko and Paul Bartram*
8. Small Boat Bigeye and Yellowfin Tuna Operations and Regulatory Scenarios in the Main Hawaiian Islands. *Ed Glazier and John Petterson (Impact Assessment Inc.)*
9. Social Aspects of Pacific Pelagic Fisheries, Phase I: The Hawai'i Troll and Handline Fishery. *Marc Miller*
10. Social Aspects of Pacific Pelagic Fisheries, Phase II: The Hawai'i Troll and Handline Fishery. *Marc Miller*
11. Sociological Baseline of Hawai'i-Based Longline Fishery: Extension and Expansion of Scope. *Stewart Allen*
12. A Sociological Baseline of Hawai'i's Longline Fishery. *Sam Pooley and Stewart Allen*
13. A Sociocultural Study of Pelagic Fishing Activities in Guam. *Donald Rubinstein and Thomas Pinhey*

Protected Species

1. Comparing Sea Turtle Distributions and Fisheries Interactions in the Atlantic and Pacific. *Molly Lutcavage and Selina Heppell*
2. Development of a Hierarchical Model to Estimate Sea Turtle Rookery Contributions to Mixed Stocks in Foraging Habitats. *Ben Bolker, Karen Bjorndal and Alan Bolten*
3. Diet Dynamics and Trophic Relations of Laysan and Black-footed Albatrosses. *David Duffy and Jeremy Bisson*
4. Direct Tests of the Efficacy of Bait and Gear Modifications for Reducing Interactions of Sea Turtles with Longline Fishing Gear in Costa Rica. *Yonat Swimmer*
5. A General Bayesian Integrated Population Dynamics Model for Protected Species. *Mark Maunder*
6. Integrated Statistical Model for Hawaiian Albatross Populations. *Daniel Goodman and Jean-Dominique Lebreton*
7. Robust Statistical Re-evaluation of the Effect of Pelagic Longline Fisheries on Loggerhead Sea Turtle Stocks in the Pacific. *Milani Chaloupka*

Trophodynamics Projects

1. Assessment of the Impacts of Mesoscale Oceanographic Features on the Forage Base for Oceanic Predators. *Jeffrey Drazen and Reka Domokos*
2. Climate and Fishing Impacts on the Spatial Population Dynamics of Tunas. *Patrick Lehodey and Olivier Maury*
3. Examining Latitudinal Variation in Food Webs leading to Top Predators in the Pacific Ocean. *Jock W. Young, Robert Olson, Valerie Allain and Jeffrey Dambacher*
4. Integrating Conventional and Electronic Tagging Data into the Spatial Ecosystem and Population Model SEAPODYM. *Inna Senina, Patrick Lehodey and Francois Royer*
5. Intra-Guild Predation and Cannibalism in Pelagic Predators: Implications for the Dynamics, Assessment and Management of Pacific Tuna Populations. *Tim Essington, Mark Maunder, Robert Olson, James Kitchell and Enric Cortes*

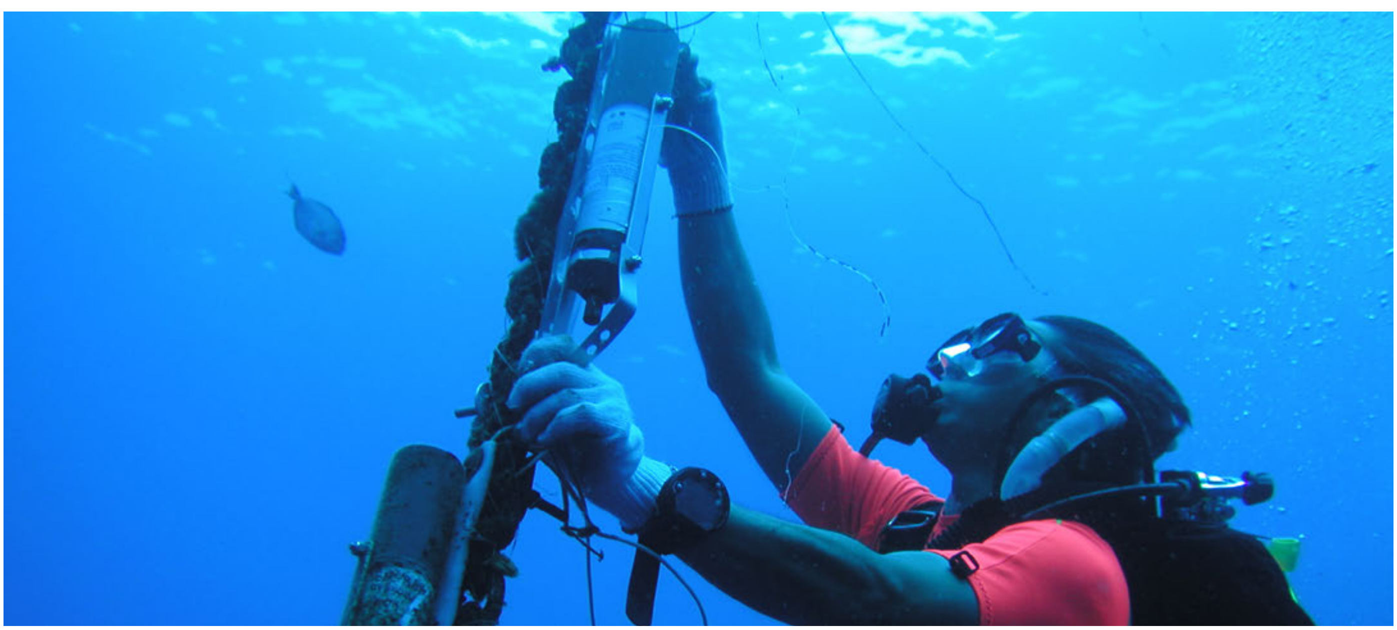


Fig. 27. Swapping out an acoustic receiver mounted below an anchored FAD in Hawai'i. These devices receive and store data from tuna that have been marked with coded transmitter tags to study FAD-associated behavior. David Itano photo.

Appendix 4: Meetings Convened, Co-Convened and Supported by PFRP

The PFRP regularly convened meetings of PIs and co-convened other workshops in association with some of them. The PFRP also strongly supported other meetings and pelagic fisheries initiatives. Documents and agendas for the meetings listed below are available at https:\\www.soest.hawaii.edu/PFRP/meetings.html.

Table 3. Meetings convened, co-convened or supported by PFRP.

Year	Meeting
1998	**Pacific Bigeye Tuna Research Coordination Workshop**, Nov. 9–10, East-West Center, Honolulu, Hawai‘i
2000	**Report of the MULTIFAN-CL Workshop Feb. 1–3**, Imin Conference Center, UH Manoa, Honolulu, Hawai‘i **Symposium on Tagging and Tracking Marine Fish with Electronic Devices** Feb. 7–11, Imin Conference Center, UH Manoa, Honolulu, Hawai‘i
2001	**PFRP PI Meeting: Ecosystem-Based Management of Pelagic Fisheries** Dec. 4–6, Campus Center Ballroom, UH Manoa, Honolulu, Hawai‘i **Protected Species Modeling Workshop**, Nov. 13–14, Imin Conference Center, UH Manoa, Honolulu, Hawai‘i
2002	**Standing Committee on Tuna and Billfish (SCTB) 15**, July 22–27, Hawai‘i Convention Center, Honolulu, Hawai‘i **First Meeting of the Scientific Coordinating Group**, July 29–31, East-West Center, Honolulu, Hawai‘i **International Workshop on the Current Status and New Directions for Studying Schooling and Aggregation Behavior of Pelagic Fish**, Oct. 7–9, UH Hawai‘i Institute of Marine Biology, Kane‘ohe, Hawai‘i **PFRP PI Meeting and “Tying One On” Workshop**, Dec. 4–6, Hemenway Theater, UH Manoa, Honolulu, Hawai‘i
2003	**PFRP PI Meeting, Data Rescue: Discovery, Verification, Documentation and Analysis of Long-Term Data** Dec. 9–11, Imin Conference Center, UH Manoa, Honolulu, Hawai‘i
2004	**PFRP PI Meeting, Ecosystem Approaches to Fishery Management (processes occurring at mid-trophic levels)** Nov. 29–Dec. 1, Imin Conference Center, UH Manoa, Honolulu, Hawai‘i
2006	**PFRP PI and Climate Impacts on Oceanic Top Predators (CLIOTOP) Working Group 3 Workshops** Nov. 14–17, Imin Conference Center, UH Manoa, Honolulu, Hawai‘i
2007	**Pelagic Longline Catch Rate Standardization Meeting** Feb. 12–16, Imin Conference Center, UH Manoa, Honolulu, Hawai‘i **2nd International Symposium on Tagging and Tracking Marine Fish with Electronic Devices** Oct. 8–11, Donostia-San Sebastian, Spain **Climate Impacts on Oceanic Top Predators - 1st CLIOTOP Symposium**, Dec. 3–7, La Paz, Mexico
2008	**PFRP PI Workshop**, Nov. 18–19, Imin Conference Center, UH Manoa, Honolulu, Hawai‘i
2009	**PFRP PI Workshop**, Nov. 19–20, Imin Conference Center, UH Manoa, Honolulu, Hawai‘i
2010	**PFRP PI Workshop**, Dec. 15–16, Imin Conference Center, UH Manoa, Honolulu, Hawai‘i
2011	**PFRP PI Meeting**, Dec. 15–16, Imin Conference Center, UH Manoa, Honolulu, Hawai‘i
2012	**PFRP PI Meeting**, Nov. 26–27, Imin Conference Center, UH Manoa, Honolulu, Hawai‘i

Appendix 5: List of PFRP Newsletter Issues and Articles

October 1996 (volume 1, number 1)
- About the Pelagic Fisheries Research Program
- Using DNA to analyze the population structure of swordfish and Pacific blue marlin
- Bigeye tuna population structure in the Pacific Ocean
- Were dolphinfish once an endangered species?
- Schedule of upcoming events

January 1997 (volume 2, number 1)
- Social sciences in fisheries research
- Price determinants in the marketing of fresh Pacific tuna
- Tuna economics in the Pacific Islands
- The 1993 Hawai‘i-based longline fleet
- The social value of Hawai‘i’s troll and handline fishery
- Schedule of upcoming events

April 1997 (volume 2, number 2)
- Tuna tagging in Hawai‘i
- The Western Pacific region: Small islands, big changes
- Schedule of upcoming events

July 1997 (volume 2, number 3)
- Oceanography and fishery management
- Current and eddy statistics for the Hawai‘i EEZ
- Tracking fish by mapping ocean features
- Modeling the ocean circulation around the main Hawaiian Islands
- Schedule of upcoming events

October 1997 (volume 2, number 4)
- Tuna behavior and physiology
- Tuna telemetry in Tahiti
- How tuna physiology affects tuna movements and distribution
- Yellowfin tuna biology and fisheries in the Pacific
- Schedule of upcoming events

January 1998 (volume 3, number 1)
- Managing highly migratory species
- Legal considerations for managing highly migratory fish
- The importance of tuna to the Pacific Islands
- School behavior and site fidelity of monitored tuna
- PFRP technical reports
- Schedule of upcoming events

April 1998 (volume 3, number 2)
- Economics and fishery management
- How many purse seiners should exploit the Western Pacific tuna fishery
- Access fees, economic benefits in the Western Pacific U.S. purse-seine tuna fishery
- Biological “threats” to sustainable tuna fisheries
- Upcoming events

July 1998 (volume 3, number 3)
- Keeping our eye on bigeye
- Archival tags—a wealth of information
- All things considered, eating fish is better
- Tracking Hawai‘i’s tuna
- Preparing for the Hawai‘i Tuna Tagging Project (HTTP)
- How to assist the HTTP
- Upcoming events
- PFRP technical reports

October 1998 (volume 3, number 4)
- Do you know where your longline is?
- How to set a longline to a desired depth
- Reducing longline bycatch
- Predicting the shape of longlines
- Recovered archival tag loaded with data
- Schedule of upcoming events

January–March 1999 (volume 4, number 1)
- Workshop consensus: International project on bigeye tuna needed
- Creating the big picture for Pacific bigeye tuna
- New data fuels old debate on bluefin tuna
- Schedule of upcoming events

April–June 1999 (volume 4, number 2)
- MHLC4 sets convention area, calls for scientific support
- How to get the best science into regional fishery management
- Archival tags—the good, the bad and the desired
- Upcoming events

July–September 1999 (volume 4, number 3)
- New Pacific bigeye tuna projects
- Oceanography's role in bigeye tuna aggregation and vulnerability
- Pacific-wide stock assessment of bigeye tuna
- Upcoming events

October–December 1999 (volume 4, number 4)
- Status of South Pacific tuna stocks
- Pacific blue marlin stock is healthy says new analysis
- Upcoming events

January–March 2000 (volume 5, number 1)
- More data required to assess bigeye tuna population
- Reflections on MHLC5
- Fishermen rewarded for return of archival tag
- Upcoming events.

April–June 2000 (volume 5, number 2)
- Tagging and tracking with electronic devices (Tagging Symposium)
- The substitution effect of area closures
- The trophic ecology of two Hawaiian Ommastrephid squids
- Upcoming events.

July–September 2000 (volume 5, number 3)
- MHLC6 assesses science and costs of migratory stock management
- IATTC tags bigeye tuna in EPO
- Protected species workshops
- Charter fishing patronage in Hawai‘i
- Conference targets marine debris
- Economic contributions of Hawai‘i's marine fisheries
- Tournament-tagged marlin.

October–December 2000 (volume 5, number 4)
- Swordfish fisheries and management today
- December workshop for PFRP PIs
- NMFS workshops for longliners well attended
- New PFRP projects funded in FY 2000
- Upcoming events.

January–March 2001 (volume 6, number 1)
- PFRP research continues to diversify
- The importance of local knowledge in fisheries management

April–June 2001 (volume 6, number 2)
- Bluefin spawning in central North Atlantic
- Luring anglers to research
- A sociocultural study of pelagic fishing in Guam
- Bigeye moorings recovered/deployed
- MHLC7—Evaluation and comment (interview with Ziro Suzuki)

July–September 2001 (volume 6, number 3)
- New discoveries in visual performance
- The associated tuna-school fishing technique
- MHLC7—Evaluation and comment (interview with Talbot Murray)

- Blue shark study nets early results
- MHLC: Years remain to bring order to high seas tuna fisheries
- PSATs will tell swordfish secrets
- Upcoming events

October–December 2001 (volume 6, number 4)
- Trends in NE Atlantic and Mediterranean bluefin abundance
- Fourteenth SCTB: Conservation, recruitment FADs and MSY
- December gathering for PFRP PIs
- MHLC7—Evaluation and Comments (interview with Peter Ward)
- Upcoming events.

January–March 2002 (volume 7, number 1)
- Incidental catches of fishes by Hawai'i longliners
- Meetings in 2002 (from SPC listing)
- PFRP PIs workshop 2001—Introducing ecosystem-based management
- Pacific agency's technology nabs Atlantic scofflaw
- The marine mammal authorization program
- Protected species workshops continue for Hawai'i longliners
- PrepCons advance MHLC
- Giant "mystery squid" caught on video
- Upcoming events

April–June 2002 (volume 7, number 2)
- Quantifying sea turtle mortality with PSATs
- New discoveries in the olfactory capability of sea turtles
- MHLC7—Evaluation and comment (Robin Allen, IATTC)
- Compendium—Fisheries research in brief.

July–September 2002 (volume 7, number 3)
- Predicting post-release survival in pelagics
- Recreational meta-data: Using tournament data to describe a poorly documented pelagic fishery
- Upcoming events
- Longlining in American Samoa—The fleet and its economics
- PrepCon2—Progress on MHLC financing and scientific structure
- Upcoming events

October–December 2002 (volume 7, number 4)
- Tuna scientists aggregate in Honolulu for 15th SCTB and 1st MHLC Scientific Coordinating Group
- PFRP PIs to gather in December
- PrepCon2 to meet in Manila
- Status of yellowfin tuna in the Western and Central Pacific
- Fisheries research in brief
- Abstract: Status of the U.S. Western Pacific tuna purse-seine fleet
- MHLC—Evaluation and comment (Anna Willock, Traffic Oceania, Australia)

January–March 2003 (volume 8, number 1)
- Hawai'i cyclonic eddies and blue marlin catch patterns
- A FAD of a different function
- PrepCon3 moves MHLC forward
- Compendium—Fisheries research in brief
- Upcoming events

April–June 2003 (volume 8, number 2)
- Population dynamics of bigeye and yellowfin tuna in Hawai'i's fishery
- The hazards of tying one on
- Upcoming events
- Compendium—Fisheries research in brief

July–September 2003 (volume 8, number 3)
- The biology of FAD-associated tuna: Temporal dynamics of association and feeding ecology
- After the storm—Highly migratory species area closures: Do the predictions match the results?
- Pacific Tuna Treaty on track for 2004 entry into force: New commission taking shape
- Upcoming events
- Report on the International Workshop on Current Status and New Directions for Studying Schooling and Aggregation Behavior of Pelagic Fish

October–December 2003 (volume 8, number 4)
- Tuna and Billfish Forum meets for annual scientific assessments
- Upcoming events

January–March 2004 (volume 9, number 1)
- Do tuna and billfish see colors?
- Seeking responsible commercial fishing solutions in Costa Rica: Study tests new bait to reduce accidental capture of sea turtles
- Developmental changes in the visual pigments of the yellowfin tuna, *Thunnus albacares*
- Upcoming events
- WCPFC shapes up in Rarotonga

April–June 2004 (volume 9, number 2)
- A sociological baseline of the Hawai'i longline fishery
- Web sites related to pelagic fisheries
- Comparing the environmental baggage of longline fisheries
- Ocean atlases to provide data for fisheries and resource management of the Pacific
- Upcoming events
- Publications of note

July–September 2004 (volume 9, number 3)
- Nations gather for PrepCon6
- Commission to meet in December
- Principal investigators workshop set
- Ocean Commission report calls for balance in national policy
- PFRP Collaborator Arauz wins top U.K. conservation award
- Managing our nation's fisheries
- Accomplishments cited in PFRP online report
- Upcoming events

October–December 2004 (volume 9, number 4)
- Convergent evolution of vertical movement behavior in swordfish, bigeye tuna and bigeye thresher sharks
- Vertical niche partitioning in the pelagic environment as shown by electronic tagging studies
- Fishery monitoring and economics program
- Upcoming events
- Integrated model for protected species
- Publications of note
- Correction

January–March 2005 (volume 10, number 1)
- Climate Impacts on Oceanic Top Predators (CLIOTOP) Working Groups focus on climate, ecosystem dynamics study
- PFRP PI Workshop tackles ecosystem approaches to management
- Publications of note
- PFRP new projects—FY 2004
- Upcoming events

April–June 2005 (volume 10, number 2)
- The effect of ocular heating on vision in swordfishes
- U.S. Pacific Island fishery managers address overfishing of bigeye tuna
- Fishing regulations recommended for proposed Northwestern Hawaiian Islands Sanctuary
- Publications of note
- Upcoming events

July–September 2005 (volume 10, number 3)
- End of the line: Using instrumented longline to study vertical habitat of pelagic fishes
- Council votes for federal permits, logbooks; addresses Pacific bigeye tuna and bottomfish overfishing

- A novel approach for improving shark bycatch species identifications by observers at sea
- Community fishery projects selected to receive federal funding
- Electronic tagging data repository
- A facility for information exchange
- Let's talk about sex: The development of sex-specific molecular markers for three species of billfish-striped marlin *(Tetrapturus audax)*, blue marlin *(Makaira nigricans)* and black marlin *(Makaira indica)*
- Publications of note
- PFRP new projects—FY 2005
- Upcoming events

October–December 2005 (volume 10, number 4)
- Highly migratory scientists meet in Noumea
- Deploying satellite tags on swordfish using the California harpoon fleet
- Longline fishers announce 12-point plan
- Upcoming events
- Publications of note

January–March 2006 (volume 11, number 1)
- Behavior of bigeye and skipjack tunas within large multi-species aggregations associated with floating objects
- PFRP updates research priorities: Changes form new basis for 2006 RFPs
- 2005 PFRP PIs project presentation updates and Research Priorities Workshop guest speakers
- U.S. Pacific Islands offshore fisheries benefit from change to place-based management
- Upcoming events

April–June 2006 (volume 11, number 2)
- The new PFRP tag: Using stable isotope techniques to better understand the trophic ecology and migration patterns of tropical tuna
- Economic assessment of open fishing tournaments in Hawai'i
- Analyses of incidental catch and bycatch by the Hawai'i-based longline fishery
- A short history of pelagic fishing in the Mariana Islands
- Upcoming events

July–September 2006 (volume 11, number 3)
- The effect of pelagic longline fishing on Laysan and black-footed albatross diets
- Trade-offs between sea turtle interactions and profitability of the Hawai'i-based longline fleet
- Scientist discuss fisheries issues; Council votes on recommendations
- 2006 PFRP projects
- Upcoming events

October–December 2006 (volume 11, number 4)
- Process or progress? Time to fish or cut bait for Western Pacific Commission
- Spatial-temporal distribution of albacore catches in the North-Eastern Atlantic and its relationship with SST
- The role of squid in pelagic marine environment
- Upcoming events

January–June 2007 (volume 12, number 1)
- Western and Central Pacific Fisheries Commission cuts more bait
- CLIOTOP/PFRP Workshop: The role of squid in pelagic marine ecosystems
- Papua New Guinea tuna-tagging project
- Pelagic fisheries science in the Pacific, 2005 and beyond—PIFSC and PFRP
- Climatic oscillations and tuna catch rates in the Indian Ocean
- Mapping the seasonal distribution of bluefin tuna
- From physics to fish: An example of the Madden-Julian Oscillation
- Upcoming events
- Erratum
- Publications of note

July–September 2007 (volume 12, number 2)
- The Pacific albacore troll and baitboat fishery data collection program at the Southwest Fisheries Science Center
- A study of the swimming behavior of skipjack and small yellowfin and bigeye tunas around drifting FADs to develop mitigation measures reducing the incidental catch of juvenile yellowfin and bigeye tunas
- Pelagic longline catch-rate standardization
- Upcoming events

October–December 2007 (volume 12, number 3)
- Regime shifts and recruitment in the WCPO
- The importance of monitoring the social impacts of fisheries regulations
- Upcoming events

January–April 2008 (volume 13, number 1)
- The Pacific-Atlantic Sea Turtle Assessment Project: Bringing disciplines together to evaluate the causes of sea turtle decline
- Oceanographic investigation of the American Samoa albacore habitat and longline fishing ground
- Upcoming events

May–August 2008 (volume 13, number 2)
- What if you don't speak "CPUE-ese"?
- Pelagic fishing in prehistoric Guam, Mariana Islands
- Publications of note
- Upcoming events

September–December 2008 (volume 13, number 3)
- Patterns of change in Hawai'i's small-boat commercial handline fisheries
- The influence of Hawaiian seamounts and islands on the forage base for oceanic predators

2009 Annual Issue (volume 14, number 1)
- Predation, cannibalism and the dynamics of tuna populations
- A graph-theoretic approach to analyzing food webs leading to top predators in three regions of the Pacific Ocean
- Supply, demand and distribution of pelagic seafood on O'ahu: Select results from the PFRP Seafood-Distribution Project
- Hawai'i Tuna Tagging Project Two (HTTP2)
- Proceedings of the National Academy of Sciences Publication for Graduate Student
- Upcoming events

No issue published for 2010

2011 Annual Issue (volume 15, number 1)
- Nursery origin of yellowfin tuna in the Hawaiian Islands
- TUMAS: A tool to allow analysis of management options using WCPFC stock assessment
- PFRP publications of note 2010–2011
- Socioeconomic linkages of Hawai'i's fishery sector
- Upcoming events

2012 Annual Issue (volume 16, number 1)
- Novel research into the impacts of ocean acidification upon tropical tunas
- Integrating conventional and electronic tagging data into SEAPODYM
- PFRP-supported research underlies conservation measures for the Oceanic whitetip shark
- How much seafood does Hawai'i consume?
- Upcoming events
- Publications of note

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Pelagic Fisheries Research Program

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Fig. 28. Participants at the PFRP PI meeting, Nov. 1997: (Front) John Sibert, Paul Bartram, Dodie Lau, John Kaneko, Judith Swan, David Itano; (2nd row) Paul Callaghan, Craig MacDonald, Robert Skillman, Marcia Hamilton, Michael Travis, Craig Severance, Richard Brill; (3rd row) Charles Daxboeck, Patrick Bryan, Keiichi Nemoto, Ujjayant Chakravorty, Harry Campbell, Cheryl Anderson, Minling Pan; (4th row) Sam Herrick, Sam Pooley, Tom Pinhey, Marc Miller, PingSun Leung, Knut Heen, Khem Sharma, Fang Ji. (Not shown) Tony Kingston, Stuart Nakamoto, Shankar Aswani, Ed Glazier, Michael Seki, Ray Clarke, Jeff Nagel, Thomas Kraft, Deane Neubauer, Dan Curran, Mike Musyl, Scott Miller, Rose Pfund, Bob Franco. PFRP photo.

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