DRAFT
Analysis of Management Options for Development of a Plan to End Overfishing of Pacific Bigeye Tuna

PREFACE

Pacific bigeye tuna are subject to overfishing Pacific-wide and this document sets out alternatives that might be used to end overfishing. Bigeye tuna, like other highly migratory species (HMS) are nomadic in behavior, thus do not recognize boundaries that management, policy, or science have established. Bigeye tuna are fished by many nations in addition the United States, thus future efforts to reduce fishing mortality on bigeye tuna in the Eastern Pacific Ocean (EPO) will require coordination and communication among all relevant regional fisheries stakeholders. The capacity for unilateral action by the United States to prevent overfishing, as required under National Standard 1 of the Magnuson-Stevens Act (16 U.S.C. 1851(a)(1), is limited, as is the capacity of the Pacific Fishery Management Council (Council), which is required to develop a plan to end overfishing, under 50 CFR 600.310(e)(4)(i)).

Pacific-wide, the U.S. annually lands approximately 200,000 metric tons (mt), or about five percent of the total bigeye catch. The Pacific-wide catch for bigeye tuna in the EPO between years 1999 and 2003 was between 88,000 mt and 142,000 mt. The U.S. West Coast commercial catch for this period was less than one percent, thus any unilateral action by U.S. fisheries to end overfishing would have little effect on the stock. Multilateral management action is essential to ensure that overfishing on bigeye tuna in the Pacific Ocean ends.

The current resolution that places conservation and management measures on fishing nations in the EPO for bigeye tuna is set to expire in 2006, thus this document provides future management options that would address overfishing of Pacific bigeye tuna in the EPO. The Council will choose a West Coast position to advance to the U.S. delegation to the Inter-American Tropical Tuna Commission (IATTC), as domestic management for 2007 and beyond depends on international management actions to reduce fishing on bigeye tuna stocks.

1.0. PURPOSE AND NEED FOR ANALYSIS

1.1 Purpose and Need

This document is intended to provide the Council with information needed to form a position on how to control fishing mortality on Pacific bigeye tuna in the EPO. Management and conservation options are a shared responsibility of both domestic and international fisheries management entities, and thus the requirement to reduce fishing mortality will dictate that the United States find an appropriate balance between protecting the resource and achieving sustainable utilization of the resource within its straddling jurisdictions. Once the Council approves a strategy to reduce fishing mortality it will be presented to the U.S. delegation for the consideration by the IATTC. Any new conservation and management measures adopted by the IATTC, as a result of its June 2006 meeting will be implemented domestically.

To provide context for the development of a strategy, the stock status, the contribution of U.S. fisheries to fishing mortality in the EPO, the sources of fishing mortality, the current regulatory framework for HMS on the West Coast, and existing conservation and management measures relevant to bigeye tuna are described within this document.

After consideration of this document, the Council will determine its preferred strategy for the conservation and management of bigeye tuna in the EPO. In the event that regulatory action is considered, the Council will direct the preparation of a management document for public review, including environmental analysis consistent with the National Environmental Policy Act (NEPA). This will ensure adequate consideration of the impacts of a broad range of alternatives as the Council formulates recommendations.

1.2 History of Action

NOAA's National Marine Fisheries Service (NMFS) notified the Council that it must take action to address overfishing of bigeye tuna by June 14, 2005. A similar notification was given to the Western Pacific Fishery Management Council. At the June 2005 meeting, the Council moved to begin work on Amendment 1 to the FMP for U.S. West Coast Fisheries for HMS as the proper response to address this issue. NMFS Southwest Region agreed to take lead responsibility on developing the amendment package for Council consideration. At its November 2005 meeting, the Council was to have adopted a preliminary range of alternatives for public review. However, because of time constraints at that meeting, the agenda item was deferred for a future meeting. This has also allowed NMFS staff, who initiated the preparation of an environmental assessment (EA) containing the alternatives and analysis of them, to provide a more complete document for the Council to review.

Shortly after NMFS staff began the development of the EA, it was determined that no regulatory action would result from an amendment since future actions are dependent on conservation and management measures adopted internationally. Therefore, at this juncture, a management options analysis for the development of a West Coast position on how to control fishing mortality on Pacific bigeye tuna in the eastern Pacific is a more relevant approach than is an environmental effects analysis of proposed conservation and management measures. The management options analysis will provide the Council with the information needed to form a position, which has the potential to influence any new conservation and management decisions adopted by the relevant international bodies governing bigeye tuna stocks in the eastern Pacific, in future years.

1.3 Current Management Controls

Primary management of Pacific bigeye tuna occurs internationally by the IATTC in the EPO and by the Convention on the Conservation and Management of Highly Migratory Fish Stocks in the Western and Central Pacific Ocean (WCPFC). The IATTC was established by international convention in 1950 and is responsible for the conservation and management of tuna fisheries and other species taken by tuna fishing activity in the EPO. The organization consists of a Commission where each member country may be represented by up to four commissioners and a Director of Investigations, or the Director who is responsible for drafting research programs, budgets, administrative support, directing technical staff, coordination with other organizations and preparing reports to the Commission.

Staff scientists at the IATTC coordinate and conduct research, observer programs, and the collection, compilation, analysis and dissemination of fishery data and scientific findings. The work of the IATTC research staff is divided into two main groups: The IATTC Tuna-Billfish Program and the IATTC Tuna-Dolphin Program. Current membership of the IATTC includes Costa Rica, Ecuador, El Salvador, France, Guatemala, Japan, Mexico, Nicaragua, Panama, Peru, Spain, USA, Vanuatu and Venezuela. Canada, China, the European Union, Honduras, Korea and Chinese Taipei are Cooperating Non Parties or Cooperating Fishing Entities.

On September 5, 2000, the WCPFC was adopted. The Convention, which is subject to ratification, establishes a Commission that would adopt management measures for HMS throughout their ranges. The U.S. has yet to sign onto the Convention, but is participating as a cooperating non-member. Both Commissions affect West Coast-based HMS fisheries. Figure 1 illustrates the geographical delineation of the WCPO and the EPO.

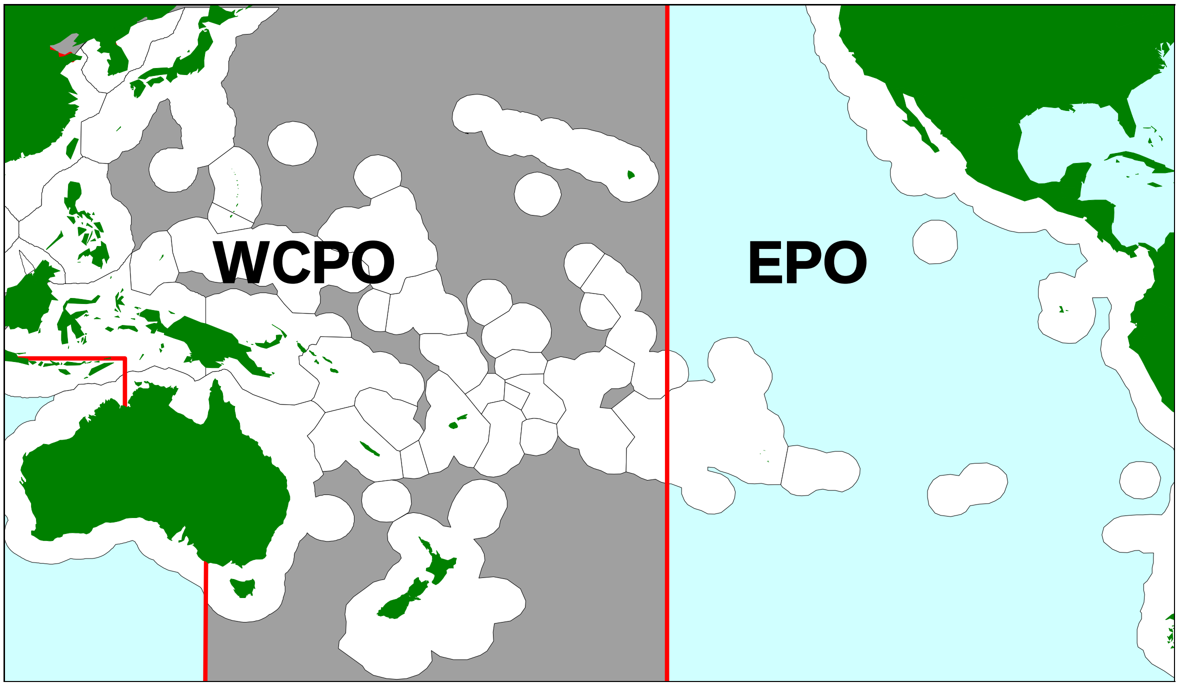

Figure 1. The geographical delineation of the Western and Central Pacific from the Eastern Pacific Ocean for statistical purposes.

The West Coast HMS FMP includes management context to carry out recommendations of the IATTC. In particular and of interest to the FMP, regulations are in place to collect data on vessels harvesting HMS in the Convention Area, with the intent of assisting the IATTC in monitoring international fisheries as well as enforcing conservation measures. The vessels register system is also intended to assist the Council in monitoring West Coast based HMS fisheries north Pacific albacore, yellowfin, bigeye, skipjack, Pacific bluefin, common thresher shark, pelagic thresher, bigeye thresher, shortfin mako, blue shark, striped marlin, Pacific swordfish and dolphinfish.

In June of 2004, the IATTC adopted Resolution C-04-09 on Tuna Conservation Measures. The resolution established a multi-annual program to protect tuna in the EPO for years 2004 through 2006. The resolution includes conservation measures for yellowfin, bigeye, and skipjack tunas. Purse seine vessels fishing in the EPO will be affected by these conservation measures. The conservation resolution includes a national choice of one of two possible six week closures of the Convention Area. The possible choices are either a six-week closure in the summer or winter. Longline vessels fishing for bigeye tuna will be restricted to a national catch not to exceed their national catch for the year 2001. The 2004 conservation resolution introduced a precedent-setting multi-year management framework with a review of the stock(s) response in 2005 and 2006. The multi-annual plan allows the industry to plan and minimize economic impacts. Pole-and-line and sportfishing vessels are not subject to this resolution. Also, members of the IATTC agreed to compliance measure prohibiting landings, transshipments, and commercial transactions involving tunas caught in contravention of the conservation measures in this resolution.

1.4 Management Option Process

March 2006 Council Meeting: Management Options for a West Coast Strategy to Address Overfishing of Bigeye Tuna in the Eastern Pacific Ocean document goes out for Council and public review. At this time the Council reports on its preferred management option.

April 2006 Council Meeting: Report on Public Comment.

April 2006 – May 15th 2006: Finalize document.

May 16th: Submission to the GAC for their review, contemplation, and consideration as an agenda item for their June 1st meeting.

The expectation here is that the GAC will embrace the Council's preferred strategy in part or whole as a part of their strategy and advice to the U.S. Section of the IATTC, which meets in late June to discuss future management options for bigeye tuna.

June 1st 2006: 5th meeting of the GAC.
June 22 – 30th 2006: IATTC meeting in Korea.

2.0 SUMMARY OF THE MANAGEMENT OPTIONS

2.1 Management Objective

The Council will choose a strategy for the establishment of a West Coast position to end overfishing of bigeye tuna in the EPO. The strategy should include measures that meet requirements to end overfishing contained in the MSA as well as meet international obligations. Conservation and management measures to explore include time/area closures for fishing effort in the EPO; limits on mortality of juvenile bigeye associated with fishing on floating objects; and finally, if successful, the United States would then implement the IATTC program for bigeye tuna through quotas and/or time/area closures.

2.2 Management Option 1 (No Action)

NMFS and the Council would not develop and implement controls necessary to end overfishing by Pacific-wide fishermen, nor submit comments or actively participate in the development of input and recommendations on the conservation and management of Pacific bigeye to the U.S. delegation to the IATTC.

2.3 Management Option 2

The Council would work with NMFS to develop conservation and management recommendations for Pacific bigeye tuna, of which NMFS would then recommend to the IATTC. Management options would include a combination of measures that if adopted may include:

(1) Closure of the purse seine fishery in the EPO for two months;

(2) Reduce the purse seine fishing effort on Pacific bigeye by 50 percent in 2007, and possibly beyond, with one or more of the following management options:

> a) Close the purse seine fishery for six months in the area between 8^{o}N and 10^{o}S west of 95^{o}W (this closure would not be intended to occur simultaneously with the two month EPO closure); or
>
> b) Close the purse seine fishery on floating objects for six months in the area west of 95^{o}W (this closure is not intended to occur simultaneously with the two month EPO closure); or
>
> c) Limit the total annual catch of bigeye by each purse seine vessel that is required to carry an observer to 500 metric tons, estimated either by the observer or, at the request of the fishing vessels Captain, by scientific sampling of the vessel's catch conducted by IATTC staff at the time of unloading. If this latter option is chosen, the vessel would be responsible for the costs of the sampling.

(3) Reduce longline catches in the EPO to 2000 levels; and

(4) Prohibit landings, transshipments and commercial transactions in tuna or tuna products that have been positively identified as originating from fishing activities that disregard conservation and management options specified for Pacific bigeye tuna.

Management Option 2 allows NMFS and the Council to work collaboratively in the development of a proposal to IATTC, as the relevant Regional Fishery Management Organization (RFMO). The NMFS and the Council would respond in a formal manner to any resolution adopted by IATTC by implementing appropriate fishery management requirements in the eastern Pacific.

2.4 Management Option 3

Management Option 3 would include all management options contained in alternative 2, plus would exempt fleets that catch 1 percent or less of the total Pacific bigeye tuna landings in the EPO and establish an annual international fishing quota (total allowable catch) of which the amount is to be divided among all nations in the EPO fishing on the stock. Each nation’s quota would be based on historical effort. Additionally, this option would explore possible minimum size limitations on juvenile bigeye.

2.5 Management Option 4

Same as Management option 3 plus either use the existing control date or re-establish a more current control date to notify present and potential participants that a limited entry and/or another management program may be considered by the Council for west coast fisheries in the EPO so as to avoid excess capacity.

2.6 Management Option 5

Close all fisheries under the Council's jurisdiction that target Pacific bigeye tuna in the EPO.

3.0 DESCRIPTION OF THE AFFECTED ENVIRONMENT

The following summary of the oceanography of the Pacific Ocean is taken from the West Coast HMS FMP published in 2004, which is believed to be a complete and accurate account of that ecosystem. For a complete list of citations referenced in this document please see the West Coast HMS FMP.

The west coast of North America from the Strait of Juan De Fuca to the tip of Baja California is part of an eastern boundary current complex known as the California Current System. The U.S. West Coast EEZ encompasses one of the major coastal upwelling areas of the world, where waters provide a nutrient-rich environment and high densities of forage for HMS species, especially from the Columbia River Plume south to the southern California Bight. The region is influenced by various currents and water masses, the shifting nature of which affects the occurrence and distribution of HMS at particular times of the year and from year to year. Diverse bathymetric features also influence current patterns and concentrations of HMS prey and their predators. Large-scale currents within this region include the surface-flowing California Current and Inshore Countercurrent (Davidson Current), and the subsurface California Undercurrent. The region includes two major river plumes (Columbia River and San Francisco Bay), several smaller estuaries, numerous submarine canyons (especially in the north), and the complex borderland of the Southern California Bight with its offshore islands, undersea ridges and deep basins. The system generally contains waters of three types: Pacific Subarctic, North Pacific Central and Southern (or Subtropical Equatorial). Pacific subarctic water, characterized by low salinity and temperature and high oxygen and nutrients is advected equatorward along the coast by the California Current.

The California Current forms the eastern limb of a large clockwise circulation pattern in the North Pacific Ocean, being broader in the north and narrower in the south, extending approximately to the outer EEZ boundary south 40° N latitude. The cold, low salinity water of the California Current dominates much of the EEZ. Its position and intensity changes seasonally and from year to year with shifts in the southeastern extension of the Subarctic Frontal Zone (California Front). Shoreward it mixes with plumes of cold, more saline upwelled water in the north, or warm countercurrent and gyre water of the Southern California Bight in the south.

Seaward, the California Current mixes with the more oceanic waters of the Transition Zone. This zone lies between the Subarctic and Subtropical fronts, separating the Subarctic Water Mass and North Pacific Central Water Mass (Saur 1980; Lynn 1986; Smith et al. 1986). During the winter and spring, westerlies in the denser portion of this Transition Zone and trade winds to the south create convergent fronts where colder water from the north meets warmer, less dense water from the south. In this area, extending across northern the Pacific, is a chlorophyll front located at the boundary between the low chlorophyll subtropical gyres and the high chlorophyll subarctic gyres. This chlorophyll front is distinct from the subtropical and subarctic fronts, but seasonally migrates through these two features (Polovina 2001). Areas of convergence along this front concentrate phytoplankton and other organisms (shrimps, squids and other fishes), serving as forage habitat for higher trophic level predators, such as albacore, skipjack tuna, bluefin tuna, swordfish, marlin, blue shark and dolphinfish (Pearcy 1991; Polovina et al. 2000; Polovina et al. 2001).

Physical oceanographic features of the environment change seasonally and also during periods of large scale, oceanic regime shifts such as El Niño. The California Current generally flows southward year round, with strongest flows in spring and summer. Inshore, these flows may be reversed by the seasonal appearance in fall and winter of the surface poleward-flowing Inshore Countercurrent (Lynn and Simpson 1987). The California Undercurrent primarily intensifies in late spring and summer as a narrow ribbon of high-speed flow which presses northward at depth against the continental slope, generally beneath the equatorward flowing upper layers (Lynn and Simpson 1987). Coastal upwelling of cold, salty and nutrient-rich water to the surface occurs primarily in spring and summer in California and into early fall off Oregon, driven by prevailing seasonal winds. Upwelling is often most intense near such promontories as Cape Mendocino and Point Conception. During El Niño events, flow in the California Current is anomalously weak, the California Undercurrent is anomalously strong, and the water in the upper 500 m of the water column is anomalously warm (Chelton et al. 1982).
Although the coastline is relatively straight between the Strait of Juan de Fuca and Baja California, a large bend occurs from Point Conception to San Diego. This region, called the Southern California Bight (SCB), differs dramatically from regions to the north and south (Hickey 1998). The shelves in this area are generally very narrow (< 10 km), but can also be relatively wide in certain areas such as Santa Monica Bay and the San Pedro Shelf south of Long Beach. The sea bed offshore is cut by a number of deep (> 500 m) basins. South of Point Conception a portion of the California Current turns in a counterclockwise gyre. This feature is called the Southern California Countercurrent during years when the northward flow successfully rounds Point Conception, or the Southern California Eddy, when the flow recirculates within the Bight (Hickey 1998). The ocean is generally warmer and more protected here than areas to the north, especially inshore of a line roughly drawn from San Miguel Island to San Clemente Island.

Within the EEZ south of Point Conception, the California Current serves as a cold water barrier between the warmer, more tropical waters of the Southern California Bight inshore of the Santa Rosa-Cortes Ridge, and the warmer, higher salinity oceanic waters to the west beyond the outer EEZ boundary (Hickey 1998; Lynn and Simpson 1990; Lynn et al. 1982, Norton 1999). The pattern and intensity of the California Current and of upwelled waters, can influence habitats by serving as a cool barrier, preventing incursion of warm water into more northerly EEZ waters. Conversely, relaxation of these cold-water barriers can increase habitat in the EEZ for warm water tunas and billfishes from the west and south. Additionally, intensification of the northerly flowing Davidson Current, or other incursion of warm, southerly waters from Mexico, can enhance and extend habitat for warm water tunas and billfish into the inshore waters of the U.S. EEZ.

From Point Conception northward to off Cape Flattery, Washington, the coastline is relatively unprotected from the force of the sea and prevailing northwest winds. In contrast to the Southern California Bight, rugged water and sea state conditions are common north of Point Conception. During much of the year, the coastal waters of central Oregon to offshore central Washington are under the influence of the eastern portion of the eastward flowing Subarctic Current or West Wind Drift. The current has a moderating influence on coastal temperatures during the summer, when sea surface temperatures may be several degrees warmer from off northern Oregon to central Washington than to the south off California and the north off British Columbia (Squire and Smith 1977). In this region the Columbia River freshwater plume also has a considerable effect on oceanographic features along the northwest coast. The plume flows poleward over the shelf and slope in fall and winter, and equatorward well offshore of the shelf in spring and summer, extending its influence as far south as Cape Mendocino, California (Hickey 1998).

3.2 Biological Environment

The following summary of the biological environment of the Pacific Ocean is taken from the West Coast HMS FMP published in 2004, which is believed to be a complete and accurate account of that ecosystem. For a complete list of citations referenced in this document please see the West Coast HMS FMP

In addition to highly migratory species, the marine ecosystem offshore Washington, Oregon and California is home to groundfish species (shelf and slope rockfishes, Pacific whiting, flatfishes, sablefish, lingcod, greenlings, sturgeon; sharks; skates, rays); four species of Pacific salmon; steelhead; small coastal pelagic species (sardines, herring, anchovy, mackerels, smelts, and squid); marine mammals (California sea otter and various whales, porpoises and dolphins, sea lions, and seals); pelagic seabirds (including northern fulmar, brown pelican, albatrosses, shearwaters, loons, murres, auklets, storm petrels and others) (Leet et al. 2001).

The California Current system is particularly rich in microscopic organisms (diatoms, tintinnids and dinoflagellates) which form the base of the food chain, especially in upwelling areas. This rich supply of diatoms and other small plankters also provides food for many zooplanktonic organisms such as euphausiids, shrimps, copepods, ctenophores, chaetognaths, oceanic squids, salps, siphonophores, amphipods, heteropods, and various larval stages of invertebrates and fishes. Grazers like small coastal pelagic fishes and squid depend on this planktonic food supply, and in turn provide forage for larger species nearer the apex of the food chain, such as highly migratory tunas, marlin, swordfish, sharks and dorado. Certain seabirds and turtles and also baleen whales also depend on the planktonic food supply, and many fishes, seabirds and toothed cetaceans feed on fishes that are plankton feeders. In the outer EEZ and to the west also lies the rich chlorophyll front that moves seasonally through the subtropical and subarctic fronts, serving as a rich forage habitat for a variety of organisms (Polovina 2001). In the more coastal areas, multi-celled alga like the giant kelp also provide temporary refuge and foraging opportunities for HMS such as dorado and juvenile tunas. The kelp also provides food, shelter, substrate and nursery areas for nearly 800 animal and plant species (Bedford 2001). In addition to the thirteen HMS management unit species and species mentioned above, many other species inhabit the oceanic pelagic zone and are taken by

HMS gear in waters of the EEZ and beyond. These include louvar, oarfish, lancetfishes, escolar, oilfish, opah, saury, common mola, spearfish, sailfish, blue marlin, wahoo, bonito, black skipjack, and 18 species of sharks and rays.

Episodic oceanographic events such as El Niño (warm water incursion) and La Niña (cooler water incursion) may effect the occurrence and distribution of organisms and the short-term productivity of the system. Longer periods of certain ocean temperature regimes that persist for decades can also affect reproduction and recruitment of marine species (e.g., sardine, rockfish) for several generations and result in substantial changes in abundance over time (Leet et al. 2001). During episodic or persistent warm periods, the more tropical species (such as striped marlin, pelagic thresher shark, dorado, tropical tunas, loggerhead sea turtles) may become more abundant within the EEZ, along with some of the more tropical prey species upon which they feed (e.g., pelagic red crab).

Fishery Resources

According to NMFS (1999), the Pacific Coast fisheries resources have a prorated U.S. long term potential yield of approximately 852,263 mt. The major species are Pacific salmon, Pacific groundfish, coastal pelagic species, Pacific halibut, highly migratory species, and nearshore resources. The West Coast HMS FMP provides a detailed description of the above mentioned resources which includes information on production, abundance, and stock status. Also, please refer to the HMS FMP for a complete list of references.

Threatened and Endangered Species

The following table outlines threatened and endangered species that occur in the Council's jurisdiction, which may be affected by the fisheries managed in the West Coast HMS FMP. Each species is identified as either endangered or threatened following guidelines under the ESA (CH indicates that critical habitat has been distinguished as well).

Amphibians and Reptiles

Loggerhead Sea Turtle	*Caretta caretta*	Threatened
Green Sea Turtle	*Chelonia mydas*	Threatened
Leatherback Sea Turtle	*Dermochelys coriacea*	Endangered, CH
Olive (Pacific) ridley Sea Turtle	*Lepidochelys olivacea*	Threatened

Fish

Chum Salmon (Hood Canal summer, Columbia River)	*Oncorhynchus keta*	Threatened
Coho Salmon (Central California)	*Oncorhynchus kisutch*	Threatened
Coho Salmon (S. Oregon. N. Calif. Coast)	*Oncorhynchus kisutch*	Threatened
Steelhead (Upper Columbia River, S. California)	*Oncorhynchus mykiss* ssp.	Endangered
Steelhead (Snake River Basin)	*Oncorhynchus mykiss* ssp.	Threatened
Steelhead (Upper Willamette River)	*Oncorhynchus mykiss* ssp.	Threatened
Steelhead (Columbia River)	*Oncorhynchus mykiss* ssp.	Threatened
Steelhead (South-Central California, Central Valley, Northern California)	*Oncorhynchus mykiss* ssp.	Threatened
Sockeye Salmon (Snake River)	*Oncorhynchus nerka*	Endangered, CH
Sockeye Salmon (Ozette Lake)	*Oncorhynchus nerka*	Threatened
Chinook Salmon (Lower Columbia River)	*Oncorhynchus tshawytscha*	Threatened
Chinook Salmon (Upper Willamette River)	*Oncorhynchus tshawytscha*	Threatened
Chinook Salmon (Snake River Spring/Summer/Fall runs)	*Oncorhynchus tshawytscha*	Threatened, CH
Chinook Salmon (Sacramento River Winter, Upper Columbia River Spring)	*Oncorhynchus tshawytscha*	Endangered
Chinook Salmon (Central Valley Spring, California Coastal)	*Oncorhynchus tshawytscha*	Threatened
Tidewater Goby	*Eucyclogobius newberryi*	Endangered

Marine Mammals

Blue Whale	*Balaenoptera musculus*	Endangered
Fin Whale	*Balaenoptera physalus*	Endangered
Humpback Whale	*Megaptera novaeangliae*	Endangered
North Pacific Right Whale	*Eubalaena glacialis*	Endangered
Sei Whale	*Balaenoptera borealis*	Endangered
Sperm Whale	*Physeter macrocephalus*	Endangered
Steller Sea Lion	*Eumetopias jubatus*	Threatened, CH
Guadalupe Fur Seal	*Arctocephalus townsendi*	Threatened
Southern Sea Otter	*Enhydra lutris nereis*	Threatened

Birds

Short-tailed Albatross	*Phoebaotria albatrus*	Endangered
Bald Eagle	*Haliaeetus leucocephalus*	Threatened
Brown Pelican	*Pelecanus occidentalis*	Endangered
California Least Tern	*Sterna antillarum browni*	Endangered
Western Snowy Plover	*Charadrius alexandrinus*	Threatened
Marbled Murrelet	*Brachyramphus marmoratus*	Threatened, CH
California Clapper Rail	*Rallus longirostris obsoletus*	Endangered

Invertebrates

White Abalone	*Haliotis sorenseni*	Endangered

Chapter 4 of the West Coast HMS FMP summarizes information about the marine species that occur in or near the management area that are listed under the ESA and for which assessments of potential impacts from the fisheries are necessary. Potential impacts of specific proposed actions and alternatives are also assessed separately, by alternative, in Chapter 9. More detail about these species can also be found in Appendix E of the West Coast HMS FMP.

3.2.1 Pelagic Management Unit Species

The MSA defines "highly migratory species" as tuna species, marlin (*Tetrapturus* spp. and *Makaira* spp.), oceanic sharks, sailfishes (*Istiophorus* spp.) and swordfish (*Xiphias gladius*). The term "tuna species" includes albacore tuna (*Thunnus alalunga*), bigeye tuna (*T. obesus*), bluefin tuna (*T. thynnus* and *T. orientalis*), skipjack tuna (*Katsuwonus pelamis*) and yellowfin tuna (*T. albacares*). The Council examined a number of different criteria and alternatives for species to be included in the management unit, which allows for active management, i.e., the fisheries for these species are regulated by the federal government.

The Council established the pelagics management unit species based on the following criteria:

- Occur in the Pacific Council's management area;
- Occur in West Coast highly migratory species fisheries;
- Are defined as HMS in the MSA or the Law of the Sea Annex I;
- Have importance (moderate to high value) in the landings or to a fishery; and
- Are managed by the Western Pacific Fishery Management Council.

According to the MSA, the species included in the pelagic management unit (Table 1) are managed according to maximum sustainable or optimum yield (bio-analytically-based or proxy). The proxy specific to bigeye tuna has yet to be specified and as such the Council has directed the HMS management team to scope management reference points for bigeye tuna, as well as for albacore and bluefin tuna.

Table 1. HMS Species included in the West Coast Fishery Management Plan.

Common Name	Scientific Name
striped marlin	*Tetrapturus audax*
swordfish	*Xiphias gladius*
common thresher shark	*Alopias vulpinus*
pelagic thresher shark	*Alopias pelagicus*
bigeye thresher shark	*Alopias superciliosus*
shortfin mako (bonito shark)	*Isurus oxyrinchus*
blue shark	*Prionace glauca*
North Pacific albacore	*Thunnus alalunga*
yellowfin tuna	*Thunnus albacares*
bigeye tuna	*Thunnus obesus*
skipjack tuna	*Katsuwonus pelamis*
northern bluefin tuna	*Thunnus thynnus*
Dorado (a.k.a. mahi mahi, dolphinfish)	*Coryphaena hippurus*

3.2.2 Pacific Bigeye Tuna (*Thunnus obesus*)

As this management options analysis is concerned with measures to address overfishing of bigeye tuna, a detailed account of bigeye tuna life history and stock assessments is presented in this section. The following account of bigeye tuna life history, habitat movement and stock stricture are from the WPFMC's Amendment 14 to the Pelagics Fishery Management Plan, which also addresses overfishing of the bigeye stock in the WCPO and the EPO. Please refer to Amendment 14 for a complete list of citations referenced in this section.

3.2.3 Life History and Habitat

Bigeye tuna are believed to have recently evolved from a common parent stock of yellowfin tuna (*Thunnus albacares*), remaining in a close phylogenetic position to yellowfin with similar larval form and development. Although the species shares a similar latitudinal distribution with yellowfin tuna worldwide, bigeye have evolved to exploit cooler, deeper and more oxygen poor waters when compared to yellowfin in a classic example of adaptive niche partitioning. Several investigators have demonstrated that this has been accomplished through a combination of physiological and behavioral thermoregulation and other anatomical adaptations for foraging at depth, e.g. respiratory adaptations, eye and brain heaters (Holland and Sibert 1994; Lowe, et al 2000; Fritsches, and Warrant 2001). In this way, the species is considered to be intermediate between a tropical tuna (e.g. yellowfin, blackfin <*T. atlanticus*>, longtail tuna <*T. tonggol*>) and the temperate water tunas (e.g. albacore <*T. alalunga*>, the bluefin tunas). This combination of traits can be characterized by rapid growth during the juvenile stage, movements between temperate and tropical waters to feed and spawn, equatorial spawning with high fecundity -- combined with a preference for cool water foraging and a protracted maturity schedule, an extended life span and the potential for broad spatial movements. It is believed that bigeye tuna are relatively long lived in comparison to yellowfin tuna but not as long lived as the three bluefin tuna species.

Feeding is opportunistic at all life stages, with prey items consisting of crustaceans, cephalopods and fish (Calkins 1980). There is significant evidence that bigeye feed at greater depths than yellowfin tuna, utilizing higher proportions of cephalopods, and mesopelagic fishes and crustaceans in their diet thus reducing niche competition (Whitelaw and Unnithan 1997).

Spawning spans broad areas of the Pacific and occurs throughout the year in tropical waters and seasonally at higher latitudes at water temperatures above 24°C (Kume 1967; Miyabe 1994). Hisada (1979) reported that bigeye tuna require a mixed layer depth of at least 50 m with a sea surface temperature (SST) of at least 24°C. While spawning of bigeye tuna occurs across the Pacific, the highest reproductive potential was considered to be in the EPO based on size frequencies and catch per unit of effort inferred abundance (Kikawa, 1966).

Basic environmental conditions favorable for survival include clean, clear oceanic waters between 13°C and 29°C. However, recent evidence from archival tags indicates that bigeye can make short excursions to depths in excess of 1000 m and to ambient sea temperatures of less than 3°C (Schaefer and Fuller 2002). Juvenile bigeye tuna in the smaller length classes occupy surface mixed layer waters with similar sized juvenile yellowfin tuna. Larger bigeye frequent greater depths, cooler waters and areas of lower dissolved oxygen compared to skipjack and yellowfin. Hanamoto (1987) estimated optimum bigeye habitat to exist in water temperatures between 10° to 15°C at salinities ranging between 34.5 percent to 35.5 percent where dissolved oxygen concentrations remain above 1 ml/l. Recent data from archival tagging has largely corroborated these earlier findings while extending the actual habitat range of the species.

The determination of age, growth and maturity schedules for bigeye tuna are only now becoming better defined. There is no doubt that bigeye tuna are considerably longer lived, slower growing and therefore more vulnerable than the yellowfin. It is now considered that bigeye mature at 3 – 4 years of age after which growth slows considerably with fish capable of living well past ten years. Critical to the understanding of bigeye biology and management are better estimates of maturity schedules by area which are just now beginning to become available. Preliminary results indicate that earlier assessments may have been utilized unrealistically low estimates of size at "maturity" for the species. For the purposes of this review paper, the following categories of bigeye life stage will be used:

1) egg/larval/early juvenile;	< 20 cm
2) juvenile;	20 – 75 cm
3) sub-adult;	76 – 110 cm
4) adult.	> 110 cm

Egg, larval and early juvenile development

The eggs of bigeye tuna resemble those of several scombrid species and can not be differentiated by visual means. Therefore, the distribution of bigeye eggs has not been determined in the Pacific Ocean. However, the duration of the fertilized egg phase is very short, approximately one day, meaning egg distributions are roughly coincident with documented larval distributions. Eggs are epipelagic and buoyed at the surface by a single oil droplet until hatching occurs.

Kume (1962) examined artificially fertilized bigeye eggs in the Indian Ocean, noting egg diameters ranging from 1.03 to 1.08 mm with oil droplets measuring 0.23 to 0.24 mm. Hatching began 21 hours post-fertilization, and larvae measured 1.5 mm in length. Larval development soon after hatching has been described by Kume (1962) and Yasutake et al. (1973). Descriptions of bigeye larvae and keys to their differentiation from other Thunnus species are given by Matsumoto et al. (1972) and Nishikawa and Rimmer (1987). However, the early larval stages of bigeye and yellowfin are difficult or impossible to differentiate without allozyme or mitochondrial DNA analyses (Graves et al. 1988). An indexed bibliography of references on the eggs and early life stages of tuna is provided by Richards and Klawe (1972).

The distribution or areas of collection of larval bigeye in the Pacific has been described or estimated by Nishikawa et al. (1978), Strasburg (1960) and Ueyanagi (1969). Data compiled by Nishikawa et al. (1978) indicates that bigeye larvae are relatively abundant in the western and eastern Pacific compared to central Pacific areas and are most common in the western Pacific between 10^{o}N and 15^{o}S. The basic environment of bigeye larvae can be characterized as warm, oceanic surface waters at the upper range of temperatures utilized by the species, which is basically a consequence of preferred spawning habitat.

Bigeye larvae appear to be restricted to surface waters of the mixed layer well above the thermocline and at depths less than 50 to 60 m, with no clear consensus on diurnal preference by depth or patterns of vertical migration (Matsumoto 1961, Strasburg 1960, Ueyanagi 1969). Prey species inhabit this zone, consisting of crustacean zooplankton at early stages, shifting to fish larvae at the end of the larval phase and beginning of early juvenile stages. The diet of larval and juvenile bigeye tuna is similar to that of yellowfin tuna, consisting of a mix of crustaceans, cephalopods and fish (Uotani, et al. 1981).

The age and growth of larval, post-larval and early juvenile bigeye is not well known or studied. Yasutake et al. (1973) recorded newly hatched larvae at 2.5 mm in total length, growing to 3.0 and 3.1 mm at 24 and 48 hours. The early post-larval stage was achieved at 86 hours after hatching. However, it is likely that the early development of bigeye tuna is similar to that of yellowfin tuna which is the subject of current land based tank studies by the IATTC (IATTC 1997). The larval stages of bigeye tuna likely extend for approximately two to three weeks after hatching. The short duration of the larval stage suggests that the distribution of bigeye larvae is nearly coincident with the distribution of bigeye spawning and eggs. It has been suggested that areas of elevated productivity are necessary to support broad spawning events that are characteristic of skipjack, yellowfin and bigeye tuna whose larvae would subsequently benefit from being in areas of high forage densities (Sund et al. 1981, Miller 1979, Boehlert and Mundy 1994; Itano 2000).

Juvenile and sub-adult stages (20 – 110 cm)

The juvenile phase of bigeye is not clearly defined in the literature. Technically, the term "juvenile" should refer to all sexually immature fish. Calkins (1980) suggests grouping bigeye into larval, juvenile, adolescent, immature adult and adult stages. For the purposes of this management related review, length/age classes were selected in relation to their landings in major fisheries coupled with their size-related vulnerability to various gear types and fishing methods and what is known of bigeye maturity schedules.

Defined this way, the "Juvenile" category will refer to bigeye tuna of 20 – 75 cm fork length which closely corresponds to their size at first recruitment to surface fisheries and includes the majority of surface catches, e.g. purse seine, pole and line, troll. The "Sub-Adult" category of 76 – 110 cm includes the interesting middle size class of bigeye that first enter longline fisheries, are also taken by surface fisheries but are generally not sexually mature or contributing to the spawning biomass.

Juvenile and sub-adult – Habitat and feeding

It is well known that juvenile tunas, including bigeye aggregate strongly to floating objects or to large, slow-moving marine animals, such as whale sharks and manta rays (Calkins 1980, Hampton and Bailey 1993). This behavior has been exploited by surface fisheries to aggregate juvenile yellowfin and bigeye tuna to anchored or drifting FADs (Sharp 1978; Hampton and Bailey 1993). Juvenile, sub-adult and adult bigeye tuna are also known to aggregate near seamounts and submarine ridge features where they are exploited by pole-and-line, handline and purse-seine fisheries (Fonteneau 1991, Itano 1998a; Hallier and Delgado de Molina 2000; Itano and Holland 2000).

Juvenile bigeye form mono-specific schools at or near the surface with similar-sized tuna or may form mixed aggregations with skipjack and/or juvenile yellowfin tuna (Calkins 1980). Yuen (1963) has suggested that these mixed-species schools are actually separate single-species schools that temporarily aggregate to a common element such as food. Echo sounder, sonar data and test fishing strongly suggest a vertical separation of bigeye, yellowfin and skipjack schools that are aggregated to the same floating object. A great deal of circumstantial evidence supports species specific vertical stratification of tuna on drifting objects, with bigeye being the deepest, yellowfin intermediate and skipjack closest the surface. Several studies have come very close to defining these issues using sophisticated sonar and echo sounder equipment capable of measuring target strength readings of individual fish (Josse, et al. 2000; Josse and Bertrand 2000). However, species specific remote sensing of tuna needs further study. An added complication is that normal daytime deep diving behavior of bigeye tuna appears to break down when in association with drifting and anchored FADs where the fish tend to remain within the mixed layer (Schaefer and Fuller 2002; Musyl et al. 2003).

The majority of feeding studies on bigeye tuna have sampled gut contents of large longline-caught fish. Very few studies have specifically examined the feeding behavior of juvenile bigeye tuna. Collette and Nauen (1983) state that juvenile bigeye have been noted to feed opportunistically during day and night on a wide variety of crustaceans, cephalopods and fish in a manner similar to yellowfin of a similar size. Prey items include epipelagic or mesopelagic members of the oceanic community or pelagic post-larval or pre-juvenile stages of island-, reef-or benthic-associated fish and crustaceans. Alverson and Peterson (1963) state that juvenile bigeye less than 100 cm generally feed at the surface during daylight, usually near continental land masses, islands, seamounts, banks or floating objects. Much of this information should be considered dated or incomplete in nature.

Recent and ongoing work in Hawaiian waters may significantly alter the perception that juvenile bigeye feed on epipelagic fauna in a similar manner to similar sized yellowfin tuna. Grubbs et al. (2002) found that small and medium sized juvenile yellowfin and bigeye tuna in a size range of 40 – 80 cm exploited similar broad groups of prey but significantly different species. Yellowfin were noted to feed almost exclusively on epipelagic fish or crustaceans or mesopelagic organisms that vertically migrate into the shallow mixed layer at night. Bigeye tuna of the same size and in the same aggregations fed primarily on a deeper dwelling complex of mesopelagic crustaceans, cephalopods and fish, and fed more successfully near seamounts compared to yellowfin. Interestingly, neither species appears to feed well on anchored FADs but continue to exploit different species that are apparently advected past the FAD by currents or exist in the surrounding waters: yellowfin eating epipelagic organisms and bigeye concentrating on mesopelagic organisms of the sound scattering layer.

Schaefer and Fuller (2002) characterized vertical behavior by association type for bigeye archivally tagged in association with drifting FADs in the equatorial EPO. An interesting behavioral pattern was evident during 27.7 percent of the time (pooled data) with fish remaining shallow during the night and most of the day as is characteristic of FAD associated bigeye tuna. However, extended deep diving activity took place during afternoon which may have represented a temporary break in the association to forage at depth. Additional archival data in conjunction with acoustic surveys and gut analysis is necessary to resolve these issues.

Juvenile and sub-adult importance to fisheries

Juvenile bigeye are regularly taken as an incidental in surface fisheries, and occasionally as targeted catch, such as in the seamount and FAD associated offshore handline fishery of Hawaii (Adam et al. 2003). Juvenile bigeye tuna of very small sizes are taken in the equatorial Philippine ringnet and small purse seine fishery, but are poorly documented due to mixing in the statistics with yellowfin tuna and other tuna species (Lawson 2004). These fisheries are based on anchored FADs, taking advantage of the strong tendency of juvenile tuna to aggregate to floating objects.

Juvenile bigeye are regularly taken as an incidental in pole and line fisheries, especially when floating objects or FADs are utilized. Tsukagoe (1981) describes interesting techniques used by distant water Japanese pole and line skipjack vessels to target juvenile and sub-adult bigeye tuna on drifting logs in the tropical western Pacific. However, bigeye as small as 32 cm are taken in the Japanese coastal pole-and-line fishery (Honma et al. 1973). Bigeye tuna have also been recorded from a seamount-associated handline fishery and FAD-based pole-and-line and handline fisheries in Hawaii as small as approximately 40 cm FL (Boggs and Ito 1993, Itano 1998). Smaller sized fish are apparently available but not retained due to marketing preferences. The smallest bigeye tuna of 7957 bigeye tag releases achieved during the Hawaii Tuna Tagging Project was 29.0 cm captured by handline gear (Itano and Holland 2000).

Both juvenile and sub-adult bigeye are taken as an incidental catch in floating object sets in western Pacific purse seine fisheries. In the eastern Pacific Ocean, purse seine catches of sub-adult bigeye have been quite high in some years and should be considered as a retained component of the catch in the skipjack floating object fishery. Schaefer and Fuller (2002) from archival tag data noted that bigeye less than 110 cm spent a greater percentage of their time in association with drifting FADs in the EPO but that the larger bigeye still had an affinity for aggregating to floating objects. Very small bigeye tuna are also taken in equatorial purse seine fisheries though may be discarded or poorly enumerated due to market demands and mixed reporting with juvenile yellowfin tuna.

Juvenile and sub-adult bigeye of increasing size appear in higher latitude fisheries, suggesting portions of the population move away from equatorial spawning/nursery grounds to feed and grow, only to return later to spawn. The distribution of these juvenile and sub-adult tuna becomes better understood as they begin to enter catch statistics of temperate water fisheries. The sub-adult size bigeye figure significantly in several handline and longline fisheries. For example, the Hawaii based longline fishery takes primarily sub-adult bigeye tuna. During the 16 year period 1987-2002, annual average size of bigeye ranged from 111 – 120 cm (WPRFMC, 2004B).

Adult distribution and habitat preference

Adult bigeye are distributed across the tropical and temperate waters of the Pacific, between northern Japan and the North Island of New Zealand in the western Pacific, and from 40oN to 30oS in the eastern Pacific (Calkins 1980). Numerous references exist on the distribution of Pacific bigeye tuna in relation to general distribution and migration (Hanamoto 1986; Kume 1963, 1967, 1969a, 1969b; Kume and Shiohama 1965; Laevastu and Rosa 1963); the oceanic environment (Blackburn 1965, 1969; Hanamoto 1975, 1976, 1983, 1987; Nakamura and Yamanaka 1959; Suda et al. 1969; Sund et al. 1981; Yamanaka et al. 1969); the physiology of tunas (Magnuson 1963; Sharp and Dizon 1978; Stretta and Petit 1989); and fish aggregation devices (Holland et al. 1990).

There is some consensus that the primary determinants of adult bigeye distribution are water temperature and dissolved oxygen levels. Salinity does not appear to play an important role in tuna distribution in comparison to water temperature, dissolved oxygen levels and water clarity. Hanamoto (1987) reasons that optimum salinity for bigeye tuna ranges from 34.5 percent to 35.5 percent given the existence of a 1:1 relationship between temperature and salinity within the optimum temperature range for the species. Alverson and Peterson (1963) state that bigeye tuna are found within SST ranges of 13° to 29°C with an optimum temperature range of 17° to 22°C. However, the distribution of bigeye tuna cannot be accurately described by SST data since the fish spend a great deal of time at depth in cooler waters. Hanamoto (1987) analyzes longline catch and gear configurations in relation to vertical water temperature profiles to estimate preferred bigeye habitat. He notes that bigeye are taken by longline gear at ambient temperatures ranging from 9° to 28°C and concludes from relative catch rates within this range that the optimum temperature for large bigeye lies between 10° and 15°C if available dissolved oxygen levels remain above 1ml/l. In a similar study in the Indian Ocean, the optimum temperature for bigeye tuna was estimated to lie between 10° and 16°C (Mohri et al. 1996).

According to several authors, bigeye can tolerate dissolved oxygen levels as low as 1 ml/l, which is significantly lower than the dissolved oxygen requirements of skipjack and yellowfin tuna (Sund et al. 1981). Brill (1994) has proposed a physiological basis to explain how bigeye are able to utilize oxygen in a highly efficient manner, thereby allowing them to forage in areas that are not utilized by other tuna species. He theorizes that bigeye tuna spend the majority of their time at depth, making short excursions to the surface to warm up. Lowe et al. (2000) demonstrate that the blood of bigeye tuna has a significantly higher affinity for O_2 compared to other tunas, thus explaining their ability to exploit O_2 poor regions and depths.

This vertical movement pattern, which has been clearly demonstrated by sonic tracking experiments of bigeye tuna, is exactly the opposite pattern demonstrated by skipjack and juvenile yellowfin tuna (Holland et al. 1992). Sonic tracking and archival tagging of bigeye tuna consistently indicate deep foraging during the daytime near or below the thermocline and shallow swimming behavior at night.

The use of sonic and archival tagging technologies has greatly expanded our knowledge of bigeye behavior and habitat selection. Schaefer and Fuller (2002) noted that bigeye in the EPO spend most of the day at depths of 200 – 300 m and ambient temperatures of 13 – 14^{o}C, although dives to below 1500 m and ambient temperatures of < 3^{o}C were noted.

Size at maturity and the classification “sub-adult” and “adult” bigeye

Estimates of size at maturity for Pacific bigeye vary widely between authors (Whitelaw and Unnithan 1997). This is likely due to a mixing between estimates and/or observations of “size at first spawning”; “size of fish observed in running ripe condition” or some estimate or guess of “size at sexual maturity for the stock” as determined by a variety of methods using vastly different temporal and spatial sampling protocols. Maturity of bigeye is most accurately indicated by the presence of hydrated oocytes in the ovarian lumen or microscopically observed post-ovulatory follicles of recent age or for the male, by a variety of visual observations of the testis (Nikaido, et al., 1991). Large-scale stratified sampling over multi-year periods may be necessary to adequately address area effects and inter-annual variation in oceanographic conditions, e.g. ENSO effects.

Kikawa (1957, 1961) estimated size at first maturity for males at 101–105 cm and 91–95 cm for female bigeye and selected 100 cm as a general size for "potential maturity" for Pacific bigeye. Kume (1962) recorded a running ripe female bigeye of 93 cm, and McPherson (1988) recorded mature bigeye of 100 cm using histological methods. The study by Yuen (1955) agreed with Kikawa (1953) with an estimated size at first spawning for central Pacific bigeye at roughly 90 – 100 cm. In a later study, Kikawa (1962) reported finding very few sexually mature female bigeye less than 100 cm in fork length. Sun (1999) reported on a year of bigeye port sampling of Taiwanese longline vessel catch from the far western Pacific and noted the smallest mature female sampled measured 99.7 cm. Nikaido et al. (1991) reported that most of the bigeye over 100 cm were "sexually very active" from taken near Java and from waters south of Johnston Atoll. These observations are incomplete and clearly unsuitable for stock assessment purposes.
The IATTC is in the process of concluding and publishing results of a two-year investigation on the reproductive biology of bigeye tuna from the Eastern Pacific Ocean that evaluated 1869 gonad samples from male and female bigeye ranging between 80 and 163 cm FL to determine spawning habitat, maturity, fecundity and sex ratios. Histological methods were used to evaluate sexual maturity, spawning periodicity and spawning time. The smallest female bigeye tuna histologically classified as mature was 120 cm FL and only 4 percent of fish 120.0-124.0 cm FL (n=70) were mature (IATTC 2004). Approximately 54 percent of samples 140.0-144.9 and 78 percent of fish 150.9-154.9 were classified sexually mature.

These initial findings suggest considerably larger sizes at maturity for bigeye tuna in the EPO in comparison to observations made in the central and western Pacific. However, it should be noted that spawning of bigeye has been linked with sea surface temperatures above 24^{o}C. It has been suggested that sexual maturity, or more accurately, the development into active spawning condition appears to be linked to mixed layer water temperatures above 26^{o} C (Mohri 1998). Kume (1967) noted a correlation between mature but sexually inactive bigeye at SSTs below 23^{o} to 24^{o}C, which appears to represent a lower limit to bigeye spawning activity

Sea surface temperatures are considerably lower in the equatorial EPO compared to the WCPO which could depress and lengthen maturity schedules of bigeye tuna in the EPO if they remained in that area for extended periods. For example, mean annual SSTs measured at oceanographic buoys in the area of the EPO study at 0^{o}, 95^{o}W and at 0^{o}, 180^{o} during 2000 (the time period of the sampling by Schaefer) were 23.1 and 27.5^{o}C respectively.

In other words, bigeye maturity schedules and spawning patterns need to be examined on a regional basis. A broad scale investigation of bigeye maturity and reproductive parameters using histological methodology is clearly indicated.

In review of the available information, the categorization of 100 cm bigeye tuna as "generally mature" may be inaccurate and potentially dangerous for stock assessment purposes. The selection of 100 cm to describe mature bigeye would be similar to selecting a size of ~ 60 cm to describe mature yellowfin when this actually represents the size when a few yellowfin first enter maturity. Estimates of L50 for WCPO and EPO yellowfin are 105 cm and 92 cm respectively (Itano 2000; Schaefer 1998).

For the purposes of this review, a conservative value of 110 cm has been selected to differentiate sub-adult populations from adult bigeye.

Reproduction

Sex ratios: Information on sex ratios of bigeye by area are incomplete and somewhat inconsistent though there is general agreement that males are more abundant, particularly in the larger size classes. Most studies agree that sex ratios of bigeye tuna are close to the expected 1:1 up to a fork length of approximately 140 cm after which several authors have noted an increase in the proportion of males in the population (Miyabe and Bayliff 1998; Miyabe 2001; Sun et al. 2004). Bigeye larger than 160 cm are predominantly males, and females appear to be completely absent from the largest size classes.

The cline in sex ratios after 140 cm may be related to a slowing of growth, increased natural mortality, increased catchability or some factor related to courtship and spawning. The cline in sex ratios toward males near the size of maturity for females has lead many investigators to speculate that the energetic costs of maturation and spawning may slow somatic growth in females, eventually leading to higher natural mortality. Estimates of differential cost of spawning on the basis of gonadal production, bioenergetics modeling (locomotion, metabolism, energy loss and growth) or some combination of both have been made for yellowfin tuna (Olson and Boggs 1986; Schaefer 1996: 1998). Although several energetic factors may not be fully addressed in these studies, they do agree that energetic costs for females and the massive cytoplasmic investment of females in daily expenditures of ova far outweigh that expended by the males. In short, it appears that female tuna, particularly the tropical tunas simply burn out and stop growing or die young as a consequence of massive reproductive output.

Reproductive parameters: Bigeye tuna spawn throughout the year in equatorial regions, engaging in night time mass spawning events in oceanic waters above approximately 24°C, but ideally closer to 26°C. Kume (1967) noted a correlation between mature but sexually inactive bigeye at SSTs below 23° to 24°C, which appears to represent a lower limit to bigeye spawning activity. Bigeye tuna are serial spawners, capable of repeated spawning events at daily or near daily intervals during extended spawning periods of unknown length (Nikaido et al. 1991). Spawning takes place during the late afternoon or evening hours at or near the surface (McPherson 1991a). Spawning peaks in the evening from about 1900 to 2400 hours, with batch fecundities of millions of ova per spawning event. Batch fecundity, as with many fishes, increased dramatically with body length with estimates of bigeye batch fecundities ranging from around one to five million eggs per spawn for fish ranging from 120 to 180 cm FL (Nikaido, et al. 1991). Sun et al.

(1999) estimated average batch fecundity for western Pacific bigeye of 3.47 million oocytes, or 59.5 oocytes per gram of body weight for samples.

Additional information on the maturity and spawning of western and central Pacific bigeye is provided by Kikawa (1953, 1957, 1961, 1962, and 1966). However, none of these older studies applied histological techniques that are necessary to accurately define maturity stages and reproductive parameters of tuna populations (Schaefer 2001). Goldberg and Herring-Dyal (1981) provide one of the few accessible studies on bigeye maturity using histological techniques.

Spawning areas and seasons: In a general sense, bigeye tuna are believed to spawn throughout the year in tropical regions (10^{o}N – 10^{o}S) and during summer months at higher latitudes (Collette and Nauen 1983). A study by McPherson (1991a) in eastern Australian waters supports this concept of equatorial spawning of bigeye throughout the year with seasonal spawning of bigeye in the north Australian zone, e.g. higher latitudes. Hisada (1979) noted from a study in the central and eastern Pacific that a temperature of 24^{o}C to a depth of 50 m were necessary for maturity and spawning, suggesting a similar seasonal pattern of spawning in the western Pacific. It can be assumed that bigeye spawning and larval development are common at SSTs above 26^{o}C, but may occur in some regions with surface mixed layers of 23^o-24^{o}C and above.

Yuen (1955) found fully mature, spawning condition bigeye in samples collected in the western Pacific, Caroline and Marshall Islands (1^o – 7^{o}N latitude) throughout the period of his sampling (April – October). Sampling at similar latitudes among the central Pacific, Line Islands of Kiribati suggested two peak spawning periods in January through February and July through October. However, these results were considered preliminary due to restricted sample sizes and periods. A large data set from the Hawaiian Islands revealed no bigeye tuna in spawning condition with the nearest spawning condition bigeye sampled 400 miles southeast of Hawaii.

Two years of ovary sampling of Hawaiian bigeye revealed a definite increase in relative ovary weight from winter to summer, peaking in June, but no fully mature or spawning-condition bigeye were ever sampled (Yuen 1955). June also coincides with the annual low in the landings of large bigeye in Hawaiian waters. Yuen (1955) suggested that large bigeye in maturing stages leave Hawaii in spring and summer to spawn, presumably to the south. Gear selectivity was not considered a plausible explanation for the reduced summertime catches, as the same gear takes large, spawning condition bigeye at that time of year near Palmyra Atoll, 800 nmi south of Hawaii. This would also concur with a central equatorial spawning season of July - October, peaking in August - September as was inferred by the Line Islands samples examined in the same study.

Nikaido et al., (1991) noted bigeye in active spawning condition in waters described as “south-western offshore of Hawaii.” Several tables and graphs in the paper are labeled as “Hawaii samples”, which has lead to some confusion of the status of bigeye spawning in Hawaiian waters. His “Hawaii” samples were actually taken from locations 11^o- 13^{o}N, and 163° – 176°W which are well south of Johnston Atoll and over 700 miles from the closest Hawaiian island. Nevertheless, the sampling occurred from May 27 – July 10.

Boehlert and Mundy (1994), in larval fish tows around the Hawaiian island of Oahu tentatively identified five bigeye tuna larvae collected in June using visual criteria. However, these identifications are now considered suspect due to more recent work defining visual characters of tuna larvae using DNA techniques (Graves et al. 1988; Mundy, pers. comm.).

Sun et al. (1999), examined bigeye tuna gonads taken in the western Pacific longline fishery over a one year period. Based on monthly variation in gonad size and oocyte stage he proposed that the spawning season of western Pacific bigeye extended from February to September with peaks from March to June. These samples were taken primary from areas east and west of the Philippines; therefore around 10°N. 120° - 130°E.

Age and growth

Whitelaw and Unnithan (1997) provide a summary of early studies on the age and growth of bigeye tuna in the Pacific and Indian Oceans using primarily analyses of modal progression in size frequencies. Pertinent references include Iverson (1955), Kume and Joseph (1966), Marcille and Stequert (1976), Peterson and Bayliff (1985), Tankevich (1982) and Talbot and Penrith (1960). Yukinawa and Yabuta (1963) examined scale increments. Lehodey et al. (1999) and Sun et al. (2001) provide summarized tables of growth parameters derived by bigeye studies in the Pacific and Atlantic Oceans.

Significantly, the IATTC has completed an otolith age validation study on central Pacific bigeye tuna in collaboration with the University of Hawaii, Pelagic Fisheries Research Program (IATTC 2002). Saggital otoliths from recaptured bigeye tuna previously marked with oxytetracycline (OTC) from Hawaiian waters and the Eastern Pacific Ocean were evaluated. The study concluded that daily microincrements were deposited on bigeye otoliths within the range of sampling (38-135 cm FL), but that expanded sampling and evaluation was necessary to expand the significance of the work.

In more recent studies, Hampton and Leroy (1998) developed a von Bertelanffy growth curve fitted to tag recapture data and otolith readings for western and central Pacific bigeye tuna, resulting in the growth curve as depicted in Figure 10 of Hampton et al. (1998b). Lehodey et al. (1999) refit the composite model, excluding otolith readings from fish >110 cm FL due to difficulties in reading daily increments beyond three years. Figure 6 in Lehodey et al (1999) was felt to provide a reasonably good fit to both tagging and otolith data, with the tagging data providing estimated $L\infty$ within a more realistic framework.

Within the past few years, CSIRO has developed techniques to age bigeye tuna using seasonal annuli on otoliths (Farley et al. 2003). Annuli are not clearly defined during the first two years of life due to rapid growth but become easily discernable after two or three years of life. Leroy (1991) concludes that the second and third annuli can be accurately determined by visual enumeration of daily microincrements in prepared saggital otoliths. Therefore, a combination of daily and annular readings of otoliths should provide accurate estimates of bigeye growth.

In an independent study, Sun et al. (2001) used presumed annular marks on the first dorsal spine of western Pacific bigeye tuna to develop estimates of age and growth. Spines from 1149 specimens ranging between 45.6 and 189.2 cm FL were examined. Age estimates of mean and back calculated fork lengths of bigeye up to ten year estimates are provided.

Stequert and Conand (2004) examined the age and growth of bigeye tuna sampled from the western Indian Ocean. Presumed daily microincrements on saggital otoliths were interpreted using scanning electron microscope for 164 samples. A growth curve was derived indicating bigeye in this region measure 59 cm at year 1,111 cm at year 3 and 147 cm at 6 years. Marks on the first dorsal spines of 140 bigeye were also interpreted. Comparable results were reached using otoliths and spines up to estimated ages of three years, but they did not feel that spines were suitable for ageing larger fish.

These studies in combination with tag recapture data suggest that bigeye growth is rapid and parallels yellowfin growth for the first two years, after which it slows down significantly prior to the onset of sexual maturity. The disparity in results by area also suggests that studies need to be carried out on a regional basis and results from one area should be used with caution in other areas if at all. Maximum age of bigeye is not known, but tag recapture data provides empirical evidence that bigeye tuna grow to at least 12+ years of age which is considerably longer than yellowfin. Recently, large bigeye tuna have been aged using a combination of daily and annular marks at 13 to 15 years of age (Leroy pers. comm.).

Adult diet and feeding

Several investigators have proposed that the greater depth distribution of bigeye is a foraging strategy to exploit regions less utilized by yellowfin or skipjack tuna, thus reducing niche competition. Bigeye tuna are opportunistic feeders like yellowfin, relying on a mix of crustaceans, fish and cephalopods with feeding taking place during the day and night (Calkins 1980; Collette and Nauen 1983). However, the composition of adult bigeye diet differs significantly from that of similar-sized yellowfin (Watanabe 1958, Talbot and Penrith 1963, Kornilova 1980). Adult bigeye prefer to forage at significant depths, utilizing a higher proportion of squid and mesopelagic fishes compared to yellowfin. Solov'yev (1970) suggests that the preferred feeding depth of large bigeye is 218–265 m, which is the most productive depth for longline catches. Miyabe and Bayliff (1998) summarize diet items of bigeye in the Pacific in tabular form from studies by Alverson and Peterson (1963), Blunt (1960), Juhl (1955), King and Ikehara (1956) and Watanabe (1958).

Any discussion of preferred bigeye habitat must address the vertical temperature structure, thermocline depth and local characteristics of the sound scattering layer (SSL) of the region in discussion. Josse et al. (1998) used tracking of bigeye and yellowfin marked with depth transmitting tags with simultaneous recording of biotic elements of the water column to examine tuna behavior during the day and night. The study clearly illustrated the importance of the SSL and prey to tuna movements and presumed feeding behavior. Sonic tracking and the use of archival data loggers have clearly shown the ability of adult bigeye to exploit prey and forage in a much deeper environment when compared to yellowfin (Dagorn et al. 2000; Musyl et al. 2003).

Bigeye tuna are also known to aggregate to large near surface concentrations of forage, such as the spawning aggregations of lanternfish (Diaphus sp.) [MYCTOPHIDAE] that occur seasonally in the Australian Coral Sea (Hisada 1973, McPherson 1991b).

Adult importance to fisheries

Large, mature-sized bigeye tuna are sought by high value sub-surface fisheries, primarily longline fleets landing sashimi grade product. Adult bigeye tuna aggregate to drifting flotsam and anchored buoys, though to a lesser degree than juvenile fish. Large bigeye also aggregate over deep seamount and ridge features where they are targeted by some longline and handline fisheries.

Regions of elevated primary productivity and high zooplankton density—such as near regions of upwelling and convergence of surface waters of different densities that are very important to the distribution of skipjack and yellowfin tuna—are less important to the distribution of adult bigeye. This is logical if one assumes skipjack and yellowfin are inhabitants of the upper mixed layer while adult bigeye are sub-surface in nature, more closely tied to the thermocline and organisms of the deep scattering layer. Water temperature, thermocline depth and season appear to have much stronger influences on the distribution of large bigeye (Calkins 1980). The fact that large bigeye take longline hooks at greater depths than yellowfin coupled with a rising demand for sashimi-grade tuna and improved storage techniques prompted a shift to deep longline gear to target bigeye tuna during the late 1970s and early 1980s (Sakagawa et al. 1987, Suzuki et al. 1977). This development promoted numerous studies on differential catch rates and gear configurations to define productive hooking depths for bigeye given different oceanographic conditions (Bahar 1985, 1987; Boggs 1992; Gong et al. 1987, 1989; Hanamoto 1974; Nishi 1990; Saito 1975; Shimamura and Soeda 1981; Suzuki and Kume 1981, 1982; Suzuki et al. 1979).

Hanamoto (1987) proposed that productive longline fishing grounds for bigeye do not necessarily equate to regions of higher abundance, but “are nothing more than areas where the hook depths happened to coincide with the optimum temperature layer and where the amount of dissolved oxygen happened to be greater than the minimum required for bigeye tuna (1ml/l).” Nakamura (1969) suggests that bigeye tuna are closely associated with particular water masses or current systems during different life stages. Fish taken in the higher latitude longline fishing grounds tend to be large sub-adults, reproductively inactive young adults, or spent (mature but reproductively inactive) adults, while the fish taken in the equatorial longline fishery are actively spawning adults (Calkins 1980).

3.2.4 Movement

Horizontal movements

There have been relatively few bigeye tagged in the Pacific in comparison to skipjack and yellowfin due to the difficulty in capturing quantities of bigeye in suitable condition for tagging. The South Pacific Commission tagged and released approximately 147,000 tuna from 1989 – 1992, of which only 5.5 percent were bigeye. As a result, horizontal movement data from conventional tagging programs is not conclusive.

Miyabe and Bayliff (1998) present summary information of some long distance movements of tagged bigeye in the Pacific. Hampton and Williams (2005) describes 8,074 bigeye releases made in the western Pacific by the South Pacific Commission (SPC) Regional Tuna Tagging Project (RTTP) during 1989–1992. An overall recapture rate of 12.5 percent of bigeye releases was reported.

For large release data sets in the Philippines and from the Coral Sea of Australia, more than 80 percent of recaptures were reported within 200 nmi of release. In contrast, about 50 percent of equatorial releases occurred beyond 200 nmi from their point of release and 10 percent beyond 1000 nmi. The authors suggest the difference may be due to a greater tendency for bigeye to remain close to large land masses, FADs or tightly packed island groups. The equatorial releases were made in high seas areas or near isolated, oceanic islands and atolls.

Approximately 63 percent of all SPC/RTTP bigeye tag releases were made in the northeastern Australian EEZ, most of which were captured in large feeding aggregations in the Coral Sea at approximately 17-18^{o} S latitude (Itano and Bailey 1991). Hampton and Gunn (1998) examined a release dataset of 4,277 bigeye using a tag-attrition model with seasonally variable catchability and targeting options. Tag recaptures supported some linkage of Australian bigeye to the broader western and central Pacific and as far east as 130-140 W longitude. However, the majority of recaptures came from the general area of release with a significant seasonal pulse during mid-year. Various explanations are given but some degree of localization of bigeye can not be discounted.

The Hawaii Tuna Tagging Project (HTTP) conventionally tagged and released 7,440 yellowfin and 7,957 bigeye tuna throughout the Hawaiian archipelago, primarily from 1996 – 1999. Most of the bigeye releases were juvenile fish (mean 59.8 cm) tagged and released near a large seamount feature in the Hawaii EEZ or on offshore buoys that were acting as fish aggregation devices (Itano and Holland 2000). Bigeye recaptures reached 15 percent overall, which were primarily short term recaptures at or near their point of release, reinforcing the importance of aggregation and schooling to juvenile bigeye tuna behavior. Recaptured bigeye apparently remained within the Hawaii zone for at least two or three years, repeatedly aggregating to the same seamount or FADs where recaptures continued to be reported. Adam et al. (2003) supported some degree of regional fidelity or island association of these juvenile and sub-adult phase bigeye with a low level of mixing with the broader WCPO. In this respect, the results were somewhat similar to those reported by Hampton and Gunn (1998) for bigeye tuna in the Australian Coral Sea.

Sibert et al. (2003) applied a Kalman filter statistical model to refine horizontal movement data from geolocating archival tags recovered from Hawaiian bigeye tuna. Juvenile and sub-adult bigeye recoveries showed little real movement and a strong tendency to remain at the seamount and FADs where they had been tagged. The only large bigeye (131 cm) apparently remained associated with the coastal features and nearshore bathymetry of the island of Hawaii during 84 days at liberty. The authors suggest that large features, such as islands may also act as points of attraction and aggregation for bigeye tuna. This is a commonly held belief of traditional handline fishermen in Polynesia who target deep swimming tunas at specific locations close to atolls and high islands. There are several of these traditional handline areas along the south shore of the island of Hawaii that are known to hold bigeye and yellowfin tunas (Rizutto 1983).

However, over time, increasing numbers of HTTP recaptures have been reported radiating out from the Hawaiian islands in all directions, but primarily to the south of Hawaii toward Johnston and Palmyra Atolls. This recapture pattern may reflect different life stages of bigeye tuna, with semi-resident juveniles and sub-adults strongly aggregated to island and seamount features, expanding out into oceanic environments and tropical spawning grounds with their development to maturity. It should be noted that higher recapture rates to the south of Hawaii are undoubtedly influenced by differential fishing effort, but effort and abundance are often closely related.

Horizontal movements of bigeye in relation to FADs and drifting objects are not well described, although a great deal of anecdotal information is available from the fishing industry. Schaefer and Fuller (2005) noted that bigeye tended to remain tightly aggregated and upcurrent of anchored FADs and downcurrent from the drifting research vessel during the day. At night, the bigeye aggregations became more diffuse when it was presumed that individuals were foraging on organisms of the SSL. Bigeye returned to their daytime positions at dawn, often forming monospecific schools at the surface, usually termed a "breezer."

Bigeye tuna can move freely throughout broad regions of favorable water temperature and dissolved oxygen values; and are capable of large, basin-scale movements as documented by tag recoveries. However, most bigeye recaptures have occurred within 200 miles of their point of release. However, these results may be confounded by the preponderance of juvenile fish in tag release cohorts, a protracted time to reach adult stages, reporting problems for recaptures of large fish from high seas fleets and a general paucity of adequate tag release data.

If the majority of spawning takes place in equatorial waters, then this infers mass movements of juvenile and sub-adult fish to higher latitudes, and presumably some return movements of mature or maturing fish to spawn. However, the extent to which these are directed movements is unknown and the extent of bigeye movement between the western, central and eastern Pacific remains unclear. An increase in tag releases of medium and large bigeye tuna throughout their range, incorporating fishery independent technologies where possible is needed.

Vertical movements

A great deal of information on the vertical behavior of bigeye tuna has been inferred from commercial or research derived longline data. However, this indirect source of information has been largely superceded by fisheries independent depth data either transmitted or recorded in situ and at fine time scales using sonic and archival (data logging) tags. Holland et al. (1990) tracked FAD associated bigeye tuna (72.0, 74.5 cm) fitted with pressure-sensitive (= depth recording) ultrasonic transmitters in Hawaiian waters. The fish exhibited a deep daytime (220 – 240 m) vs. shallow night-time (70 – 90 m) behavior. This pattern broke down when FAD-associated, when average on-FAD daytime depths of 50 – 60 m. were noted. Daytime behavior was characterized by large, regular, but brief vertical excursions between the thermocline and the bottom of surface mixed layer, oscillating between the 14^{o} and 17^{o}C isotherms.

Holland and Sibert (1994) examined thermoregulation in Hawaiian bigeye tuna with data produced by depth and temperature transmitters and simultaneous use of expendable bathythermographs for vertical temperature profiling. Juvenile and sub-adult bigeye (65 – 80 cm) exhibited regular vertical daytime movements as described in Holland et al. (1990). These excursions consistently began when internal body temperatures declined to 17.5 to 18^{o}C, suggesting this may represent a lower body temperature limit for this medium size bigeye tuna.

Dagorn et al. (2000) tracked large bigeye in open ocean environments in French Polynesia, noting the same shallow night-time vs. deep daytime behavior. The largest adult bigeye tuna (estimated 50 kg body weight) rose from daytime base depths of 400 – 460 m to mixed layer depths of 74 – 119 m moving through a temperature gradient of 11.5 – 25.6^{o}C. This fish made only four upward excursions, one every 2.5 hours compared to eleven upward excursions per day recorded by Holland et al. (1990) for a much smaller bigeye tuna in Hawaii (74.5 cm). The authors attribute the difference to differences in body size, thermal inertia and the more frequent need for smaller bigeye to rise to the surface to warm core temperatures. A comparison of day and night swimming depth and simultaneous recording of the prey-rich sound scattering layer (SSL) indicated that bigeye tuna appear to maximize their time within the SSL; deep in the daytime and shallow at night. Vertical movements through the SSL were noted, possibly indicative of hunting/feeding behavior (Josse et al. 1998).

Schaefer and Fuller (2002) report on the largest documented archival dataset for bigeye: 27 sub-adult or potentially adult size fish (88 – 124 cm) tagged and released in drifting FAD aggregations in the equatorial Eastern Pacific Ocean. Vertical behavior was characterized into unassociated, drifting object associated, intermediate, or deep diving.

Classic unassociated behavior was characterized as remaining at mostly < 50 m during the night and spending most of the day at 200 – 300 m within ambient sea temperatures of 13 – 14^{o}C. Fish associated with a drifting FAD generally remained within the shallow mixed layer throughout the day and night above 50 m, although the daytime depth was slightly deeper. An intermediate behavior was noted in the data characterized by remaining shallow at night and day coupled with some deeper diving periods in the afternoon. The authors speculated that this behavior may have been representative of a fish associated with a drifting FAD that broke that association to feed at depth, or a fish feeding on forage aggregated unusually shallow during the daytime as sometimes occurs with some mesopelagic fishes. Sporadic, deep diving behavior was noted when bigeye tuna quickly dove to below 1000 m and ambient temperatures of < 3^{o}C. The archival tags employed were only capable of reading to 1000 m, but it was inferred from ambient sea temperatures that some fish may have reached depths of 1500 m. It is not known why bigeye would dive so deep, but predator avoidance (i.e. marine mammals) or feeding was proposed.

Pooled data characterized the behavior of tagged bigeye as 54.3 percent unassociated, 27.7 percent intermediate-type behavior and only 18.7 percent of the time associated with a floating object, e.g. FAD as natural logs are very rare in this region of the EPO. Daytime diving depths were noted to be significantly shallower than those recorded in the central/western Pacific. The authors suggested that the main determinant of bigeye depth preferences at night and day had to do with their prey and feeding within the vertically migrating sound scattering layer. FAD associations were noted to be of short duration (mean residence time 3.1 days) but were though to contribute significantly to fishing mortality and vulnerability as evidenced by the high recapture rate of this tag release cohort (30 percent overall).

Musyl et al. (2003) report on the vertical movements of bigeye tuna equipped with similar archival tags that had been released and recaptured from different types of aggregations in Hawaiian waters. Bigeye frequenting open-water areas exhibited the classic deep-daytime vs. shallow-night time behavior observed by Schaefer and Fuller (2002). Bigeye periodically rose from daytime depths of ~300 – 500 m to spend short periods in the upper mixed layer, presumably to warm up after foraging at depth. All fish rose to very shallow depths at dusk only to sink down again at dawn. A strong positive correlation was found between body size and daytime depth as Dagorn et al. (2000) had suggested. Bigeye tuna tagged and later recaptured in association with an offshore anchored FAD spent the majority of their time in the upper mixed layer around 50 - 100 m. It is not known if the fish remained in association with the FAD during their entire time at liberty, but they exhibited this shallow "abnormal" behavior after release and when recaptured on the FAD. Bigeye tagged and recaptured on an offshore seamount feature exhibited vertical behavior similar to but not as regular as the vertical behavior of unassociated bigeye. In agreement with previous studies, bigeye in open water areas and on the seamount appeared to maximize their time within the SSL, presumably to maximize foraging success. In contrast to the observations of Holland et al. (1990) from brief sonic tracking data, internal temperatures of juvenile and sub-adult bigeye (52 – 86 cm) were recorded to fall to a minimum of ~ 12 – 13^{o}C. The deepest recorded depth was

817 m and the coldest ambient temperature visited was 4.7°C, but fish spent very little time at these extremes.

By using a combination of archival tags and ultrasonic telemetry, Schaefer and Fuller (2005) report on the vertical behavior of bigeye tuna in mixes species aggregations on an anchored FAD. A larger bigeye (108 cm) occupied significantly deeper waters, day and night, compared to a smaller fish (59 cm). For the large fish, mean depths were significantly deeper during the day vs. night. However, this pattern was curiously reversed for the smaller bigeye. Generally, the presence of FADs or drifting objects appears to significantly influence the vertical behavior of bigeye tuna.

Archival tag data is essential to characterize the habitat and behavior of tuna and billfish to refine habitat based models and to estimate the impact of fisheries. Currently, the SPC is attempting to obtain data on the vertical behavior of principal tuna species across a wide expanse of the WCPO that covers a wide range of oceanic environments.

3.2.5 Stock Structure

The geographic distribution of bigeye tuna is pan-Pacific with no physical or oceanographic barriers to movement within temperature extremes. Analyses of genetic variation in mitochondrial DNA and nuclear microsatellite loci have been conducted on bigeye otoliths from nine geographically scattered regions of the Pacific (Grewe and Hampton 1998). The study noted some evidence for restricted gene-flow between the most geographically distinct samples (Ecuador and the Philippines). However, the data otherwise failed to reject the null hypothesis of a single Pacific-wide population of bigeye tuna. In other words, the study supported the possibility of some degree of population mixing throughout the basin; results that may be termed inconclusive. It should be noted that in a separate study, Grewe et al, (2000) found no evidence to suggest that bigeye from the Indian Ocean were genetically different from the Pacific Ocean samples examined in the earlier study. This suggests that the methodology currently used may be an inappropriate tool for determining the issue of stock structure.

Miyabe and Bayliff (1998) suggest that there is insufficient information currently available to definitively determine the stock structure of bigeye in the Pacific, and therefore, a single stock hypothesis is usually adopted for Pacific bigeye tuna. However, consistent areas of low catch separate principal fishing grounds in the eastern and central/western regions (around 165 – 170°W) and there appears to be little mixing of tagged populations: although the tagging data is quite limited. Due to these considerations and the existence of two major, geographically separated fishing grounds and fisheries coupled with the possibility of ocean basin movements of Pacific bigeye tuna, stock assessments have been carried out on both a Pacific-wide basis and a two-stock hypothesis: separating the WCPO from the EPO. The two-stock hypothesis conforms to the definition of yellowfin stocks proposed by Suzuki et al. (1978) as "*...an exploitable subset of the population existing in a particular area and having some uniqueness relative to exploitation.*"

The results of the genetic analyses are broadly consistent with SPC tagging experiments on bigeye tuna; most stay close but some go far. Bigeye tagged in locations throughout the western tropical Pacific have displayed eastward movements of up to 4,000 nautical miles (nmi) over periods of one to several years. The widespread distribution of bigeye spawning throughout the tropical Pacific and the greater longevity of bigeye relative to other tropical tunas, such as yellowfin (Hampton et al. 1998), are also consistent with a high potential for basin-scale gene flow. However, large-scale movements of bigeye > 1,000 nmi have accounted for only a small percentage of returns, with most recaptures occurring within 200 nmi of release. In addition, a significant degree of site fidelity of bigeye tuna in some locations has been suggested, such as near large land masses, island-rich archipelagos and possibly areas of high FAD densities.

Sibert and Hampton (2003) estimated median lifetime displacements of skipjack and yellowfin tuna in the order of some hundreds of nautical miles, rejecting the notion that these tropical tuna species are widely ranging by nature and "highly migratory." These findings are consistent with the concept of "semi-discrete stocks" of yellowfin in the Pacific as proposed by Suzuki et al. (1978). Bigeye tuna, representing a unique blend of traits between a tropical and temperate tuna species with a protracted life span, may be expected to remain in a general area for extended periods of time and to also range further and have a higher potential for broader displacements throughout their extended life span. Stock assessments are currently carried out for 1) the entire Pacific bigeye stock; 2) the western and central Pacific regional stock and 3) the eastern Pacific regional stock. For purposes of this amendment, only the EPO regional stock assessment will be discussed in this document (Section 3.3.2).

3.3 Fisheries

Sources of bigeye tuna fishing mortality as they pertain to West Coast fisheries include the California recreational fishery; the U.S. purse seine fishery in the EPO; and the U.S. longline fishery on the high seas (Table 2). The total Pacific wide fishing mortality of bigeye is roughly 200,000 mt annually, which is about five percent of total Pacific-wide landings. West Coast landings amount to less than 1 percent of the Pacific wide catch.

Table 2. U.S. Sources of bigeye tuna fishing mortality in the Pacific Ocean.

Fishery	**Authorities**	**2003 Reported Landings (mt)**
California Recreational Fishery	MSA (West Coast HMS FMP)	200 *fish*
California Longline Fishery (High Seas Fishing only)	MSA (West Coast HMS FMP) Tuna Conventions Act (IATTC)	30
Hawaii Recreational Pelagic fisheries	MSA (WP Pelagics FMP) State of Hawaii	unknown
Hawaii Longline Fishery (including High Seas Fishing)	MSA (WP Pelagics FMP) South Pacific Tuna Act Tuna Conventions Act (IATTC)	3,620
Hawaii Commercial Handline and Troll Fishery	MSA (WP Pelagics FMP) State of Hawaii	180
American Samoa Longline Fishery (including High Seas Fishing)	MSA (WP Pelagics FMP) South Pacific Tuna Act	240
U.S. Purse Seine Fishery (EPO)	Tuna Conventions Act (IATTC)	2,600
U.S. Purse Seine Fishery (WCPO)	South Pacific Tuna Act	3,580
Total		**~10,250**

3.3.1 EPO Tuna Fisheries and Bigeye Landings

The following discussion relates to tuna fisheries operating in the Pacific Ocean, with particular focus on the EPO. A more detailed discussion HMS fisheries in the Pacific Ocean can be found in Chapter 2 of the West Coast HMS FMP. For a complete list of citations referenced in this section please see the West Coast HMS FMP.

U.S. fishers harvest eastern Pacific yellowfin, skipjack and bigeye tunas with three main types of fishing gear, purse seines, pole-and-line (baitboat), and longlines. Some quantities are also caught with troll and rod-and-reel gears. Over the 1981-99 period, the most important HMS in terms of landings by all gear types were yellowfin, skipjack, and albacore tunas, swordfish, and common thresher shark. In recent years, the most important HMS have been albacore tuna, swordfish, and common thresher shark. By the end of the 1990s landings of yellowfin and skipjack tuna were substantially less than the amounts landed in the early 1980s. Bluefin tuna landings during the period were characterized by a high degree of variability. Through the 1980s and into the early 1990s albacore landings fell sharply, but by the late 1990s they had returned to relatively high levels of the late 1970s. Swordfish landings declined during the 1980s, but were on the rise through most of the 1990s. Common thresher shark landings followed a pattern similar to that for swordfish over the period. Landings of shortfin mako shark exhibited a fairly sharp decline over the 1981-99 period. Landings of pelagic thresher, bigeye thresher and blue sharks as well as dorado were relatively minor during the 1981-99 period.

Over the 1981-1999 period, the most important HMS in terms of exvessel revenue (constant $1999), were albacore and swordfish, except for yellowfin and skipjack tunas in the early 1980s. Although variable, bluefin tuna exvessel revenues were comparatively high during the period. Swordfish and common thresher shark exvessel revenues peaked in the mid-1980s, and then declined rather steadily through 1999. Over the more recent

1994-1999 period, albacore exvessel revenues have ranged from $12.4 million to $28.6 million, yellowfin tuna exvessel revenues from $1.5 million to $5.9 million, skipjack tuna exvessel revenues from $1.9 million to $5.6 million, bigeye tuna exvessel revenues from $0.3 million to $0.6 million, bluefin tuna exvessel revenues from about $1 million to $4.2 million, swordfish exvessel revenues from $6 million to $10.5 million, and from $0.5 million to $0.6 million for common thresher shark. Exvessel revenues from other HMS sharks and dorado during 1994-1999 were much smaller.

Purse seine fishery: Tropical tuna caught in the U.S. purse seine fishery are canned as light meat tuna. Catches have been delivered or transshipped to canneries in California, Puerto Rico, American Samoa, and other canneries in the Pacific Rim or to Europe. In 1980, there were 20 U.S. tuna processing plants in operation, declining to seven in 1990. By mid-1982, Bumble Bee had closed its plants in Hawaii and San Diego. In 1984, Van Camp closed its San Diego plant and Star-Kist closed its Terminal Island (San Pedro) plant. These plants were shut down because of their high costs of operation relative to foreign competition. Conditions that led to the closure of mainland tuna processing plants and a major restructuring of the U.S. tuna industry during the 1980s and 90s are documented in four reports by the U.S. International Trade Commission (USITC 1984, 1986, 1990, 1992). Today only four U.S. plants are in operation, two in America Samoa (conventional canneries), and one in California and one in Puerto Rico, the latter two processing imported loins only.

Until recently, most of the U.S. purse seiners operating in the EPO have been Inter-American Tropical Tuna Commission (IATTC) class 6 vessels (more than 360 mt carrying capacity); lately however, smaller purse seine vessels have outnumbered the larger vessels. The U.S. fleet of purse seiners in the EPO reached approximately 144 vessels in 1979 but by 1999, had decreased to 10 vessels. U.S. purse seine vessels employ a standard purse seine. Generally, three types of sets have been historically used: sets associated with schools of dolphin, unassociated free-swimming school sets and log or other floating object associated sets. Dolphin sets are now rare as most U.S. purse seiners currently operate in the central-western Pacific where this mode of fishing does not occur. In the WCPO most (90 percent in 1999) of the purse seine sets are on artificial floating objects known as fish aggregating devices or FADS, the remainder on free-swimming schools. The remaining U.S. tropical tuna purse seine vessels in the EPO now also set on FADs. With most the U.S. tropical tuna purse seine fishing now taking place in the WCPO catches are delivered or transshipped directly to canneries in American Samoa. Landings and corresponding exvessel revenues at West Coast ports have greatly decreased since the 1980s, when the major West Coast canneries began relocating overseas. Most of the tropical tuna landings on the West Coast are now made by “wetfish” (sardine, mackerel, anchovy) purse seiners that catch relatively small quantities of tropical tunas when they are seasonally available.

In 1999, 10 U.S. purse seiners participated in the EPO tuna fishery, five in IATTC size classes 2-5, and five in class 6. No tuna seiners have been constructed for U.S. documentation since 1990, and sales of existing U.S. seiners to foreign citizens are expected to continue in 2001. Since 1992, U.S. tuna vessels have been adversely affected by restricted access to historic fishing grounds located within the EEZs of EPO nations to the south of California. This kindled interest by many of the displaced vessels in purse seining for coastal pelagic species within the U.S. West Coast EEZ, particularly with the resurgence of the Pacific sardine. However, some were then thwarted by the limited entry program for coastal pelagic finfish instituted under the Pacific Fishery Management Council's, Coastal Pelagic Species Fishery Management Plan.

Longline Fishery: The longline fishery targets mainly swordfish and bigeye tunas. The U.S. longline fishery catches eastern Pacific yellowfin tuna mainly as an incidental catch species. Yellowfin tuna are caught in the northern extremes of the eastern Pacific yellowfin tuna range, between Hawaii and the West Coast, while targeting bigeye tuna. Catches have ranged between 350 mt in 1992 and 1,100 mt in 1997. Most of the catch is landed in Hawaii with lesser amounts in California. The catches are utilized in fresh fish markets and restaurants. Vessels range in length from 20 to 35 m. The U.S. fleet total (East and West Pacific) has ranged between 141 vessels in 1991 and 105 in 1997. The U.S. fleet uses a typical longline gear with a mainline up to 30 nm in length and a series of floats and branch lines. A set may fish 1,200 or more hooks. The gear is deployed at various depths depending on the target species sought and light sticks are used to enhance catches.

The U.S. longline fishery also catches eastern Pacific skipjack tuna as an incidental species catch. Skipjack tuna are caught in the northern extremes of the eastern Pacific skipjack tuna range, between Hawaii and the U.S. West Coast, while the vessels are targeting bigeye tuna. Catches have ranged between 1 mt in and 106 mt. Most of the catch is landed in Hawaii with lesser amounts in California. The catches are utilized in fresh fish markets and restaurants.

Eastern Pacific yellowfin, skipjack and bigeye tunas are also caught as incidental catch in U.S. troll fisheries and as target species in recreational fisheries.

General profile of domestic HMS fisheries: There are no directed fisheries for tropical tunas off of Oregon or Washington; however California still maintains a substantial commercial fishery for tropical tunas. Several large purse seine vessels continue to use California as a home base, while a larger number of small "wetfish" seiners fish for tropical tunas on a more seasonal basis. These vessels may not be dependent on tuna as their principal target species, which are instead coastal pelagics; however, when tunas are available, these vessels will target on tuna for local markets. Total landings have been between 8,000 mt and 12,000 mt in recent years, valued at more than $12 million per year.

Under California law, longline fishing in the EEZ off California is prohibited. However, California registered vessels are allowed to land longline caught fish in California ports as long as fishing takes place outside of the EEZ. In 1991, there were three longline vessels that fished beyond the EEZ targeting swordfish and bigeye tuna and unloaded their catch and re-provisioned in California ports. In 1993, a Gulf coast fish processor set up an infrastructure at Ventura Harbor, California to provide longline vessels with ice, gear, bait, and fuel, and fish offloading and transportation services (Vojkovich and Barsky 1998). Consequently, longline vessels seeking an alternative to the Gulf of Mexico longline fishery, and precluded from entering the Hawaii fishery, began arriving in Southern California. By 1994, 31 vessels comprised this California based fishery, fishing beyond the EEZ, and landing swordfish and tunas into California ports. These vessels fished side-by-side with Hawaiian vessels in the area around 1350 W longitude in the months from September through January.

General profile of international HMS fisheries: Numerous foreign fisheries target and catch species covered by the West Coast HMS FMP. These fisheries operate throughout the range of the various stocks. With the exception of the Canadian troll fishery for albacore, no foreign fisheries operate in the U.S. EEZ under the jurisdiction of the Council. However, each of the foreign fisheries exploiting a common stock with U.S. fisheries may have a direct impact on the abundance of the species in question and may, under international management, affect domestic management measures. Because of the implications, an understanding of the major foreign fisheries is thoroughly discussed in Chapter 2 of the HMS FMP.

Currently, Japan, Korea and Taiwan, and to a lesser extent China, operate large, specialized, industrial longline fisheries for catching tropical tunas, temperate tunas and billfish, including swordfish throughout the Pacific Ocean. In the Pacific Ocean alone industrial longline fisheries operate more than 3,800 vessels fishing for HMS. By comparison the U.S. industrial longline fleet operating in the Pacific is estimated not to exceed 120 vessels with the vast majority operating out of Hawaii.

Both Spain and Chile operate small industrial longline fleets in the EPO. Spain is reported to have approximately 40 vessels operating throughout the mid-1990s with as few as 10 vessels at the end of the decade. Chile had about 120 vessels operating in the early 1990s in the EPO although the numbers declined to 40 or less by 1996.

Industrial longline vessels in the Pacific range in size from 30 to 1,000+ gross t with the smaller vessels being generally home-based. Larger vessels (50 - 1000+ gross t) may be foreign-based or deck-loaded motherships. Most of the larger vessels are modern, have super-cold (-40 to -60^{o}C) freezing capability and can remain at sea up to 3-4 months between fueling stops. These vessels may remain away from home port in excess of a year and return to land their frozen catch. Smaller vessels generally fish closer to home ports.

Longline operations in the higher latitudes (30 to 50^{o} north and south) produce target catches of albacore and swordfish. Fishing in the subtropics produces a mix of yellowfin, bigeye and albacore tunas, marlins and swordfish. Fishing in tropical waters produces catches of bigeye and yellowfin tunas, marlins and limited amounts of swordfish and albacore. High catches of selected species such as bluefin tuna, marlins and swordfish occur in limited time/area strata on the order of 1 or 2 - 5x5 degree squares over a 2 or 3 month period. Industrial longline fisheries operate in the EPO) (east of 150° W longitude to the U.S. EEZ) and in the remainder the WCPO.

The international purse seine fishery targets yellowfin and skipjack tunas, although substantial quantities of bigeye tuna also are taken. Much smaller quantities of bonito, albacore and black skipjack also are taken. In the EPO in 1997, purse seine catches of yellowfin, skipjack and bigeye tunas exceeded 250,000 t, 150,000 t and 50,000 t, respectively. In the WCPO in 1997, purse seine catches of yellowfin, skipjack and bigeye tunas exceeded 230,000 t, 600,000 t and 28,000 t, respectively.

Bigeye Landings

As Table 3 illustrates, Japan has the highest bigeye landings, followed by Taiwan, South Korea and China. 2003 landings were the highest to date, information on landings following imposition of the 2004-2006 IATTC quota are unavailable at this time. Under this quota, countries were to reduce their landings to those reported in 2001. Approximately 5 percent of Hawaii-based longline bigeye landings are estimated to come from the EPO, as well as 100 percent of longline bigeye landings from domestic vessels ported on the west coast (i.e. in California).

Table 3. EPO longline catches of bigeye tuna (mt) (IATTC, 2005).

Year	Japan	South Korea	Taiwan	China	Other fleets	USA	Total
1999	22,224	9,431	910	660	961	228	34,414
2000	27,929	13,280	5,214	1,320	3,719	162	51,624
2001	37,493	12,576	7,953	2,639	4,169	147	64,977
2002	33,794	10,358	16,692	7,351	3,597	132	71,924
2003	20,517	10,272	12,501	10,065	1,292	232	54,879
Total	141,957	55,917	43,270	22,035	13,738	901	277,818
Percent of total	51.1%	20.13%	15.57%	7.93%	4.94%	0.32%	100%

Three U.S. flag purse seiners > 1,001 gross ton were active in the EPO fleet during 2004. These vessels operate within the jurisdiction of the IATTC and are also monitored by NMFS. The vessels are monitored by mandatory logbooks, the IATTC observer and port sampling programs, national surveillance activities and cannery records. EPO purse seine fisheries account for approximately 40 percent of the EPO bigeye catch, and in 2003 reported catching 40,122 t of bigeye tuna.

3.3.2 EPO Regional Stock Assessment

From Maunder and Hoyle 2005.

The IATTC Working Group on Stock Assessment found that their analysis suggests that by the beginning of 2004, the spawning stock biomass of bigeye in the EPO dropped below levels required to produce the average maximum sustainable yield (AMSY), and was predicted to drop to historic lows by 2007 – 2008 due to recent weak recruitments and high fishing mortality. The average weight of fish in the catch of all fisheries combined has been below the critical weight (about 49.8 kg) since 1993, suggesting that the recent age-specific pattern of fishing mortality is not satisfactory from a yield-per-recruit perspective.

The EPO assessment assumes no stock recruitment relationship and estimates below average recruitment in recent years. The researchers agree that recruitment is highly variable and difficult to predict, strengthening the importance of gaining increased understanding of recruitment processes.

The impact of purse seine and longline fisheries on the stock is considered to be highly significant. The analysis suggests that the initial decline in stock biomass was caused by longline fishing but accelerated declines since 2000 are mainly attributable to floating object based purse seine fishing. Under the current model, Spawning Biomass Ratio (SBR) levels are predicted to remain at very low levels for many years unless fishing mortality is significantly reduced or recruitment increases for several years.

Available information has shown that FADs substantially increase catchability of bigeye in offshore waters where they were formerly unexploited and that the floating object purse seine fishery has caused significant increases in fishing mortality of juvenile bigeye. A significant and more concerning matter is that that the EPO floating object FAD fishery takes a far higher proportion of sub-adult size bigeye compared to the WCPO fishery that harvests mainly smaller juvenile size bigeye. It might be expected that impacts on sub-adults would have a greater impact on potential spawning stock biomass and stock condition.

The authors conclude that the purse-seine fishery on floating objects has the greatest impact on the EPO bigeye tuna stock. Restrictions applied only to a single fishery (e.g. longline or purse-seine), particularly restrictions on longline fisheries, are predicted to be insufficient to allow the stock to rebuild to levels that will support the AMSY. Large (50%) reductions in effort (on bigeye tuna) from the purse-seine fishery will allow the stock to rebuild towards the AMSY level, but restrictions on both longline and purse-seine fisheries are necessary to rebuild the stock to the AMSY level in ten years. Simulations suggest that the restrictions imposed by the 2003 Resolution on the Conservation of Tuna in the EPO will not be sufficient to rebuild the stock.

There have been important changes in the amount of fishing mortality caused by the fisheries that catch bigeye tuna in the EPO. On average, the fishing mortality for bigeye with an age of less than about 20 quarters old has increased substantially since 1993, and that on fish with an age of more than about 24 quarters old has increased slightly. The increase in average fishing mortality on the younger fish was caused by the expansion of the fisheries that catch bigeye in association with floating objects. The base case assessment suggests that:

- The use of FADs has substantially increased the catchability of bigeye by fisheries that catch tunas associated with floating objects, and

- Bigeye are substantially more catchable when they are associated with floating objects in offshore areas.

Recruitment of bigeye tuna to the fisheries in the EPO is variable, and the mechanisms that explain variation in recruitment have not been identified. Nevertheless, the abundance of bigeye tuna being recruited to the fisheries in the EPO appears to be related to zonal-velocity anomalies at 240 meters during the time that these fish are assumed to have hatched. Over the range of spawning biomasses estimated by the base case assessment, the abundance of bigeye recruits appears to be unrelated to the spawning potential of adult females at the time of hatching.

There are two important features in the estimated time series of bigeye recruitment. First, greater-than average recruitments occurred in 1977, 1979, 1982-1983, 1992, 1994, 1995-1997, and during the second quarters of 2001 and 2002. The lower confidence bounds of these estimates were greater than the estimate of virgin recruitment only for 1994, 1997, and the recruitment in 2001 and 2002. Second, aside from these two recruitment pulses in 2001 and 2002, recruitment has been much less than average from the second quarter of 1998 to the end of 2003, and the upper confidence bounds of many of these recruitment estimates are below the virgin recruitment. Evidence for these low recruitments comes from the decreased CPUEs achieved by some of the floating-object fisheries, discard records collected by observers, length-frequency data, and poor environmental conditions for recruitment. The extended sequence of low recruitments is important because, in concert with high levels of fishing mortality, they are likely to produce a sequence of years in which the spawning biomass ratio (the ratio of spawning biomass to that for the unfished stock; SBR) will be considerably below the level that would support the average maximum sustainable yield (AMSY).

The biomass of 1+-year-old bigeye increased during 1980-1984, and reached its peak level of about 586,000 t in 1986. After reaching this peak, the biomass of 1+-year-olds decreased to an historic low of about 156,000 t at the start of 2004. Spawning biomass has generally followed a trend similar to that for the biomass of 1+-year-olds, but lagged by 1-2 years. There is uncertainty in the estimated biomasses of both 1+-year-old bigeye and spawners. Nevertheless, it is apparent that fishing has reduced the total biomass of bigeye present in the EPO. Both are predicted to be at their lowest levels by the end of 2004. There has been an accelerated decline in biomass since the small peak in 2000. Analysis of the impacts attributed to each fishery indicates that the initial decline can be attributed to longline fishing but the most recent declines are mainly attributed to purse-seine fishing. The estimates of recruitment and biomass were not sensitive to the range of alternative parameterizations of the assessment model considered or to the alternative data source included in the assessment. However, in the current assessment, a narrower range of alternative analyses were considered.

At the beginning of January 2004, the spawning biomass of bigeye tuna in the EPO was declining from a recent high level. At that time the SBR was about 0.14, about 32% less than the level that would be expected to produce the AMSY, with lower and upper confidence limits (± 2 standard deviations) of about 0.07 and 0.21. The estimate of the upper confidence bound is only slightly greater than the estimate of (Spawning Biomass Ratio-Average Maximum Sustainable Yield) SBRAMSY (0.20), suggesting that, at the start of January 2004, the spawning biomass of bigeye in the EPO was less than the level that is required to produce the AMSY. The dramatic change from being above the SBRAMSY level to below it has been predicted by the past three assessments. Estimates of the average SBR projected to occur during 2004-2014 indicate that the SBR is likely to reach an historic low level in 2007-2008, and remain below the level required to produce the AMSY for many years unless fishing mortality is greatly reduced or recruitment is greater than average levels for a number of years. This decline is likely to occur because of the recent weak cohorts and the high estimated levels of fishing mortality.

The average weight of fish in the catch of all fisheries combined has been below the critical weight of about 49.8 kg since 1993, suggesting that the recent age-specific pattern of fishing mortality is not satisfactory from a yield-per-recruit perspective. The average weight of purse-seine-caught fish is currently about 10 kg, while the average weight of longline fish is about 60 kg. Recent catches are estimated to have been about 26% above the AMSY level. If fishing mortality is proportional to fishing effort, and the current patterns of age-specific selectivity are maintained, the level of fishing effort that is estimated to produce AMSY is about 62% of the current level of effort. Decreasing the effort to 62% of its present level would increase the long-term average yield by 8% and would increase the spawning potential of the stock by about 156%.

The AMSY of bigeye in the EPO could be maximized if the age-specific selectivity pattern were similar to that for the longline fishery that operates south of 15°N because it catches individuals close to the critical size. All analyses considered suggest that at the start of 2004 the spawning biomass was below the level that would be present if the stock were producing the AMSY. AMSY and the fishing mortality (F) multiplier are sensitive to how the assessment model is parameterized, the data that are included in the assessment, and the periods assumed to represent average fishing mortality, but under all scenarios considered, fishing mortality is well above the level that will produce the AMSY. Presently the purse-seine fishery on floating objects has the greatest impact on the bigeye tuna stock. Restrictions that apply only to a single fishery (e.g. longline or purse-seine), particularly restrictions on longline fisheries, are predicted to be insufficient to allow the stock to rebuild to levels that will support the AMSY. Large (50%) reductions in effort (on bigeye tuna) from the purse-seine fishery will allow the stock to rebuild towards the AMSY level, but restrictions on both longline and purse-seine fisheries are necessary to rebuild the stock to the AMSY level in ten years. Simulations suggest that the restrictions imposed by the 2003 Resolution on the Conservation of Tuna in the EPO will not be sufficient to rebuild the stock. Projections indicate that, if fishing mortality rates continue at their recent (2002 and 2003) levels, longline catches and SBR will decrease to extremely low levels. As the base case does not include a stock recruitment relationship, recruitment will not decline, so purse-seine catches are predicted to decline only slightly from recent levels under this model.

Table 4 illustrates bigeye stock status; however note that at this time the stock structure of bigeye tuna in the Pacific Ocean is unresolved. NMFS is requesting that the HMS

Management Team and the HMS Advisory Sub-Panel look at establishing biological reference points for bigeye tuna, which are necessary before NMFS can support an overfished determination. If NMFS determines that bigeye tuna is overfished in the Eastern Pacific, the agency would provide formal notification of that determination to the Council; that determination would trigger the requirement in the MSA to prepare a rebuilding plan.

Table 4. Recent stock status with respect to management criteria (Pacific Fishery Management Council 2005).

Stock	$F_{Recent/}$ F_{MSY}[1]	Overfishing? (F/F_{MSY}>1.0)	$B_{Recent/}$ B_{MSY}	B_{MSST}/ B_{MSY}1	Overfished? (B_{Recent}/ B_{MSST})	B_{Flag} (1.25B_{MMST} /B_{MSY})	Assessment
Bigeye (EPO)	1.61[2]	Yes	0.57	0.6	Yes		IATTC, Harley and Maunder 2004
Bigeye (WCPO)	0.89-1.02[3]	Possibly[3]	1.75-2.28[3]		No		SCTB, Hampton et al., 2004

4.0 CONSEQUENCES OF MANAGEMENT OPTIONS CONSIDERED

4.1 Management Option 1: No Action

IATTC staff scientists determined that under the current exploitation patterns, and assuming recruitment at recent average levels, yields of bigeye tuna are expected to decline in the near future to levels below the average maximum sustainable yield, potentially leading to an overfished condition.

By implementing the no action management option (i.e. failure to implement measures that end overfishing) it is likely that a continued decline in Pacific bigeye stocks would result. If the Council chooses management option 1 as their strategy (no action), the stock could become overfished. Additionally, no action would be contrary to requirements in international agreements and to requirements of the MSA.

4.2 Management Option 2

Impacts on target and non-target stocks: As discussed previously (Table 3), west coast fisheries for bigeye tuna are small compared to other fishing nations and often are not a main target species. If management option 2 were adopted as part of the U.S. foundation

[1] Measures of F_{MSY} and B_{MSY} are not available. Various proxies for these values have been used in the preparation of this table. However, the Council has not adopted the use of a particular proxy and hence the designation of Overfished should be considered preliminary.
[2] EPO Bigeye and yellowfin results based on a base case assessments assuming no stock recruitment relationships.
[3] WCPO Bigeye results are based on 4 models where longline catchability was assumed constant over time. The probability that F_{Recent} /F_{MSY}>1 was greater than or equal to 0.67.

plan, domestic fishing mortality on bigeye could be reduced through regulatory controls, such as time/area closures. Additional controls on domestic fisheries for bigeye tuna would reduce future impacts to bigeye in the EPO; however, this action may overly burden U.S. fishermen that have a relatively minor role in bigeye tuna fishing mortality.

Because bigeye landings by West Coast fisheries are so small relative to Pacific-wide fishing nations, none of the regulatory controls considered here would be anticipated to have measurable impacts on bigeye stocks. Similarly, because landings of all non-target species are small relative to Pacific-wide landings, and options are not expected to adversely affect the catches of any of these fisheries, they are not anticipated to result in measurable impacts on non-target stocks.

Impacts on marine habitat: Purse seine and longline fisheries operations do not involve contact with the seabed, and because measures under management option 2 are not expected to alter these fishing operations, no adverse impacts on marine habitat are anticipated.

Impacts on biodiversity and ecosystem functions: The overall West Coast catch of bigeye tuna is less than 1 percent of the total Pacific-wide catch, thus adverse impacts to the tropical and subtropical pelagic ecosystems and biodiversity are not expected to occur.

Impacts to public health and safety: None of the measures contained in management option 2 are expected to require participants to fish in ways noticeably outside of historical patterns, and thus no impacts on public health and safety are anticipated.

Impacts on fishery participants and fishing communities: Anticipated impacts to affected participants would vary widely according to the severity of any new fishery management reduction in quota or fishing opportunities. However, because west coast bigeye tuna fishery participants are not highly dependent on bigeye for a majority of their landings the effects of any fishing restrictions could potentially be offset over time with increased landings of other species.

If management option 2 were adopted it would provide for the sustained participation of fishing communities by helping to ensure the long-term availability of bigeye tuna, however there would likely be a short-term reduction in economic benefits from the fisheries until the stock recovers.

Impacts on data collection and monitoring: Under this management option no new data collection or monitoring requirements are required.

4.3 Management Option 3

Impacts on target and non-target stocks: See section 7.2. Additionally, any measure that imposes minimum size limits on bigeye could potentially have a positive impact on the population by reducing fishing mortality on juvenile species. Management option 3 would also consider minimum size regulations on juvenile bigeye, which would prevent fishing nations from retaining and/or landing fish below a determined minimum size. Minimum size regulations are intended to conserve juvenile fish in three ways. First, prohibition on landing and/or sale prevents development of a commercial market for small fish, thereby discouraging fishermen from targeting them. Secondly, some of the small fish that are discarded will survive and mature to reproduce and contribute to the stock biomass. Third, a minimum size results in fewer fish being retained per mt than would be otherwise. However, to the extent that fishermen cannot control the size composition of the fish they catch, minimum sizes can result in significant discards of undersized fish. The objective to minimize bycatch and bycatch mortality, and the requirement to end overfishing should be considered when evaluating this management option.

Overall, greater restrictions on purse seine FAD fishing combined with minimum size limits would likely have a measurable beneficial impact on bigeye tuna conservation.

Impacts on marine habitat: See section 7.2.

Impacts on biodiversity and ecosystem function: See section 7.2.

Impacts on public health and safety: See section 7.2

Impacts of fishery participants and fishing communities: See section 7.2. Additionally, if fleets that catch 1 percent or less of the total Pacific bigeye tuna in the EPO are exempted then the focus of management and conservation would be on the fisheries with the greatest impacts and on the regions of highest catches. An exemption recognizes the need to avoid overly burdening those fleets and countries which are peripheral in generating fishing mortality for bigeye tuna.

Impacts on data collection and monitoring: See section 7.2.

4.4 Management Option 4

See sections 7.2 and 7.3 for impact determinations.

This control date would not bind the Council to establishing limited access or other management programs for these fisheries, but it would notify current and prospective fishery participants that additional management measures may be taken by the Council for these fisheries. The implementation of a control date would be in recognition of the fact that unlimited expansion of purse seining and longline fishing is untenable with the conservation of bigeye tuna.

4.5 Management Option 5

Closure of all fisheries under the Council's jurisdiction that catch bigeye tuna in the EPO would appear to address the contribution to overfishing from U.S. vessels in the eastern Pacific. However, this unilateral action would place an unfair burden on U.S. fishermen by threatening their livelihoods without any significant impact on reducing bigeye fishing mortality. This would not be consistent with the Council objective of addressing overfishing in a cost-effective and equitable manner and for that reason this alternative was not analyzed in detail.

5.0 MITIGATION AND UNAVOIDABLE ADVERSE IMPACTS (To be completed after Council decisions)

5.1 Mitigating Measures

5.2 Unavoidable Adverse Impacts

5.3 Irreversible and Irretrievable Commitment of Resources

6.0 LIST OF PREPARERS

Heidi Taylor

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