APPENDIX F

U.S. WEST COAST HIGHLY MIGRATORY SPECIES: LIFE HISTORY ACCOUNTS AND ESSENTIAL FISH HABITAT DESCRIPTIONS

(Originally Appendix A to the FMP)

U.S. West Coast Highly Migratory Species Plan Development Team
Pacific Fishery Management Council

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LIFE HISTORY ACCOUNTS AND HMS ESSENTIAL FISH HABITAT DESCRIPTIONS

Review of Methods

EFH designations are based largely on presence/absence and relative abundance data from fishery and fishery-independent sources, supplemented by other environmental information if available, such as preferred temperature ranges and water depths; current associations; centers of known target prey distribution; and other environmental preference information reported in the literature. The foundation of much of this material is commercial passenger fishing vessels logbook information[1]; data collected by federal observers aboard drift net and set net vessels fishing off California and Oregon; and catch data recorded by skippers in commercial fishing vessel logbooks (1990-1999)[2]. Some of the observer data allow us to analyze species distribution by size and sex and often by depth preference. Plots of drift net and set net observer effort are provided in Fig. 1 and 2. Where data were available, catch frequency distribution by bottom depth were also analyzed to determine isobath boundaries of designated EFH (see Chapter 4, Fig. 2 for bathymetry configuration within the U.S. West Coast EEZ). In the case of HMS species or life stages whose distributions were deemed coastal or where insufficient documentation exists as to the oceanic nature of their distribution, outer boundaries of EFH reflect the isobaths within which 95% of observed catches were recorded. Thus EFH designations represent the most important areas occupied, even though about 5% of individuals observed to utilize EEZ waters may occur infrequently in other areas within the zone. The textual accounts serve as the legal description of EFH, maps are provided as supplemental material, with observed catch locations by sex, size frequency and life stage to help facilitate visualization of boundaries. If preferred temperatures are provided in the EFH description, EFH areas for a species life stage that do not meet those preferred temperature requirements are not considered EFH. In general, designations of EFH are a combination of data from fishery and fishery-independent sources, life history information, expert opinion regarding the importance of certain areas, tagging and tracking data, and other pertinent information related to the environmental ecology of each species.

Definitions

The following habitat terms are defined as follows: *Epipelagic*: Vertical habitat within the upper ocean water column from the surface to depths generally not exceeding 200 m (0-109 fm), i.e., above the mesopelagic zone; *Mesopelagic*: Vertical habitat within the mid-depth ocean water column, from depths between 200 and 1000 m (109-547 fm); *Oceanic*: Inhabiting the open sea, ranging beyond continental and insular shelves, beyond the neritic zone; *Neritic*: Inhabiting coastal waters primarily over the continental shelf; generally over bottom depths equal to or less than 183 m or 100 fm deep.

1.0 SHARKS

1.1 Common thresher shark (*Alopias vulpinus*)

1.1.1 General Distribution

Epipelagic in neritic and oceanic waters in the Atlantic Ocean, Mediterranean Sea, Indian Ocean and central and western Pacific; in the eastern Pacific from Goose Bay, British Columbia south to off Baja California; also off Panama and Chile. Occurs in temperate and warm oceans, penetrating into tropical waters, being most abundant over continental and insular shelves and slopes (Compagno 1984). Adults, juveniles, and postpartum pups occur within the U.S. West Coast EEZ. Abundance once thought to decrease rapidly beyond

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[1] California Department of Fish and Game, 2000. Debbie Aseltine-Nielsen, California Commercial Passenger Fishing Vessel data, preliminary data analysis, unpub., CDF&G P.O. Box 271, La Jolla, CA, 92038.

[2] National Marine Fisheries Service. Unpub. California-Oregon Skipper Logbook and Drift Net Observer Program data and analyses for years 1990-1999, Rand Rasmussen, Southwest Fisheries Science Center, La Jolla, CA 92038.

40 miles from the coast, (Strasburg 1958; Litvinov 1990) but recent data indicate catches 100 miles offshore and beyond are not uncommon. This species is often associated with areas characterized by high biological productivity and 'green' water, the presence of strong frontal zones separating regions of upwelling and adjacent waters, and strong horizontal and vertical mixing of surface and subsurface waters—habitats conducive to production and maintenance of schooling pelagic prey upon which it feeds (Gubanov 1978; Kronman 1998). Off the U.S. West Coast during 1997-99, a period spanning warm and cool water years, common thresher shark catches were associated with sea surface temperatures (SSTs) from 13° to 25°C, with highest catches between 15° and 22°C (NMFS 2000a unpub observer data). Most years, concentrations of young occur within two to three miles off the beaches from Santa Barbara County through Santa Monica Bay; during warm water years nursery habitat extends northward to Monterey Bay and beyond (Bedford 1992). Young appear to prefer open coast and semi-enclosed bays (Eschmeyer et al. 1989; Dubsky 1974) with high concentrations of schooling prey on which they feed. Catches of pups <101 cm FL in offshore waters 200-300 fm deep, while less common than inshore captures, suggest parturition may occur offshore, after which time the pups move to inshore nursery areas. Habitat of subadults extends northward up the coast as the summer season progresses and may extend northward to the Columbia River mouth and to 48° N during warm water years (J. Fisher, comm. driftnet fisher, 3/5/02, PMFC briefing materials, ODFW 2002 unpub. data). The northern habitat boundary of adults and subadults may contract southward in cool water years and seasons.

1.1.2 Growth and Development

Maximum size to 610 cm TL; off the U.S. West Coast the largest reported is 550 cm TL (Eschmeyer et al. 1983). Size at first maturity has been variously estimated and interpreted and needs re-examination. Applying published data on size and sexual maturity (Bigelow and Schroeder 1948; Strasburg 1958; Gubanov 1978; Compagno 1984) to their growth curve, Cailliet and Bedford (1983) concluded that females mature at 260-315 cm TL and 3-4 years; males at 333 cm TL at 7 years old. A recently revised and updated von Bertanlanffy growth model, using a more precise alternate length to total length conversion, and incorporating new data from aged vertebrae from the California drift net fishery, indicates that females mature at 303 cm TL (160 FL) and 5.3 yrs old and males at about the same size and age (4.8 yr; 293-311 cm TL or 155-165 FL) (Smith et. al., In prep.[3]). For plotting life stage distributions we chose a conservative maturity boundary size of 166 cm FL for both sexes. Size at birth varies considerably, ranging from 115 cm to 156 cm TL, with only slight variation among geographical regions around the world (Bigelow and Schroeder 1948, Hixon 1979, Moreno et al. 1989). The species has been variously estimated to reach a maximum age of from 19 to 50 years (Cailliet and Bedford 1983, Smith et al. 1998).

1.1.3 Trophic interactions

Anecdotal reports of prey items from California and other waters, mention anchovy (*Engraulis* and *Anchoa* spp.), Pacific sardine (*Sardinops sagax*) herring (Clupeidae), mackerel (*Scomber* spp.), Pacific hake (*Merluccius productus*), lancetfish (*Alepisaurus*), lanternfishes (Myctophidae), Pacific salmon (*Oncorhynchus* spp.), squids, octopus, pelagic red crab (*Pleuroncodes planipes*), and shrimp (Gubanov 1972, Stick and Hreha 1989, Bedford 1992). Results of a recent food habit study of samples collected during the warm-water period of 1998 from the California-Oregon drift gill net fishery, revealed a varied diet of primarily northern anchovy, Pacific hake, and Pacific mackerel; secondarily sardine, market squid (*Loligo opalescens*), pelagic red crab, and louvar (*Luvarus imperialis*); and less importantly, jackmackerel (*Trachurus symmetricus*), shortbelly rockfish (*Sebastes jordani*); grunion (*Leuresthes tenuis*) and other atherinids, white croaker (*Genyonemus lineatus*), queenfish (*Seriphus politus*), and Pacific sanddab (*Citharichthys sordidus*) (Preti et al. 2001 in press). For sharks collected north of 34° N latitude, hake was the most important identifiable species in the diet; north anchovy was most important to the south, but was not identified in stomachs collected north of Point Conception. Diet appears to diversify with age/size, with anchovy an important staple among juvenile fish less than 160 cm FL (Preti et al. in press 2001). Alopiids have been observed to use their long caudal fin to bunch

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[3] Smith, S.E., R.C. Rasmussen, and D.A. Ramon. In prep. a. Biology and ecology of thresher sharks (Family Alopiidae). Submitted for inclusion *In* (E. Pikitch and M. Camhi, eds). Sharks of the Open Ocean. Blackwell Scientific Publications.

up, disorient and stun prey at or near the surface and are often caught on longlines tailhooked. Although this species can occur in schools, there is no documented accounts of cooperative feeding behavior. Predation on this species, other than by man, has not been documented.

1.1.4 Migrations, movements and stock structure

Common thresher sharks tagged by NMFS (Fisheries Resources Division, La Jolla, CA) with satellite pop-up tags in June 1999 off Laguna Beach and Santa Monica Bay have traveled to off Baja California Mexico by the following October and 540 miles southwest of La Paz, Mexico by the following January, confirming active transboundary migration in this species. Other, more indirect evidence, including spacio-temporal patterns of catches, suggest a seasonal north-south migration between San Diego/Baja California Mexico and Oregon and Washington. Bedford (1992) proposed that large adult common thresher sharks pass through southern California waters in early spring of the year, remaining in offshore waters from one to two months during which time pupping occurs. Pups are then thought to move into shallow coastal waters. The adults then continue to follow warming water and perhaps schools of prey northward, and by late summer, arrive off Oregon and Washington. Subadult members of the stock appear to arrive in southern California waters during early summer, and as summer progresses move up the coast as far north as San Francisco, with some moving as far north as the Columbia River area. In fall, these subadults are thought to move south again, arriving in the Channel Islands area. Little is known about the presumed southward migration of the large adults, which do not appear along the coast until the following spring. Genetic analyses of tissue biopsies collected off the U.S. West Coast and Mexico, grouping and comparing samples from off Oregon/Washington with samples collected off California and Baja California, Mexico, showed no significant differences in haplotypic frequencies, indicating a single homogenous West Coast population (Eitner 1999).

1.1.5 Reproduction

Ovoviviparous; normal brood size appears to be 2-4 fetuses (Gubanov 1978; Bedford 1992; Cailliet and Bedford 1983), although broods of up to 7 fetuses have been recorded off Spain (Moreno et al. 1989), indicating there may be some plasticity in this trait. The developing fetuses are oophagous (Gubanov 1978, Moreno et al. 1989, Bedford 1992, Gilmore 1993). Mating presumably takes place in midsummer along U.S. West Coast EEZ with a gestation period of about 9 months (Goldman and Amorim *In press*); parturition is thought to occur in the spring months off California, judging from the cluster of postpartum-sized pups taken in the catch at this time (Bedford 1992; NMFS drift net observer data).

1.1.6 Vital Rates/Statistics

Age at female maturity = 5 years; maximum reproductive age = 25; M = 0.179; potential rate of population increase = 0.04-0.07; maximum sustainable level of total mortality Z = 1.5M (Smith et al. b In prep[4]; Au et al. In prep[5])

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[4] Smith, S.E., D.W. Au, and C. Show. In prep b. Review of Shark Intrinsic Rates of Increase with Emphasis on Pelagic Sharks. Submitted for inclusion *In* (E. Pikitch and M. Camhi, eds). Sharks of the Open Ocean. Blackwell Scientific Publications.

[5] Au, D.W., S.E. Smith and C. Show. In prep. Estimating productivity and fishery-entry ages that guard reproductive potential and collapse thresholds of sharks. Submitted for inclusion *In* (E. Pikitch and M. Camhi, eds). Sharks of the Open Ocean. Blackwell Scientific Publications.

Growth for combined sexes estimated by Calliet et al. (1983) using the Von Bertalanffy equation and L_t = total length in cm,

$$L_t = 650.9[1-e^{-0.108(t-(-2.362))}]$$

An updated version of this equation (Smith et al. In prep. Ibid.), based on more precise length measurements and additional data points is as follows:

$$L_t = 464.9[1-e^{-0.129(t-(-2.879))}]$$

1.1.7 Fishery Utilization

This is currently the leading commercial shark taken in California, where it is taken primarily by drift nets (78%), followed by set gill nets (18%), and other assorted gears (4%) (CDFG 1999b). Area and season closures and other regulatory measures have greatly reduced the effort on this species since inception of the drift gill net fishery in the late 1970s when annual commercial catches averaged 510 mt per year from 1977-1989, peaking at 1059 mt in 1982. More recently, catches from 1990 through 1998 averaged 199 mt per year, with a low of 155 mt in 1995 and a high of 344 mt in 1991. A cooperative, tri-state interjurisdictional management plan was developed for this species in 1990 (PSMFC 1990). Directed fishing for this species is not allowed in Oregon and Washington, although beginning in 1999, bycatch landings are permitted in the Oregon swordfish drift net fishery at a ratio of one thresher shark for two swordfish landed. In 1999, 1.1 mt of thresher landed in Oregon–7 landed with trawl gear and 1 with drift gill net gear. It is taken only incidentally in the Washington trawl and Indian salmon fisheries. Directed recreational angling for thresher shark is popular in southern California, although this effort, primarily from private boats, is inadequately sampled. The West Coast stock is thought to be rebounding from its previously overfished condition, and is now estimated at just above MSY stock size (see Pelagics Sharks section, Ch. 3). Past exploitation reduced the population as indicated by a decline in CPUE, but estimates of the magnitude of the decline are complicated by the various area and time closures, and the offshore expansion when the fishery shifted target emphasis to swordfish. Recent levels of fishing appear to have allowed stock regrowth, as seen in the rise of CPUEs in certain areas, but new turtle-protection regulations may result in a shift in fishing effort to more southerly waters, which possibly may increase effort on threshers. But observer coverage should help anticipate any such increases.

1.1.8 Essential Fish Habitat for Common Thresher Shark (Figures 3 to 6): (Based on California drift gill net logbook (1981-1991); Oregon Dep. Fish and Wildl. driftnet logbook data 1991-2001Oregon driftnet log data drift net observer data (1990-1999). Food habit information from Stick and Hreha (1989), Bedford (1992) Preti et al. (in press 2001).

- Neonate/early juveniles (<102 cm FL): Epipelagic, neritic and oceanic waters off beaches, in shallow bays, in near surface waters from the U.S.-Mexico EEZ border north to off Santa Cruz (37° N) over bottom depths of 6 to 400 fm, particularly in water less than 100 fm deep and to a lesser extent further offshore between 200-300 fm. Little known of the food of early juveniles; presumably feeds on small northern anchovy and other small, schooling fishes and invertebrates.

- Late juveniles/subadults (> 101 cm FL and < 167 cm FL): Epipelagic, neritic and oceanic waters off beaches and open coast bays and offshore, in near-surface waters from the U.S. -Mexico EEZ border north to off Pigeon Point, California (37° 10' N) from the 6 fm to 1400 fm isobaths. Known to feed primarily on northern anchovy, Pacific hake, Pacific mackerel and sardine; secondarily on a variety of other fishes, squid and pelagic red crab (warm water years). Northern anchovy especially important for juvenile fish < 160 cm FL.

- Adults (> 166 cm FL): Epipelagic, neritic and oceanic waters off beaches and open coast bays, in near surface waters from the U.S.-Mexico EEZ border north seasonally to Cape Flattery, WA from the 40 fm isobath westward to about 127° 30' W longitude north of the Mendocino Escarpment and from the 40 to

1900 fm isobath south of the Mendocino Escarpment. Known to feed primarily on northern anchovy, Pacific hake, Pacific mackerel and sardine; secondarily on a variety of other fishes, squid and pelagic red crab (warm water years).

1.2 Pelagic thresher shark (*Alopias pelagicus*)

1.2.1 General Distribution

Epipelagic in oceanic and neritic waters throughout the tropical Indo-Pacific, occurring during exceptionally strong El Niño years in the eastern North Pacific rarely as far north as Cape Blanco, Oregon; more commonly distributed from the mouth of the Gulf of California, Mexico, south to the Galapagos Islands, Ecuador (Compagno 1984; Hanan et al. 1993; Holts et al.1999). The species also occurs in the western and central Pacific from Japan south to Australia and Tahiti and around the Hawaiian Islands. Distributional information is somewhat hampered by identification problems and confusion with the common thresher, *Alopias vulpinus*. When this species moves into the U.S. West Coast EEZ during warm water years, most catches are made in the Southern California Bight. It is the most tropical of known Alopiidae. Within the water column it ranges in depth from the surface to at least 152 m (Compagno 1984; Holts et al. in prep[6]). Tracking studies in the eastern tropical Pacific have indicated a water column temperature range of 14-28°C, with a night depth preference of 60-70 m (17-21°C water) with a slightly deeper daytime maxima of 70 to 100 m (and slightly cooler water (14-17°C). Numerous presumed feeding forays were tracked from these daytime cooler depths into much shallower and warmer water (23-28°C) (Nakano and Matsunaga, 1997 unpub[7]). All individuals observed in the California-based drift net fishery 1990-1998 were captured within 56 km from shore and in water 180 to 672 fm deep; with females, many (41%) pregnant, outnumbering males 5 to 1 (Holts et al. in prep. ibid.). Suitable nursery habitat is largely unknown within the EEZ and likely exists to the south off Mexico closer to the center of this species' distribution. A single neonate-size individual was observed in the drift net catch during the years 1990-99, near the U.S.-Mexico border. Because mature and pregnant females with late stage fetuses are known to move into the EEZ during warm water years and enter the drift net catch, the southern California Bight may serve as a pupping area on a sporadic basis, but to what extent these pups survive is not known.

1.2.2 Growth and development

Liu et al. (1999), who examined specimens from Taiwanese waters, report size at 50% sexual maturity at 145-150 cm PCL (282-292 cm TL;~163-167cm FL) and 140-145 cm PCL (267-276 cm TL;~157-161 cm FL) for females and males, respectively. Age of maturity for females was estimated to be 8.0-9.2 years, which is older than that estimated for *A. vulpinus* (~4-5 years), even though it is a smaller species. The size at birth ranges from 158-190 cm TL (112-125 cm FL) and represents the largest ratio of pup to maximum adult size of the three species of *Alopias* (Liu et al. 1999).

1.2.3 Trophic interactions

Little is known; presumably feeds on small schooling fishes and squid (Compagno 1984). Results of acoustic tracking in the eastern tropical Pacific (Nakano and Matsunaga, 1997, ibid.) suggest it is primarily a daytime feeder.

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[6] Holts, D.B., R. Rasmussen, and D. Ramon. In prep 2000. Occurrence of the pelagic thresher shark (*Alopias pelagicus*) in the eastern North Pacific. NOAA NMFS Southwest Fish. Sci. Ctr., P.O. Box 271, La Jolla, CA 92038. Presented International Pelagic Workshop, Monterey, CA, Feb 2000.

[7] Nakano H., and H. Matsunaga. 1997. unpub. rep. Acoustic tracking of bigeye thresher shark, *Alopias superciliosus*, in the eastern Pacific Ocean. National Research Institute of Far Seas Fisheries, Shimizu,Japan. Presentation, Indo-Pacific Fish Conference, Noumea, New Caledonia.

1.2.4 Migrations, movements and stock structure

Movements and migration are poorly understood, except that during exceptionally warm years there is a pronounced shift northward of what appears to be largely a Mexican stock (Compagno 1984; Holts et al. 2000 ibid.). Biopsy collections are continuing to be being made from the Hawaii longline and California drift net fishery in the event resources can be made available for genetic sequencing work to determine the relationship of the stocks found off Mexico-California and Hawaii.

1.2.5 Reproduction

Ovoviviparous; with a litter size of two (one embryo developing in each uterus); fetuses are oophagous (Otake and Mizue 1981; Compagno 1984; Liu et al. 1999). Liu et al. (1999) found a wide range of embryo sizes in fish they examined from Taiwan waters, and thus concluded that this species does not have a resting state or particular pupping season, at least in Taiwan. The gestation period has not been estimated. Reproductive tracts and fetuses collected by drift net observers during those years are currently being examined at the Southwest Fisheries Science Center (D. Ramon, pers. comm, NMFS, SWFSC, La Jolla 1999).

1.2.6 Vital Rates/Statistics

Age at female maturity = 9 years; maximum reproductive age = 29; M = 0.155; potential rate of population increase = 0.0243; maximum sustainable level of total mortality Z = 1.5M. Liu et al. (1999) estimated the following von Bertanlaffy growth equation for the two sexes using L = Precaudal length (PCL) in cm:

$$♀L_t = 197.2[1-e^{-0.085(t -(-7.67))}]$$

$$♂L_t = 182.2[-e^{-0.118(t-(-5.48))}]$$

Liu et al. (1999) provide a PCL to TL conversion as follows:

♀TL = 2.34 + 1.93 PCL

♂TL = 2.33 + 1.89 PCL

1.2.7 Fishery Utilization

Occurs in the California commercial catch primarily during warm water years, mostly in the Southern California Bight. Since 1981, annual landings of *Alopias pelagicus* in the drift net fishery have ranged from 0 to 20.7 metric tons, with peak catch in the 1997 warm water year (Holts et al. 2000, ibid.). The flesh is considered inferior in quality compared to that of the common thresher. In Oregon, it is rare in the commercial catch in El Niño years; there are no known records from Washington waters. This species may enter the California recreational fishery during warm water years.

1.2.8 Essential Fish Habitat for Pelagic Thresher Shark (Figures 7 to 9): (Based on California drift gill net logbook (1981-1991) and drift net observer data (1990-1999).

- Neonate/early juveniles (<137 cm FL): There is no evidence of successful nursery habitat within the EEZ, presumably pupping takes place to the south off Mexico closer to the center of this species' distribution. Nothing known of diet; presumably feeds on small schooling fishes and squids.

- Late juveniles/subadults (>136 cm FL and < 162 cm FL): Epipelagic and predominantly oceanic waters along coastal California from the U.S. Mexico border as far north as 34° N latitude, from the 100 fm isobath about out to the Santa Rosa-Cortes Ridge, particularly between San Diego and Long Beach, California. (Line extends south from Ridge to a point on the EEZ boundary at 31° 36' N and 118° 45' W).

Associates with sea surface temperatures of 21°C or warmer; nothing known of diet; presumably feeds on small schooling fishes and squids

- Adults (≥ 161 cm FL, predominantly adult females): Epipelagic and predominantly oceanic waters along coastal California from the U.S. Mexico border as far north as 34° N latitude, from the 100 fm isobath about out to the Santa Rosa-Cortes Ridge, particularly between San Diego and Long Beach, California. (Line extends south from Ridge to a point on the EEZ boundary at 31° 36' N and 118° 45' W). Associates with sea surface temperatures of 21°C or warmer. Nothing known of diet; presumably feeds on small pelagic schooling fishes and squids e, in near surface waters from the U.S.-Mexico EEZ border north to off Pigeon Point, California,

1.3 Bigeye thresher shark (*Alopias superciliosus*)

1.3.1 General Distribution

The bigeye thresher occurs in the Atlantic Ocean, western Mediterranean, western Indian Ocean and central and western Pacific; in the eastern Pacific from Vancouver, British Columbia, south to the Gulf of California; Mexico; usually south of 45° N latitude. An epipelagic and mesopelagic species, it occurs in both oceanic and neritic waters, over continental and insular shelves, and occasionally in shallow areas (Gruber and Compagno, 1981; Compagno 1984). Like the common thresher, the bigeye is found in tropical, sub-tropical and warm-temperate seas, but is known to range deeper than the former species. Sometimes co-occurs in the catch with the common thresher, but in general more offshore, especially north of Point Conception. The first reported catch within the U.S. West Coast EEZ occurred in 1963 when a bigeye was taken in a set gill net in southern California (Fitch and Craig 1964); it is now a regular incidental species in the drift net fishery. Depths of occurrence range from the surface down to an observed maximum depth of 723 m, with tracked individuals found to occur in deeper (200-550 m) and cooler (6-11°C) water during the day, shifting upwards to the mixed layer (at about 50 to 130 m) and warmer water temperatures (15-26°C) at night (Nakano and Matsunaga, 1997, unpub., ibid). Bigeye can reportedly stay in cooler water and for longer periods of time than other pelagic sharks. It is taken in drift nets in California waters from the surface to near bottom at 110-183 m and associated with SST of 15-24°C. The population off California and Oregon appears to be predominantly adult males (71% of observed catches are mature males) which range north to off Oregon, and immature females which primarily occur south of Monterey Bay and in the Southern California Bight. Juveniles off the U.S. West coast appear to be associated with a broader range of sea surface temperatures (15°-25°C) than adult males (15-18.5°C), judging from observed temperatures at catch locations 1997-99, although more data are needed to determine actual temperature preferences off the U.S. West Coast.

1.3.2 Growth and development

Maximum size reported is 461 cm TL (~258 cm FL; New Zealand); females average larger than males (Gruber and Compagno 1981). Although this species averages smaller in size than at least some world populations of *Alopias vulpinus* (e.g., in the Atlantic), bigeyes recorded by fishery observers in the drift net fishery are often large specimens (190-260 cm FL), compared to the 150-180 cm FL specimens of *A. vulpinus* that dominate the catch. These large bigeyes are mostly mature males.

This species appears to grow much more slowly than the common or pelagic thresher shark, but as with other *Alopias* spp., current growth estimates depend on the assumption of the one-centrum band-pair-per-yr assumed for this group, which has yet to be validated. Liu et al. (1998), after ageing 214 females and 107 males from waters off northeastern Taiwan, and comparing their results with the reproductive findings of Chen et al. (1997), estimated sizes and ages at female maturity to be 332-341 cm TL (189-194 cm FL) and 12.3-13.4 years, and for males, 270-288 cm TL (156-165 cm FL) and 9-10 year. They estimate maximum age at about 20 years. Size at maturity is very similar to that in populations examined elsewhere (Chen et al. 1997; Stillwell and Casey 1976; Moreno and Moron 1992), although age and growth have not been studied in the eastern Pacific. Size at birth is at least 100 cm TL (64.5 cm FL) (Moreno and Moron 1992) with the average probably between 145-149 cm TL (89-91 cm FL) (Chen et al. 1997; Liu et al. 1998).

1.3.3 Trophic interactions

Very little is known. One specimen taken off California contained Pacific whiting, *Merluccius productus* (Fitch and Craig 1964); another (403 cm TL male taken off northern California in water 1819 fm deep) examined by Ramon and Preti (SWFSC, NMFS, pers. commun, unpub. data, 9/2000) contained two king-of-the-salmon (*Trachipterus altivelis*) approximately 84 cm long, and one *Gonatus sp*. squid. Elsewhere known to feed commonly on squid and also pelagic teleosts such as scombrids, alepisaurids, clupeids, and istiophorids (Stillwell and Casey 1976; Gruber and Compagno 1981). Also reported to prey on other elasmobranchs in Australian waters (Bass et al. 1975). Bigeye threshers have specialized eyes that can roll up into upward-directed sockets, possibly allowing them to feed on prey silhouetted from above. Tracked individuals have exhibited a nighttime oscillating swimming pattern of slow ascent then rapid descent, probably a strategy to maximize their upward searching time (Nakano and Matsunaga 1997, unpub., ibid.). Like the common thresher, the bigeye appears to use its tail to either herd, stun, or disorient prey in feeding; there are many reports of this species utilizing its long tail to strike at baits (e.g., Gubanov 1972; Stillwell and Casey 1976).

1.3.4 Migrations, movements and stock structure

Long-term migrations have not been studied in this species and stock structure is poorly understood. Acoustic telemetry has been used to identify water column preference and short-term horizontal and vertical movement in the eastern Pacific off Central and South America between 100° W and 120° W (Nakano and Matsunaga 1997, unpub., ibid.). Results suggest diel vertical migration and primarily night feeding in this species, especially in the area of the thermocline, and an ability to adjust to water temperatures ranging from 6-26°C. Bigeye thresher in the Atlantic are known travel 1,000 to 2,000 miles from the shelf off New Jersey eastward into the central Atlantic and southward into the Gulf of Mexico, and from North Carolina south to off Cuba (Kohler et. al 1998).

1.3.5 Reproduction

Ovoviviparous; fetuses are oophagous as in other lamnids and odontaspids; litter size is commonly 2, one in each uterus, rarely 4 (Moreno and Moron 1992). A ‘probable’ period of gestation has been estimated at 12 months (Holden 1974) and appears not to be seasonal (Moreno and Moron 1992; Gruber and Compagno 1981.)

1.3.6 Vital Rates/Statistics

Age at female maturity = 12-13 years; maximum reproductive age = 20 (Chen et al. 1997; Liu et al. 1998); M = 0.223; rate of population increase under sustainable exploitation = 0.0156; maximum sustainable level of total mortality Z = 1.5M. Liu et al. (1998) estimated the following von Bertalanffy growth equation for the two sexes where L = Precaudal Length (PCL) in cm:

♀ $L_t = 224.6[1-e^{-0.092(t -(-4.21))}]$

♂ $L_t = 218.8[-e^{-0.088(t-(-4.24))}]$

Liu et al. (1998) provide PCL to TL conversions as follows:

♀ TL = 15.3 + 1.81PCL

♂ TL = 15.1 + 1.76PCL

1.3.7 Fishery Utilization

Taken primarily in the California drift net fishery from August to November with a peak in September, and as far north as Cape Blanco, Oregon (Hanan et al. 1993). Between 1981 through 1998 an average of 20.2 mt per year of this species was landed from the drift net fishery (range = 0 to 56.5 mt) with highest catches in 1983-1985. There is no fishery in Oregon, but some are taken off Oregon by the California-based drift net fishery. It is not known if this species enters the California recreational fishery on any regular basis; presumably only few are taken, and there are no records from the recreational fishery off Oregon or Washington.

1.3.8 Essential Fish Habitat for Bigeye Thresher Shark (Figures 10 to 12): (Based on California drift gill net logbook (1981-1991); drift net observer data (1990-1999); Nakano and Matsunaga, 1997, unpub. ibid.). Diet information from Fitch and Craig (1964) and Ramon and Preti (SWFSC, NMFS, pers. commun., unpub. data, 9/2000)

- Neonate/early juveniles (~90 to 115 cm FL, 0 to 2 and 3 yr olds): These size classes are not known to occur in U.S. West Coast EEZ.

- Late juveniles/subadults (>115 cm FL and < 155 cm FL males and < 189 cm females): Coastal and oceanic waters in epi- and mesopelagic zones from the U.S.-Mexico border north to 37° N latitude off Davenport, California. South of 34° N latitude from the 100 fm isobath to the 2000 fm and north of 34° N the 800 fm isobath out to the 2200 fm isobath. Nothing known of diet in our region; presumably feeds on pelagic fishes and squids.

- Adults (> 154 cm FL males and >188 cm FL females): Coastal and oceanic waters epi-and mesopelagic zones from the U.S.-Mexico border north to 45° N latitude off Cascade Head, Oregon. In southern California south of 34° N latitude from the 100 fm isobath out to the 2000 fm isobath. North of 34° N latitude from the 800 fm isobath out to the outer EEZ boundary. Little known of the diet in our region; presumably feeds on pelagic fishes and squids, including Pacific hake and king-of-the-salmon.

1.4 Shortfin mako shark (*Isurus oxyrhinchus*)

1.4.1 General Distribution

Oceanic and epipelagic in warm-temperate and tropical seas worldwide; in the eastern Pacific from Chile to the Columbia River; juveniles are also common in neritic waters. Found within the U.S. West Coast EEZ from the U.S.-Mexico border northward to Washington; most common off California. Once reported as occurring primarily within 93 km of shore and seldom north of 40° N latitude (Holts and Bedford 1993; Hanan et al. 1993). More recent drift net observer data indicate a more northerly and offshore distribution north to off Oregon, probably due to a combination of factors, including the increase in drift net effort in these northern and offshore areas and/or increased water temperatures in recent decades that have expanded northward. The species is known to occur from the surface to at least 150 m depth; with catches observed off California associated with sea surface temperatures ranging from 15°C to 25°C (NMFS 2000a).

Much of the U.S. West Coast catch is comprised of juvenile fish with some adult-sized males; adult females are rarely taken. When large specimens are caught, they usually occur around the Channel Islands and outer banks of the Southern California Bight in late summer, suggesting some limited seasonal incursion of adults around this time. Geographical, size and sex distribution of California drift net fishery-observed catches of shortfin mako sharks in 1990-99 (n = 2578) shows occurrences as far north as 45° N latitude and a bi-modal size distribution with peaks at 90 and ~130 cm FL, and an overall sex ratio approximately 1:1. Oregon driftnet logbook data from 1991-2001 indicates catches to 47° N and beyond off Washington. The southern and western boundaries of the nursery area have yet to be defined. From the distribution of pups ≤ 100 cm FL in the observed CA/OR drift net catch, nursery habitat utilization appears concentrated in the Southern California Bight area, particularly south of Los Angeles to the Mexico-California border. Habitat usage north of Monterey by young fish occurs predominantly during warm water years; the northern habitat boundary contracting with cooling water temperatures seasonally and interannually. Water column preference of subadults is little known except from tracking studies in the Southern California Bight which showed primary distribution above the thermocline in the mixed layer, with frequent diving from the surface to 25 m, and only rare forays below the thermocline in cooler water, with no diel pattern (Holts and Bedford 1993). Water column preference of adult fish is little known except from tracking of one adult in the Atlantic which revealed large vertical movements between the surface and 450 meters during the day, with small excursions down to the thermocline at night (Casey and Kohler 1992).

1.4.2 Growth and Development

Maximum size reported for shortfin mako worldwide is a 400- cm TL (~355 cm FL) specimen harpooned off Maine on 8 Aug 1997[8]. The largest documented off the U.S. West Coast was a 351 cm TL (312 FL) individual (Cailliet et al. 1983). Normal size [of most large specimens] caught off the U.S. West Coast is from 213-244 cm TL (189-217 cm FL) (Roedel and Ripley 1950; drift net observer data 1990-2000). Results differ between age and growth studies done to date, primarily depending on whether one assumes one (Cailliet et al. 1983) or two (Pratt and Casey 1983) band pairs is deposited annually in vertebral centra used for aging. Some differences may also be due to the difficulty of interpreting growth rings and length frequency modes in older age classes, and Atlantic-Pacific stock differences. Males are thought to attain sexual maturity at a much smaller size (and presumed age) than females, which is estimated at about 195 cm TL or 174 cm FL (Stevens 1983). Females reportedly mature at 280 cm TL (249 cm FL) off New South Wales (Stevens 1983) and 298 cm TL (265 cm FL) in the western North Atlantic (Mollet et al. 2000). Gubanov's (1978) age at female maturity estimate of 188 cm TL (167 cm FL) for the Indian Ocean, and Bigelow and Schroeder's (1948) estimate of 183 cm TL (163 cm FL) for the Northwest Atlantic are now questioned, primarily because they are based on anecdotal secondary-source reports with inconclusive evidence of actual sexual maturity. Steven's (1983) length of female maturity (280 cm TL/249 cm FL) applied to the one-band pair per year growth curve for California fish of Cailliet et al. (1983), calculates to an age at first maturity of 25 yrs, which seems improbable. If applied to the Pratt and Casey (1983) curve, age at first maturity would be 5 yrs. At present, the best fit to observed growth patterns appears to be the two pair deposition/year hypothesis, and the faster growth rate of Pratt and Casey (1983), but this aging issue can only be resolved by empirically validating the periodicity of band formation.

1.4.3 Trophic interactions

Eschmeyer et al. (1983) report that this species preys on schooling fishes such as sardines and mackerel, and also swordfish, blue shark, and cephalopods. In-depth trophic studies have not been undertaken off the West Coast or elsewhere, and information on the feeding habits of large adult shortfin mako is scarce. Higher research longlining catches during the day versus night suggests the species feeds predominantly during the day. Hanan et al. (1993) report that off California makos feed on mackerel, bonito, anchovy, tuna, other sharks, and squid. Stomach contents of two large sport-caught makos caught off southern California in 1999 were recently examined by NMFS biologists (D.Holts, NMFS, SWFSC, La Jolla, pers. comm. 10/16/2000). A 3.4 m TL female contained remains of a young harbor seal, a small common dolphin, and vertebrae of one or more unidentified small sharks. A 2.7 TL m male was found to contain remains of a billfish, tentatively identified as a striped marlin, and another unidentified teleost.

1.4.4 Migrations, movements and stock structure

Juvenile fish that inhabit southern California waters appear to be resident for an estimated two years after birth, judging from the high tag recapture rates of tagged juvenile in the Southern California Bight and presumed size at age estimated by Bedford (1992) and Cailliet and Bedford (1983). Thereafter, they presumably move offshore or to the south. Many fish tagged in the Southern California Bight (mostly juveniles) have been recaptured locally, but some have been taken as far north as Point Area, northern California; as far south as Acapulco, Mexico; and as far west as off Hawaii (Hanan et al. 1993; California Department of Fish and Game, 1997; 1999a; 2000b). Much of the tagging data has not been subjected to formal analyses to date and no migratory pattern has become obvious; but these documented movements

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[8] Mollet, H. F. pers. commun., Monterey Bay Aquarium, 886 Cannery Row, Monterey CA 93940, 9/99.

do suggest that the California-Mexico stock (at least that composed of larger juveniles and adults) is a wide-ranging population that may be the same as that exploited in the central Pacific. Along the Atlantic Coast, this species is thought to seasonally move inshore and northward from more offshore wintering grounds with warming of inshore waters in the spring (Casey and Kohler 1992; Kohler et al. 1998).

1.4.5 Reproduction

Shortfin mako are ovoviviparous and oophagous, the fetuses feeding on a supply of eggs continuously ovulated by the female. Little is known about the reproductive cycle and there are few records of pregnant females. There is a wide range in estimates of fecundity, which may be due to stock differences, female size sampled, and/or fetuses being aborted on capture. Relatively few data are available because there are few records of pregnant females. Litters 6-10 (Gohar and Mazhar 1964; 1968; Gubanov 1972, 1978), and 4 to 25-30 pups (Stevens 1983; Mollet et al. 2000) have been observed. The gestation period has been variously estimated at from 12 to 18 months (Mollet et al. 2000; Pratt and Casey 1983; Cliff et al. 1990; Bedford 1992). Mollet et al. (2000) report that litter size ($\bar{x}$=12.5 pups) increases with maternal size, and present evidence for a 3 year reproductive cycle, although a 2-year cycle could not be ruled out.

1.4.6 Vital Rates/Statistics

Age at female maturity has been estimated at 5 - 25 yrs, depending on the growth curve applied (Pratt and Casey 1983 or Cailliet and Bedford 1983, respectively). Maximum reproductive age estimated by Smith et al. (1998) taking age at size of 90% of L_∞ of Cailliet and Bedford's (1982) growth curve is 28 years, but again, the growth curve upon which this estimate is made may not be accurate. The largest specimen recorded by Pratt and Casey (1983; 376 cm TL/328 cm FL) would be 14-15 yrs old according to their growth curve, while a fish near their L_∞ size of 386 TL/345 cm FL would calculate to an age of about 34 yrs. Assuming an average maximum age of 15, age of female maturity of 6 yrs, and annual female pup production of 3, the following parameters are estimated: M = 0.160; potential rate of population increase = 0.036 - 0.062; maximum sustainable level of total mortality Z = 1.5M. Growth for combined sexes estimated by Calliet et al. (1983) using the Von Bertalanffy equation where L = total length in cm is given as:

$$L_t = 321.0[1-e^{-0.072(t-(-3.75))}]$$

Pratt and Casey's (1983) growth function for females and males, where L = fork length (FL) where FL = (0.929-1.931) TL, is given as:

$$♀\ L_t = 345.0[1-e^{-0.203\ (t-(-1.0))}]$$

$$♂\ L_t = 302.0[1-e^{-0.266\ (t-(-1.0))}]$$

1.4.7 Fishery Utilization

The shortfin mako is currently considered the 2nd most important commercial shark in California, where it is taken primarily in the drift net fishery targeting swordfish. Much less is commercially landed now (~79 mt/yr) than in the peak fishing year of 1982 (~244 mt/yr) due to drift net restrictions imposed by the Pacific states. From 1988 to 1991, an experimental drift longline fishery targeting makos and blue sharks was conducted off California, subject to a 80 mt total allowable catch. This experimental fishery terminated in 1992 in state and federal waters because the fishery could not develop a viable market for blue sharks and because of concern over the predominance of juvenile mako sharks in the catch. A new high-seas drift longline fishery that fishes beyond the EEZ developed between 1991 and 1994 for sharks and swordfish, with the catch landed at California ports. A small amount of mako sharks is landed in this fishery (PFMC 1999) with catches between 1991 and 1994 ranging from 0.9 to 13.3 mt. (Vojkovich and Barsky 1998). No fisheries exist for this species in Oregon, although some are taken incidentally by the swordfish drift net fishery, especially in warm water years. It is not landed in Washington state waters. The shortfin mako shark does not occur regularly in the recreational catch north of Point Conception, but appears to be the leading pelagic shark sought by southern

California anglers. Trends in the stock as reflected by the fisheries are complicated by variations in the distribution of catchable fish within the West Coast EEZ relating to shifts in water temperature regimes. Mako average size in the drift net fishery declined by almost 40% between 1981 and 1985, increased again through 1990, then showed a slow but continuing decline in mean length through 1994 (Holts et al. 1998). A slight decline in density and average size has also been noted research surveys conducted by NMFS 1994-1997. In contrast, the number of makos landed by commercial passenger fishing vessels has shown a dramatic increase from 26 fish landed in 1982 to 794 fish in 1997. This effort is considered only a portion of the total recreational effort for this species. Higher catches are associated with warmer water periods.

1.4.8 Essential Fish Habitat for Shortfin Mako Shark (Figures 13 to 16): Based on California drift gill net logbook (1981-1991);Oregon Dep. Fish and Wildl. driftnet logbook data 1991-2001; drift net observer data (1990-1999); longline and gillnet catch data from Nakano (1994); California Department of Fish and Game tagging data; Holts and Bedford (1993); and Casey and Kohler (1992)) Food habits information from Hannan et al. (1993); Eschmeyer et al. (1983); D. Holts (NMFS, SWFSC La Jolla, pers. comm. 10/16/2000).

- Neonate/early juveniles (< 101 cm FL): Oceanic and epipelagic waters of the U.S. West Coast from the 100 fm isobath out to the 2000 fm isobath (and possibly beyond) from the Mexico border to Point Pinos, CA, especially the Southern Calif. Bight, from the 1000 fm isobath out to 2000 fm isobath from Monterey Bay north to Cape Mendocino; and from the 1000 fm isobath out to the EEZ boundary north of Cape Mendocino to latitude 46° 30' N latitude. Occupies northerly habitat during warm water years. Nothing documented on food of neonates; presumably feeds on small pelagic fishes.

- Late juveniles/subadults (> 100 cm FL and < 180 cm FL males and < 249 cm FL females): Oceanic and epipelagic waters from the U.S.-Mexico EEZ border north to 46° 30' N latitude from the 100 fm isobath out to the EEZ boundary north to San Francisco (38° N), and from 1000 fm out to the EEZ boundary north to San Francisco (38° N) and from 1000 fm out to the EEZ boundary north of San Francisco. Shortfin mako off the West Coast reportedly feed on mackerel, sardine, bonito, anchovy, tuna, other sharks, swordfish and squid. Since the large majority of makos within the EEZ are juveniles, presumably this diet refers to primarily to juveniles and subadults.

- Adults (> 179 cm FL males and > 248 cm FL females--Most adults within the U.S. West Coast EEZ are males.): Epipelagic oceanic waters from the U.S.-Mexico EEZ border north to 46° 30' N latitude extending from the 400 fm isobath out to the EEZ boundary south of Point Conception, from 1000 fm isobath out to the EEZ boundary and beyond north of Point Conception, and from the 1000 fm isobath out to the EEZ boundary and beyond, North of Point Conception, CA. Little is known of diet of large adults. Two adult shortfin mako over 250 cm TL were found to contain remains of a harbor seal, common dolphin, small sharks, and marlin (D. Holts, NMFS, SWFSC La Jolla, pers. comm. 10/16/2000). As with juveniles, presumably mackerel, sardine, bonito, anchovy, tunas, squid and swordfish may also be taken by adults, but existing published information on diet in our region is not broken down by mako size.

1.5 Blue shark (*Prionace glauca*)

1.5.1 General Distribution

Primarily epipelagic, oceanic and circumglobal in warm seas worldwide; sometimes occurring near the coast where the shelf narrows or is cut by submarine canyons close to shore. In the eastern Pacific, the blue shark occurs from the Gulf of Alaska to Chile; abundant in offshore and coastal waters of the western United States and Mexico (Compagno 1984). Found from the sea surface to about 350 m (Compagno 1984). This is probably the most wide-ranging of all sharks, being found throughout tropical and temperate seas from 60° N to 50° S latitude. In the Pacific, it is present in greatest abundance between 20° N and 50° N, where it shows strong fluctuations in seasonal abundance related to population shifts northward in summer and southward in winter (Nakano and Seki *in press*). There is considerable sexual segregation in populations with females more abundant at higher latitudes than males.

Within the U.S. West Coast EEZ, there also appears to be distributional differences with blue shark size and sex. In general, juveniles are abundant off California, especially in the Southern California Bight and Monterey Bay area from May to October (Sciarrotta and Nelson 1977; Tricas 1979; Hanan et al. 1993), but there may not be partitioning of pups in defined nursery areas apart from larger and older individuals, as previously thought. Examination of the distribution of 0-1 year old pups (≤ 82 cm Fl or 101 cm TL) in the drift net fishery, has revealed that their distribution is as broad as the total catch distribution, and they appear not to extend as far inshore as larger juveniles and adults. Pupping grounds for this species reportedly lies within the North Pacific Transition Zone (NPTZ) in the latitudinal band 35°-45° N and the larger nursery area extends slightly above and below this band. Judging from the occurrence of pups of this size in the drift net catch, this nursery area extends from 31° to 47° N within the U.S. West Coast EEZ.

Driftnet observer data indicate that the sex ratio off the U.S. West Coast is near 1:1 in very young fish until they reach about 100 cm FL, after which time, males begin to dominate. After females reach about 100 cm FL, they decline sharply from the catch. Given that females and males mature somewhere between 130 and 160 cm FL, it appears that mature females leave the West Coast EEZ or otherwise become increasingly unavailable to the fishery upon approaching or reaching maturity. The finding of equal or male-weighted sex ratios in juveniles is contradictory to the findings of Harvey (1989), who found that females predominated among the immature blue sharks he sampled in Monterey Bay, although his sampling may have reflected localized or smaller-scale sexual segregation. Among adult-sized fish, females predominate in the observed drift net catch north of Monterey Bay, and adult males predominate to the south, especially in the southern California Bight. Both sexes, but with males still predominating approximately 2 to 1, occur off central California between 35° and 37° N latitude. The size composition of the U.S. West Coast blue shark catch differs from that of the Hawaii-based longline fishery, which appears to be made up of mostly adults (J. Wetherall, pers. commun. NMFS, Honolulu Laboratory).

Among the HMS sharks, blues are tolerant of a relatively wide range of water temperatures. According to Compagno (1984) and Eschmeyer et al. (1983), the species apparently prefers relatively cool water at 7° to 16°C, but can tolerate water at 21°C or more; in the tropics it occurs at greater depths. Nakano and Nagasawa (1996) using surface salmon research drift net data in the North Pacific found that large females tend to occur in a wider range and cooler water temperatures (8° to 21°C) than males (12-14° to 21°C), with young sharks smaller than 68 cm TL (~57 cm FL) in water 12° to 19°C. Sea surface temperatures associated with blue shark drift net catches off the U.S. West coast range from 12°-25°C, but over 90% of the catches, which occur north of 33° N latitude, are taken in water 14°-18°C. This agrees generally with the results of Sciarotta and Nelson (1977) who tracked blue sharks off California and found they spent 75% of tracking time in water 14° to 16°C. Strasburg (1958), who compared hooking rates and catch depths of blues, found that north of 30° N latitude blue sharks preferred shallower depths less than 85 meters; however, Nakano et al. (1997) found no difference in catch rates with fishing depth in the equatorial Pacific and northeast of Hawaii.

1.5.2 Growth and Development

Maximum reported size for the blue shark is 396 cm TL (326 cm FL) (Bigelow and Schroeder 1948), but blues taken off the U.S. West Coast average much smaller (Cailliet and Bedford 1983) and are seldom over 260 cm TL (214 cm FL) (Strasburg 1958; OR/CA drift net observer data). For Pacific blue shark, Nakano (1994) reports size and age at 50% maturity in males is 203 cm TL (167 cm FL) and 4-5 years old, and in females at 186-212 cm TL (153-174 cm FL) and 5-6 years old. Maximum age is estimated to be at least 20 years (Cailliet and Bedford 1983; Nakano 1994).

1.5.3 Trophic interactions

In coastal waters off the U.S. West Coast, blue sharks reportedly feed on anchovy, jack mackerel, hake, flatfishes, dogfish, squids and pelagic crustaceans including euphausiids (Tricas 1979; Harvey 1989; Brodeur et al. 1987). Brodeur et al.(1987) examined the diet of 14 blue sharks (100-333 cm TL) captured off Washington and Oregon. Diet items, in descending order of importance, were Pacific hake, northern anchovy, flatfishes, Pacific herring and squid (flatfishes were taken predominantly in the warm water year of 1983).

Harvey (1989), sampling predominantly immature blue shark (most 130-190 cm TL) in Monterey Bay (N=150), CA, found blue sharks seasonally fed predominantly on northern anchovy, euphausiid swarms (primarily *Thysanoessa spinifera*), and Pacific hake. Spiny dogfish, Pacific herring, and five genera of squid were also taken. Tricas (1979), who examined the diet of blue sharks in southern California (predator size unspecified), found northern anchovy and squid to be important prey. Histioteuthid squids appear to be the most significant cephalopod prey offshore, while market squid, *Loligo opalescens* is important inshore, especially when large spawning aggregations form at night. Elsewhere this species is also known to feed on small sharks and seabirds (Compagno 1984), although presumably the latter only incidentally. Sciarrotta and Nelson (1977) noted that the blue shark fed around the clock but was more active at night, with highest activity in the early evening. These authors observed a twilight movement from offshore to shallower waters around Santa Catalina Island, California, during March and June, but a shift to offshore waters during late June to October, suggesting a response to a change in prey availability.

1.5.4 Migrations, movements and stock structure

According to Strasburg (1958), in the North Pacific, seasonal migrations occur between latitudes 20° N and 50° N, with northward movements extending into the Gulf of Alaska as waters warm during the summer months, and southward movements occurring during the winter months. In coastal waters, mature females are thought to start their northward journey in early spring as warm water moves northward, while juveniles of both sexes follow closely; large males start later and tend to stay further offshore (Hanan et al. 1993). Nakano (1994) has proposed a migration model for blue shark in the North Pacific where birth occurs in early summer in nursery areas located at 35-45° N, then 1-5 year old females move north of these latitudes, while 2-4 year males move south. On reaching maturity, blues apparently migrate to the subtropics and tropics to join the reproductively active population (Nakano and Seki *in press*). Adults occur mainly from equatorial waters to the area just south of the nursery grounds. Mating takes place in early summer at 20-30° N in the North Pacific Transition Zone, and pregnant females migrate to parturition grounds by the next summer. The pupping and nursery grounds areas are located in the Sub-arctic Boundary and Transition Zone where there is a large prey biomass for the juveniles. Blue sharks tagged off southern California have been recaptured to the south off Baja California and Acapulco, Mexico; northward to off Oregon, and westward to off the Hawaiian Islands and Midway in the central Pacific, indicating a wide ranging stock that may overlap with the population fished by longliners in the central Pacific Ocean (CDFG 1997; 1999b; 2000). The species is known to undertake extensive trans-oceanic migrations in the Atlantic (Kohler et al. 1998). The population structure is not known, although some authors have suggested the possibility of separate northern and southern hemisphere stocks in the Pacific (Nakano 1994; Litvinov 1990).

1.5.5 Reproduction

Viviparous; young nourished by a yolk sac, then from the bloodstream by a maternal placental connection. Litters average about 30, with maximum litter size reported at 135; gestation period is about 9-12 months (Strasburg, 1958; Stevens, 2000 *in press*). Reproduction has been reported as seasonal in most areas, with birth often in spring or summer (Pratt 1979; Nakano 1994; Stevens 1983), although periods of ovulation and parturition may be extended (Strasburg 1958; Hazin et al. 1994). Off California, parturition reportedly occurs in early spring, and mating occurs during late spring to early winter (Hanan et al. 1993). Although Hanan et al. (1993) suggest that the Southern California Bight is a major pupping and nursery area for this species, the pattern of young pups in the observed drift net catch suggest the nursery habitat may also extend northward to off the Columbia River mouth, and primarily offshore of the 100 fm isobath.

1.5.6 Vital Rates/Statistics

Age at female maturity = 5-6 years; maximum reproductive age estimated from age at 90% of L_∞ of Calliet and Bedford's (1983) von Bertanlanffy growth equation = 20; M = 0.223; potential rate of population increase = 0.035-0.060; maximum sustainable level of total mortality Z = 1.5M. Growth for combined sexes estimated by Calliet and Bedford (1983) using the Von Bertanlanffy equation, where L = total length (TL) in cm, is given as

$$L_t = 265.5[1-e^{-0.223(t-(-0.802))}]$$

Total Length to Fork Length (FL) conversion is (Rasmussen, NMFS, SWFSC, La Jolla pers. comm):

$$FL = (TL * 0.286)-2.365$$

1.5.7 Fishery Utilization

This species is predominantly taken as bycatch in the commercial drift net fishery with some recreational targeting in California. Observer and other data from the drift net fishery off southern California indicates that up to 20,000 blue sharks were caught and discarded annually during the early years of the fishery (1980-83), and between 6,700 and 28,000 per year from 1984 and through 1994. Based on observer data and an average fish weight of 8 kg in the 1990s, an estimated average of 100 mt/yr was taken in the DGN fishery, most of which was discarded. Blue shark bycatch in the fishery has been estimated at 1.1 shark for every swordfish landed (Holts et al. 1998). The flesh of blue shark deteriorates rather rapidly if not bled immediately and frozen or iced, therefore market demand for its flesh is low with current handling methods. Landing of fins detached from the carcass has been prohibited in California since January 1996 for this species and other sharks (except for threshers where tails and fins may be removed if landed with carcass).

This species is also taken in longline fisheries. A short-lived experimental longline fishery for blue sharks was conducted in California waters in 1979 and 1980 to market high-quality fresh-bled carcasses, but ended because of uncertainty in market demand and inconsistent product quality (Holts et al. 1998). Another longline fishery was attempted from 1988 to 1992, primarily for mako sharks, but with the stipulation that blues, which accounted for 62% of the catch (O'Brien and Sunada 1994), be utilized as well. This fishery was also discontinued due to the concern over the high numbers of juvenile blues and makos in the catch, and lack of a viable market for blue shark. Additionally, between 1991 and 1994, another California-based longline fishery developed for swordfish and tunas taken beyond the U.S. Exclusive Economic Zone. In 1993 the California Department of Fish and Game began dockside sampling and tracking of these longline landings and established a logbook program. The major bycatch in this fishery is blue shark, but existing documentation does not include the extent of this bycatch. This fishery was recently reviewed by Vojkovich and Barsky (1998), who report that the fleet grew from 3 vessels in 1990-93 to 31 vessels in 1994, then declined to 22 vessels in 1995. This high seas fishery targets mainly swordfish (59%-79% of landings by weight), tunas (11%-24%), and sharks (3%-11%). While the longliners do not fish in local waters, they unload their catch and reprovision in California ports.

In Oregon, incidental landings of blue shark have occurred in the sablefish longline, groundfish trawl, salmon troll, and swordfish drift net fishery (PFMC 1999). In addition, from 2 to 6 Developmental Fisheries Program permits (with a cap of 10) were issued per year between 1995 and 1997 to fish for blue shark to willing participants interested in developing a fishery for blue shark off Oregon, but this fishery has never been active. Total Oregon landings of blue shark in 1998, the highest landings in a decade, amounted to only 2.1 mt (Camhi 1999). In Washington, the commercial catch of blue sharks has been very minor; less that 0.5 mt in 1998 (PFMC 1999).

Blue shark is the dominant shark species taken in the Hawaii-based pelagic longline fishery (Ito and Machado 1997) and a major bycatch in international Pacific Ocean fisheries. In 1998, an estimated 91,228 fish were caught in the fishery, of which 55,410 were kept finned, 35,771 fish released and 47 fish retained whole (Camhi 1999). Because the fins were the most marketable product from the blue shark, few sharks were landed whole. Finning has been an issue within the Western Pacific Fisheries Management Council's jurisdiction, where finning was permitted through the year 2000. Federal legislation was passed in January 2001 banning the practice of landing fins without the accompanying carcass. There is some indication that blue shark catch rates have been declining in the Hawaiian longline fishery in recent years, but it is unclear to what extent these data reflect localized depletion or shifts in the fishery from swordfish to tuna (fewer sharks are caught on tuna longlines) (Camhi 1999).

Only rough estimates have been made of the Pacific-wide catch of blue sharks. Stevens (1996) estimated that 138,000 t of blues were caught by the international high-seas longline fleets in the Pacific in 1994. Nakano (1996) reported a 20% decline in blue shark CPUE in the North Pacific Japanese longline fishery over the 23-year period 1971-1993, but said there was insufficient evidence pointing to a critical stock decline Pacific-wide. A comprehensive stock assessment of blue shark is currently underway within NMFS' Southwest Region in cooperation with Japanese scientists.

The blue shark is targeted by anglers along the California coast, although most are released alive (86% and 99% in 1997 and 1998, respectively according to U.S. Department of Commerce's Marine Recreational Fisheries Statistics Survey). Only a few anglers target sharks in Oregon, although they are taken incidentally by anglers fishing for salmon or bottomfish. The species is generally not sought after by anglers in the state of Washington.

1.5.8 Essential Fish Habitat for Blue Shark (Figures 17 to 20): (Based on California drift gill net logbook (1981-1991); drift net observer data (1990-1999); Nakano and Nagasawa (1996); and Nakano (1994)). Diet information based on Tricas 1979; Harvey 1989; and Brodeur et al. 1987.

- Neonate/early juveniles (< 83 cm FL): Epipelagic, oceanic waters from the U.S.-Mexico border north to the U.S.-Canada border from the 1000 fm isobath seaward to the outer boundary of the EEZ and beyond; extending inshore to the 100 fm isobath south of 34° N latitude. Size-specific information on diet of neonates is not available for our region.

- Late juveniles/subadults (> 82 cm FL and < 167 cm FL males and < 153 cm FL females): Epipelagic, oceanic waters from the U.S.-Mexico border north to 37° N latitude (off Santa Cruz, CA) from the 100 fm isobath seaward to the outer boundary of the EEZ and beyond; and north to the U.S.-Canada border from the 1000 fm isobath seaward to the EEZ outer boundary. Within the U.S. West Coast EEZ known to feed on northern anchovy, Pacific hake, squid, spiny dogfish, Pacific herring, flatfishes, and opportunistically on surface-swarms of the euphausiid, *Thysanoessa spinifera*, and inshore spawning aggregations of market squid, *Loligo opalescens*.

- Adults (> 166 cm FL males and > 152 cm FL females): Epipelagic, oceanic waters from the U.S.-Mexico border north to the U.S.-Canada border from the 1000 fm isobath seaward to the outer boundary of the EEZ and beyond; extending inshore to the 200 fm isobath south of 37° N latitude off Santa Cruz, CA. Although diet information is lacking for fish of this specific size group, blue sharks in coastal waters off the U.S. West Coast reportedly feed on northern anchovy, Pacific hake, squid, spiny dogfish, herring, flatfishes, and opportunistically on surface-swarms of the euphausiid, *Thysanoessa spinifera*, and inshore spawning aggregations of market squid, *Loligo opalescens*.

2.0 TUNAS

There are eight species in the genus *Thunnus*, a member of the Thunnini tribe of the family Scombridae; subfamily Scombrinae. Tunas of this genus are unique in possessing a high metabolic rate and vascular heat exchanger systems allowing thermo-regulation and endothermy.

2.1 Albacore Tuna (*Thunnus alalunga*)

2.1.1 General Distribution

Adult albacore in the North Pacific are generally distributed in a band centered on 35° N in the Kuroshio Current, the North Pacific Transition Zone, and the California Current. The distribution extends as far as 50° N in the eastern Pacific (IATTC 2000a). In the South Pacific, they are concentrated between 10° and 40° S. This tuna is infrequently caught in equatorial waters; spawning occurs in tropical and subtropical waters.

Temperature is a major determining factor in the distribution of albacore. Juveniles are often found near oceanic fronts or temperature discontinuities. Adults occur to at least 380 m deep, depending on vertical thermal structure. The 15.6° to 19.4°C SST isotherms appear to delimit the habitat of juveniles, while the deep-swimming adults occur in waters between 13.5° and 25.2°C (Saito 1973). Foreman's (1980) maps show that deep-swimming adult albacore are more abundant in the western Pacific.

Laurs and Lynn (1991) suggest the preferred temperature may be even broader, and also describe the distribution of juvenile North Pacific albacore in terms of the North Pacific (subartic-stubtropical) Transition Zone. This zone lies between the cold, low-salinity waters north of the sub-arctic front and the warm, high-salinity waters south of the sub-tropical front (between 40° and 20-35° N). Their telemetry experiments demonstrated that albacore will enter water as cold as 9.5°C for short periods of time. They argue that the temperature range for juvenile albacore is as great as 10°-20°C in waters with a dissolved oxygen saturation level greater than 60%.

Larvae and very young juveniles of albacore are not known to occur within the U. S. Pacific Coast EEZ, but their distribution has been studied elsewhere. Davis et al. (1990) studied larval distribution off northwest Australia and found that the larvae migrate to the surface in the day and are deeper at night. Total vertical range was limited by pycnocline depth, which was 16-22 m in the study area. The larvae may forage during daylight hours and sink to neutral buoyancy depths at night when they cease swimming. Other studies also indicate that the top boundary of the pycnocline can be an area of concentration of larvae. Leis et al. (1991) found high concentrations of tuna larvae, including albacore, at sample sites near coral reefs on three islands in French Polynesia. They note that while tuna larvae are sparsely distributed in the open ocean, they possibly become concentrated near islands. Their findings are similar to Miller's (1979) findings around Oahu, Hawaii. Since their sampling had not been intended for tuna larvae (they were studying reef fish larvae), it was not possible to establish how the larvae become concentrated. Foreman (1980) provides a map showing distribution of larval albacore which gives some idea of their preferred habitat. If the suggestion made by Leis et al. (1991) is correct, it may be that inshore areas represent a habitat feature of special value to larval stage albacore. Larval distribution has also been described by Nishikawa et al. (1978,1985). Small juvenile albacore have been found in coastal waters from a number of areas in the Western Pacific including the Mariana Islands, Japanese coastal waters, Fiji, waters east of Australia and Tuvalu, and from Hawaiian waters. Larger immature albacore prefer cooler water and enter the tropics as adults.

Within the U.S. Pacific Coast EEZ, juveniles $\leq$ 85 cm FL and adults > 85 cm FL are distributed in epipelagic waters generally beyond the 100 fm isobath from the U.S.-Mexico EEZ border north to U.S.-Canada border, and westward to the outer edge of the EEZ boundary. Concentrations occur off southern and central California and in the area of the Columbia River Plume (Drift Gill Net Catch Data 1990-99 and troll vessel logbook data 1961-99, R. Rasmussen, pers. comm. and data analysis, NMFS, SWFSC, La Jolla, CA). The vast majority of fish taken by the troll fishery are immature (3-4 yr olds). However, Hanan et al. (1993) found that the size of gill net-caught fish sampled in 1981-91 in the market averaged 103 cm FL (adult-sized, with range 50-133 cm FL). Thus adults apparently do occur within the EEZ, although probably much less abundantly than younger fish. Longliners fishing just outside the EEZ also are known to catch large adult-sized fish (A. Coan, 2000, pers. comm., NMFS, SWFSC, La Jolla, CA). Large fish are normally distributed deeper but may occasionally become susceptible to capture by gill nets that are fished in the upper water column, but generally lower than the fishing depth of the surface troll fishery.

2.1.2 Growth and Development

North Pacific albacore mature at approximately 5 years of age, or about 85 cm FL, and maximum longevity is believed to be around 10 years (Ueyanagi 1957; Otsu and Uchida 1959). According to Bartoo and Foreman (1994) NP albacore have the following size at age: 1 yr-35 cm, 2- 52 cm, 3- 65 cm, 4-76 cm, 5- 85 cm, 6- 93 cm FL.

2.1.3 Trophic Interactions

Albacore are considered to feed opportunistically, with fish and squid the predominant prey categories found in stomach contents (Iversen 1962). Smaller (younger) fish are known to have a higher proportion of squid in their diet. Gempylids and bramids are more prevalent in the diet of fish from near the equator; saury predominate in temperate waters. Squids are more prevalent in the diet of fish further from the equator (outside of 5°S-5° N) and, in the tropics, increased in the diet with greater distance from land. Pinkas et al. (1971) found that in 1968-69 in southern California, anchovies and sauries predominated, cephalopods followed next in importance, and crustaceans occurred occasionally. In central California, fish were significant, with anchovy and saury important but less so than in southern California, with other fish, such as blue lanternfish, barracudina, and rockfish spp. increasing in importance. Crustaceans replaced cephalopods as the second-most important group of food organisms in central California, with *Euphausia pacifica* and *Phronima sedentaria* being frequently taken. Off Oregon and Washington, northern anchovy and saury again dominated the diet, with crustaceans such as *Sergestes similis* being second in importance, and a variety of squids (e.g.,*Gonatus anonychus, Loligo opalecens, Gonatus fabracii*) occurring relatively frequently.

Foreman's (1980) summary emphasizes that albacore feed steadily during both night and day, although less so at night since they are visual feeders.

Larval albacore feed during the day, although there is some evidence of increased activity around dusk. In the Indian Ocean, Young and Davis (1990) found copepods to be major prey.

2.1.4 Migrations, movements and stock structure

Albacore have a complex migration pattern, with the North and South Pacific stocks having similar general patterns. Most migration is undertaken by pre-adults, 2-4 years old. The model suggested by Otsu and Uchida (1963) shows trans-Pacific migration by year class. Generally speaking, a given year class migrates west to east in a band between 30° and 45° N, leaving the northwest Pacific in springtime and reaching waters off North America at least by late summer. They then return to the west. As they reach 2-6 years old, they begin entering sub-tropical waters south of 30° N and west of Hawaii (Kimura, et al. 1997) where they spawn. Migration may also be influenced by large-scale climate events that affect the Kuroshio Current regime (Kimura, et al. 1997). Albacore may migrate more strongly to the eastern Pacific when the Kuroshio takes a large meander path.

Expanding on Otsu and Uchida's (1963) model, more recent work by Laurs and Lynn (1991) indicates that there may be substocks in the North Pacific with different migratory routes. Albacore tagged off the U.S. West Coast north of 40° N apparently undertake a more westward migration (58% of tag returns come from the Western Pacific west of 180° W) than those tagged to the south (only 10% were recovered in the Western Pacific, 78% from the tagging area).

Murray (1994), summarizing the work of Jones (1991), described migration in the South Pacific. Juveniles move from the tropics into temperate waters at about 35 cm FL and then more generally eastward along the Sub-Tropical Convergence Zone. They do not return to the tropics until they are about 85 cm FL. Juveniles move south into temperate waters in the austral spring. Adults occur at depth from the tropic to temperate zones throughout the year.

2.1.5 Reproduction

Immature fish generally have an even sex ratio, but males predominate in catches of mature fish. Mature male-female ratios range from up to 2.66:1 (Foreman 1980, Table 4). Fecundity is estimated at 0.8-2.6 million eggs per spawning (Foreman 1980).

Albacore spawn in the summer in sub-tropical waters, and there is evidence of multiple spawning (Otsu and Uchida 1959). Foreman's (1980) map shows a spawning area that is centered on 20° N and 160° E and does not extend east of about 150° W. In the South Pacific, the spawning area is narrower, centered at about 25° S and stretching from the sea east of Queensland, Australia, to about 110° W. Ramon and Bailey (1996) found October to December was the peak spawning season near New Caledonia and Tonga. Maturing albacore were mostly taken between 20° and 23° S. Description of larval distribution is also provided by Nishikawa et al. (1978,1985).

2.1.6 Vital Rates/Statistics

IATTC (2001a) and Foreman (1980) summarize estimates of von Bertalanffy equation parameters in tabular form. Growth rates for fish below 38° N are reportedly higher than those taken to the north. Estimates of the size at one year range from 38 to 57 cm FL, about a third of estimates for size at the von Bertalanffy asymptote, 104-145 cm. Juvenile growth has been estimated at 3.12 cm per month (Yoshida 1979). Bartoo and Foreman (1994) give the following von Bertalanffy parameters as the most reasonable for assessment purposes: L_∞ = 135.6 cm, K = 0.17 and t_0 = -0.87. IATTC (2001a) summarizes current estimates of M and F for North Pacific albacore with M estimates of 0.32 to 0.67 using growth data and an assumed average temperature of 17.5°C. Based on tagging data, Bertignac et al. (1999) estimated an average M to be 0.6 for North Pacific albacore after recruitment to the fishery, assuming that about 90 percent of those recaptured are reported. Intrinsic rate of population increase of a population at the MSY level, assuming 25% increase in average fecundity at B_{MSY} and F_{MSY} = M, has been estimated at r = 0.12 (Au et al. *in press*)

2.1.7 Fishery Utilization

The main albacore fisheries in the Pacific can be characterized as either surface or deep water, and Foreman (1980) and Bartoo and Foreman (1994) provide maps of the major fishing areas. Generally, the surface fisheries occur in cooler waters and target immature fish; the deep water longline fishery targets deep-swimming fish in both tropic and temperate waters, mainly the northwest and South Pacific. The surface fisheries include trolling operations off the American coast from Baja California to Canada and westward in Transition Zone waters as far as the Emperor Seamounts; baitboat operations south of Japan along the Kuroshio Front and south to the equator; and troll operations from New Zealand waters to 110° W along the Subtropical Convergence, and a recently developed fishery south of Tahiti. In the past, albacore were also taken by drift net fisheries in the 1980s in both the North and South Pacific, but these fisheries ended in the early 1990s. Taiwanese and Japanese high seas drift gillnetters rapidly expanded effort for albacore in the South Pacific after 1988, but a number of regional and international initiatives were put forward to limit or ban this fishery, and by 1990 operations had ceased (Wright and Doulman 1991). Similarly, drift net fisheries in the North Pacific that expanded rapidly in the 1980s targeting mainly squid (but also taking albacore), were terminated after 1992 (Nakano et al. 1993). Purse seine fishing, another surface method, is not a major fishery. Albacore are occasionally taken incidentally in other tuna fisheries.

Within the U.S. Pacific Coast EEZ, albacore are taken by commercial surface trollers and live bait fishermen and by recreational anglers; they are also taken incidentally in gill net and purse seine fisheries. The U.S. albacore fishery operating from the U.S. West Coast is predominantly comprised of troll vessels, some with the capability of using live bait on occasion (PFMC 1999), and these vessels land approximately 14-19% of the North Pacific-wide catch (see Ch. 3, Table 3.3.5-1; IATTC 2001a , Table 2.3.1a). A review of available fisheries data for the Technical Consultation with Canada on the U.S.-Albacore Treaty (11/00) has confirmed a significant increase in Canadian troll fishing effort for albacore in the U.S. EEZ over the past five years. According to the Western Fishboat Owners Association (letter to PFMC, dated 3/4/02 , draft HMS FMP comments) the U.S. jig albacore fleet currently catches about 5-7% of the world catch of albacore, and 15% of albacore harvested in the north Pacific above latitude 20° N. This North Pacific stock above 20° N is mainly caught by pole and line methods (jig or baitboat) by Japanese, Korean and Taiwanese fleets. The North Pacific stock of albacore is now under IATTC international management and is also coordinated under the U.S./Canadian Albacore treaty. In the future, it may also come under management consideration of the new international Multi-Lateral High level Conference for Conservation and Management of Tuna and Tuna-like Species of the Centeral and Western Pacific (MHLC), although the albacore fishing nations--Japan, Korea and China--are not yet signators to this agreement as of March 2002.

2.1.8 Essential Fish Habitat for Albacore Tuna (Figures 21):

(Based on drift net observer data (1990-1999); California Commercial Passenger Fishing Vessel data; and Saito (1973); Laurs and Lynn (1991); Bartoo and Forman (1994); and Hanan et al. (1993). Diet information from Iverson (1962) and Pinkas et al. (1971).

- Eggs and Larvae - No habitat within the U.S. West Coast EEZ.

- Juvenile < 85 cm FL. Oceanic, epipelagic waters generally beyond the 100 fm isobath from the U.S.-Mexico EEZ border north to U.S.-Canada border, and westward to the outer edge of the EEZ boundary. Habitat concentrations off southern and central California and the area of the Columbia River Plume area. Reported to feed opportunistically, predominantly on fishes (e.g., Pacific saury) and squids. Associated with SSTs between 10°C and 20°C in waters of the North Pacific Transition Zone in dissolved oxygen saturation levels greater than 60%. Smaller (younger) fish are known to have a higher proportion of squid in their diet. In our region, may aggregate in the vicinity of upwelling fronts to feed on small fishes (northern anchovy, saury, rockfish spp., Myctophids, barracudina), squids (e.g., *Loligo, Gonatus* and *Onychoteuthis* sp.) and crustaceans (Sergestid shrimp, pelagic red crab, *Phronima* amphipods, euphausiids).

- Adult >84 cm FL. Oceanic, epipelagic waters generally beyond the 100 fm isobath from the U.S.-Mexico EEZ border north to U.S.-Canada border, and westward to the outer edge of the EEZ boundary. Associated with SSTs between 14°C and 25°C in waters of the North Pacific Transition Zone in dissolved oxygen saturation levels greater than 60%. Reported to feed opportunistically, predominantly on fish (e.g., Pacific saury) and squid. Large fish tend to prey increasing more on fish and less on squid.

2.2 Bigeye Tuna (*Thunnus obesus*)

2.2.1 General Distribution

Bigeye tuna are trans-Pacific in distribution, occupying epi- and mesopelagic waters. The distribution stretches between northern Japan and the north island of New Zealand in the western Pacific and from 40° N to 30° S in the eastern Pacific (Calkins 1980; Miyabe and Bayliff 1998). The species also occurs in the Atlantic and Indian oceans.

The distribution of bigeye tuna larvae is better known than that of young juveniles less than 35 cm FL. Areas of collection of larvae in the Pacific have been described by Nishikawa et al. (1978, 1985). They are most common in warm surface waters between 30° N and 20° S in the Pacific, being relatively more abundant in the western and eastern Pacific compared to the central Pacific and most common in the western Pacific between 10° N and 15° S. Bigeye larvae appear to be restricted to the mixed layer well above the thermocline and at depths less than 50 to 60 m, with no clear evidence of diurnal preference by depth or patterns of vertical migration (Matsumoto 1961).

The distribution of juvenile bigeye tuna less than 35 cm FL is not known, but is assumed to be similar to that of larvae (i.e., occupying warm surface waters). The distribution of juveniles greater than 35 cm FL is better understood, as they begin to enter catch statistics of purse seine, pole-and-line and handline fisheries worldwide. Bigeye as small as 32 cm are taken in the Japanese coastal pole-and-line fishery (Honma et al. 1973). Juvenile bigeye aggregate strongly to drifting or anchored objects, large marine animals and regions of elevated productivity, such as near seamounts and areas of upwelling (Blackburn 1969; Calkins 1980; Hampton and Bailey 1993).

Juvenile and pre-adult bigeye of 35 cm to approximately 99 cm are regularly taken in the eastern and western Pacific purse seine fisheries, usually on sets made in association with floating objects (Hampton and Bailey 1993). Larger juvenile and pre-adult bigeye appear in higher latitude fisheries; so one can infer a movement away from tropical spawning areas as the fish grow and increasingly prefer sub-surface habitats. Juvenile bigeye form mono-specific schools of similar-sized fish at or near the surface, or they may be mixed with skipjack and/or juvenile yellowfin tuna (Calkins 1980). Yuen (1963) has suggested that the mixed-species schools are actually separate single-species schools that temporarily aggregate to a common factor such as food. Echo sounders, sonar traces and test fishing strongly support a separation of bigeye, yellowfin and skipjack schools that are aggregated to the same floating object, with the bigeye deeper than the other species.

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 40° N to 30° S in the eastern Pacific (Calkins 1980). Numerous references exist on the distribution of Pacific bigeye tuna relative to general distribution and migration. 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 although Hanamoto (1987) reasons that optimum salinity for bigeye tuna ranges from 34.5‰ to 35.5‰ given the existence of a 1:1 relationship between temperature and salinity within the optimum temperature range for the species.

Hanamoto (1987) analyzed longline catch and gear configurations in relation to water temperature profiles to estimate preferred bigeye habitat. He noted that bigeye are taken by longline gear at ambient temperatures ranging from 9° to 28°C and concluded 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 1 ml/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). Hanamoto (1987) also proposes that bigeye range from the surface to as deep as 600 m in areas where suitable temperatures exist at that depth. Evidence from archival tagging experiments suggests that bigeye tuna are capable of diving to greater depths and to temperatures well below the values cited by Alverson and Peterson (1963) or estimated by Hanamoto (1987).

Adult bigeye tuna aggregate to drifting flotsam and anchored buoys, though to a lesser degree than juvenile fish. Bigeye also aggregate over deep seamount and ridge features. 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. Water temperature, thermocline depth and season appear to have strong influence on the distribution of large bigeye (Calkins 1980). Nakamura (1969) suggests that bigeye are closely associated with particular water masses or current systems during different life stages. Fish taken in the northern longline fishing grounds around 30° N are immature adults or spent spawners while the fish taken in the equatorial longline fishery are actively spawning adults (Calkins 1980).

2.2.2 Growth and Development

Larval stages of bigeye likely extend for approximately two to three weeks after hatching (Yasutake et al. 1973). It has been suggested that areas of elevated productivity are necessary to support both the broad spawning characteristic of tropical tunas such as bigeye and the resulting larvae (Sund et al. 1981, Miller 1979, Boehlert and Mundy 1994).

Whitelaw and Unnithan (1997) provide a useful summary of studies on the age and growth of bigeye tuna in the Pacific and Indian Oceans. There is some consensus, which is supported by tagging data, that the growth of bigeye is rapid during the first few years before slowing, similar to yellowfin tuna. It is also believed that bigeye have a longer lifespan than yellowfin although further age studies of bigeye tuna are now needed. A recent study by Matsumoto (1998) analyzing presumed daily otolith increments found a relationship indicating 200 and 400 increments corresponding to fish 40 and 55 cm FL.

Estimates of size at maturity for Pacific bigeye vary between authors (Whitelaw and Unnithan 1997). Kikawa (1957, 1961) estimate size at first maturity for males at 101-105 cm FL and 91-95 cm FL for females and select 100 cm FL as a general size for "potential maturity." Uosaki and Bayliff (1999) estimate that sexual maturity begins at about 120 cm Eye-Fork Length.

2.2.3 Trophic Interactions

Feeding appears to be opportunistic at all life stages, with prey items consisting primarily of crustaceans, cephalopods and fishes (Calkins 1980). The diet of larval and young juvenile bigeye tuna is similar to that of yellowfin tuna, consisting of crustaceans, cephalopods, and fish (Uotani et al. 1981). Young juvenile bigeye also feed opportunistically during day and night, similar to yellowfin of similar size (Collette and Nauen 1983). Prey species are epi- or mesopelagic, consisting of crustacean zooplankton at first, then shifting to fish larvae at the late larval and early juvenile stages. 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. The remainder of feeding studies conducted on bigeye tuna have examined large longline-caught fish. There is significant evidence that bigeye feed at greater depths than yellowfin tuna, utilizing higher proportions of cephalopods and mesopelagic fishes and thereby reducing niche competition (Whitelaw and Unnithan 1997). Solov'yev (1970) suggests that the preferred feeding depth of large bigeye in the Indian Ocean is 218-265 m, which is the most productive depth for longline catches. Feeding depth undoubtedly varies throughout its range, as water temperature, thermocline depth, and other structural features vary. Nothing is known of the diet of bigeye tuna within the U.S. West Coast EEZ.

2.2.4 Movements and Stock Structure

A single, Pacific-wide stock has been proposed as well as a two-stock hypothesis separating the eastern Pacific from a central/western Pacific stock. Mitochondrial DNA and DNA microsatellite analyses of bigeye otoliths from nine geographically scattered regions of the Pacific (SPC 1997) have yielded inconclusive results (Miyabe and Bayliff 1998), and a single stock hypothesis is generally accepted for this species. For the purposes of this FMP, within the region of the PFMC, a single stock is assumed.

Bigeye tuna are capable of large-scale movements which have been documented by tag and recapture programs (Miyabe and Bayliff 1998); however, most recaptures have occurred within 200 miles of the point of release. The species appears to move freely within broad regions of favorable water temperature and dissolved oxygen values. If the majority of spawning takes place in tropical waters, then there must be movement of juvenile fish to higher latitudes as well as return movements of mature fish to spawn. In general, there have been far fewer bigeye tagged in the Pacific compared to skipjack and yellowfin, and movement data from tagging programs are inconclusive. Hampton et al. (1998) describe 8,000 bigeye releases made in the western Pacific during 1990-1992. Most of the fish were recaptured close to the point of release, approximately 25% had moved more than 200 nm and more than 5% had moved more than 1,000 nm. No tags were recovered in the Indian Ocean or eastern Pacific.

2.2.5 Reproduction

Spawning spans broad areas of the Pacific and occurs throughout the year in tropical waters and seasonally at higher latitudes at water temperatures above 23° or 24°C (Kume 1967). Bigeye are serial spawners, capable of repeated spawning at near daily intervals with batch fecundities of millions of ova per spawning event (Nikaido et al. 1991). Spawning takes place during the afternoon or evening hours at or near the surface (McPherson 1991). Eggs are epipelagic, buoyed at the surface by a single oil droplet until hatching occurs. Kume (1962) examined artificially fertilized bigeye eggs in the Indian Ocean, and found that hatching began 21 hours post-fertilization, and the larvae measured 1.5 mm in length. Larval development soon after hatching has been described by Kume (1962) and Yasutake et al. (1973). The early larval stages of bigeye and yellowfin are difficult or impossible to differentiate without allozyme or mitochondrial DNA analyses (Graves et al. 1988).

2.2.6 Vital Rates/Statistics

According to PFMC (1999) age and size at first maturity = ~3 years and 90-100 cm FL; maximum reproductive age = 9 years and about 200 cm. Kume and Joseph (1969) provide von Bertalanffy growth parameters of L_∞ = 186.95 cm FL; annual k = 0.38; and t_o =0.5275. See Watters and Maunder (2001) for current estimates of how M could vary with age. Intrinsic rate of population increase of a population at the MSY level, assuming 25% increase in average fecundity at B_{MSY} and $F_{MSY} = M$, has been estimated at $r = 0.17$ (Au et al. *in press*)

2.2.7 Fishery Utilization

Large, mature-sized bigeye tuna are sought by sub-surface fisheries, primarily longline fleets for the sashimi grade product. Similarly, juvenile fish are taken in many surface fisheries, either targeted or incidentally caught with other tuna species (Miyabe and Bayliff 1998). Major fisheries for bigeye exploit their aggregating behavior either by targeting biologically productive areas such as deep and shallow seamount and ridge features, or by utilizing artificial fish aggregation devices (FADs) that attract concentrations of bigeye. In the U.S. West Coast EEZ, bigeye are taken in the coastal purse seine fishery and the recreational fishery, primarily off southern California; also this tuna is taken incidentally in the drift net fishery for swordfish/shark and in the surface fishery for albacore. The U.S. West Coast catch is less than 1% of the Eastern Pacific catch of this species (Ch. 3, Table 3.3.5.1). Outside the EEZ, bigeye are taken in the pelagic longline fishery (PACFIN data base; Drift Net Observer Program data; Calif. CPFV data). During the period 1971-1986, Japanese longline catches of bigeye were distributed primarily between 35 ° N and 35° S in the eastern Pacific Ocean, with heaviest catches in the north, generally west of 120° W in waters off Baja, California, Mexico and southern California (Calkins et al. 1993).

2.2.8 Essential Fish Habitat for Bigeye Tuna (Figure 22-Juveniles and Adults): (Based on California drift gill net observer data (1990-1999); California Commercial Passenger Fishing Vessel data; Kikawa (1957, 1961); and Alverson and Peterson (1963).

- Eggs and Larvae - No habitat within the U.S. West Coast EEZ.

- Juvenile - < 100 cm FL. Oceanic, epipelagic and mesopelagic waters beyond the 200 fm isobath out to the EEZ boundary from the U.S.-Mexico EEZ border north to Point Conception, CA, some years extending northward to Monterey Bay (37° N lat). Associated with SSTs between 13°C and 29°C with optimum between 17°C and 22°C. Habitat concentrated in the Southern California Bight primarily south of 34° N latitude from the 100 fm isobath out to the 1000 fm isobath. Nothing is known of the diet of juvenile bigeye in the U.S. West Coast EEZ.

- Adult - >100 cm FL. Oceanic, epipelagic and mesopelagic waters beyond the 200 fm isobath out to the EEZ boundary from the U.S.-Mexico EEZ border north to Point Conception, CA, some years extending northward to Monterey Bay (37° N latitude). Associated with SSTs between 13°C and 29°C with optimum between 17°C and 22°C. Habitat concentrated in the Southern California Bight primarily south of 34° N latitude from the 100 fm isobath out to the 1000 fm isobath. Nothing is known of diet of adult bigeye in the U.S. West Coast EEZ.

2.3 Northern Bluefin Tuna (*Thunnus orientalis*)

2.3.1 General Distribution

The northern bluefin tuna stock that is fished throughout the North Pacific originates in the western Pacific. Larvae of bluefin have been found only in the vicinity of Japan and between Japan and the Philippines (Bayliff 1994, 2001) and it is assumed that spawning occurs only in those areas. The general range of the species in the eastern Pacific is from about 20° N and 42° N, sometimes extending northward in warm years to 48° N and beyond. In the western Pacific, especially west of 180°, Hawaiian Islands, the distribution extends southward to off New Zealand, eastern Australia, and New Guinea, and westward to Japan, the East China Sea and the Philippines (Tomlinson 1996; Bayliff 2001). Bluefin tuna have occurred as incidental catch in the drift gillnet fishery off the U.S. West coast north to near 47° N latitude off Grays Harbor, Washington, with occasional records as far north as Vancouver, B.C. (Driftnet Observer data 1990-99; Squire 1983). Sporadic catches of northern bluefin have been recorded by Japanese longliners off Peru and Chile (Tomlinson 1996).

According to Bayliff (1994), after originating in the western Pacific, some bluefin migrate to the eastern Pacific in their first or second year of life; others remain in the western Pacific. Most fish taken in the eastern Pacific are in their second or third year of life, but some older, larger fish are also taken. After a sojourn in the eastern Pacific, which may or may not be interrupted by visits to the central or western Pacific, the survivors return to the western Pacific, where they spawn, beginning at about age five (Bayliff 1994).

In the western Pacific off Japan, optimal sea surface temperatures are reported as between 14° and 19°, but juvenile fish have been caught by Japanese coastal fishers in warmer water, as high as 29°C for fish 15 to 31 cm. Preferred temperature range reportedly increases with size; in the eastern and central Pacific, it is defined by SSTs between 17° and 22°-23°C (Bell 1963). Bayliff (1994) provides maps of the areas of the North Pacific bounded by the 17° and 23°C isotherm by season; in winter this band is centered on 30° N latitude and in summer on 40° N. In addition to these temperature ranges, habitat features mentioned by Bayliff (1994), which may affect population abundance and density, include the California Current in the eastern Pacific, Transition Zone, North Pacific Subarctic Boundary, and the Kuroshio Current off Japan. Anglers off California report catching bluefin tuna off central California in waters as cool as 14°C (PFMC draft HMS FMP comments received 1/18/02 through 3/5/02).

In the eastern Pacific, bluefin are caught mostly between Cabo San Lucas, Baja California, Mexico, and Point Conception, California. Within the U.S. West Coast EEZ, bluefin occur in oceanic, epipelagic waters usually beyond the 100-400 fm isobath out to the EEZ boundary from the U.S.-Mexico EEZ border north to Point Conception, CA (Bayliff 1994; Squire 1993) and intermittently north to the U.S.-Canada border and beyond. In warm water years they are known to occur north to off Washington (CDF&G California Commercial Passenger Vessel Data and NMFS Driftnet Observer data, 1990-1999, ODFW 2002). Occasionally they are caught even further north off Vancouver, B.C. and to Shelikoff Strait in Alaska, but only during extreme warm water years (Radovich 1961; Squire 1983).

Bluefin off the U.S. West Coast have been caught during every month of the year, but most fish are taken spring through fall (Bayliff 2001). In developing his bluefin habitat index, Bayliff (1996) assumed that the most suitable habitat for bluefin off Baja California and the U.S. West Coast existed from May through October when the bluefin's preferred SSTs (17°C and 23°C or 63°and 73°F, Bell 1963) tended to prevail in that area. The northerly migratory extension appears dependent on the position of the North Pacific Subarctic Boundary.

There appears to be no regular habitat within the U.S. West Coast EEZ for adult fish over 150 cm FL, although large fish are occasionally caught in the vicinity of the Channel Islands off Southern California and rarely off the central California coast (Bayliff 1994). Also, fish of at least six or seven age classes are caught in the eastern Pacific, so it is possible that some may be resident and utilize habitat in our area for several years. The largest of eastern Pacific fish are probably 10 years old. It is unclear where these 'giant' adult bluefin come from that intermittently show up on the U.S. West Coast. Larger fish seem to have occurred more regularly earlier in the 20th century, judging from early accounts from the historic Catalina Tuna Club days (e.g., Collins 1892; Holder 1914). Older fish that are taken off our coast may have arrived from the western Pacific shortly before they were caught, or may have made more than one round trip across the Pacific (Bayliff 1994). Catches of exceptionally large-sized bluefin were made by purse seiners in the eastern Pacific during November and December of 1988 (Foreman and Ishizuka 1990).

2.3.2 Growth and Development

Bayliff et al. (1991) used tagging data to study the growth of Pacific bluefin and found it best represented by a two-stanza model (see Vital Rates/Statistics below). Estimates for size at age for one-year-old fish range from 43 to 76.3 cm and for four-year-old fish, 113.1 to 178 cm. Bluefin are estimated to reach maturity at 3-5 years, with 5 yrs more likely, an age equivalent to a size of about 150 cm FL and 60 kg (Bayliff 1994; Harada 1980). Bluefin may be sexually dimorphic with respect to growth and size as is common in other tunas; fish raised in captivity reached a size of 119 cm for males and 135 cm for females at three years of age (Hirota et al. 1976). Bluefin from the Pacific have lived as long as 16 years in captivity (Bayliff 1994).

2.3.3 Trophic Interactions

Feeding habits of bluefin in the eastern Pacific have been reviewed by Bayliff (1994). Major prey items of juveniles include anchovies, red crab (predominately in fish taken south of 29°N), saury, squid, and hake. Pinkas et al. (1971) examined 650 stomachs containing food from purse seine-caught bluefin off California and Baja California in 1968 and 1969 and found that the northern anchovy was the primary food, overshadowing all other ingested species, singularly or in any combination (86% numerically, 80% volumetrically, and 72% in frequency). The pelagic red crab, *Pleuroncodes planipes*, was the second most important animal species (primarily off Mexico), and saury ranked third. Other species taken less frequently off southern California were the market squid, jack mackerel, and *Sebastes* spp.

Anchovies, crustaceans, and squids are also reported as the main prey items for immature fish caught in the western Pacific. Adult prey items are squids and a variety of fishes including anchovies, herring, pompanos, mackerel, and other tunas. In the western Pacific, bluefin are also reported to associate with schools of sardine which are probably their prey. Larvae reportedly feed on small zooplankton, mainly copepods (Uotani et al. 1990).

2.3.4 Migrations, Movements and Stock Structure

Bayliff (1998, 2001) has summarized what is known to date on bluefin movements and migrations, and references preliminary archival tag-recapture results recently obtained by the National Research Institute of Far Seas Fisheries. Spawning occurs in the western Pacific Ocean (WPO) where some fish apparently remain their entire lives, while others migrate, primarily in their first and second years of life, to the eastern Pacific Ocean. According to NRIFSF archival tagging data (Itoh et al. 1999[9], ISC Bluefin Tuna Working Group 2000[10]), the journey from the western to the eastern Pacific is known to take as little as fifty-five days, after which time tagged fish have been known to remain off the coasts of California and Baja California for up to 2 years before returning to the western Pacific. Bayliff (1994) suggests that their migratory path is within the North Pacific Subarctic-Subtropical Transition Zone. It is unclear how long fish remain in the eastern Pacific or whether they make multiple migrations back and forth, but eventually they return to the western Pacific to spawn. Some juvenile fish also move southward from the spawning areas off the Philippines and Japan.

2.3.5 Reproduction

Bluefin spawn in the western Pacific north of the Philippines and off Japan. Miller (1979) reported larvae off of Oahu, Hawaii, but later, more extensive sampling in Hawaii failed to turn up these larvae (e.g., Bayliff 1994). Given the distance from known spawning areas, it would seem unlikely the bluefin larvae normally occur in Hawaiian waters. No bluefin with maturing gonads have been sampled in the eastern Pacific (Uosaki and Bayliff 1999). Male-female sex ratios reported in Bayliff (1994) range from 45:0 for fish caught in the Eastern Pacific by purse seine to 1:1.68 for longline-caught fish landed off of Taiwan. Fecundity has been estimated at 10 million eggs for fish 270-300 kg (Yamanaka and staff 1963).

2.3.6 Vital Rates/Statistics

While von Bertalanffy parameter estimates have been made, Bayliff et al. (1991) argue for a two-stage model with separate parameter estimates for fish less than 564 mm following the Gompertz model (values 581 mm and 4.32 for L_∞ and K, respectively) and linear growth for fish greater than 564 mm at a rate of 0.709 mm per day. Estimates for size at age for one-year-old fish range from 43 to 76.3 cm and for four-year-old fish, 113.1 to 178 cm. Using the growth equations presented by Bayliff (1994) maximum age is about 9.5 years, but bluefin from the Pacific have lived as long as 16 years in captivity. Bayliff (1994) discusses the coefficient of

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[9] Itoh, T., S. Tsuji, and A. Nitta. 1999. Trans-Pacific migration of bluefin tuna observed with archival tags. Proc. 50th Annual Conf., Lake Arrowhead, California, May 24-27, 1999.

[10] ISC Bluefin Tuna Working Group. 2000. Report of the ISC Bluefin Tuna Working Group Meeting, Nov 30-December 1, 2000, Shimizu, Japan.

natural mortality and arrives at a range of 0.161-0.471 for the 90% confidence interval. Using these figures, at ten years about 79% and 99%+ mortality is achieved, respectively. Intrinsic rate of population increase of a population at the MSY level, assuming 25% increase in average fecundity at B_{MSY} and $F_{MSY} = M$, has been estimated at r = 0.11 (Au et al. *in press*)

2.3.7 Fishery Utilization

According to Bayliff (2001) the major fishery for bluefin in the eastern Pacific is the commercial purse seine fishery off the U.S. West Coast and Baja California, Mexico. Nearly all the catch is made west of Baja California and California within about 100 nm of the coast, between about 23° N and 33° N. Most of the bluefin purse seine catch in the U.S. West Coast EEZ during 1970-1989 was captured south of Point Conception and east of 120° W (Bayliff 1994). Lesser amounts of bluefin are caught by recreational anglers, mostly north of 29° N and south of 38° N (California Commercial Passenger Vessel Data 1990-1998; Bayliff 2001). Small amounts of bluefin have been caught off by drift gill net vessels fishing north to off Washington[11], and by U.S. and Mexican longline vessels fishing west of California (outside EEZ) and northern Baja California, respectively. Bluefin are also known to occur as far north as Vancouver, B.C. during warm water years (Squire 1983). In the western Pacific, a variety of gears is used, primarily in coastal fisheries. Purse seiners take age-1 fish in an area about 30°-42° N and 140°-152° E. Catches of bluefin in the Eastern Pacific Ocean consist mostly of age-1 and age-2 fish. Regional catches of bluefin tuna from West Coast-based U.S. recreational and commercial vessels represents an estimated 15% of the North Pacific-wide landings (Ch. 3, Table 3.3.5-1; Bayliff 2001).

2.3.8 Essential Fish Habitat for Northern Bluefin Tuna (Figure 23) (Based on California drift gill net observer data (1990-1999); driftnet logbook data 1991-2001, Oregon Dep. Fish and Wildlife,unpubl. data, 5/02; Uosaki and Bayliff (1999); Bayliff (1994); Harada 1980; Squire 1983). Food habits based on Bayliff (1994)

- Eggs and Larvae - No habitat within the U.S. West Coast EEZ.

- Juvenile - <150 cm FL and 60 kg, Bayliff 1994; Harada 1980). Oceanic, epipelagic waters beyond the 100 fm isobath from the U.S.-Mexico EEZ border north to U.S.-Canada border, and westward to the outer edge of the EEZ boundary. Associated with SST' between 14°C and 23°C. Northerly migratory extension appears dependent on position of the North Pacific Subarctic Boundary. A major prey item of juvenile bluefin in our region is the northern anchovy; other food items reported from off southern California include saury, market squid, (up to 80% of stomach contents by volume), saury, squid, and hake. May feed on pelagic red crab when this species occurs in the EEZ, since it is a significant component of the diet off Mexico.

- Adult - (≥150 cm FL and 60 kg, Bayliff 1994; Harada 1980). No regular habitat within the U.S. West Coast EEZ, although large fish are occasionally caught in the vicinity of the Channel Islands off Southern California and rarely off the central California coast. Adult prey items are squids and a variety of fishes including anchovies, herring, pompanos, mackerel, and other tunas.

2.4 Skipjack Tuna (*Katsuwonus pelamis*)

2.4.1 General Distribution

Skipjack are epipelagic and oceanic in warm, well-mixed surface waters of tropical, subtropical, and warm temperate waters of all oceans. In the western Pacific, its habitat is bounded by the 15°C isotherm or roughly between 45° N and S. This range is more restricted in the eastern Pacific due to the basin-wide current regime, which brings cooler water closer to the equator; east of 150° W longitude, the habitat is distributed between 40° N and 40° S latitude and off the coastlines of U.S., Mexico, Central America and South America.

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[11] ODFW. 2002 (unpub). Logbook data on incidental driftnet catches of bluefin tuna off Oregon and Washington.

During El Niño events, skipjack may inhabit areas as far north as 50° N along the U.S. West Coast (IATTC 2000d; PFMC 1999)

Larval distribution is concentrated in, though not exclusively restricted to, tropical equatorial waters. Like adults, larvae have a wider latitudinal distribution in the western than in the eastern Pacific. Kawasaki (1965) suggests that the center of abundance of skipjack tuna larvae in the Pacific lies between 5° N and 4° S and 160° E and 140° W. Matsumoto (1975) later reported the center of abundance between 160° E and 140° W, but with moderate abundance also between 100° W and 140° W and 120° E and 160° E. Areas north of 20° N with relatively high larval abundance include the Hawaiian Islands. The distribution of larvae has been documented in the entire Pacific by Japanese research vessel net tows (Ueyanagi 1969, Nishikawa et al.1978; 1985). No information on small juvenile fish habitat is available, although the range is probably similar to that of larvae. Matsumoto et al. (1984) noted that distribution in the Pacific is generally from 35° N to 35° S in the west and between 10° N and 5° S in the east.

Barkley (1969) described the hypothetical habitat for skipjack as areas where a shallow salinity maximum occurs seasonally or permanently. Matsumoto et al. (1984) describe the habitat in terms of temperature and salinity: a lower temperature limit around 18°C; a lower dissolved oxygen level of around 3.5‰; and a speculative upper temperature limit, ranging from 33°C for the smallest skipjack tuna caught in the fishery to 20°C or less for the largest. These limits describe hypothetical habitat that can be mapped (Barkely et al. 1978) and represent constraints on activity based on available dissolved oxygen level of 2.45 ml/l in order to maintain basal swimming speed. Since skipjack lack a swim bladder, Sharp (1978) calculated that a 50-cm skipjack must swim 60.5 km/d just to maintain hydrodynamic stability and respiration.

2.4.2 Growth and Development

Skipjack grow rapidly and mature early. Matsumoto et al. (1984) have summarized larval growth, development and growth to maturity. Once fertilized, eggs hatch in about one day, depending on temperature. Spawning is assumed to be coincident with larval distribution since eggs hatch rapidly. The minimum size for female skipjack at maturity is 40 cm FL and initial spawning occurs between 40-45 cm FL. Based on growth estimates, skipjack are about one year old or less at this size (Wild and Hampton 1994).

Mori (1972) defines ‘juveniles’ as smaller than 15 cm (but above 12-15 mm, the upper limit for larvae as defined by Matsumoto et al.1984) while ‘young’ are 15-35 cm. Relatively little is known about the juvenile phase (especially the adolescent or pre-adult stage) since they do not appear in plankton tows and are too small to enter any fishery. Most have been collected from the stomachs of larger tunas and billfish (Wild and Hampton 1994).

2.4.3 Trophic Interactions

Skipjack are opportunistic foragers, and an extensive range of species has been found in their stomachs. Matsumoto et al. (1984) note that smaller skipjack tuna rely mainly on crustaceans for food, presumably zooplankton. Matsumoto et al. (1984) also document taxonomic groups found in various studies analyzing stomach contents; 11 invertebrate orders and 80 or more fish families are listed. In the Western and Central Pacific, fishes are the most important prey of adult skipjack, followed by mollusks and crustaceans. Scombrids are the most important group of fish consumed by skipjack. Off Baja California, Mexico and southern California, pelagic red crab and northern anchovy are important constituents of the skipjack’s diet, with euphausiids, Pacific saury and squid also taken (Alverson 1963, sampling in 1957-1959). Like the tropical tunas, pelagic red crab, normally found to the south of the U.S. EEZ, shifts northward during warm water years.

In the wild, skipjack exhibit feeding peaks in the early morning and late afternoon. Experiments with captive skipjack indicate that an intense feeding period occurs in the early morning (Nakamura 1962; Magnuson 1969;). In one experiment, fish ate over the entire day, most intensively during the first two-hours and then in smaller amounts throughout the day; they could not feed effectively at night.

2.4.4 Migrations, Movements and Stock Structure

Morphological and genetic research indicate that skipjack tuna is one worldwide species, and no sub-species are recognized. Serological and genetic analyses of Pacific populations have not conclusively clarified the sub-population structure. The species is genetically heterogeneous across the Pacific. Pre-recruits are thought to disperse from the central Pacific, arriving in the eastern Pacific at 1 to 1 ½ years old and returning to the central Pacific at 2 to 2 ½ years old (Wild and Hampton 1991; Hunter et al. 1986). Migrants to the eastern Pacific split between a northern and southern group off of Mexico and Central and South America respectively. Large-scale current patterns in the region might account for this north-south distribution (Iannelli 1993). In the western Pacific, data indicate that there is relatively little movement, particularly in the Papua New Guinea and Solomon Islands area (Wild and Hampton 1994). There is also evidence of an eastward migration in the Micronesian region (Mullen 1989, Polacheck 1990).

2.4.5 Reproduction

Young skipjack have sex ratios dominated by females, and older fish have a higher proportion of males (Wild and Hampton 1994). Iversen et al. (1970) observed courtship behavior between pairs of tuna. Although relatively little has been published on the fecundity of skipjack, in the Pacific the reported range is between 100,000 and 2 million ova for fish 43-87 cm. Skipjack spawn more than once in a season, as often as every 1.18 days (Hunter et al. 1986). They spawn year-round in tropical waters and seasonally, spring to early fall, in sub-tropical areas.

2.4.6 Vital Rates/Statistics

A reliable means for establishing an age-length relationship does not exist. Josse et al. (1979) published an early paper on skipjack growth, and Matsumoto et al. (1984) provides an extensive review of growth estimates. A maximum age of 8-12 years is based on the largest individual documented in the literature (Miyake 1968) as in 106.5-108.4 cm size class. Estimates for a one year old are 26-41 cm and 54-91 cm for four-year olds. Bayliff (1988) also provides skipjack growth information, as estimated from tagging.

Skipjack populations are noted for their fluctuations, which likely reflect movements and changes in natural mortality. There are no reliable estimates of average M for adult skipjack, but its value may be 1.5 or higher (Shomura et al. 1995). Intrinsic rate of population increase of a population at the MSY level, assuming 25% increase in average fecundity at B_{MSY} and $F_{MSY} = M$, has been estimated at $r = 0.40$ (Au et al. *in press*)

2.4.7 Fishery Utilization

Historically, bait boats (pole-and-line) were the main gear used in catching skipjack. Since the 1980s, purse seine fishers have come to dominate the fishery. Some skipjack are also caught incidentally by longline fishers targeting bigeye and yellowfin tuna. There are two major fisheries in the eastern Pacific. The most important is located east of 100° W off of Central and South America. The northern fishery, separated by a region of low abundance from the southern, occurs near Baja California, the Revillagigedo Islands and Clipperton Island. Eastern Pacific skipjack are fished by several countries and multiple gears, including Mexico (pole and line, purse seine), Ecuadaor (purse seine, pole and line), Venezuela (purse seine), Columbia (purse seine), Vanuatu (purse seine), and the U.S. (primarily purse seine and pole and line)(PFMC 1999). Regional landings of skipjack from West Coast-based vessels represent less than 1% of the Pacific-wide skipjack catch (Ch. 3, Table 3.3.5-1).

2.4.8 Essential Fish Habitat for Skipjack Tuna (Figure 24): (Based on California drift gill drift net observer data (1990-1999); California Commercial Passenger Fishing Vessel data; Matsumoto et al. 1984; and PFMC 1999.). Diet information based largely on Alverson (1963)

- Eggs and Larvae - No habitat within the U.S. West Coast EEZ.

- Juvenile - No habitat within the U.S. West Coast EEZ.

- Adult - Oceanic, epipelagic waters beyond the 400 fm isobath out to the EEZ boundary from the U.S.-Mexico EEZ border northward to Point Conception, CA, and northward beyond the 1000 fm isobath north to about 40° N latitude. Associated with SSTs between 18°C and 20°C and dissolved oxygen level ≥ 3.5 ppm. Habitat concentrated, esp. in warm years, in the Southern California Bight primarily south of 33° N latitude. Off Baja California, Mexico and southern California, pelagic red crab and northern anchovy are important constituents of the diet. Euphausiids, Pacific saury and squid are also taken.

2.5 Yellowfin Tuna (*Thunnus albacares*)

2.5.1 General Distribution

Yellowfin tuna are trans-Pacific in distribution, occupying the surface waters of all warm oceans, and the target of large surface and sub-surface fisheries. Their distribution in the Pacific lies roughly within latitudes 40° N to 40° S, as indicated by catch records of the Japanese purse seine and longline fishery (Suzuki et al. 1978). SSTs play a primary role in the horizontal and vertical distribution, particularly at higher latitudes. Blackburn (1965) suggests the range of yellowfin distribution is bounded water temperatures between 18°C and 31°C with commercial concentrations occurring between 20°C and 30°C.

Yellowfin are known to aggregate to drifting flotsam, fish aggregating devices (FADs), anchored buoys, dolphin and other large marine animals (Hampton and Bailey 1993). Adult yellowfin also aggregate in regions of elevated productivity and high zooplankton density, such as near seamounts and regions of upwelling and convergence of surface waters of different densities, presumably because of more abundant forage (Blackburn 1969, Cole 1980).

Larval distribution has been described by Matsumoto (1958), Strasburg (1960), Ueyanagi (1969), Nishikawa et. al (1978, 1985), Harada et al. (1980), and Boehlert and Mundy (1994). The larvae are trans-Pacific in distribution and found throughout the year in tropical waters, but are restricted to summer months in sub-tropical regions. For example, peak larval abundance occurs in the Kuroshio Current during May and June and in the East Australian Current during the austral summer (November to December). Yellowfin larvae have been reported close to the MHI in June and September, but were not found in December and April. Their basic environment can be characterized as warm, oceanic surface waters, in the mixed layer above the thermocline, with preference toward the upper range of temperatures for the species. It can be assumed that yellowfin larvae are common at SST above 26°C, but may occur in some regions with SST down to 24°C. Harada et al. (1980) hatched normal larvae most frequently in laboratory water temperatures between 26.4°C to 27.8°C, with no normal larvae hatched in water less than 18.7°C or greater than 31.9°C. The distribution of early juveniles less than 35 cm FL has not been well documented, but is assumed to be similar to that of larval yellowfin.

Juvenile fish (> 35 cm FL) are distributed in warm oceanic surface waters above the thermocline and are found throughout the year in tropical waters. Accounts on captures of juvenile tuna have been summarized by Higgins (1970). Juveniles have been reported in the western Pacific between 31° N near the east coast of Japan to 23° S, and from 23° N near the Hawaiian Islands to 23° S in the central Pacific region. Juveniles often will aggregate beneath drifting objects or large, slow moving animals such as whale sharks and manta rays (Hampton and Bailey 1993). This characteristic has been exploited by surface fisheries using anchored or drifting FADs that aggregate yellowfin tuna, mostly juveniles. Like adults, juveniles are also known to aggregate near seamounts and submarine ridges (Fonteneau 1991). Juvenile yellowfin form single-species schools of similar-sized fish at or near the surface or may be mixed with other tunas such as skipjack or juvenile bigeye tuna. Yuen (1963) has suggested that the mixed-species schools are actually separate single-species schools that temporarily aggregate to a common factor such as food. Within the U.S. Pacific Coast EEZ, most fish taken in the fisheries are juveniles <95 cm FL; these fish are generally distributed seasonally in epipelagic oceanic waters from the U.S.-Mexico EEZ border north to Point Conception, CA, extending in some warm-water years northward to Monterey Bay (in SSTs ≥18°C).

2.5.2 Growth and Development

The species is characterized by rapid growth and development to maturity with high natural mortality and a relatively short life span. The majority of yellowfin likely reach maturity between 2 and 3 years of age on the basis of growth rate (Ueyanagi 1966). Estimates of length at maturity for central and western Pacific yellowfin vary widely with some studies, suggesting faster maturity in coastal or island waters (Cole 1980). Research on yellowfin larvae collected at sea and identified as yellowfin tuna by mitochondrial DNA analysis indicate that wild larvae grow at a rate approximately twice that of laboratory-reared larvae and average sizes are 1.5 to 2.5 larger than laboratory reared specimens of a similar age (IATTC 1999; Wexler, J.B., IATTC, pers. comm. 4/2/01). We adopt the size of 50% maturity as in Schaefer (1998), who determined maturity in eastern Pacific fish using histological criteria. He found that the minimum length at sexual maturity of females was 59 cm FL with length at 50% maturity at 92 cm FL; males reach 50% maturity at 69 cm FL. It is generally believed that most yellowfin taken within the U.S. West Coast EEZ are juvenile fish, but occasionally large fish are taken. Bayliff (1988) reports that for yellowfin $\geq$ 50 cm FL tagged north of the equator, average growth was 0.85 mm/day.

Longevity for the species has not been determined, but a maximum age of 6 to 7 years appears likely based on growth estimates and tag recapture data.

The larval development from artificially fertilized eggs has been described by Harada et al. (1971), Mori et al. (1971) and Harada et al. (1980) and IATTC (1999).

2.5.3 Trophic Interactions

Feeding is opportunistic at all life stages and occurs primarily during the day, with prey items consisting primarily of crustaceans, cephalopods and fish (Reintjes and King 1953, Watanabe 1958; Cole 1980). According to Alverson (1963) off the west coast of Baja California, Mexico, and southern California, pelagic red crab is an important constituent of the diet, and, secondarily, northern anchovy. Cephalopods occur in the diet less frequently in these areas, although become more important in the Gulf of California (sampling period, 1957-59, bracketed an El Niño regime).

Larvae reportedly feed in the upper mixed layer on crustacean zooplankton at early stages of the yellowfin larval phase with some fish larvae at the end of the larval phase (Uotani et al. 1981). Juvenile prey items are epipelagic or mesopelagic members of the oceanic community or pelagic post-larval or pre-juvenile stages of island-, reef- or benthic-associated organisms. Adults feed similarly, with larger adults taking larger prey items, large squid and fish species becoming increasingly more important in the diet. Yesaki (1983) notes a high degree of cannibalism of juvenile tunas among large FAD-associated yellowfin in the southern Philippines. The baiting of longlines with saury, mackerel and large squid also implies that mature fish will take large prey items if available.

2.5.4 Migrations, Movements and Stock Structure

Eastern Pacific yellowfin are clearly capable of large-scale movements, which have been documented by tag and recapture programs, but most recaptures occur within several hundred miles of release (Wild 1994; Hunter et al. 1986; Uosaki and Bayliff 1999). Yellowfin appear to move freely within broad regions of favorable water temperature and are known to make seasonal excursions to higher latitudes as water temperatures increase with season. However, the extent to which these are directed movements is unknown, and the nature of yellowfin migration in the central and western Pacific remains unclear.

2.5.5 Reproduction

Yellowfin have a high spawning frequency and fecundity. Spawning spans broad areas of the Pacific and occurs throughout the year in tropical waters and seasonally at higher latitudes at water temperatures over 24°C. Yellowfin are serial spawners, capable of repeated spawning at near daily intervals with batch fecundities of millions of ova per spawning event (June 1953; McPherson 1991; Schaefer 1996, 1998). Sex ratio is commonly accepted to be essentially 1:1 until a length of approximately 120 cm after which the proportion of males increases (Kikawa 1966; Yesaki 1983; Wild 1986).

Several different areas and seasons of peak spawning for yellowfin have been proposed for the central and western equatorial Pacific. Koido and Suzuki (1989) propose a peak spawning period for yellowfin in the western tropical Pacific from April to November. Kikawa (1966) reports the peak spawning potential of yellowfin in the western tropical Pacific (120° E-180°) to occur December-January and April-May east of the dateline (180°-140° W). Fish taken by purse seine gear are more reproductively active with a higher spawning frequency than longline caught fish in the same areas. A positive relationship between spawning activity and areas of high forage abundance has been noted (Itano 1997). Yellowfin spawn in Hawaiian waters during the spring to fall period.

2.5.6 Vital Rates/Statistics

Wild (1994) provides a review of vital rates; see also Maunder and Watters (2001). Age at 50% female maturity = 2.5 years; maximum reproductive age = 6-7 yrs; M = .80 all males and females during first 30 months, thereafter increasing linearly to 4.8 for females at 80 months (Hennemuth (1961; Francis 1974; Murphy and Sakagawa 1977); total annual instantaneous mortality Z = ~2.0 M. Wild (1994) estimated the following von Bertalanffy growth equation for the two sexes within range of 30 to 168 cm FL where L = Fork Length in cm:

$$L_t = 188.2(1.0 + 0.434 \exp [-0.724\{ t \text{ (yr)} -1.825\}])^{-2.30}$$

The intrinsic rate of population increase of a population at the MSY level, assuming 25% increase in average fecundity at B_{MSY} and F_{MSY} = M, has been estimated at r = 0.20 (Au et al. *in press*)

2.5.7 Fishery Utilization

Yellowfin tuna are exploited in the eastern Pacific by several countries and multiple gears, including Mexico (purse seine, pole-and-line), Ecuador (purse seine, pole-and-line), Venezuela (purse seine), Colombia (purse seine), Costa Rica (purse seine), and the U.S. (purse seine, pole-and-line, longline, troll, and recreational gear) (PFMC 1999). There are three different types of purse seine methods (sets on floating objects, unassociated schools, and schools associated with dolphins). Yellowfin aggregate to drifting flotsam, large marine animals and regions of elevated productivity, such as near seamounts and areas of upwelling (Blackburn 1969); major fisheries for yellowfin exploit this behavior by either by utilizing artificial fish aggregation devices (FADs) or by targeting areas with vulnerable concentrations of tuna (Sharp 1978). The commercial and recreational landings of U.S. West Coast-based vessels is estimated to comprise 2% of the current eastern Pacific catch of yellowfin tuna (Ch. 3, Table 3.3.5-1).

2.5.8 Essential Fish Habitat for Yellowfin Tuna (Figure 25): (Based on California Commercial Passenger Fishing Vessel data; drift gill net observer data (1990-1999); Uosaki and Bayliff (1999); Block et al. (1997); IATTC (1990; 2000e); Schaefer (1998); N. Bartoo, SWFSC, NMFS, La Jolla, CA pers. comm.). Diet information based largely on Alverson (1963).

- Eggs and Larvae - No habitat within the U.S. West Coast EEZ.

- Juvenile - females: <92 cm FL; males: <69 cm FL. Oceanic, epipelagic waters from the U.S.-Mexico EEZ border north to Point Conception, CA, some years extending northward to Monterey Bay (37° N latitude). South of Pt Conception from the 100 fm isobath out to the EEZ boundary; north of Point Conception from 300 fm isobath out to the EEZ boundary. Associated with SSTs between 18° to 31°C. Pelagic red crab is an important constituent of the diet off the west coast of Baja California, Mexico, and southern California (warm water years), and, secondarily, northern anchovy. Cephalopods also occur in the diet less frequently.

- Adult - females: ≥92cm FL; males: ≥69 cm FL. Adult yellowfin tuna do not regularly occupy habitat within the U.S. West Coast EEZ.

3.0 STRIPED MARLIN (*Tetrapturus audax*)

3.0.1 General Distribution

The striped marlin is widely distributed in oceanic epipelagic waters throughout most tropical, sub-tropical and temperate waters of the Pacific and Indian Oceans, being apparently more abundant in the eastern and north central Pacific than elsewhere, and associated with sea surface temperatures of 20-25°C (Nakamura 1974; 1985). Based on Japanese longline data, Pacific striped marlin has a U-shaped distribution, occurring in greatest numbers in two supra-equatorial bands that join at the eastern tropical margin (Nakamura 1974; Squire and Suzuki 1990). Generally, distribution corresponds to the 20° and 25°C isotherms (Howard and Ueyanagi 1965). These authors distinguish a Northern Pacific Group found west of 140° W and north of 15° N, and an Eastern Pacific Group east of 120° W and south of 15° S. These authors and others (Squire and Suzuki 1990) indicate that striped marlin occur in the equatorial region (the center of the U), but in very low densities. El Nino-related warming of waters along the American coast apparently leads to a northerly shift in striped marlin range (Squire 1987). Striped marlin are found in greater numbers in the North Pacific with higher catch rates found in the north central, northeast, and southeast Pacific (Shomura 1975).

Spawning does not occur within the U.S. West Coast EEZ , but in the North Pacific, larvae are recorded mainly west of 150° W and also off central Mexico. Those that spawn in the northwest Pacific are thought to migrate eastward as juveniles (Squire and Suzuki 1990). Subadult fish occur in high abundance around the tip of the Baja Peninsula, and mainly adult fish (some sub adults) occur seasonally within the Southern California Bight (SCB) most years, and north to San Francisco and beyond in warm water years (Holts, 2001a, *in press*). Analysis of Japanese longline catches in the eastern Pacific Ocean by Uosaki and Bayliff (1999) indicate that striped marlin also occur just west of the U.S. EEZ in moderate concentrations from about 22° N to 37° N latitude and west of 125° W longitude. Because of lack of fishing effort in the outer waters of the EEZ, it is not known to what extent the striped marlin distribution is continuous from the SCB westward to the EZZ boundary, although it is likely discontinuous at least in the area influenced by the California Current, which tends to form a barrier of colder, less saline water between the SCB and the warm oceanic waters generally west of 125° W (Lynn and Simpson 1990; Lynn et al. 1982).

Distribution of eggs is unknown (presumably epipelagic); larvae may make diurnal vertical migrations in the top 50 m of the water column (Ueyanagi and Wares 1975). Very little is known about juvenile marlin habitat.

3.0.2 Growth and Development and Vital Rates

Description of larvae is based on specimens 2.9-21.2 mm in length (Ueyanagi and Wares 1975). Since marlin cannot yet be accurately aged, it is difficult to determine age and duration of different life stages. Females are reported to reach first maturity at 50-80 lbs; it is not possible to determine onset of sexual maturity in males because change in the size of testes is slight (Squire and Suzuki 1990). Holts (in press 2001a) has estimated that most striped marlin caught in the southern California sport fishery are three-to-six years old and weight 120 to 200 pounds, and though not reproductively active, appear to be adult-sized. Intrinsic rate of population increase of a population at the MSY level, assuming 25% increase in average fecundity at B_{MSY} and $F_{MSY} = M$, has been estimated at $r = 0.13$ (Au et al. *in press*)

3.0.3 Trophic Interactions

Little is known about the time of first feeding and food preferences. Juvenile striped marlin larvae may consume copepods up to about 13 mm (observed in the Atlantic sailfish larvae) and other fish larvae after reaching a size of about 7 mm (Ueyanagi and Wares (1975). Nakamura (1985) states that adult striped marlin feed on more epipelagic organisms and less on mesopelagic ones. Common food items are squid, scombrids, and gempylids. In California, food species include saury, anchovy, sardine, and jack mackerel

(Hubbs and Wisner 1953, Nakamura 1985, Ueyanagi and Wares 1975). Holts (*in press* 2001a) reports that off southern California, marlin feed on mackerel, sardine, anchovy, squid and pelagic red crab.

3.0.4 Migrations, Movements and Stock Structure

Squire and Suzuki (1990) contend that striped marlin make long-term migrations between spawning and feeding areas. The spawning areas are in the northwest and to a lesser extent the southwest Pacific. Young fish migrate eastward to feeding areas off the Central American coast and return westward as adults. Seasonal patterns generally conform to water temperature-related changes in range. In Hawaiian waters, striped marlin are more common in the winter months (Ueyanagi and Wares 1975). The smaller fish appear in catches off Hawaii in the winter season, and they grow to 50-60 lbs in May and June while in this area. They disappear from these waters during the summer. This indicates the fish migrate to northern waters during this time where they stay several months and grow. Then they migrate back to Hawaiian waters (Howard and Ueyanagi 1965).

Tracking of adult striped marlin in Hawaiian waters using ultrasonic telemetry (Brill et al. 1993) indicate that they spend a significant amount of time in the upper 10 m of the water column. The tracked fish spent about 40% of their time between 51-90 m. The authors conclude that depth preference is governed by temperature stratification, with striped marlin preferring to remain in the mixed layer above the thermocline; the fish they tracked spent the vast majority of time in waters within 2°C of the mixed layer temperature and never ventured into waters 8°C colder than the mixed layer temperature. Thus, these fish spent about 80% of their time in waters between 25.1° and 27°C and never ventured into waters below 18°C. This generally corresponds to the upper mixed layer for Hawaiian waters. There was no discernible diurnal pattern in horizontal movement. Striped marlin are also reported to swim very slowly at the surface with strong wind and high waves (Nakamura 1985).

Stock structure is unclear, and opinions vary. Recent evidence suggests striped marlin are a single, Pacific-wide biological stock although the possibility of a north-south separation does exist (PFMC 1999). Holts (*in press* 2001a) proposes that striped marlin are probably a single Pacific-wide stock because of the generally continuous distribution throughout the Pacific, spawning in the south and northwest Pacific and eastern Pacific off Mexico, and based on tag-recapture studies. Other researchers divide the population into two separate stocks, at least for management purposes, because it is distributed in two supra-equatorial bands that join at the eastern tropical margin (Shomura 1975). Additionally, according to Graves and McDowell (1994), genetic analysis of mitochondrial DNA suggests a corresponding spatial partitioning in genotypes, confirming the belief in distinct stocks. The authors suggest that this differentiation may be due to spawning site fidelity. Genetic divergence between striped marlin and white marlin (*T. albidus*), which occurs in the Atlantic Ocean, is apparently not much greater than variation within the Pacific striped marlin population, suggesting that striped and white marlin are not in fact separate species. Also, recent analysis of mitochondrial DNA (Finnerty and Block 1995) suggests that billfish (Istophoridae and Xiphiidae) should be separated from the suborder Scombroidei to which they have traditionally been assigned.

3.0.5 Reproduction

Spawning does not occur within the U.S. West Coast EEZ, but rather to the south far offshore Mexico and westward in a band across the central equatorial Pacific. In the northwestern Pacific, peak abundance is in May-June (Ueyanagi and Wares 1975) in the area of the spawning grounds described by Squire and Suzuki (1990). Thus, spawning is probably seasonal and confined to the early summer months in both hemispheres. There is probably a separate spawning ground in the southwest Pacific. This would seem to be supported by genotype variability based on mitochondrial DNA analysis (Graves and McDowell 1994). In the North Pacific, larvae are recorded mainly west of 150° W, although more recently also off central Mexico. There is no sexual dimorphism in this species, in contrast to blue marlin.

3.0.6 Fishery Utilization

Region- and basin-wide major catches of striped marlin are made by Japan, Taiwan and Korea (PFMC 1999). Important fishing areas include FAO Fishing Area 61 (northwest Pacific) where about 50% of the catch is made. Most of the catch is made by surface longlining that targets tunas (Nakamura 1985). In the management plan area, striped marlin are targeted in the recreational catch-and-release fishery in southern California and are taken occasionally as bycatch (regulatory discard) in the drift net fishery. The recreational catch and commercial by-catch of striped marlin by U.S. West Coast-based vessels is estimated to be less than 1% of the Pacific-wide take of this species (Ch. 3, Table 3.3.5-1).

3.0.7 Essential Fish Habitat for Striped Marlin (Figure 26, Adults): (Based on Uosaki and Bayliff (1999); California drift net observer data (1990-1999 and angler tag-release data (D. Holts and D. Prescott, pers. comm. NMFS, SWFSC, La Jolla, CA, and diet information from Hubbs and Wisner (1953), Nakamura (1985), Ueyanagi and Wares (1975), and Holts *in press* (2001a).

- Eggs and Larvae - No habitat within the U.S. West Coast EEZ.

- Juvenile - No regular habitat within the U.S. West Coast EEZ.

- Adult - >150 cm EFL or 171 JFL. Oceanic, epipelagic waters of the Southern California Bight, above the thermocline, from the 200 fm isobath from the U.S.-Mexico EEZ border to about 34° 09' N latitude (Pt. Hueneme, CA), east of the Santa Rosa-Cortes Ridge (a line from South Point, Santa Rosa Island, southeast to the EEZ boundary at approx. 31° 36' N and 118° 45' W). Preferred water temperature regimes bounded by 68° to 78°F (20-25°C). Food species off California include Pacific saury, northern anchovy, Pacific sardine, jack mackerel, squid and pelagic red crab.

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4.0 BROADBILL SWORDFISH (*Xiphias gladius*)

4.0.1 General Distribution

Broadbill swordfish are worldwide in distribution in all tropical, subtropical, and temperate seas, ranging from around 50° N to 50° S (Nakamura 1985, Bartoo and Coan 1989; Barrett et al. 1998). They occur throughout the entire region of the Council's jurisdiction and in all neighboring states, territories and adjacent high seas zones. Oceanographic features that tend to concentrate forage species apparently have a significant influence on adult swordfish distributions. Swordfish are relatively abundant near boundary zones where sharp gradients of temperature and salinity exist (Palko et al. 1981). Sakagawa (1989) and Sosa-Nishizaki and Shimizu (1991) also note that swordfish are found in areas of high productivity where forage species are abundant near current boundaries and frontal zones. In a study of the dynamics of the Hawaii swordfish longline fishery, DiNardo and Kwok (1998) found that areas of high fishing effort moved progressively north and west, concentrating in the North Pacific Transition Zone, along the Subarctic Boundary, and in the subarctic frontal zone. These are areas where squid, the primary prey of swordfish, are known to form dense seasonal concentrations. The relationship between large-scale frontal systems, forage species and swordfish distribution and abundance in the North Pacific is currently being studied by the NMFS (SWFSC Honolulu Laboratory).

The adults can tolerate a wide range of water temperature, from 5°- 27°C but are normally found in areas with SSTs above 13°C (Nakamura 1985). Optimal SSTs for swordfish are around 25°-29°C (Taning 1955), although swordfish probably spend the majority of their time in cooler sub-surface waters. Most large-sized fish are females, which appear to be more common in cooler waters. According to Beckett (1974) and Palko et al. (1981) few males tend to occur in waters below 18°C, and make up the majority of warm water landings.

There are few specific references on the distribution of juvenile swordfish in the Pacific, although they recruit to longline gear at juvenile sizes of approximately 50 to 80 cm (Eye-Fork Length). Dewees (1992) states that like adults, they tend to concentrate along productive thermal boundaries between cold upwelled water and warmer water masses where they feed on fish and squid. Gorbunova (1969) suggested that juvenile swordfish in the Pacific are restricted to areas of upwelling and high productivity and do not move far during the first year of life. Yabe et al. (1959) state that young swordfish originate in tropical and subtropical regions and migrate to higher latitudes as they increase in size.

According to Ward and Elscot (2000) citing others, swordfish do not seem to have a discrete spawning ground or spawning season. Larvae and juveniles tend to occur in warmer tropical and subtropical regions--no egg and larval habitat has been reported for the U.S. West Coast EEZ. The geographical distribution of larvae suggests that spawning occurs in waters where SSTs are above 24°C; this isotherm rarely extends north of 35° N or south of 35° S. Larvae have been observed in waters of the three major oceans between about 30° N and 30° S. Spawning occurs throughout the year in equatorial waters, but is progressively restricted to spring-summer at higher latitudes. In the eastern Pacific the distribution narrows, probably because of lower water temperatures associated with the Peru Current and upwelling in that region. Larvae are believed to occupy surface waters where almost all catches have been made using plankton and dip nets (Taning 1955, Nishikawa and Ueyanagi 1974). Larval swordfish are found within a SST range of 24° to 29°C and have been found in the Pacific where salinity ranged from 34.4-36.4% (Matsumoto and Kazama 1974). Larval abundance is high along sharp thermal and salinity gradients. However, this phenomenon may be due to passive collection along boundary areas.

4.0.2 Growth, Development and Vital Rates

Swordfish grow extremely fast during their first year of life, and by one year of age may reach 90 cm EFL (Uchiyama et al. 1998; Ward and Elscot 2000). Growth is highly variable among fish of the same age and sex, and there is a marked difference in growth rate between males and females. After two years of age, females tend to grow faster than males, grow to a larger size, and are proportionately heavier at the same length (Palko et al. 1981).

Information on age and growth of swordfish is the subject of continuing study, and findings have been somewhat contradictory. Age studies based on otolith analysis and other methods (length frequency, vertebrae, fin rays, growth studies) are reviewed by Sosa-Nishizaki (1996) and Ehrhardt (1996). Wilson and Dean (1983) estimated a maximum age of 9 years for males and 15 years for females from otolith analysis. Radtke and Hurley (1983), using otoliths estimated a maximum age of 14 years for males and 32 years for females. The assumed daily and annular increments used in these analyses have not yet been validated. Uchiyama et al. (1998) provide the following provisional von Bertalanffy growth equation for the two sexes using hard parts from swordfish from northwest of Hawaii, where L = Eye-Fork Length in cm:

$$L_t = 321[1.0 - e^{-0.14\,(t+1.3)}]$$

This estimated growth is similar to that estimated by Yabe et al. (1959) who earlier analyzed the length frequency distribution of swordfish landed in the western North Pacific.

In the Hawaii-based pelagic longline fishery, males mature at 102 cm Eye Fork Length (EFL) or 118 cm Lower Jaw Length (JFL); females at 144 cm EFL or 163 cm JFL (DeMartini et al. 2000).

The intrinsic rate of population increase of a population at the MSY level, assuming 25% increase in average fecundity at B_{MSY} and $F_{MSY} = M$, has been estimated at r = 0.10 (Au et al. *in press*)

4.0.3 Trophic Interactions

According to Markaida and Sosa-Nishizaki (1998) and others, swordfish are voracious and opportunistic feeders at all life stages; their diet generally reflecting the presence and abundance of available prey species in any given geographic region. The larval and young swordfish actively feed on zooplankton during the day and become piscivorous by 11-12 mm in length, feeding on a variety of epipelagic fish larvae (Arata 1954; Gorbunova 1969). Yabe et al. (1959) observed that Pacific swordfish of 9.0-14.0 mm fed on crustacean zooplankton and did not graduate to fish prey until 21 mm in length. Larval swordfish are rapacious feeders known to swallow prey as long as themselves (Taning 1955). Adults feed opportunistically on a wide range of squids, fish and crustaceans preying heavily on squid and various fish species. Fry (1971) enumerated northern anchovy, squid, hake, jack mackerel, rockfish, barracudinas, black smelt, ribbonfish, and shrimp as swordfish prey off California, and suggested that swordfish may undergo ontogenetic change in feeding habits, foraging at greater depths with age. Mearns et al. (1981) examined stomach contents of 15 swordfish caught near the Southern California Channel Islands and found that northern anchovy and hake each accounted for over 40% of the index of relative importance, the remainder being unidentitifed fish. Fitch and Lavenberg (1971) report that examination of a large sample of swordfish captured in the harpoon fishery revealed that most had fed on northern anchovy and squid, but that they also depended on other fish prey such as hake, jack mackerel, and shortbelly rockfish. Off Baja California Mexico, Markaida and Sosa-Nishizaki (1998) found that a variety of fishes, including Pacific hake, *Merluccius productus*, was important in the diet as well as cephalopods, especially the flying purple squid, *Sthennoteuthis oualaniensis*, and jumbo squid, *Dosidicus gigas*.

Swordfish can forage at great depths and have been photographed at a depth of 1,000 m by a deep diving submersible (Mather 1976). Carey (1982) and other researchers have suggested that specialized tissues warm the brain and eyes, allowing swordfish to successfully forage at great depths in frigid waters. It is generally accepted that swordfish in the pelagic environment feed on squid and mesopelagic fish and forage on demersal fish when in shallower waters (Scott and Tibbo 1968; Palko et al. 1981; Nakamura 1985; Stillwell and Johler 1985; Bello 1990; Carey 1990; Moreia 1990; Markaida and Sosa-Nishizaki 1994; Barreto et al. 1996; Clarke et al. 1995; Hernandez-Garcia 1995; Orsi Relini et al. 1995).

4.0.4 Migrations, Movements and Stock Structure

Little is known about migration in Pacific swordfish, although limited tagging data support a general west-to-east movement from Hawaii toward North America. An association with cephalopod prey concentrated near frontal boundaries appears more significant in determining the distribution of swordfish in the North Pacific, and further research on the role of food and frontal systems is ongoing (Seki 1993, 1996). The horizontal and vertical movements of several swordfish tracked by acoustic telemetry in the Atlantic and Pacific are documented by Carey and Robison (1981). Studies have noted a general pattern of remaining at depth, sometimes near the bottom, during the day and rising to near the surface during the night which is believed to be a foraging strategy. They further proposed that differences in preferred diving depths between areas were due to an avoidance of depth strata with low dissolved oxygen. Holts et al. (1994) used acoustic telemetry to monitor an adult swordfish which spent about 75% of its time in or just below the upper mixed layer at depths of 10 to 50 m in water temperatures about 14°C, and made excursions to approximately 300 m where the water was close to 8°C. Stock structure of swordfish in the Indian and Pacific oceans is unclear; several studies have been unable to reject the hypothesis that swordfish comprise a single, homogenous population in the Pacific, although Reeb et al. (*in press*) cited in Ward and Elscot (2000) have concluded that swordfish are not homogenous in the Pacific. Using analysis of mtDNA, they found significantly different northern and southern populations in the western Pacific. They also suggest that several overlapping populations might occur in the eastern Pacific so that swordfish appear to be genetically continuous there. They suggest that gene flow between populations occurs through a horseshoe-shaped corridor, running between the north-western Pacific, across to the eastern Pacific and back to the south-western Pacific.

4.0.5 Reproduction

Broadbill swordfish have no apparent sexual dimorphism, although females attain a larger size. Fertilization is external and the fish are believed to spawn close to the surface. A swordfish ovary contains hundreds of millions of eggs, portions of which mature throughout the life of the fish after it reaches maturity (Joseph et al. 1994). There is some evidence for pairing up of spawning adults as the fish apparently do not school (Palko et al. 1981). Peak spawning occurs in the North Pacific between May and August, from December to January in the South Pacific and March to July in the Central Pacific (Nishikawa et al. 1978, Palko et al. 1981). Sexually mature and ripening female swordfish have been noted in Hawaiian waters during the spring and early summer (Uchiyama and Shomura 1974). This observation is in agreement with an estimated spawning period of April to July based on the collection of larvae and juveniles near Hawaii (Matsumoto and Kazama 1974). It is probable that some degree of spawning occurs throughout the year in tropical waters between 20°

N and 20° S, with the distribution of larvae associated with SSTs between 24° and 29°C (Taning 1955, Yabe et al. 1959, Nishikawa and Ueyanagi 1974). Swordfish eggs measure 1.6-1.8 mm in diameter, are transparent and float at the sea surface due the presence of a single oil droplet (Sanzo 1922). The incubation period is approximately 2.5 days (Palko et al. 1981). Newly hatched yolk-sac larvae have been measured at 4.0-4.45 mm in length (Fritzsche 1978, Yasuda et al. 1978).

4.0.6 Fishery Utilization

Broadbill swordfish support major fisheries in all oceans of the world. Major Pacific Ocean fishing areas are off Japan, the North Pacific Transition Zone north of Hawaii, the west coasts of the U.S., Mexico, Ecuador, Peru, Chile, and off Australia and New Zealand (Holts, 2001b *in press*). Along the U.S. West Coast EEZ, swordfish are targeted primarily by the drift net fishery off California and Oregon (Holts and Sosa-Nishizaki 1998), by a small harpoon fishery operating within the Southern California Bight (Coan et al. 1998), and by a California-based longline fishery that fishes beyond the U.S. West Coast EEZ (Vojkovich and Barsky 1998). Although difficult to catch by rod and reel, they are also taken in small numbers by southern California recreational anglers. In the Hawaii area, swordfish are targeted by a Hawaii-based longline fishery that occurs north of the Hawaii EEZ. Incidental or targeted catches within the Hawaii EEZ are made by longline and handline vessels fishing primarily for tuna species. The catch by U.S. West Coast-based vessels is estimated to be about 5% of the Pacific-wide catch of swordfish (Ch. 3, Table 3.3.5-1).

4.0.7 Essential Fish Habitat for Broadbill Swordfish (Figures 27 and 29): (Based on California drift gill net observer data (1990-1999); Oregon driftnet logbook data 1991-2001, Oregon Dep. Fish and Wildlife,unpubl. data, 5/02; and DeMartini et al. (2000); diet information from Fitch and Lavenberg (1971) Mearns et al. 1981 and Markaida and Sosa-Nishizaki (1998).

- Eggs and Larvae - No habitat within the U.S. West Coast EEZ.

- Juvenile - (Males <102 EFL or 118 cm JFL; females <144 cm EFL or <163 JFL). Oceanic, epipelagic and mesopelagic waters from the U.S.-Mexico EEZ border north to 41° N latitude. In the Southern California Bight primarily south of the Santa Barbara Channel Islands from the 400 fm isobath out to the EEZ boundary. North of Point Conception from the 1000 fathom isobath westward to the EEZ outer boundary and northward to 41° N latitude. Food species within the U.S. West Coast EEZ have not been documented for this size category. Diet is thought to be largely opportunistic on suitable-sized prey. Off southern California, swordfish of unspecified size are reported to feed on Pacific hake, northern anchovy, squid, Pacific hake, jack mackerel, and shortbelly rockfish; squids are also important prey off western Baja California, Mexico.

- Adult - (Males > 102 cm EFL or 117 JFL; females > 144 cm EFL or 162 JFL): Oceanic, epipelagic and mesopelagic waters out to the EEZ boundary inshore to the 400 fm isobath in southern and central California from the U.S.-Mexico EEZ border north to 37° N latitude; beyond the 1000 fm isobath northward to 46° 40' N. Food species within the U.S. West Coast EEZ have not been documented for this size category. Off southern California, swordfish of unspecified size are reported to feed on Pacific hake, northern anchovy, squid, Pacific hake, jack mackerel, and shortbelly rockfish; squids are also important prey off western Baja California, Mexico. Large swordfish are capable of foraging in deep water and may also feed on mesopelagic fishes.

5.0 DORADO (MAHIMAHI, *Coryphaena hippurus*)

5.0.1 General Distribution

The dorado is epipelagic and oceanic in tropical and subtropical waters worldwide in seas warmer than 19-20°C; usually $\geq$ 24°C (Ambrose 1996; Palko et al. 1982; Norton 1999). In the Pacific Ocean, greatest concentrations appear to occur along the eastern and western margins. It is also common around islands, including Hawaii's EEZ. The species associates with floating and drifting objects.

In the eastern Pacific, dorado are most abundant off Mexico, Panama, Ecuador and Peru, and around the Galapagos Islands (WPFMC 1986). They move into U.S. West Coast waters generally during warm water years as far north as Grays Harbor, Washington, although usually south of Pt. Conception, CA. Largest concentrations of dorado have occurred in late summer and early fall within the Southern California Eddy System associated with oceanic intrusions where temperatures exceed 20°C and northern geostrophic flow is greatest (Norton 1999). During warm water incursions the dolphin fish usually inhabit water offshore the 6 fm isobath along coastal California from the U.S.-Mexico border generally as far north as Pt. Conception, CA (34° 34' N), primarily east of the 1400 fm isobath. Norton (1999) points out that these warm water incursions have become more frequent in the 1980s and 1990s. This species generally occurs inshore of the cooler, southerly flowing plume of water that usually persists west of offshore banks and islands. It has a very high metabolic rate, which vertically limits its habitat to the oxygen-rich near-surface layers above 30 m (Kraul 1999; Ambrose 1996). Small-sized males and all sizes of females may spend more time associated with floating objects than large sized males, which tend to spend more time in open water, possibly traveling between female-dominated schools below rafts (Oxenford 1985).

5.0.2 Growth and development

Growth is extremely rapid. Fish reach maturity in less than a year (at about 35 cm FL or ~7 mo old), and only rarely live beyond 3-4yrs of age (Beardsley 1967; Palko et al. 1982; Lasso and Zapata 1999). Actual growth rates vary among regions and are sensitive to prevailing water temperatures. In captivity, dolphin grow 1.33 mm per day at 18°C, 3.22 mm per day at 25°C, and 5.74 mm per day at 29°C (Kraul 1999). Kraul (1999) and Uchiyama et al. (1986) estimate fish in the wild have an average growth of about 2 mm per day. In the western Pacific Kojima (1966) found this species to reach 38 cm FL the first year, 68 cm FL the second year, 90 cm FL the third year, and 108 cm FL the fourth year.

5.0.3 Trophic interactions

According to Shcherbachev (1973) the larvae feed mainly on crustaceans, particularly pontellid copepods, with fish larvae appearing in the diet of young juveniles > 20 mm SL. In the Pacific, adult common dolphin are mainly piscivorous, with flying fish being the most important in volume and occurrence. Jacks, mackerels, rabbitfishes, squids and portunid crabs are also taken in various parts of their range (Palko et al. 1982; Lasso and Zapata 1999). Adults can swim faster than 10 meters per second, and can feed at low light levels (Kraul 1999). All life stages of dolphin serve as prey for oceanic fishes, particularly marlin, epipelagic sharks, swordfish, sailfish, and members of their own kind (Parin 1970; Takahashi and Mori 1973; Brock 1984; Palko et al. 1982). Gorbunova (1969) reported that dolphin larvae are a significant food source for swordfish larvae in the Pacific and Indian Oceans.

5.0.4 Migrations, movements and stock structure

There is little information about Pacific Ocean migrations, but dorado are thought to migrate relatively long distances in the western Atlantic and Mediterranean (Oxenford and Hunte 1986). In the eastern Pacific, temperature seems to be an important factor in defining the range and possibly the movements of this species, the northern barrier being the California Current, and in the south, the Peru Current (Lasso and Zapata 1999). Various authors report seasonal patterns in catches, possibly relating to spawning migrations or seasonal intrusion of preferred warm water temperatures (Palko et al. 1982). Norton (1999) noted the dramatic increase in recreational catches of dorado off southern California and northern Mexico over the past 30 years (especially over the last decade). He suggested that the habitat of dorado has been expanding northward in response to an oceanic and atmospheric regime shift that has brought periods of warmer water and enhanced northerly current flow to California. It has also brought less cold water upwelling off northern Mexico, which had formerly inhibited northward dispersal. Little is known of stock structure in the Pacific. Because of the dorado’s brief life cycle and seasonal catch patterns (size and abundance modes, e.g. Kraul 1999) it seems improbable that the U.S.-Mexico stock is shared with Hawaii or fishing nations in the central and western Pacific, however, stock mixing cannot be ruled out. The relationship of the Mexico stock to stocks occurring further south along the West Coast of Central and South American is not known. Because seasonal migrations in the North Pacific show a reverse tendency to that in the southern hemisphere, there may be at least two stocks in the Pacific Ocean separated by the equator (Kojima 1966).

5.0.5 Reproduction

Dorado are oviparous with pelagic eggs and larvae; fertilization is external. Spawning is thought to occur year round in waters ≥ 24°C, although there may be reproductive peaks with eggs released in batches within a given reproductive pulse (Lasso and Zapata 1999). Beardsley (1967) found that fecundity increased sharply with size, and assuming three spawnings a year, estimated that total egg production would vary from about 240,000 to almost 3 million eggs per year for fish ranging in size from 50-110 cm FL. Certain times of year may be more conducive to larval survival, e.g., in Hawaii the strongest cohorts are spawned in July (Kraul 1999). Spawning of the California-Mexico dorado population evidently takes place in waters south of our West Coast EEZ. In CalCOFI larval fish surveys, larvae have been collected off central and southern Baja California, Mexico, and only occasionally off southern California in warm years, with peak abundance in August and September (Ambrose 1996).

5.0.6 Vital Rates/Statistics

Age at female maturity = 0.6 years; maximum reproductive age = 4; M = 1.0617, using Hoenig's (1983) Ln M = 1.46 -1.01 ln (max age). Intrinsic rate of population increase of a population at the MSY level r = 0 .29. In the eastern Pacific of Columbia and Panama, Lasso and Zapata (1999) estimated growth using the following von Bertanlaffy growth equation (FL in cm):

$$L_t = 194\ [1-e^{-0.91(t-(-0.1049))}]$$

5.0.7 Fishery Utilization U.S. West Coast EEZ

The dorado occurs in the California recreational catch primarily during warm water years, mostly in the Southern California Bight, especially in the area south of Los Angeles. According to Norton (1999), before 1972, the annual California Commercial Passenger Fishing Vessels (CPFV) catch during the July-October fishing season seldom exceeded a few hundred fish. Thereafter more than 1000 dorado were taken in 23 out of the next 25 seasons. The next shift was in 1990 when the catch exceeded 31,000 fish, and between 1990-97 when it averaged 15,602 fish per year (range: 1000-31548).

In the commercial fisheries, an estimated annual average of 1084 dorado have been landed and 324 released per year by the high-seas longline fishery landing in California during the period August 1,1995 through December 31, 1999 (Marija Vojkovich, CDFG, 7/11/2000, pers. commun). It is occasionally taken by albacore bait boats, albacore troll and tuna purse seine vessels (PACFIN data base). It is rare in the drift net catch, possibly because its surface-swimming habits take it above the reach of the top of the nets. Judging from the length of net extenders deployed, observed sets have averaged about 11 m below the surface over the past decade (net extenders 1990-99 mean = 37 ft; range 3-99 ft, NMFS drift net observer data base). Also during the summer of 1996, when over 21,000 dorado were taken by the CPFV fleet, the >20°C layer was observed to be less than 10 m deep, indicating a very shallow suitable habitat zone for dorado (J. G. Norton, pers. commun. 9/2000). This is also a species that commonly associates with surface floating objects, and thus may have evolved avoidance capabilities that prevent it from becoming entangled in drifting materials.

5.0.8 Fishery Utilization Hawaii EEZ

The dorado is an important recreational and commercial fish in Hawaii, with commercial landings from 1987-1996 ranging from 150 mt to 600 mt per year. A declining trend in CPUE for mahimahi in the Hawaii longline, troll and handline fisheries over 1962-78 was noted by Skillman and Kamer[12].

5.0.9 Fishery Utilization outside U.S. Pacific EEZ

In the Pacific Ocean, there are established, fairly large-scale surface fisheries for dorado (mahimahi) off Japan and Taiwan in the western Pacific and off Ecuador and Panama in the eastern Pacific, as well as numerous small-scale fisheries throughout the Pacific Basin. Also, incidental catches of this species occur in the well-developed tuna purse seine fishery in the central, western and eastern tropical Pacific.

5.0.10 Essential Fish Habitat for Dorado or Dorado (Figure 30): (Based on California Commercial Passenger Fishing Vessel catches; Norton (1999); and Ambrose (1996). Diet information based on Eschmeyer et al. (1983) and Palko at al. (1982)

- Spawning, eggs and larvae - (<13.7 cm FL): Primarily outside of the U.S. West Coast EEZ. Spawning restricted to water ≥ 24°C; off southern Baja California, Mexico, with peak larval production in August and September (Ambrose 1996).

- Juveniles and subadults - (> 13.6 cm FL and < 35 cm FL): Epipelagic (≤30 m deep) and predominantly oceanic waters offshore the 6 fm isobath along coastal California from the U.S. Mexico border generally as far north as Point Conception, CA (34° 34' N) and within the U.S. West Coast EEZ primarily east of the Santa Rosa-Cortes Ridge. (Line extends from Point Conception south-southeast to a point on the EEZ boundary at 31° 36' N and 118° 45' W). Prefers sea surface temperatures 20°C and higher during warm water incursions. Nothing documented on the diet of juvenile dolphin within the EEZ; presumably feeds on other epipelagic fishes (e.g, small flying fish), crustaceans and squids.

- Adults - (>34 cm FL): Epipelagic (≤30 m deep) and predominantly oceanic waters offshore the 6 fm isobath along coastal California from the U.S. Mexico border generally as far north as Point Conception, CA (34° 34' N) and within the U.S. West Coast EEZ primarily east of the Santa Rosa-Cortes Ridge. (Line extends from Point Conception south-southeast to a point on the EEZ boundary at 31° 36' N and 118° 45' W). Prefers sea surface temperatures 20°C and higher during warm water incursions. Nothing is known of the diet of adult dolphin within the U.S. EEZ, but in the Pacific, adult common dolphin are reportedly mainly piscivorous, with flying fish being the most important in volume and occurrence.

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