WESTERN
PACIFIC
REGIONAL
FISHERY
MANAGEMENT
COUNCIL

Essential Fish Habitat Descriptions for Pacific Pelagic Fishery Ecosystem Plan Management Unit Species

Western Pacific Regional Fishery Management Council
1164 Bishop Street, Suite 1400
Honolulu, Hawaii 96813

December 1, 2005

Essential Fish Habitat Descriptions for Western Pacific Pelagic Fishery Ecosystem Plan Pelagic Management Unit Species

(Crustacean, Bottomfish, Precious Coral and Coral Reef Ecosystem Species)

TABLE OF CONTENTS

1 Introduction 3
2 Pelagic Habitat 3
3 Pelagics Yield 4
4 Biological Information 6
5 Life History 8
  5.1 Eggs and larval stages 8
  5.2 Juvenile 8
  5.3 Adults 8
  5.4 Forage and prey 8
  5.5 Reproductive biology 8
6 Life Histories and Habitat Descriptions for Pelagic Species 9
  6.1 Habitat description for *Coryphaena hippurus* and *C. equiselis* (dolphinfish, mahimahi) 9
  6.2 Habitat description for wahoo (*Acanthocybium solandri*) 16
  6.3 Habitat description for Indo-Pacific blue marlin (*Makaira mazara*) 22
  6.4 Habitat description for black marlin (*Makaira indica*) 30
  6.5 Habitat description for striped marlin (*Tetrapturus audax*) 34
  6.6 Habitat description for shortbill spearfish (*Tetrapturus angustirostris*) 41
  6.7 Habitat description for broadbill swordfish (*Xiphias gladius*) 45
  6.8 Habitat description for sailfish (*Istiophorus platypterus*) 55
  6.9 Habitat description for blue shark (*Prionace glauca*) 60
  6.10 Habitat description for pelagic sharks (Alopiidae, Carcharinidae, Lamnidae, Sphynidae) 66
  6.11 Habitat description for albacore tuna (*Thunnus alalunga*) 87
  6.12 Habitat Description for Bigeye tuna (*Thunnus obesus*) 95
  6.13 Habitat Description for Yellowfin tuna (*Thunnus albacares*) 113
  6.14 Habitat description for northern bluefin tuna (*Thunnus thynnus*) 122
  6.15 Habitat description for skipjack tuna (*Katsuwonus pelamis*) 127
  6.16 Habitat Description for kawakawa (*Euthynnus affinis*) 136
  6.17 Habitat description for dogtooth tuna (*Gymnosarda unicolor*) 140
  6.18 Habitat Description for Moonfish (*Lampris guttatus*): Opah or Moonfish 145
  6.19 Habitat Description for Oilfish Family (Gempylidae): the escolar (*Lepidocybium flavobrunneum*) and the oilfish (*Ruvettus pretiosus*) 150
  6.20 Habitat Description for Pomfret (family Bramidae): the sickle pomfret (*Taractichthys steindachneri*) and the lustrous pomfret (*Eumegistus illustris*) 154
  6.21 Habitat description for bullet tuna (*Auxis rochei*) and frigate tuna (*A. thazard*)...... 159

1 INTRODUCTION

The most important fish (economically, culturally and socially) in the Pacific are oceanic and pelagic, meaning they live in the near-surface waters of the ocean, often far from shore. Tuna, billfish and other large pelagic species are among the world's most popular fish sought for food and sport. These fish are noteworthy for their rapid growth and, for the tunas, high rates of reproduction, as well as their remarkable swimming speed and stamina. Unlike nearshore pelagic species or bottom-dwelling fish that spend most of their lives near islands, pelagic fish move freely in the oceanic environment. Variations in the distribution and abundance of these nomadic species are often related to differences between their life history profiles, migration patterns and habits that are affected by ever-changing environmental influences, such as water temperatures, current patterns and the availability of food.

2 PELAGIC HABITAT

Species of oceanic pelagic fish live in tropical and temperate waters throughout the world's oceans, including the Pacific. They are capable of long migrations that reflect complex relationships to oceanic environmental conditions. These relationships are different for larval, juvenile and adult stages of life. The larvae and juveniles of most species are more abundant in tropical waters, whereas the adults are more widely distributed. Geographic distribution varies with seasonal changes in ocean temperature. In both the northern and southern hemispheres, there is seasonal movement of tunas and related species toward the pole in the warmer seasons and a return toward the equator in the colder seasons. In the western Pacific, adults of pelagic fish range from as far north as Japan and as far south as New Zealand. Albacore, striped marlin and swordfish can be found in even cooler waters at latitudes as far north as 50°N and as far south as 50°S. As a result, fishing for these species is conducted year-round in tropical waters and seasonally in temperate waters.

Migration patterns of pelagic fish stocks in the Pacific Ocean are not easily understood or categorized, despite extensive tag-and-release projects for many of the species. This is particularly evident for the more tropical tuna species (yellowfin, skipjack, bigeye) which appear to roam extensively within a broad expanse of the Pacific centered on the equator. In other words, their migrations appear to be mainly restricted by water temperature and continental land masses and are often linked to large-scale water movements that physically transport fish from one area to another within a favorable temperature range. Although tagging and genetic studies have shown that some interchange does occur, it appears that short life spans and rapid growth rates restrict large-scale interchange and genetic mixing of eastern, central and far-western Pacific stocks of yellowfin and skipjack tuna. Morphometric studies of yellowfin tuna also support the hypothesis that populations from the eastern and western Pacific derive from relatively distinct sub-stocks in the Pacific. The stock structure of bigeye in the Pacific is poorly understood, but a single, Pacific-wide population is assumed.

The movement of the cooler-water tuna (bluefin, albacore) is more predictable and defined, with tagging studies documenting regular and well-defined seasonal movement patterns relating to specific feeding and spawning grounds. The oceanic migrations of billfish are poorly understood, but the results of limited tagging work conclude that most billfish species are capable of transoceanic movement, and some seasonal regularity has been noted.

Large pelagic fish are closely associated with their physical and chemical environment. Tuna tend to be most concentrated where food is abundant, commonly near islands and seamounts that create divergences and convergences, near upwelling zones along ocean current boundaries and along gradients in temperature, oxygen and salinity. Swordfish tend to concentrate along food-rich temperature fronts between cold, upwelled water and warmer oceanic water masses.

Gradients in temperature, oxygen or salinity determine whether or not the surrounding water mass is suitable for pelagic fish. Fishermen sometimes use satellite images to help locate these thermal fronts. Oceanic pelagic fish such as skipjack and yellowfin tuna and blue marlin prefer warm surface layers, where the water is well mixed by waves and is relatively uniform in temperature. Other fish such as albacore, bigeye tuna, striped marlin and swordfish, prefer cooler, more temperate waters, often meaning higher latitudes or greater depths. Preferred water temperature often varies with the size of the fish. Adult pelagic fish usually have a wide temperature tolerance, and during spawning they generally move to warmer waters that are preferred by larval and juvenile stages. Large-scale oceanographic events (such as the El Niño – Southern Oscillation) change the characteristics of water temperature and productivity across the Pacific, and these events have a significant effect on the habitat range and movements of pelagic species.

Tuna movements are related to oceanographic characteristics, particularly water temperature and oxygen concentration. In the ocean, light penetration and water temperature diminish rapidly with increasing depth and, once below the thermocline, the water temperature is only a few degrees above freezing. Many pelagic fish make vertical migrations through the water column. They tend to inhabit surface waters at night and deeper waters during the day, but several species make extensive vertical migrations between surface and deeper waters throughout the day. Certain species, such as swordfish and bigeye tuna, are more vulnerable to fishing when they are concentrated near the surface at night. Bigeye tuna may visit the surface during the night, but generally, longline catches of this fish are highest when hooks are set in deeper, cooler waters just above the thermocline (275–550 m or 150–300 fm). Surface concentrations of juvenile albacore are largely concentrated where the warm mixed layer of the ocean is shallow (above 90 m or 50 fm), but adults are caught mostly in deeper water (90–275 m or 50–150 fm). Swordfish are usually caught near the ocean surface but are known to venture into deeper waters.

3 PELAGICS YIELD

Tuna, billfish, dolphinfish and wahoo are caught collectively by a variety of fishing gear types. At the latitudes of the US Pacific islands, tuna and billfish are generally caught by fishermen during predictable seasons. Their actual abundance in any particular year, however, is difficult or impossible to predict and is subject to countless factors in the oceanic environment. This variability is probably related to annual fluctuations in standing stock size and oceanographic characteristics.

The rates at which pelagic fish grow vary greatly among species and to a large degree determine the level of fishing pressure a species can withstand. For instance, skipjack tuna that grow and mature quickly can be safely harvested at very high levels, while slower growing bluefin tuna are easily overfished.

Yellowfin Tuna—Semi-independent stocks may exist in the western and central Pacific, which are considered relatively distinct from eastern Pacific yellowfin, but the maximum sustainable yield (MSY) of these stocks is still not well known despite considerable scientific research. Estimates based on surface fisheries (purse seine) and sub-surface fisheries (longline) provide different perspectives The western and central Pacific regional catch has reached 375,000 mt per year (of which, less than 1% comes from domestic landings in the US Pacific islands region). It appears that western Pacific yellowfin stocks are not yet fully utilized, but fishing effort and catch are expected to steadily increase in coming years.

Bigeye Tuna—A single ocean-wide stock of bigeye tuna is assumed. The Pacific-wide catch has reached 152,000 mt per year (of which, about 1% comes from domestic landings in the US Pacific islands region). This is close to the estimated MSY, and the stock is considered fully utilized. Because juvenile bigeye are known to associate strongly with flotsam, increasing purse seine catches around flotsam and fish aggregating buoys raises concern about potential overfishing.

Skipjack Tuna—Tagging results indicate considerable movement of skipjack tuna in the Pacific. Even so, complete mixing of the population does not occur across the whole region within one generation of fish. Contradictory results of genetic studies suggest uncertainty about stock structure. The total annual catch from the central and western Pacific is approaching 800,000 mt (of which, less than 1% is produced by domestic fisheries of the US Pacific islands). Although the current level of catch and fishing effort is at a record high, fishing mortality accounts for only a small fraction of stock attrition because of the skipjack tuna's high rates of reproduction, growth and mortality. Thus, while MSY has yet to be determined, the stocks appears to be underutilized and is expected to easily sustain expanded fishing pressure by expanding fisheries.

Albacore—Discrete spawning areas and larval distributions are apparent for North and South Pacific albacore stocks. Low catches of adults in equatorial waters suggest that the fish is limited between hemispheres. Domestic fisheries from the US Pacific islands produce less than 1% of the 59,000 mt annual Pacific-wide catch. MSY estimate for albacore in the North and South Pacific appeared to give reasonable stock assessments before the development of the high seas drift gillnet fishery. With the rapid development and cessation of the driftnet fishery, however, there are now uncertainties about the reliability of those earlier stock assessments. Adult fish in the South Pacific stock are considered fully or overexploited. Expansion of surface fisheries targeting juvenile fish could have a detrimental impact on the abundance of adult albacore in the South Pacific. In the North Pacific, some assessments conclude that the stock is overexploited, but other research concludes that the adult stock remains stable.

Striped Marlin—Separate North and South Pacific sub-stocks are hypothesized on the basis of a north-south separation of spawning grounds, except in the equatorial eastern and western Pacific. These fish spawn in the western Pacific, are recruited into the Mexican fishery of the eastern Pacific and move westward as they mature. In the North Pacific, semi-independent sub-populations are thought to blend over time. Domestic fisheries from the US Pacific islands contribute about 4% of the annual regional catch of 10,000 mt. MSY is unknown, but the stock is considered underutilized because there has been no decline in yield under increased levels of fishing pressure.

Blue Marlin—Pacific blue marlin are thought to belong to a single, ocean-wide stock due to an observed homogeneous distribution of larval and adult fish. The current stock status is unclear. The total annual Pacific catch in recent years is estimated to be around 20,000 mt (domestic landings from the US Pacific islands comprise less than 5% of the total). A recent MSY estimate of 20,000 mt/yr was 2,000 mt/yr less than previous estimates. During the 1970s the stock may have been over-utilized, but as longline fleets have changed fishing methods to target deeper-swimming bigeye tuna, the incidental catch of blue marlin has decreased. There may have been some recovery of the stock, evidenced by an increase in the average weight of blue marlin taken by the Japanese longline fishery since 1975.

Swordfish—The stock structure of swordfish in the western, central and South Pacific is unclear. Domestic landings from the US Pacific islands (mainly the Hawaii longline fishery) produce more than 20% of the 18,000 mt of swordfish caught in the northwest and eastern central Pacific, and about 15% of the Pacific-wide catch. The distribution of catches the possibility of, at least, North and South Pacific stocks. Changes in the longline fisheries have cast doubt on the way previous MSY estimates were calculated, and current catch levels have exceeded the two previous Pacific MSY estimates. To date, however, no indication of decreasing swordfish size has been found in the Hawaii fishery and stocks do not appear to have been exploited on a Pacific-wide basis to the extent that would cause a declining trend in catch rates.

Dolphinfish and Wahoo—North and South Pacific stocks of dolphin fish are apparently separate. Little is known of the stock structure of wahoo. No estimates of MSY are available for either species. The risk of overfishing dolphinfish is probably slight due to the apparent high natural turnover (with a maximum life span of four years). Too little is known about wahoo to estimate MSY.

4 BIOLOGICAL INFORMATION

Tuna and billfish have many physiological adaptations for life in the open ocean. Tuna and tuna-like species are the fastest fish in the world. Bursts of speed exceeding 12–20 kph (20–30 mph) are not unusual. Tuna have streamlined bodies that are specifically adapted for efficient swimming. They have large white muscle masses useful for swimming long distances and red muscle masses for short bursts of speed when chasing prey or escaping predators. Tuna also have circulatory heat exchangers that can raise or lower their body temperatures in response to heating up when vigorously feeding or swimming or cooling down when entering subsurface waters. Unlike most fishes, the circulatory system of tuna can maintain their body temperatures above that of the water in which they live, effectively making them a “warm blooded” animal. This adaptation may allow tuna to utilize their energy reserves quickly, which can translate to a rapid burst of speed and increased efficiency of the brain and eyes, so necessary to hunting prey in cold, deep water.

The tuna’s circulatory and respiratory systems are unique in the fish world. Fish are cold-blooded, and, for most, the temperature difference between shallow and deep layers of the ocean is a physical barrier to vertical migrations. Tuna, however, have evolved the necessary physiological adaptations to accomplish this activity. The ability to make vertical migrations between cold, deep ocean waters and warm surface waters increases the tuna's available habitat for feeding and ability to maintain a relatively constant body temperature. Some tunas move into deeper water to dissipate excess heat produced by feeding in warmer surface waters. Other tuna exhibit the reverse behavior. The tuna's circulatory system is also designed to conserve heat when the fish is relatively inactive and to dissipate heat when activity increases.

Billfish have a large white muscle mass but a smaller mass of red muscle than tunas. Thus, billfish must rely on different defenses against the deleterious effects of changes in water temperature. For example, swordfish have heater organs that warm the brain and eyes to help to protect the central nervous system from rapid temperature changes. The bill of a billfish may also be a special adaptation to reduce drag and increase speed, as well as a weapon for killing prey and for defense.

To orient and guide themselves on their extensive migrations across the open ocean, tuna and billfish are thought to rely somehow on small particles of magnetite, a magnetic material found near nerve endings in the skulls of these fish. Combined with other environmental cues, the fish may use magnetite to navigate using a "biological compass" attuned to the earth's magnetic field.

For most species of tuna and billfish it is reasonable to assume a single, ocean-wide stock in the Pacific where a mingling of fish takes place gradually through the fish's whole life-span. The exchange of fish among areas is difficult to determine because these fish move seasonally between feeding and spawning areas, toward the poles and back. Sub-stocks may exist, with some studies supporting the idea of stock discrimination between the eastern and western Pacific. Results from genetic and tagging studies, however, indicate that some degree of mixing does occur. For albacore and striped marlin, there is evidence of distinct North and South Pacific sub-stocks.

Most of the oceanic pelagic fish form schools (wahoo less commonly so). Schools are most compact when the fish are spawning or attracted to a common food source near features such as a seamounts, flotsam or man-made fish aggregation buoys. Marlin are often seen in pairs or in groups of several males with a single female.

Direct interactions among tuna, billfish dolphinfish and wahoo species are not known, although they compete at the top of the food chain for the same prey. Tuna schools that are associated with dolphins are common in the eastern tropical Pacific, but are rare m the western and central Pacific. The distribution of surface skipjack and juvenile yellowfin tuna schools (as well as dolphinfish and wahoo) are frequently associated with logs, other flotsam and fish aggregation devices. Fishermen also search for flocks of seabirds, which help to reveal tuna schools feeding on baitfish at the surface. Although skipjack, small yellowfin and small bigeye tunas are sometimes caught together, they maintain discrete schools and their co-occurrence around flotsam is probably the result of mutual attraction to food. In the western Pacific, in addition to floating objects, yellowfin and skipjack tuna are sometimes associated with the presence of whales and whale sharks.

5 LIFE HISTORY

5.1 Eggs and larval stages

Pelagics eggs are tiny (about 1 mm diameter); they float with the help of an enclosed oil droplet. Billfish eggs are somewhat larger than those of tuna.

5.2 Juvenile

Although these pelagic fish begin life at only a few millimeters in length, they can reach large sizes. All species grow rapidly during the early years of life with a gradual slowing of growth thereafter. A young tuna may add 2–4 cm (0.8–1.6 in) per month to its body length during the first two years of life and 0.5–2 cm (0.2–0.8 in) per month thereafter. Growth rates vary considerably depending on ocean conditions and food availability. The relationship between age and size in billfish is not as well understood.

5.3 Adults

As subadults, male and female pelagic fish grow at approximately the same rate. After reaching sexual maturity, however, female tuna grow more slowly than male tuna, apparently in response to the higher energy requirements for egg maturation and spawning. In contrast, female marlin and swordfish grow faster than males after maturation and female marlin reach much larger sizes than the males. Dolphinfish males tend to be heavier than females of the same length after 68 cm (27 in) due to differences in body morphology, i.e., the large head of male dolphinfish.

5.4 Forage and prey

The energy demands of swimming are great, and tuna and other pelagic fish have voracious appetites. Some species consume as much as 25% of their own body weight every day. Most oceanic pelagic fish are opportunistic carnivores with variable diets. The major prey items can vary substantially during different stages of life, in different regions of the Pacific and in different seasons. Adults feed on a variety of small fish, shrimp and squid, while juveniles are more opportunistic, feeding on pelagic invertebrates such as crab larvae, isopods and copepods. Some species have very specific and well-known predator-prey relationships, such as dolphinfish preying on flying fish, swordfish on squid, and blue marlin on skipjack tuna. Larval and juvenile tuna are, in turn, prey for fish, seabirds, porpoises and other animals. Adult tuna are often cannibalistic, feeding on the young of their own species. The presence of tuna larvae in tuna stomach samples is common enough that this occurrence has been used to identify areas of recent tuna-spawning activity. Only humans, marine mammals and sharks are known to prey on adult tuna and billfish

5.5 Reproductive biology

Most oceanic pelagic fish spawn over vast areas of the Pacific in warm surface waters. Spawning generally occurs through out the year in the tropics, and more seasonally at higher latitudes when sea surface temperatures (SST) are over 24°C (75°F). Individual females may spawn many times during the season at short intervals. All tuna and tuna-like species have high reproductive rates, producing millions of eggs per year to compensate for the large percentage of eggs that do not survive to adults. A spawning female tuna or billfish may release about 100,000 eggs per kilogram of her body weight.

Species such as skipjack tuna and dolphinfish have short lives (4–5 years) and reach sexual maturity in their first year of life. Some billfish and larger tunas may live 10–20 years and do not reproduce until they are 3–5 years old. Swordfish may first reproduce at 5–6 years old.

6 LIFE HISTORIES AND HABITAT DESCRIPTIONS FOR PELAGIC SPECIES

6.1 Habitat description for *Coryphaena hippurus* and *C. equiselis* (dolphinfish, mahimahi)

Management Plan and Area

American Samoa, Guam, MHI, NWHI, Northern Mariana Islands, Johnston Atoll, Kingman Reff, Palmyra Atoll, Jarvis Island, Midway Island, Howland and Baker Islands and Wake Island.

Life History and General Description

There are two species of dolphinfish, or, as it is known in Hawaii, mahimahi: *Coryphaena hippurus*—by far the most common—and *C. equiselis* (the "pompano dolphin"), which is infrequent in inshore areas. Boggs and Ito (1993) describe the Hawaii fishery only in terms of *C. hippurus*. According to Kojima (1966), there are two sub-populations of *C. hippurus*—one in the Northern Hemisphere and one in the Southern—but this assertion is based on differing seasonal migration patterns.

The dolphinfish is a fast swimming primarily oceanic fish distributed throughout the tropics and sub-tropics of the world's oceans. According to Shcherbachev (1973) *C. hippurus* is widely distributed in the Pacific: longitudinally between 46ºN and 38ºS, in the central Pacific from the Hawaiian Islands in the north and the Tuamotu archipelago in the south and in the eastern part from Oregon to Peru. Although primarily an ocean fish, it may occasionally be caught in estuaries and harbors (Palko and Beardsley et al. 1982). *C. equisetis* is a more exclusively oceanic fish and is rarely caught in coastal waters. Schherbachev (1973) notes a more restricted range, 38ºN–28ºS in the western Pacific and in the east from California to around 17º20′S. Palko and Beardsley et al. (1982) state that *C. hippurus* is restricted by the 20ºC isotherm, although Shcherbachev (1967) notes that a specimen was caught in 12.4ºC in the Sea of Oshtok. Habitat conditions for *C. equisetis* are not well known but a minimum of 24ºC is suggested by Palko and Beardsly et al (1982). They also state that this species is common in Hawaiian waters. Insufficient information is available to describe the hypothetical habitat of dolphinfish beyond these temperature limits in the 20º–24º range with occasional intrusions into much cooler waters.

According to Palko and Beardsly et al. (1982) there is little information about migrations of either species. Kojima (1965) argued that dolphinfish in the Sea of Japan make a northward migration in the warmer months until September and then return south. This is evidenced in Hawaii by seasonal variations in the catch rate. In Hawaii the peak fishing season is March–April and October–November. In American Samoa peak months are July–October while in the

Marianas and Guam fish landings are highest January–April. This reflects a migration pattern away from the equator during the warmer months in both hemispheres.

Dolphinfish also segregate into schools by sex and size. Females and young may be more closely associated with floating objects (see below). According to Palko and Beardsly et al. (1982) seasonal variation may also be caused by ecological differences between adult spawning schools and young feeding schools.

Beardsly (1967), based on work in the Atlantic, notes that dolphinfish are closely associated with floating objects and that aggregations are common below windrows of floating *Sargassum* seaweed. He also reports that in the Atlantic a large school of dolphinfish was seen to follow a floating *Sargassum* mat northward some 260 km off the coast of Florida. It is apparent that dolphinefish are strongly attracted to floating objects, probably because of the availability of prey, and this may influence their movements also.

C. hippurus grow rapidly and have a short life span of about four years; no information is available on *C. equiselis* longevity. Lengths at age given by Kojima (1966) for Pacific specimens are first year: 38 cm FL; second year: 68 cm FL; third year: 90 cm FL; and fourth year: 108 cm FL.

Dolphinfish are heterosexual and sexually dimorphic: males have a steeper head profile in both species. Males are also heavier than females for any given length, and this difference increases with length (Beardsly 1967). Within schools significant variations in sex ratio occur; this is probably due to differential schooling of small and large fish and size related sexual dimorphism (Palko and Beardsley et al. 1982).

Dolphinfish have an extended spawning season: year round in the tropics and in the warmer months in sub-tropical areas (Palko and Beardsley et al. 1982). Ditty and Shaw et al. (1994) discuss larval distribution of dolphinfish in the Gulf of Mexico (see below). If larval abundance correlates with spawning activity then water temperatures of 24ºC and higher and salinities of 33 ppt and higher are preferred. Larvae were also more common offshore, particularly for *C. equisetis*. Shcherbachev (1973) notes that eggs of *C. hippurus* were found in Japanese waters during summer months when water temperatures were 21–29ºC.

Region-wide dolphinfish is not a major fishery, but it is important locally in recreational, subsistence and commercial fisheries. Fish aggregating devices are particularly effective for catching dolphinfish. In Japan a coastal “shiira-zuke” fishery targets fish with aggregating devices made from materials such as bundles of bamboo reeds.

	Longline	**Handline and Troll**	**Total**
American Samoa	5,761	7,194	12,955
Guam	NA	NA	303,957

Hawaii	230,000	475,000	700,000
Northern Mariana Islands	NA	NA	28,524
Total			1,045,436

In Hawaii dolphinfish are an important component of both the longline and troll fishery. Table 1 shows landing information from the Council's most recent *Annual Report for the Pelagics Fishery*.

Egg and Larval Distribution

The ova of *C. hippurus* are buoyant, colorless and spherical, measuring 1.2–1.6 mm diameter, with a single yellow oil globule (Mito 1960). Hatching occurs within 60 h after fertilization at 24–25ºC. At 26ºC larvae hatched within 40 h (Ditty and Shaw et al. 1994).

Ditty and Shaw et al. (1994) describe larval development and distribution in the Gulf of Mexico. In the Pacific, Mito (1960) describes larval development. Palko and Beardsley et al. (1982) state that dolphin gradually metamorphose from larvae into adults without clear breaks between phases. They describe juveniles as being between 9 to 200 mm in length. Ditty and Shaw et al. (1994) were able to distinguish between larvae of the two species as small as 3.5 mm SL based on morphometrics and pigmentation.

Palko and Beardsley et al. (1982) describe larval development. Descriptions indicate that the transition from larval to juvenile phase occurs between 15–30 days. During this period larvae grow at about 1 mm per day. (A 15-day-old larva is described as 15 mm in length; a 30-day-old larva/juvenile is described as 30 mm in length.)

Some information can be obtained on diet from rearing experiments. Hendrix (1983) found that "*C. hippurus* indicate a tendency for larvae to select for *Euterpina* copepods from fist feeding through day 7 when presented a diet of both rotifers and copepods". Larvae were also fed rotifers (*Brachionus plicatilis*), *Artemia salina* nauplii and dolphinfish yolk sac larvae. Shcherbachev (1973) reports that larvae feed mainly on crustaceans and especially Copepoda of the family Pontellidae.

Shcherbachev (1973) describes distribution based on plankton tows (see Figures 4–6 in that publication). In the Pacific they are widely if sporadically distributed. This could be an artifact of non-random collection. Occurrence is most frequent in the western Pacific between 10ºN and 30ºS and in the Panama Gulf in the east. Since dolphinfish are reported to spawn in summer months off of Japan (Palko and Beardsley et al. 1982) it is likely that eggs and larvae have a similar seasonal range expansion. From this data it is not possible to specify larval distribution beyond the known range for adults.

Ditty and Shaw et al. (1994) state that “distribution of larvae, juveniles and adults is apparently limited by the 20ºC isotherm”. Spawning occurs in oceanic waters beyond the continental shelf, even in the Gulf of Mexico. Larvae were collected at highest densities at 24ºC and above and 33 ppt salinity and above. This may adequately describe a hypothetical habitat.

No information is given on habitat features affecting the abundance of eggs and larvae, but given adults’ preference for floating objects, earlier life stages may be more common near objects as well.

Juvenile

The onset of the juvenile stage is not clearly distinguished, as described above. Broadly, juveniles range in size between 15 mm and 55 cm FL. This corresponds to ages between about two weeks and one year.

No information is available on juvenile feeding habits; it is likely that at later stages food preference does not differ markedly from that of adults (see below).

Neither the hypothetical habitat for juveniles or particular features affecting abundance can be specified beyond that described above for adults.

Adult

Beardsly (1967) reports that males are heavier than females and that this difference increased with length. Maximum age is estimated at four years and the largest specimen examined by Beardsly (1967) weighed 35 kg, a sports-fishing record at the time. His data suggest that female dolphin become mature at sizes as small as 35 cm FL; most are mature by 55 cm FL.

Palko and Beardsley et al. (1982) summarize various studies on food preferences. The diet is varied; 32 species of fish from 19 families and one species of crab were reported in one study. Other studies suggest that flying fish are a common prey and that cephalopods are also consumed.

The habitat and particular features affecting abundance does not differ markedly for adults from that described earlier for the species as a whole.

Essential Fish Habitat: Tropical species complex

Dolphinfish are a wide-ranging pelagic species found throughout the tropics and sub-tropics. EFH can only be described based on its known range, temperature requirements and perhaps salinity preferences. Shcherbachev (1973) produced distribution maps (point data based on occurrence in research tows) for larvae and adults, which are reproduced in Palko and Beardsly et al. (1982).

There are no stable features that could be used to identify Habitat Areas of Particular Concern. Dolphinfish are known for their strong association with floating objects.

Habitat description for *Coryphaena hippurus* and *C. equiselis* (dolphinfish, mahimahi)

	Egg	**Larvae**	**Juvenile**	**Adult**
Duration	36 hrs	about 3 weeks	to 1 year	4 years total life span
Diet	NA	zooplankton, larval fish	(see adult)	varied diet of fish, flying fish a preferred prey, cephalopods
Distribution: General and Seasonal	Year around spawning in tropics, summer range expansion limited by 20º isotherm, preferred habitat 24º C and 33 ppt	same as eggs	same as adult	20º isotherm with occasional strays into cooler water. In western Pacific 38º N – 28º S, eastern Pacific California to 17º S
Location	open ocean	open ocean	not known to be different from adult	offshore waters, occasional strays into coastal and estuarine areas
Water Column	epipelagic	pelagic, upper mixed layer	pelagic, mixed layer	pelagic, mixed layer
Bottom Type	NA	NA	NA	variable for strays into coastal waters
Oceanic Features	not known beyond adult preferences	not known beyond adult preferences	not known beyond adult preferences	strong association with floating objects, which will be concentrated in eddies and similar

				ocean features

Bibliography

Beardsly GL. 1967. Age, growth and reproduction of the dolphin, *Coryphaena hippurus*, in the Straits of Florida. Copeia 1967(2):441–51.

Boggs CH, Ito RY. 1993. Hawaii's pelagic fisheries. Mar Fish Rev 55(2):69–82.

Ditty JG, Shaw RF, et al. 1994. Larval development, distribution and abundance of common dolphin, *Coryphaena hippurus*, and pompano dolphin, *C. equiselis* (family: Coryphaenidae), in the northern Gulf of Mexico. Fish Bull 92(2):275–91.

Hendrix SD. 1983. The early life history of mahimahi (*Coryphaena hippurus* and *C. equiselis*) and skipjack tuna (*Katsuwonus pelamis*): A report on the culture and growth of larval fish reared in the laboratory. Honolulu: National Marine Fisheries Service.

Kojima S. 1965. Studies on fishing conditions of the dolphin, *Coryphaena hippurus* L., in the western regions of the Sea of Japan. Volume 9, Schools of dolphins accompanying various kinds of flotages. Bull Jpn Soc Sci Fish 31:573–8.

Kojima S. 1966. Fishery biology of the common dolphin, *Coryphaena hippurus* L., in the western region of the Sea of Japan. Volume 13, 'Tsukegi' as a source of food for dolphins. Bull Shimane Prefectural Fish Exp Stn nr 1.

Mito,S. 1960. Egg development and hatched larvae of the common dolphinfish *Coryphaena hippurus* Linne. Bull Jpn Soc Sc. Fish 26:223–6.

Palko BJ, Beardsley GL, et al. 1982. Synopsis of the biological data on dolphin-fishes, *Coryphaena hippurus* Linnaeus and *Coryphaena equiselis* Linnaeus. Seattle: NOAA/NMFS. NOAA technical report nr NMFS circular 443; FAO fisheries synopsis nr 130.

Shcherbachev YN. 1973. The biology and distribution of the dolphins (Pisces, Coryphaenidae). Icthyo. 13 182–91.

6.2 Habitat description for wahoo (*Acanthocybium solandri*)

Management Plan and Area

American Samoa, Guam, MHI, NWHI, Northern Mariana Islands, Johnston Atoll, Kingman Reff, Palmyra Atoll, Jarvis Island, Midway Island, Howland and Baker Islands and Wake Island.

Life History and General Description

Wahoo (*Acanthocybium solandri*) is a member of the Scombrid family. Although a popular game fish, wahoo are not a target species in fisheries and are thus relatively little studied.

Wahoo are found worldwide in tropical and warm-temperate seas. In the Pacific their distribution is restricted to coastal America and westward from Hawaii in a band between about 20ºN and

5ºS in the central Pacific to the eastern Australia coast and north to southern Japan (Collete and Nauen 1985). Nothing is known about their population structure in the Pacific.

Adult wahoo are surface oriented and are usually associated with banks, pinnacles and islands and are also found around flotsam in the open ocean. Nakano et al. (1997) studied catch rates of longlines at different depths; wahoo were commonly caught at shallow depths, on hooks between 60–160 m, based on measurements of maximum hook depths of shallow gear. Iversen and Yoshida (1957) state that wahoo are rarely caught by longline gear fishing below 200 ft and surface trolling catch rates are much higher close to land. Amesbury and Babin (1990) report elevated catches around Guam in the winter months and describe this as the period when the surface mixed layer is deepest. The hypothetical habitat may thus be described as warm epipelagic and surface neritic waters (above 20ºC) in the tropics to the sub-tropics with a preference for areas of higher productivity including coastal shelves, banks and oceanic fronts.

Iversen and Yoshida (1957) state that wahoo are not found in large compact schools. Instead they travel in small groups of two to 20 fish. They appear to seasonably migratory, moving away from the equator in summer months (Iversen and Yoshida 1957). Hogarth (1976) reports one source stating that “wahoo traveled in a huge circle from Australia and New Zealand back to Ecuador and Costa Rica, and on to Baja, California” but no support is given for this assertion.

As noted above, coastal waters, particularly at the edge of steep drop-offs or reef faces are preferred habitat. Like many other fish, wahoo are attracted to floating objects. This is probably due to the micro-community that typically develops around and under such objects. Floating objects may also concentrate at oceanic fronts. These areas, along with banks and other shallow submerged features are areas of higher productivity, probably the basic reason for these habitat preferences.

According to Hogarth (1976) wahoo are short-lived. He reports the following average lengths based on a sample of 126 fish caught of Cape Hatteras, North Carolina: 1 year old—112 cm; 2 years old—128 cm; 3 years old—141 cm; 4 years old—153 cm. Four years old may be close to a maximum age, which would accord with a reported annual mortality rate of 38% reported by Hogarth (1976).

No special sexual characteristics are mentioned in the literature. Females are extremely fecund; Hogarth (1976) estimated that ovaries held between 0.56 and 45.3 million eggs. Iversen and Yoshida (1957) estimated the number as 6.1 million.

Wahoo are said to spawn year round in the tropics and seasonably in subtropical waters. Hogarth (1976) estimates that spawning occurs in the Gulf Stream off North Carolina from June to August.

In the Western Pacific Region, there are no commercial fisheries that target wahoo (Collete and Nauen 1985). They are a minor component of longline catches and are more frequently caught by surface trolling and are sought by recreational fishermen throughout the region. Wahoo are a popular food fish in Hawaii and are frequently served in restaurants.

In 1996, the most recent data available (WPRFMC 1997), the Hawaii-based longline fleet caught

130,000 lb of wahoo, about 2% of landings. Total commercial landings of wahoo were 500,000 lb, about 1.5% of total landings. Other reported landings for 1996 were 10,858 lb in American Samoa; 142,062 lb in Guam; and 8,626 lb in the Northern Mariana Islands—for a total of 161,546 lb.

Egg and Larval Distribution

Matsumoto (1966) describes a 23.7 mm individual as juvenile; smaller specimens are considered larvae. Chiu and Young (1995) also describes larvae from collections in Taiwan coastal waters.

No information is available on larval food preferences.

Based on collections in the central Pacific, Matsumoto (1966) concludes that larvae are not more abundant near land even though adults are more commonly caught inshore. He collected larvae in the tropical and subtropical Pacific between 30ºN and 25ºS and between 175º and 115ºW but notes that they were scarce in the equatorial countercurrent even though adults are caught there. The longitudinal extent reflects limits of sample stations. Chiu and Chen (1995) also found larvae in offshore areas of Taiwan in Kuroshio current regions. Occurrence of the larvae were seasonal, caught mainly from May to August in these waters. None of these authors provide information on depth distribution. Hogarth, (1976) cites research in the Atlantic demonstrating a larval preference for water depths greater than 100 m.

Seasonal reproduction and larval occurrence in the subtropics indicates a requirement for warmer water temperatures than the limits of adult tolerance. Unlike adults, larvae have no describable habitat features (i.e., proximity to land and/or shallow depths) affecting abundance and density (Matsumoto 1966).

Juvenile

There is no information on differential characteristics of juveniles. As noted, Matsumoto, (1966) described a 23.7 mm specimen as juvenile. Hogarth (1976) states that wahoo reach sexual maturity and spawn in their first year. Males are mature at 86 cm TL and females at 101 cm TL. Given average lengths for age groups this would correspond to maturity at 9–12 months.

Adult

There are no special habitat characteristics to differentiate adults from other life stages beyond the general theoretical habitat description give above in Section 2.1.
Both Iversen and Yoshida (1957) and Hogarth (1976) examined the stomach contents of adult wahoo. A high percentage of stomachs were empty, ascribed to regurgitation during capture. Iversen and Yoshida (1957) found mackerel scad (*Decapturus* sp.) and skipjack tuna the main prey items. Other identifiable items included squid, pomfret, puffer, flying fish, lantern fish and sunfish. Hogarth (1976), researching in subtropical Atlantic waters, found mackerels to be the most common prey item, followed by Stromateids (butterfishes). Other families included herrings, Carangids and flying fishes.

Essential Fish Habitat: Tropical species complex

Although wahoo are distributed throughout tropical and subtropical waters, coastal and/or shallow depth areas represent important habitat features that can be used in identifying EFH. Collete and Nauen (1985) include a map (at very small scale) showing the worldwide distribution of wahoo. Habitat features that can be used in identifying Areas of Particular Concern include reef faces and steep drop-offs as these are preferred trolling areas.

Habitat description for wahoo (*Acanthocybium solandri*)

	Egg	**Larvae**	**Juvenile**	**Adult**
Duration	unknown, probably days	unknown, probably weeks to less than a month	unknown	9-12 months to about four years
Diet	NA	unknown	unknown	fish, especially skipjack tuna and mackeral scad, squid
Distribution: General and Seasonal	tropical and seasonal (summer) in subtropical areas	same as eggs	unknown, unlikely to be different from adults	tropical and subtropical with seasonal range extension; rare or possible absent in eastern Pacific except American coast
Location	open ocean	open ocean	unknown, unlikely to be different from adult	open ocean and coastal waters; also preference banks and flotsam
Water Column	epipelagic	epipelagic	unknown, unlikely to be different from adult	epipelagic (<200 m) and neritic
Bottom Type	NA	NA	unknown, unlikely to be different form adult	preference for steep dropoffs and reef faces
Oceanic Features	unknown, does not occur near land	unknown	unknown	shallow depths (banks and neritic waters), attracted to flotsam,

				possibly associated with oceanic fronts

Bibliography

Amesbury SS, Babin M. 1990. Ocean temperature structure and the seasonality of pelagic fish species near Guam, Mariana Island (North Pacific Islands). Micronesica 23(2):131–8.

Chiu T S, Chen CS. 1995. Distribution of Scombrid larvae (Pisces: Scombridae) in the waters around Taiwan. J Fish Soc Taiwan 22(4):303–12.

Chiu T S, Young SS. 1995. Taxonomic description of Scombrid larvae (Pisces: Scombridae) occurred in the waters around Taiwan. J Fish Soc Taiwan 22(3):203–11.

Collete BB, Nauen CE. 1985. Scombrids of the world, an annotated and illustrated catalogue of tunas, mackerels, bonitos, and related species known to date. Rome: FAO. FAO fisheries synopsis nr 125, volume 2. 118 pp.

Hogarth WT. 1976. Life history aspects of the wahoo *Acanthocybium solandri* (Cuvier and Valenciennes) from the coast of North Carolina [dissertation]. Raleigh: University of North Carolina. 107 p.

Iversen ES, Yoshida HO. 1957. Notes on the biology of the wahoo in the Line Islands. Pac Sci 11:370–79.

Matsumoto WM. 1966. Morphology and distribution of larval wahoo *Acanthocybium solandri* (Cuvier) in the central Pacific Ocean. Fish Bull 66(2):299–322.

Nakano H, Okazaki M, Okamoto H. 1997. Analysis of catch depth by species for tuna longline fishery based on catch by branch lines. Bull Nat Res Inst Far Seas Fish 34:43–62.

[WPRFMC] Western Pacific Regional Fishery Management Council. 1997. Pelagic Fisheries of the Western Pacific Region, 1996 Annual Report. Honolulu: Western Pacific Regional Fishery Management Council, 26 p + appendices.

6.3 Habitat description for Indo-Pacific blue marlin (*Makaira mazara*)

Management Plan Area
American Samoa, Guam, MHI, NWHI, Northern Mariana Islands, Johnston Atoll, Kingman Reef, Palmyra Atoll, Jarvis Island, Midway Island, Howland and Baker Islands and Wake Islands.

Life History and General Description

Blue marlin (*Makaira nigricans*) is the most tropical of all marlins. It has been variously described as a single pan-tropical species (Rivas 1974) or two distinct species, *Makaira nigricans* in the Atlantic and *Makaira mazara* in the Pacific (Nakamura 1983). Recent analysis of mitochondrial DNA (Finnerty and Block 1992) suggests that billfish (Istiophoridae and Xiphiidae) should be separated from the suborder Scombroidei—also containing mackerel and tuna—to which they have traditionally been assigned. Other researchers, using similar techniques, found that “[t]he lack of significant genetic differentiation between Atlantic and Indo-Pacific samples of blue marlin and sailfish does not support…recognition of distinct Atlantic and Indo-Pacific species” (Graves and McDowell 1995).

Catches of blue marlin in the Pacific have been reported by about 10 countries with Japan and Korea taking the largest catch (Nakamura 1985). Important fishing areas include the northwest Pacific (FAO Fishing Area 61) and the central Pacific (FAO Fishing Areas 71 and 77) (Nakamura 1985). The majority are caught in the longline fishery. The Japanese have the largest fleet, fishing Pacific wide, with smaller fleets operating from Taiwan and Korea. Since the 1980s the Japanese have increasingly targeted the deeper swimming bigeye tuna (*Thunnus obesus*) resulting in declining catch of surface swimming billfish (Ueyanagi, Shomura et al. 1990). Substantial numbers of billfish were also caught in the high seas drift-net fishery until it was suspended.

Total 1996 landings in the WPRFMC management area amounted to about 911 mt (2,004,966 lb). The vast majority (about 95%) was landed in Hawaii (see Table 1). Of these Hawaii landings a little over half (1.05 million lb) were caught by longline vessels.

Entity	Landings (lb.)
American Samoa	37,682
Guam	60,500
Hawaii	1,900,00
Northern Mariana Islands	6,784
Total	2,004,966

Blue marlin is caught incidentally by longline vessels and commands a relatively low ex-vessel price (WPRFMC 1997). In Japan marlin are consumed as sashimi (Ueyanagi 1974). Marlin is consumed similarly in Hawaii (WPRFMC 1997). Blue marlin is also an important sport fish, and Kona, Hawaii, is a world renowned center for big gamefishing. In Guam and the Northern Mariana Islands marlin are caught by recreational small-boat trollers and charter boats. American Samoa has both troll and longline fisheries, although these are small in comparison to Hawaii.

Because blue marlin is a wide-ranging pelagic species, fishing effort is offshore. Trollers on small, recreational boats and charter vessels make day trips and are thus restricted in their range to tens of miles offshore. Longliners, in contrast, make multi-day trips and may fish outside of the EEZ.

Egg and Larval Distribution

Based on a long-term study of reproductive condition of blue marlin caught in Hawaii billfish tournaments, Hopper (1990) argues that these fish congregate around the Hawaiian Islands during summer months in order to spawn. They migrate from more southerly latitudes, and "Hawaii may be a focus for blue marlin spawning in the northern central Pacific because oceanographic conditions are favorable to survival of marlin larvae and juveniles," Hopper contends. Other researchers (Nishikawa, Honma et al. 1985) note that areas where larvae occur more frequently correspond to the richest summer fishing grounds. It has also been suggested that marlin spawn year-round in tropical waters (see below), but there may be a preference for summer spawning in higher latitudes both north and south of the equator.

Nakamura (1985) states that "ripe eggs in the ovary are transparent with a yellow oil globule, and measure about 0.8 to 0.9 mm in diameter." Post-larvae and young are found most abundantly in the western Pacific, especially around the Caroline and Marshall Islands (Howard and Ueyanagi 1965). These authors also state "[f]rom occurrence of larvae, condition of gonads, and sex ratio, spawning of this species is assumed to take place in the low latitudinal area (between about 20ºN to 10ºS) throughout the year; and in higher latitudinal areas (bounded by 30ºN and 30ºS) during summer seasons." Matsumoto and Kazama (1974) subsequently found blue marlin larvae heavily distributed around the Hawaiian Islands and westward between 7ºN and 24ºN in the North Pacific and south of the equator to 24ºS from Vanuatu in the west to the Tuamotu archipelago in the east. At its western end this ties in with the distribution described by the earlier authors; however, "[t]he intervening area (lat. 5º–10ºN and long. 140ºW–180º) appears to be devoid of blue marlin larvae, but this could be due to inadequate sampling; only a few surface day tows were made there" (Matsumoto and Kazama 1974).

In sum, blue marlin may spawn throughout the year in two tropical/subtropical bands north and south of the equator. These bands expand away from the equator during summer seasons, roughly corresponding to the 24º–25ºC isotherms (Matsumoto and Kazama 1974). Rivas (1974) indicates that larval stage growth is up to at least 52 mm, with a gap in description from that size to about 194 mm.

Juvenile

Because methods of age determination have not been developed for this species, age at which sexual maturity is reached cannot be determined. However, more recently developed techniques may allow age determination (Wilson, 1984). A relation can be developed between otolith weight and age based on saggitae annuli (Wilson and Dean et al. 1991). Based on smallest captures of sexually mature fish Rivas (1974) suggests that males under 35 kg and females under 47 kg are sexually immature. The species exhibits marked sexual dimorphism in size. Females can exceed 540 kg while males usually do not exceed 160 kg (Rivas 1974). As noted above, smaller fish may be more abundant in the western Pacific. There is some evidence of an eastern migration with age; at least the size distribution of captured fish tends to increase to the east. However, this could be explained by differential north-south migration (Howard and Ueyanagi 1965).

Adult

Tracking experiments (Holland and Brill et al. 1990, Block and Booth et al. 1992) show that blue marlin in Hawaiian waters spend most of their time within 10 m of the surface but make frequent and regular dives to deeper depths. This indicated a preference for water temperatures in the 22–27ºC range found in the near surface mixed layer. When near the surface they swim very slowly (<25ms^{-1}). The highest sustained speed directly measured by Block and Booth et al. (1992) was around 100 m s^{-1}, much slower than estimates. Dives are to relatively shallow depths; Block and Booth et al. (1992) recorded a maximum dive depth of 209 m. from the six marlin tracked. It was during dives that short speed bursts of up to 200 m s^{-1} were typically recorded. The authors suggest that there may be a slight preference for surface waters during daylight hours but considerable variation exists among individuals. Based on course data they conclude that "these fish are itinerant visitors [to the Hawaiian Islands] and are not part of a resident population." This conclusion is supported by genetic studies that suggest a single Pacific-wide cytochrome b DNA haplotype (Finnerty and Block 1992).

Au (1991) found that billfish were caught in about 9% of purse-seine sets in the eastern Pacific with somewhat higher catch rates for sets around logs. Out of all billfish caught, blue and striped marlin accounted for 68.6% of the total. He states that billfish "probably follow tuna both as parasitic foragers and predators; they share many prey species with tunas and also eat tunas, especially the smaller specimens."

Region wide distrbution of blue marlin are given by Howard and Ueyanagi (1965) as follows:

	West of 180°	East of 180°
10–30°N	High density from May-October with a tendency for season of highest density to progress from west to east starting in June until September	
0–10°N	High density almost year round except in December and January.	High density in May and June 180°–170°W and shifts eastward to 130°W until October.
0–10°S	Density becoming low in July through to September.	Density low from June-September.
South of 10°S	High density November–March with much greater concentration east of 160°W	

As indicated in the table, there is a north-south seasonal migration of fish that corresponds to warmer waters. These migrations may be more northwesterly and southeasterly so that northward moving groups pass the equator around 150ºE–180º and southward migrants pass the equator between 160ºE–180º (Au 1991). Genetic uniformity, mentioned above, may mean that there is a single Pacific-wide stock that migrates seasonally as increasing water temperature expands habitat away from the equator. This would suggest a clockwise radial pattern of migration.

According to trolling information, marlin feed in the morning between 1000 and 1100 hours and again in the afternoon between 1300 and 1600 hours; they apparently do not feed at night (Rivas 1974). This behavior correlates with the weakly exhibited diel depth pattern detected by Block and Booth et al. (1992). There has been much discussion of whether the marlin's bill is used in feeding. A few cases of billfish impaling marine turtles have been documented, but incidents such as these are considered accidental and the bill is not considered essential to feeding (Rivas 1974, Frazier and Fierstine et al. 1994). Using the stomach content of marlin caught in the Hawaiian International Billfish Tournament (HIBT) as a sample source, Brock (1984) found the marlin diet to be composed, in general, largely of Scrombrids but also significantly of juvenile inshore fish. However, he notes that this analysis "may be a reflection of where and when these predators were captured. The majority of the marlin caught in the HIBT are taken within 8 km of land. Moreover, the tournament is held during the summer, when many Hawaiian inshore juvenile fish recruit from the plankton to the adult habitat." Squid are another food source. Although Brock considers them relatively unimportant in Hawaiian waters, Rivas (1974) notes that they are an important part of the diet in the Philippine Sea. The size range of food is relatively large; a 340 kg blue marlin was found with a 29 kg bigeye tuna in its stomach (Rivas, 1974). Conversely, Brock (1984) notes that "adult blue marlin are capable of feeding on very small prey," and small prey in the 5–60 mm range were commonly found in his study.

Habitat description for Indo-Pacific blue marlin (*Makaira mazara*)

	Egg	**Larvae**	**Juvenile**	**Adult**
Duration	24 hr.?	to at least 52 mm (about 3 weeks?)	to 35 kg for males and 47 kg for females	
Diet	NA	zooplankton, small fish	Scrombrids, cephalopods, juvenile inshore fish	Scrombrids, cephalopods, juvenile inshore fish
Distribution: General and Seasonal	year around in tropics, seasonally in waters above 24-25º C.	year around in tropics, seasonally in waters above 24–25ºC.	year around in tropics, seasonally in waters above 24–25ºC.	I. 10–30ºN: May–Oct in east and west II. 0–10ºN: higher density Dec–Jan in west, May–Jun in east, shifting eastward to Oct III. 0–10º S: low density Jul–Sep IV. South of 10ºS high density Nov–Mar V. Preference for 22-27ºC.
Location	offshore waters	offshore waters	offshore waters	offshore waters
Water Column	epipelagic	epipelagic	pelagic, upper mixed layer	pelagic, mixed layer
Bottom Type	NA	NA	NA	NA
Oceanic Features	eddies, upwelling,	eddies, upwelling,	eddies, upwelling,	eddies, upwelling,

	oceanic fronts and other areas of high productivity	oceanic fronts and other areas of high productivity	oceanic fronts and other areas of high productivity	oceanic fronts and other areas of high productivity

Bibliography

Au DW. 1991. Polyspecific nature of tuna schools: shark, dolphin, and seabird associates. US NMFS Fish Bull 89(3):343–54.

Block B, Booth D, et al. 1992. Direct measurement of swimming speeds and depth of blue marlin. J Experi Biol 166:267–84.

Block BA, Booth DT, et al. 1992. Depth and temperature of the blue marlin, *Makaira nigricans*, observed by acoustic telemetry. Mar Biol 114(2):175–83.

Brock RE. 1984. A contribution to the trophic biology of the blue marlin (*Makaira nigricans* Lacepede, 1802) in Hawaii. Pac Sci 38(2):141–9.

Finnerty JR, Block BA. 1992. Direct sequencing of mitochondrial DNA detects highly divergent haplotypes in blue marlin (*Makaira nigricans*). Mol Mar Biol Biotechnol. 1(3):206–14.

Frazier JG, Fierstine HL, et al. 1994. Impalement of marine turtles (Reptilia, Chelonia: Cheloniidae and Dermochelyidae) by billfishes (Osteichthyes, Perciformes: Istiophoridae and Xiphiidae). Environ Biol Fish 39(1):85–96.

Graves JE, McDowell JR. 1995. Inter-ocean genetic divergence of istiophorid billfishes. Mar Biol 122(2):193–203.

Holland K, Brill R, et al. 1990. Horizontal and vertical movements of Pacific blue marlin captured and released using sportfishing gear. Fish Bull.88(2):397–402.

Hopper CN. 1990. Patterns of Pacific blue marlin reproduction in Hawaiian waters. In: Planning the Future of Billfishes, Research and Management in the 90s and Beyond, Proceedings of the Second International Billfish Symposium; Kailua-Kona, Hawaii. National Center for Marine Conservation.. Part 2; p 29–39.

Howard JK, Ueyanagi S. 1965. Distribution and relative abundance of billfishes (Istiophoridae) of the Pacific Ocean. Univ Miami Inst Mar Sci, Stud Trop Oceanogr 2:1–134.

Matsumoto W, Kazama T. 1974. Occurrence of young billfishes in the central Pacific Ocean. In: Proceedings of the International Billfish Symposium; 1972 Aug 9–12; Kailua-Kona, HI. Seattle: National Marine Fisheries Service. Part 3; p 238–51. NOAA technical report nr NMFS SSRF-675.

Nakamura I. 1983. Systematics of the billfishes (Xiphiidae and Istophoridae). Publ Seto Mar Biol Lab 28:255–396.

Nakamura I. 1985. Billfishes of the world, an annotated and illustrated catalogue of marlins, sailfishes, spearfishes and swordfishes known to date. Rome: Food and Agriculture Organization. FAO Fish Synop 5:125.

Nishikawa Y, Honma M, et al. 1985. Average distribution of larvae of oceanic species of scrombrid fishes, 1956–81. Far Seas Fish Res Lab Contrib 236:1–99.

Rivas LR. 1974. Synopsis of biological data on blue marlin, *Makaira nigracans* Lacepede, 1802. In: Proceedings of the International Billfish Symposium; 1972 Aug 9–12; Kailua-Kona, HI. Seattle: National Marine Fisheries Service. Part 3; p 1–16. NOAA technical report nr NMFS SSRF-675.

Ueyanagi S. 1974. A review of the world commercial fisheries for billfishes. Proceedings of the International Billfish Symposium; 1972 Aug 9–12; Kailua-Kona, HI. Seattle: National Marine Fisheries Service. Part 2; p 1–11. NOAA technical report nr NMFS SSRF-675.

Ueyanagi S,. Shomura RS, et al. 1990. Trends in the fisheries for billfishes in the Pacific. In: Planning the Future of Billfishes, Research and Management in the 90s and Beyond, Proceedings of the Second International Billfish Symposium; Kailua-Kona, HI. National Coalition for Marine Conservation. Part 1; p 31–45.

Wilson CA. 1984. Age and growth aspects of the life history of billfishes [dissertation]. University of South Carolina. 179 p.

Wilson CA, Dean JM, et al. 1991. An examination of sexual dimorphism in Atlantic and Pacific blue marlin using body weight, sagittae weight, and age estimates. J Exp Mar Biol Ecol 151(2):209–25.

6.4 Habitat description for black marlin (*Makaira indica*)

Management Plan and Area

American Samoa, Guam, MHI, NWHI, Northern Mariana Islands, Johnston Atoll, Kingman Reef, Palmyra Atoll, Jarvis Island, Midway Island, Howland and Baker Islands and Wake Islands.

Life History and General Description

This summary is based on Nakamura (1975) and Nakamura (1985). Little has been published on the black marlin since those synopses.

Makaira are teleost fish of the order Perciformes (suborder Xiphiidae) and family Istiophoroidae. Two other *Makaira* species are recognized: the Indo-Pacific blue marlin *(M. mazara*) and the Atlantic blue marlin (*M. nigricans*). However, the separation of these populations into distinct species has recently been questioned based on genetic analysis (Graves and McDowell 1995). Howard and Ueyanagi (1965) argue that there must be two separate stocks of black marlin in the Pacific based on their widely separated centers of abundance in the eastern and western Pacific.

Their sparse distribution across the oceanic Pacific may represent individuals moving out from these centers of abundance.

Howard and Ueyanagi (1965) state that the distribution of black marlin is "characterized by the greatest density of occurrence being on the periphery of distribution of the family in the Pacific.…In open sea areas, distribution is sparse. In tropical open seas areas, distribution is very scattered but continuous, whereas in temperate open sea areas, there is almost no occurrence of this species." Nakamura (1985) gives the range for black marlin as 35º–40ºN to 45ºS in the western Pacific and 30–35ºS in the eastern Pacific. Specifically mentioned areas of concentration are along continental margins and in Indo-Pacific archipelagic waters from Southeast Asia to Australia. Based on longline CPUE data alone, the area of greatest abundance would be in the waters north of Australia to New Guinea and the Indonesian archipelago. A second center of abundance lies of off Central America, centered on Panama. Merrett (1971) reports, based on data from the western Indian Ocean, that the highest catch rate is in water depths between 250–500 fathoms (457.2–914.4 m). No fish are reported landed it waters deeper than 2,000 fathoms (3657.6 m). Black marlin usually occur nearer the surface than most other billfish (Nakamura 1985). The reported range in SST for this species is relatively wide, 15º–30ºC, although optimum temperatures for a harpoon fishery in the East China Sea were reported as between 23º–25ºC (Morita 1952). Squire and Nielsen (1983) report an optimal temperature, based on longline CPUE off of northeast Australia, as 26.7ºC.

In terms of migration, Howard and Ueyanagi (1965) note a seasonal movement away from the equator during summer months in the respective hemispheres. Squire and Nielsen (1983) provide a hypothetical description of migration based on tag returns from sport-caught fish off of northeast Australia. Black marlin are theorized to move south and southeast towards southeast Australia and New Zealand in late (austral) summer, northeast to Kirabati waters and northeast of Papua New Guinea in winter, and back to spawning grounds in the Coral Sea in spring and early summer.

Koto and Kodama (1962, cited in Nakamura 1975) estimated growth rates at 50 cm per year for black marlin 150–200 cm, 30 cm for lengths 200–230 cm and 20 cm for lengths 230–250 cm. Estimates could not be made for sizes above and below this range. No information is provided on age and longevity.

Black marlin are heterosexual. Nakamura (1975) reports sex ratios from a number of studies; females tend to dominate in the samples listed, in most cases comprising 80%–95%. The overall ratio for these samples as reported by Nakamura is "53/514 male throughout a size range of 20 to 200 kg in body weight" for the waters around Taiwan. Although this statement is somewhat ambiguous it may mean that the male-female sex ratio is 1:9.7. He also states that females grow larger than males. Merrett (1971) suggests size at sexual maturity (based on a very few specimens) as 170–180 cm or 58.97–79.38 kg. De Sylva and Breder (1997) examined gonad histology of Atlantic specimens. Four adult males were examined; none of the females were yet adult. They state that "maturation of the oocytes must thus occur when female black marlin have reached a much larger size"; unfortunately they don't report the sizes of their specimens.

Reported spawning grounds are in the South China Sea in May or June and the Coral Sea between October and November. Given their sparse distribution in the oceanic Pacific it may be that spawning is confined to western Pacific continental margin/shelf areas.

Major fishing grounds are all on the western Pacific continental margin: around Taiwan, the East China Sea, the Coral Sea and northwest Australian waters. In these areas black marlin is caught by harpooners and trollers. A major charter-boat sports-fishery captures black marlin in northeast Australian waters. Black marlin is also caught as bycatch by tuna longliners in these areas and across the Pacific. Statistics show that highest landings are in FAO Area 61, the northwest Pacific above 20ºN and west of 175ºW (FAO 1997) . Fewer fish are caught in the area of reported high abundance north of Australia (Area 71). Total landings in 1995 were 2,077 mt, substantially less than the 1991 high of 6,342 mt. In comparison to other billfish (much less the important tuna species) black marlin catches are minor. Taiwan, Japan and Korea are the main countries landing black marlin. Black marlin are not reported separately in the NMFS Hawaii longline logbook, nor are they reported from the other areas in the western Pacific region in the most recent WPRFMC annual report. It is thus difficult to quantify landings in the region, but they are apparently very minor.

Egg and larval distribution

No information was available on egg and larval stages beyond what is reported in Nakamura (1975). He only reports on morphological descriptions of larvae. Another paper describing the larval stage (Nishikawa and Ueyanagi 1992) is in Japanese. The abstract notes that the “larvae of *M. indica* are mainly distributed in the neighboring waters of reef areas. It is assumed that the peculiarly formed rigid pectoral fins of larvae may have functions as ‘stabilizer’ in their habitats where the water moves violently compared with offshore areas.” The researchers’ collections were from the East China Sea, and it seems likely that significant concentrations of eggs and larvae are confined to the spawning areas mentioned above.

Juvenile

No information is available on juvenile distribution.

Adult

Little is known about the feeding habits of adult black marlin. The few published studies (reviewed in Nakamura 1975) indicate that Scombrids (mackerel and tuna), Gempylids, dolphinfish (*Coryphaena spp*.) and other billfish are important parts of the diet. Decapod molluscs and the larvae of Decapods, Isopods and Crustacea are also reported in other studies.

Adult habitat and distribution cannot be specified with any more precision than the very general description provided above for the species as a whole.

Essential Fish Habitat: Tropical species complex

Black marlin, although present, occurs in relatively low abundance in the Council’s management area waters. This species apparently does not spawn in these waters.

Habitat description for black marlin (*Makaira indica*)

	Egg	**Larvae**	**Juvenile**	**Adult**
Duration	unknown, days	unknown, days to weeks	unknown, to 170-180 cm	unknown
Diet	NA	no information available	unknown	mackerels, tunas, Gempylids, dolphinfish, larvae
Distribution: General and Seasonal	East China Sea and Coral Sea (based on spawning areas)?	as with eggs	unknown	mainly on continental shelf areas, especially in western Pacific, sparsely distributed in oceanic areas, seasonal expansion away from equator
Location	continental shelf areas	continental shelf areas	unknown, probably shelf areas	mainly continental shelf areas
Water Column	epipelagic	epipelagic	epipelagic	epipelagic
Bottom Type	NA	NA	NA	NA
Oceanic Features	unknown	unknown	unknown	unknown

Bibliography

De Sylva DP, Breder PR. 1997. Reproduction, gonad histology and spawning cycles of North Atlantic billfishes (Istiophoridae). Bull Mar Sci 60(3):668–97.

FAO. 1997. FAO Yearbook. Volume 80, Fishery statistics catches and landings. Rome: Food and Agriculture Organization,

Graves JE, McDowell JR. 1995. Inter-ocean genetic divergence of istiophorid billfishes. Mar Biol 122(2):193–203.

Howard JK, Ueyanagi S. 1965. Distribution and relative abundance of billfishes (Istiophoridae) of the Pacific Ocean. Univ Miami Inst Mar Sci, Stud Trop Oceanogr 2:1–134.

Koto T, Kodama K. 1962. Some considerations on the growth of marlins, using size-frequencies in commercial catches. II. Attempts to estimate the growth of so-called white marlin, *Marlina marlina* (J. and H.). Rep Nankai Reg Fish Res Lab 15:109–26.

Merrett NR. 1971. Aspects of the biology of billfish (Istiophoridae) from the equatorial western Indian Ocean. J Zool 163:351–95.

Morita T. 1952. On the relation between the yield of marlin and the water temperature around the Uotsurizima. Kagoshima Univ Mem Fac Fish 2(1):15–9.

Nakamura I. 1975. Synopsis of the biology of the black marlin, *Makaira indica* (Cuvier), 1831. In: Shomura RS, Williams F, editors. Proceedings of the International Billfish Symposium; 1972 Aug 9–12; Kailua-Kona, HI. Seattle: NOAA (NMFS). Part 3, Species synopses; p 17–27. NOAA technical report nr NMFS SSRF-675,

Nakamura I. 1985. Billfishes of the world, an annotated and illustrated catalogue of marlins, sailfishes, spearfishes and swordfishes known to date. Rome: Food and Agriculture Organization. FAO Fish Synop 5(125). 58 p.

Nishikawa Y, Ueyanagi S. 1992. On the larvae of the black marlin *Makaira indica*. Bull Nat Res Inst Far Seas Fish 29:1–7.

Squire JL Jr, Nielsen DV. 1983. Results of a tagging program to determine migration rates and patterns for black marlin, *Makaira indica*, in the southwest Pacific Ocean. National Marine Fisheries Service. NOAA technical report nr NMFS SSRF 772-19.

6.5 Habitat description for striped marlin (*Tetrapturus audax*)

Management Plan and Area
American Samoa, Guam, MHI, NWHI, Northern Mariana Islands, Johnston Atoll, Kingman Reef, Palmyra Atoll, Jarvis Island, Midway Island, Howland and Baker Islands and Wake Islands.

Life History and General Description

In the Pacific the striped marlin (*Tetrapturus audax*) is distributed in two supra-equatorial bands that join at the eastern tropical margin. This has lead some researchers to divide the population into two separate stocks, at least for management purposes (Shomura 1975). Genetic analysis (of mitochondrial DNA) suggests a corresponding spatial partitioning in genotypes (Graves and McDowell 1994), confirming the belief in distinct stocks. This contrasts sharply with tuna species, which are comparatively uniform in their genetic composition. 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 (Graves and McDowell 1995). This suggests that striped and white marlin are not in fact be separate species (Graves and McDowell 1995). In addition, recent analysis of mitochondrial DNA (Finnerty and Block 1995) suggests that billfish (Istiophoridae and Xiphiidae) should be separated from the suborder Scombroidae—also containing mackerel and tuna—to which they have traditionally been assigned.

There is no significant sexual dimorphism in this species, in contrast to the blue marlin.

Region-wide major catches of striped marlin are made by Japan and Korea. 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 only landed in appreciable numbers in Hawaii. About 453.5 mt (1.0 million lb) were landed in Hawaii in 1996 and 544 mt (1.2 million lb) in 1996 (WPRFMC 1997). Almost 90% of commercial billfish landings were made by the longline fleet (WPRFMC 1997). No landings were reported from other areas in either year.

Egg and Larval Distribution

Distribution of eggs is unknown. Larvae are reportedly found between 10º–30ºN and 10º–30ºS. Peak abundance is in May-June in the northwestern Pacific (Ueyanagi and Wares 1975). This corresponds to the spawning ground described by Squire and Suzuki (1990). Thus spawning is probably seasonal and confined to the early summer months in both hemispheres. As noted, 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 mentioned earlier (Graves and McDowell 1994). Description of larvae is based on specimens 2.9–21.2 mm in length (Ueyanagi and Wares 1975). Like other billfish, striped marlin are generally confined to pelagic surface waters; larvae may make diurnal vertical migrations in the top 50 m of the water column. Little is known about time of first feeding or food preferences. Striped marlin larvae may consume copepods up to about 13 mm (observed in Atlantic sailfish larvae) and other fish larvae after reaching a size of about 7 mm (Ueyanagi and Wares 1975).

Juvenile

Since marlin cannot yet be accurately aged, the age and duration of different life stages cannot be determined. Females are reported to reach first maturity at 50–80 lb; it is not possible to determine onset of sexual maturity in males because change in the size of testes is slight. As noted above, striped marlin spawn in the northwest Pacific and migrate eastward as juveniles (Squire and Suzuki 1990). This would account for the abundance of smaller fish in Hawaiian waters.

Adult

Tracking of adult striped marlin in Hawaiian waters using ultrasonic telemetry (Brill and Holts 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 spend spent the vast majority of time in waters within 2ºC of the mixed layer temperature and never ventured into waters 8ºC colder than the mixed layer temperature. Thus these fish spent about 80% of their time in waters between 25.1º and 27ºC and never ventured into waters below 18ºC. 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).

Au (1991) found that billfish were caught in about 9% of purse-seine sets in the eastern Pacific with somewhat higher catch rates for sets around logs. Out of all billfish caught, blue and striped marlin accounted for 68.6% of the total. He states that billfish “probably follow tuna both as parasitic foragers and predators; they share many prey species with tunas and also east tunas, especially the smaller specimens.”

As noted, striped marlin are distributed in a horseshoe pattern with the base of the U in the eastern Pacific. Generally, distribution corresponds to the 20º and 25ºC isotherms (Howard and Ueyanagi 1965). These authors distinguish a Northern Pacific Group found west of 140ºW and north of 15ºN, an Eastern Pacific Group east of 120ºW and west of 120ºW and south of 15ºS. 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 Niño-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).

Squire and Suzuki (1990) argue 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 the 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). Howard and Ueyanagi (1965) give the following seasonal distribution for the North Pacific Group for waters of the central Pacific:

From the above table it can be seen that Hawaii benefits from the southern migration during winter months. Size distribution of catch is bimodal. The smaller fish appear in catches in the winter season, and they grow to 50–60 lb 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. There the fish stay several months and grow. Then they migrate back to Hawaiian waters where they become part of larger fish in the next year (Howard and Ueyanagi 1965)

Adult marlin feed on a variety of pelagic species. Nakamura (1985) states that striped marlin "tends to feed more on epipelagic organisms and less on mesopelagic ones that the swordfish and the oceanic tunas." Common food items are squid, scombrids and gempylids (Nakamura 1985, Ueyanagi and Wares 1975). In California food species included *Cololabis saira*, *Engraulis mordax*, *Sardinops caeruleas* and *Trachurus symmetricus* (Nakamura 1985, Ueyanagi and Wares 1975).

Habitat description for striped marlin (*Tetrapturus audax*)

	Egg	**Larvae**	**Juvenile**	**Adult**
Duration	24 hr.?	to 22 mm (2–3 weeks)?	to 25–35 kg	above 25–35 kg
Diet	NA	zooplankton, fish larvae	cephalopods, scombrids, gempylids	cephalopods, scombrids, gempylids
Distribution: General and Seasonal	seasonal, early summer months in both hemispheres	seasonal, early summer months in both hemispheres	migrating eastward from spawning area in western Pacific?	very low density or absent in low tropics, except in east. 20–30ºN (and S?), seasonally to 42ºN (and S?). Prefer 20–25ºC, 18ºC apparent lower limit.
Location	offshore waters	offshore waters	offshore waters	offshore waters
Water Column	epipelagic	epipelagic	pelagic, upper mixed layer	pelagic, mixed layer
Bottom Type	NA	NA	NA	NA
Oceanic Features	depends on adult distribution	depends on adult distribution	eddies, upwelling, oceanic fronts and other areas of high productivity	eddies, upwelling, oceanic fronts and other areas of high productivity

Bibliography

Au DW. 1991. Polyspecific nature of tuna schools: shark, dolphin and seabird associates. US Nat Mar Fish Serv Fish Bull 89(3):343–54.

Brill RW, Holts DB, et al. 1993. Vertical and horizontal movements of striped marlin (*Tetrapturus audax*) near the Hawaiian Islands, determined by ultrasonic telemetry, with simultaneous measurement of oceanic currents. Mar Biol 117(4):567–76.

Finnerty JR, Block BA. 1995. Evolution of cytochrome b in the Scombroidei (Teleostei): Molecular insights into billfish (Istiophoridae and Xiphiidae) relationships. US Nat Mar Fish Serv Fish Bull 93(1):78–96.

Graves, J. E. and J. R. McDowell. 1994. Genetic analysis of striped marlin (*Tetrapturus audax*) population structure in the Pacific Ocean. Can J Fish. Aquat Sci 51(8):1762-8.

Graves JE, McDowell J R, 1995. Inter-ocean genetic divergence of istiophorid billfishes. Mar Biol 122(2):193–203.

Howard JK, Ueyanagi S.. 1965. Distribution and relative abundance of billfishes (Istiophoridae) of the Pacific Ocean. Univ Miami Inst Mar Sci, Stud Trop Oceanogr 2:1–134.

Nakamura I. 1985. Billfishes of the world, an annotated and illustrated catalogue of marlins, sailfishes, spearfishes and swordfishes known to date. Rome: Food and Agriculture Organization. FAO Fish Synop 5(125).

Shomura R. 1975. Report of the Symposium. In: Shomura R, editor. Proceedings of the International Billfish Symposium; 1972 Aug 9–12; Kailua-Kona, HI. Seattle: NOAA/NMFS. Part 1. Technical report nr NMFS SSRF-675.

Squire JL. 1987. Relation of sea surface temperature changes during the 1983 El Niño to the geographical distribution of some important recreational pelagic species and their catch temperature param. Mar Fish Rev 49(2):44–57.

Squire JL, Suzuki Z. 1990. Migration trends of the striped marlin (*Tetrapturus audax*) in the Pacific Ocean. In: Proceedings of the Second International Billfish Symposium; 1988; Kailua-Kona, HI. National Coalition for Marine Conservation. Part 2; p 67–80.

Ueyanagi S, Wares PG. 1975. Synopsis of biological data on striped marlin, *Tetrapturus audax* (Philippi), 1887. Proceedings of the International Billfish; 1972 Aug 9–12; Kailua-Kona, HI. Seattle: NOAA/NMFS. NOAA Technical Report NMFS SSRF-675. Part 3 Species Synopses. pp. 132–57.

[WPRFMC] Western Pacific Regional Fishery Management Council. 1997. Pelagic Fisheries of the Western Pacific Region, 1996 Annual Report. Honolulu: Western Pacific Regional Fishery Management Council.

6.6 Habitat description for shortbill spearfish (*Tetrapturus angustirostris*)

Management Plan and Area
American Samoa, Guam, MHI, NWHI, Northern Mariana Islands, Johnston Atoll, Kingman Reef, Palmyra Atoll, Jarvis Island, Midway Island, Howland and Baker Islands and Wake Islands.

Life History and General Description

The shortbill spearfish is an Istiophorid billfish and shares the genus with five other species. Penrith (1964) identified a cline in pectoral fin length, increasing eastward in the Pacific. This was believed to be a result of geographic variation. No other information is available to suggest possible sub-populations.

Kikawa (1975), summarizing various works, describes the total distribution as sporadic between 10ºN and 10ºS with possible range extent to 30ºN and 30ºS, based on longline catch data. Nakamura (1985) gives a range of 40ºN to 35ºS for the Pacific. While dispersed throughout the tropics, density is always low. Nakamura further states that the shortbill spearfish "is an oceanic pelagic fish which does not generally occur in coastal or enclosed waters but is found well offshore. Longline fisheries in the equatorial Indian Ocean take relatively few individuals in the upper water layers (0–200 m) over depths shallower than 914 m (500 fm) while the highest catch rates are obtained above the 915 m to 1,830 m (501 to 1000 fm) isobaths." Boggs (1992), conducting research on longline capture depth, obtained different results. On a 1989 expeditions the highest catch rates were obtained at 120-360 m with a few fish caught as deep as 280–360 m. In 1990 the highest catch rates were shallow, 40–80 m with no catch below 200 m. This distribution is described as "into the middle of the thermocline" (Boggs 1992) that begins at 120 m and 20ºC. Nakano et al. (1997), analyzing catch depth data from research cruises in the mid-Pacific, classes shortbill spearfish among fish for which catch rate declines with depth. The hypothetical habitat for this fish may be described as open ocean epipelagic or mesopelagic waters (200–1000 m.) in the tropics and subtropics. No precise data can be given on limiting environmental parameter for this habitat.

No information was found in the literature about migration patterns or seasonal changes in abundance for this species. The species is distributed sparsely and no specific habitat features affecting abundance can be identified.

No information on age is available. In his review, Kikawa (1975) gives maximum sizes; fish over 20 kg are rare and the largest reported specimen was about 52 kg.

Spearfish are heterosexual and no sexual dimorphism is reported.

Shortbill spearfish apparently spawn in winter months in tropical and subtropical waters between 25ºN and 25ºS. Kikawa (1975) notes that unlike other billfish spawning does not “take place in large groups over a very short period of time, but probably is continuous over a long period and over a broad areas of the sea.” As individual females become ripe the male fish follows the female.

There is no special fishery for spearfish; they are caught incidentally by longliners and rarely by surface troll. Nakamura (1985) states that catch statistics in Japanese longline fishery typically lump sailfish (*Istiophorus platypterus*) with the shortbill spearfish but the latter may be differentiated as those caught offshore. The spearfish proportion of the total is considered negligible.

In the western Pacific region spearfish are not differentiated in longline logbook reporting (WPRFMC 1997). Guam reported landings of 967 lb in 1996 based on its creel census. Obviously, this fish is a minor constituent of commercial fisheries and caught with extreme rarity, if at all, in recreational fisheries.

Egg and Larval Distribution

Merrett (1971) provides two estimates of fecundity: 6.2 and 2.1 million eggs for females 1.39 m long (from center of orbit to shortest caudal ray). Egg diameters range from 1.3 to 1.6 mm.

No upper limit is given for larval size although Kikawa (1975) reports a juvenile specimen as 514 mm SL. He also provides a description of larval development.

Uotani and Ueyanagi (1997) found that the *Corycaeus* copepod, *Evadne* and fish larvae were major food items for larval spearfish. (Although this paper is in Japanese, Table 1 (p 109) gives the frequency of occurrence for food items in roman text.) Fish larvae increase from 0% of the diet at 5.0 mm TL to about 40% at 15.0 mm TL.

No information is available for larval distribution beyond the presumed extent of spawning described above. The hypothetical habitat for larvae presumably accords to this spawning range.

Juvenile

No information is available on juvenile behavior or habitat.

Adult

Kikawa (1975) reports the lengths for three specimens in ripe condition; they were 1.52 m (bill tip to origin of lateral keels), 1.64 m (bill tip to caudal fork) and 1.39 m (center of orbit to shortest caudal ray). No more precise information is given for size or age at maturity.

Kikawa (1975), summarizing various studies, states that the diet of the spearfish is essentially similar to other billfish, which are in turn similar to that of tuna. Prey items include squid and fish of the Lepidotidae, Alepisauridae, Acinaceidae and Katsuwonidae.

The hypothetical habitat or known range for adults is not known to be significantly different from that for the species as described above. No features are known that affect abundance.

Essential Fish Habitat: Tropical species complex

In regards to this species, EFH is not a very useful concept because of its wide and sparse distribution. In addition, relatively little is known about its biology. EFH can only be described as epipelagic and mesopelagic tropical and subtropical waters. No features are known to identify Areas of Particular Concern. Howard and Ueyanagi (1965) provide a distribution map which is reproduced in Kikawa (1975).

Habitat description for shortbill spearfish (*Tetrapturus angustirostris*)

	Egg	**Larvae**	**Juvenile**	**Adult**
Duration	unknown	unknown	unknown, but juvenile described as 510 mm	unknown, but mature females described as about 1.5 m.
Diet	NA	fish larvae, copepods	unknown	similar to other billfish: squid, fish
Distribution: General and Seasonal	tropics between 25º N and 25º S	same as eggs	unknown	between 40ºN to 35ºS or less
Location	open ocean	open ocean	open ocean	open ocean
Water Column	epipelagic	epipelagic	unknown, presumably epipelagic	epipelagic or mesopelagic
Bottom Type	NA	NA	NA	NA
Oceanic Features	unknown	unknown	unknown	unknown

Bibliography

Boggs CH. 1992. Depth, capture time, and hooked longevity of long-line–caught pelagic fish: timing bites of fish with chips. Fish Bull 90(4):642–58.

Howard JK, Ueyanagi S. 1965. Distribution and relative abundance of billfishes (Istiophoridae) of the Pacific Ocean. Univ Miami Inst Mar Sci, Stud Trop Oceanogr 2:1–134.

Kikawa S. 1975. Synopsis on the biology of the shortbill spearfish, *Tetrapturus angustirostris* Tanaka, 1914 in the Indo-Pacific areas. In: Shomura RS,Williams F, editors. Proceedings of the International Billfish Symposium; 1972 Aug 9–12; Kailua-Kona, HI. Seattle: National Marine Fisheries Service (NOAA). Part 3, Species synopses; p 39–54. NOAA technical report nr NMFS SSRF-675.

Merrett NR. 1971. Aspects of the biology of billfish (Istiophoridae) from the equatorial western Indian Ocean. J Zool 163:351–95.

Nakamura I. 1985. Billfishes of the world, an annotated and illustrated catalogue of marlins, sailfishes, spearfishes and swordfishes known to date. Rome: FAO. FAO Fish Synop 5(125). 58 p.

Nakano H, Okazaki M, Okamoto H. 1997. Analysis of catch depth by species for tuna longline fishery based on catch by branch lines. Bull Nat Res Inst Far Seas Fish 34:43–62.

Penrith M. 1964. A marked extension of the known range of *Tertrapturus angustirostrus* in the Indian Ocean. Copeia 1964:231–2.

Uotani I, Ueyanagi S. 1997. Feeding habits of Indo-Pacific blue marlin and shortbill spearfish larvae. J Sch Mar Sci Technol Tokai Univ 43:107–16.

[WPRFMC] Western Pacific Regional Fishery Management Council. 1997. Pelagic Fisheries of the Western Pacific Region 1996 Annual Report. Honolulu: Western Pacific Regional Fishery Management Council. 26 p. + appendices.

6.7 Habitat description for broadbill swordfish (*Xiphias gladius*)

Management Plan and Area

American Samoa, Guam, MHI, NWHI, Northern Mariana Islands, Johnston Atoll, Kingman Reef, Midway Island, Palmyra Atoll, Jarvis Island, Howland and Baker Islands and Wake Island.

Life History and General Description

Numerous studies on the taxonomy, biology, diet, stock structure and exploitation of broadbill swordfish have been conducted. Information on billfishes, including swordfish is summarized in Nakamura et al. (1968) and Nakamura (1985). Palko et al. (1981) provide a detailed synopsis of the biology of broadbill swordfish from literature available at the time of their publication. A more recent review is available in Joseph et al. (1994). Recent information on the species and research being conducted on Pacific swordfish can be found in papers submitted to the First International Pacific Swordfish Symposium (1994 Dec 11–14; Ensenada, Mexico) and the Second International Pacific Swordfish Symposium (1996 Mar 3–6; Kahuku, HI). A great deal of information on Pacific swordfish is available with the NMFS Honolulu Laboratory that is conducting research in several areas, including the age, growth, reproductive biology, distribution and abundance of north Pacific swordfish.

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). 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). Larvae and juveniles occur in warmer tropical and subtropical regions where spawning also occurs. Swordfish occur throughout the entire region of the Council's jurisdiction and in all neighboring states, territories and adjacent high seas zones.

Broadbill swordfish have separate sexes with no apparent sexual dimorphism, although females attain a larger size. Fertilization is external and the fish are believed to spawn close to the surface. There is some evidence for pairing up of spawning adults as the fish apparently do not school (Palko et al. 1981).

Swordfish are voracious feeders at all life stages. Adults feed opportunistically on a wide range of squids, fish and crustaceans. Sex ratio appears to vary with fish size and spatial distribution. Most large sized fish are females and females appear to be more common in cooler waters. Beckett (1974) noted that few males were found in waters below 18°C but make up the majority of warm water landings. Details of growth, maturity, fecundity and spawning are given later in this report.

Little is known about migration in Pacific swordfish although limited tagging data supports 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).

Broadbill swordfish are targeted by a Hawaii based longline fishery that occurs primarily to the north of the EEZ. Incidental or targeted catches within the Hawaii EEZ are made by longline and handline vessels fishing primarily for tuna species. Incidental longline catches occur in other areas of Council jurisdiction but are not well documented.

Egg and Larval Distribution

Swordfish eggs measure 1.6–1.8 mm in diameter, are transparent and float at the sea surface due to 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). Larvae have been noted in tropical and subtropical waters of the three major oceans between about 30°N and 30°S. In a survey of swordfish larvae collections, Grall et al. (1983) determined that larval swordfish were abundant in the Pacific within latitudes 35°N to 25°S. 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 (Tåning 1955, Yabe et al. 1959, Nishikawa and Ueyanagi 1974).

Larval swordfish are believed to occupy surface waters where almost all catches have been made using plankton and dip nets (Tåning 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.

The larval and young 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, Grobunova 1969). The young swordfish are voracious feeders; an 8 mm specimen will swallow prey as long as themselves (Tåning 1955). In contrast, 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.

Juvenile

Young swordfish gradually metamorphose from larval state to adult, and it is difficult to elect a length or age when the juvenile stage has been reached. However, early development is rapid and juvenile fish greater than approximately 55 cm resemble a miniature adult swordfish. In the Pacific, fish of this size (51–61 cm) have been estimated to be approximately one year old (Yabe et al. 1959, Dewees 1992).

There are few specific references on the distribution of juvenile swordfish in the Pacific. However, swordfish recruit to longline gear at juvenile sizes of approximately 50 to 80 cm (rear of orbit to caudal fork), which can be monitored by catch statistics. Dewees (1992) states that swordfish 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.

Adult

Adult swordfish are the most widely distributed of all billfish species, ranging from approximately 50°N to 50°S in the Pacific as indicated by catch records of commercial longline vessels. Adult swordfish are able to occupy a very wide range of water temperatures, from 5°–

27°C with a preferred temperature range of 18°–22°C (Nakamura 1985). The species can exceed 500 kg in weight with females growing larger than males. The larger fish occupy cooler waters, with few fish less than 90 kg and few males found in waters less than 18°C (Palko 1981).

Information on age and growth of swordfish is the subject of intense 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 or 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.

Research on the reproductive biology and size at maturity of swordfish is reviewed by DeMartini (1996). Yabe et al. (1959) estimate that swordfish reach maturity between 5 and 6 years of age at a size of 150–170 cm (eye to fork length). Sosa-Nishizaki (1990) estimate that female swordfish in the Pacific mature at 140–180 cm based on gonad indices. Arocha and Lee (1995) estimated a length at 50% maturity of 179–189 cm and 119–129 cm for female and male swordfish from the northwest Atlantic fishery. Length at first maturity has been observed in females as small as 101–110 cm (Nakano and Bayliff 1992). Spawning occurs in the upper mixed layer of the water column from the surface to 75 m (Nakamura 1985). Additional information on swordfish spawning is discussed in the section describing egg and larval distribution.

Optimal SSTs for swordfish are around 25°–29°C (Tåning 1955), which implies swordfish spend the majority of their time in cooler sub-surface waters. Swordfish can forage at great depths and have been photographed at a depth of 1,000 m by 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. Holts (1994) used acoustic telemetry to monitor an adult swordfish and notes that the fish 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.

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 the 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.

Adult swordfish are opportunistic feeders, preying heavily on squid and various fish species. 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 1981, Nakamura 1985, Stillwell and Johler 1985, Bello 1990, Carey 1990, Moreia 1990, Holts 1994, Markaida and Sosa-Nishizaki 1994, Barreto et al. 1995, Clarke et al. 1995, Hernandez-Garcia 1995, Orsi Relini 1995, Barreto 1996).

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 1981). Sakagawa (1989) notes that swordfish are found in areas of high productivity where forage species are abundant near current boundaries and frontal zones. The relationship between large-scale frontal systems, forage species and swordfish distribution and abundance in the North Pacific is currently a research priority of the NMFS Honolulu Laboratory.

Essential Fish Habitat: Temperate species complex

Habitat description for broadbill swordfish (*Xiphias gladius*)

	Egg	**Larvae**	**Juvenile**	**Adult**
Duration	approximately 2.5 days	uncertain	approximately 5 years	females larger and longer lived than males, conflicting estimates of age, ranging 9–14 yr for males, 15 –32 yr for females
Diet	NA	zooplankton, larval fish	cephalopods and fish, few crustaceans	cephalopods, mesopelagic and demersal fish, few crustaceans
Season/Time	throughout the year 20°N–20°S, between 35°N and 25°S at SST between 24°– 29°C	throughout the year 20°N–20°S, between 35°N and 25°S at SST between 24°–29°C	tropical and subtropical regions, moving to higher latitudes with age	50°N –50°S, water temperatures 5°–27°C, prefer 18°–22°C. Males perfer warmer waters. Spawning throughout the year in tropics at 20°N–20°S, seasonally where SST is above 24°C
Location	offshore waters	offshore waters	offshore waters	offshore waters
Water Column	epipelagic	epipelagic	pelagic, upper mixed	pelagic, normally

			layer	subsurface, extensive vertical migration from mixed layer to well below thermocline. May employ deep day and shallow nigh foraging strategy. Known to forage for demersal prey on the sea floor.
Bottom type	NA	NA	NA	NA
Oceanic Features	areas of sharp thermal and salinity gradients	areas of sharp thermal and salinity gradients	productive thermal boundary regions, areas of upwelling and convergence	Current boundaries, frontal zones, areas of high productivity and forage

Bibliography

Arata GF Jr. 1954. A contribution to the life history of the swordfish, *Xiphias gladius* Linnaeus, from the south Atlantic coast of the United States and the Gulf of Mexico. Bull Mar Sci Gulf Carib 4(3):183–243.

Arosha F, Lee DW. 1995. Maturity at size, reproductive seasonality, spawning frequency and sex ratio in swordfish from the Northwest Atlantic. Int Comm Conserv Atl Tunas, Coll Vol Sci Pap 45(2):350–7.

Barreto C, Marcano LA, Alio JJ, Gutierrez X, Zerpa A. 1996. Feeding of *Xiphias gladius* in the area of Venezuelan Caribbean (SCRS/95/65). Collect Vol Sci Pap ICCAT/RECL Doc.Sci 5(2):337–42.

Bartoo NW, Coan AL Jr. 1989. An assessment of the Pacific swordfish resource. In: Stroud RH, editor. Second International Billfish Symposium (1988) Proceedings., Savannah, GA: National Coalition for Marine Conservation. Part 1, Fishery and stock synopses, data needs and management; p 137–51.

Beckett, J.S. 1974. Biology of swordfish, *Xiphias gladius* L., in the Northwest Atlantic Ocean. In: Shomura RS, Williams F, editors. Proceedings of the International Billfish Symposium; 1972 Aug 9–12; Kailua-Kona, HI. Part 2, Review and contributed papers; p 105–6. NOAA tecnical report nr NMFS SSRF-675.

Bello G. 1990. Role of cephalopods in the diet of the swordfish *Xiphias gladius*, from the eastern Mediterranean Sea. Bull Mar Sci 49(1–2):312–324.

Carey FG. 1982. A brain heater in the swordfish. Science 216(4552):1327–9.

Carey FG. 1990. Further acoustic telemetry observations of swordfish. In: Stroud RH, editor. Second International Billfish Symposium (1988) Proceedings., Savannah, GA: National Coalition for Marine Conservation. Part 2, Contributed papers; p 103–22.

Carey FG, Robison BH. 1981 Daily patterns in the activities of swordfish, *Xiphias gladius*, observed by acoustic telemetry. US Nat Mar Fish Serv Fish Bull 79 (2):277–92.

Clarke MR, Clarke DC, Martins HR, Silva HM. 1995. The diet of swordfish (*Xiphias gladius*) in Azorean waters. Cien Biol Mar/Life Mar Sci 13A:53–69.

DeMartini EE. 1996. Size-at-maturity and related reproductive biology session. Second International Pacific Swordfish Symposium; 1996 Mar 3–6; Kahuku, HI. Discussion paper; 6 p.

Dewees CM. 1992. Swordfish. In: Leet WS, Dewees CM, Haugen CW, editors. California's living marine resources and their utilization. Davis, CA: California Sea Grant Extension Program. p 148–50.

Ehrhardt NM. 1992. Age and growth of swordfish, *Xiphias gladius*, in the northwestern Atlantic. Bull Mar Sci 50 (2):292–301.

Ehrhardt NM. 1996. Review of age and growth of swordfish, *Xiphias gladius*, using methods other than otoliths session. Second International Pacific Swordfish Symposium; 1996 Mar 3–6; Kahuku, HI. Discussion paper; 14 p.

Fritzsche RA. 1978. Development of fishes of the mid-Atlantic bight: an atlas of egg, larval and juvenile stages. Volume 5, Chaetodontidae through Ophidiidae. Fish and Wildlife Service, US Dept of Interior. Report nr FWS/OBS-78/12.

Gorbunova NN. 1969. Breeding grounds and food of the larvae of the swordfish *Xiphias gladius* Linné (Pisces, Xiphiidae). J Ichthyl. (3):375–85.

Hernandez-Garcia V. 1995. The diet of the swordfish *Xiphias gladius* Linnaeus, 1758, in the central east Atlantic, with emphasis on the role of cephalopods. Fish Bull .93(2):403–11.

Holts DB, Bartoo NW, Bedford DW. 1994. Swordfish tracking in the Southern California Bight. US Nat Mar Fish Serv, SW Fish Sci Center, Admin Report nr LJ 94-15. 9 p.

Joseph J, Bayliff WH, Hinton MG.1994. A review of information on the biology, fisheries, marketing and utilization, fishing regulations, and stock assessment of swordfish *Xiphias gladius*, in the Pacific Ocean.

Markaida U, Sosa-Nishizaki O. 1994. Food and feeding habits of the swordfish, *Xiphias gladius* L., off the western Baja California peninsula. International Symposium on Pacific Swordfish: Development of fisheries, markets and biological research; 1994 Dec 11–14; Ensenada, Mexico. Abstracts.

Mather CO. 1976. Billfish—marlin, broadbill, sailfish. Sidney, BC, Canada: Saltaire Publishing. 272 p.

Matsumoto WM, Kazama TK. 1974. Occurrence of young billfishes in the central Pacific Ocean. NOAA. Technical report nr SSRF 675. p 238–51.

Moreira F. 1990. Food of the swordfish, *Xiphias gladius* Linnaeus, 1758, off the Portuguese coast. J Fish Biol 36(4):623–4.

Nakamura I. 1985. Billfishes of the world. FAO Spec Synop 125(5). p iv, 65.

Nakamura I, Iwai T, Matsubara K. 1968. A review of the sailfish, spearfish, marlin and swordfish of the world. [ln Jpn.] Kyoto Univ, Misaki Mar Biol Ins Spec Rep 4. 95 p.

Nakano H, Bayliff WH. 1992. A review of the Japanese longline fishery for tunas and billfishes in the eastern Pacific Ocean, 1981–1987. Inter-Am Trop Tuna Comm, Bull 20(5):183–355.
Nishikawa Y, Ueyanagi S. 1974. The distribution of the larvae of swordfish, *Xiphias gladius*, in the Indian and Pacific Oceans. In: Shomura RS, Williams F, editors. Proceedings of the International Billfish Symposium; 1972 Aug 9–12; Kailua-Kona, HI. Part 2, Review and contributed papers; p 261–4. NOAA technical report nr NMFS SSRF-675.

Nishikawa Y, Kikawa S, Honma M, Ueyanagi S. 1978. Distribution atlas of larval tunas, billfishes, and related species—results of larval surveys by R/V Shunyo Maru and Shoyo Maru 1956–1975. Far Seas Fish Rese Lab S Series 9:1–99.

Orsi Relini L, Garibaldi F, Cima C, Palandri G. 1995. Feeding of the swordfish, the bluefin and other pelagic nekton in the western Ligurian Sea. Collect Vol Sci Pap ICCAT/RECL Doc Sci 44(1):283–6.

Palko BJ, Beardsley GL, Richards WJ. 1981. Synopsis of the biology of the swordfish, *Xiphias gladius* Linnaeus. NOAA technical report nr NMFS Circular 441. 21 p.

Radtke RL, Hurley PCF. 1983. Age estimation and growth of broadbill swordfish, *Xiphias gladius*, from the northwest Atlantic based on external features of otoliths. In: Prince ED, Pulos LM, editors. Proceedings of the International Workshop on Age Determination of Oceanic Pelagic Fishes: tunas, billfishes and sharks. p 145–50. NOAA technical report nr NMFS 8.

Sakagawa GT. 1989. Trends in fisheries for swordfish in the Pacific Ocean. In: Stroud RH, editor. Planning the future of billfishes. Research and management in the 90s and beyond. Mar Recr Fish 13:61–79.

Sanzo L. 1922. Uova e larve di *Xiphias gladius* L. Memorie del Reale Comitato Talassografico Itaniano 79. 17 p.

Scott WB, Tibbo SN. 1968. Food and feeding habits of swordfish, *Xiphias gladius*, in the western North Atlantic. Jour Fish Res Bd Canada 25(5):903–19.

Seki MP. 1993. The role of the neon flying squid, *Ommastrephes bartramii*, in the North Pacific pelagic food web. In: Ito J et al., editors. INPFC Symposium on biology, distribution and stock assessment of species caught in the high seas driftnet fisheries in the North Pacific Ocean; Vancouver, Canada. Internatl N Pac Fish Comm 53(2):207–15.
Seki MP. 1996. Basin-scale swordfish habitat assessment and fishery dynamics session. Second International Pacific Swordfish Symposium; 1996 Mar 3–6; Kahuku, HI. Discussion paper; 5 p.

Sosa-Nishizaki O. 1990. A study on the swordfish *Xiphias gladius* stocks in the Pacific Ocean [dissertation]. Tokyo: University of Tokyo, Fac Agric. 246 p.

Sosa-Nishizaki O. 1996. Review of ageing swordfish, *Xiphias gladius*, using otoliths session. Second International Pacific Swordfish Symposium; 1996 Mar 3–6; Kahuku, HI. Discussion paper; 6 p.

Stillwell CE, Johler NE. 1985. Food and feeding ecology of the swordfish *Xiphias gladius* in the western North Atlantic Ocean with estimates of daily ration. Mar Ecol (Prog Ser) 22(3):239–47.

Tåning AV. 1955. On the breeding areas of the swordfish (*Xiphias*). Pap Mar Biol Oceanogr, Deep Sea Res, supplement to 3:348–450.

Uchiyama JH, Shomura RS. 1974. Maturation and fecundity of swordfish, *Xiphias gladius*, from Hawaiian waters. NOAA technical report, NMFS Spec Sci Rep Fish 675. p 142–8.

Wilson CA, Dean JM. 1983. The potential use of sagittae for estimating age of Atlantic swordfish, *Xiphias gladius.* In: Prince ED, Pulos LM, editors. Proceedings of the International Workshop on Age Determination of Oceanic Pelagic Fishes: tunas, billfishes and sharks. NOAA technical report nr NMFS 8. p 151–6.

Yabe H, Ueyanagi S,. Kikawa S, Watanabe H. 1959. Study on the life-history of the sword-fish, *Xiphias gladius* Linneaus. Rep Nankai Reg Fish Res Lab 10:107–50.

Yasuda F, Kohno H, Yatsu A, Ida H, Arena P, Greci FL, Taki Y. 1978. Embryonic and early larval stages of the swordfish, *Xiphias gladius*, from the Mediterranean. J Tokyo Univ Fish 65(1):91–7.

6.8 Habitat description for sailfish (*Istiophorus platypterus*)

Management Plan and Area
American Samoa, Guam, MHI, NWHI, Northern Mariana Islands, Johnston Atoll, Kingman Reef, Palmyra Atoll, Jarvis Island, Midway Island, Howland and Baker Islands and Wake Islands.

Life History and General Description

The main source for this description is Beardsley et al. (1975).

The sailfish is an Istiophorod billfish, sharing the genus with the Atlantic sailfish (*I. albicans*). Graves and McDowell (1995), using RFLP analysis of mitochondrial DNA, have called for a re-evaluation of the taxonomic separation of these two species (as well as other inter-oceanic distinctions among other Istophorod billfish), while noting considerable intra-oceanic genetic diversity, suggesting population structure. However, no information was found concerning possible sub-populations in the Pacific.

Howard and Ueyanagi (1965) emphasize that sailfish are more common near land masses. In the western Pacific they identify areas of high density near the land masses of Papua New Guinea, Caroline Islands and Solomon Islands, as well as in the Banda Sea, Timor Sea, East China sea and the waters east of Taiwan to southwestern Japan. They note that both adults and young are associated with the KuroshioCurrent, migrating to the coastal waters of southern Japan in this current. Beardsley et al. (1975) describe the Pacific distribution as more extensive in the western half than eastern and note that catch data show a distribution from 27ºS to 40ºN in the west and 5ºS to 25ºN in the east. In describing habitat parameters, they state, “The vertical zone of the community in which the sailfish lives is characterized by good illumination and is likely to be delimited below by temperature at the main thermocline (from 10–20 m to 200–250 m, depending on area). Temperature is apparently important also in the latitudinal distribution of the species.…” They suggest the 28º isotherm as optimal. Salinity may also have an effect. Kuwahara et al. (1982) note a negative correlation between catch and salinity for landings of Kyoto Prefecture in Japan. Nakamura (1985) notes that maximum abundance in the Indian Ocean is correlated with a maximum temperature of the East African Coastal Current of 29º–30º and low salinity of 32.2–33.3 º/00. He also notes that sailfish share habitat with the black marlin (*Makaira indica*), another managed species. Hypothetical habitat may be described based on these parameters, but only in general terms.

Howard and Ueyanagi (1965) note that there is limited information on which to postulate migration patterns. However, radioactively contaminated sailfish “began to occur throughout the entire western Pacific Ocean several months after the nuclear bomb test explosions at Bikini in 1954,” they say. This suggests interchange of fish between low and high latitude areas. There may also be a seasonal component to migration. Nakamura (1985) states that in the Sea of Japan sailfish “migrate with the Tsushima current (a branch of the Kuroshio) during summer (peak later summer), and southward against the current during autumn (peak in early autumn).” As noted above, in the eastern Pacific, migration is correlated with seasonal movement of the 28º isotherm. Sailfish form schools of 3 to 30 individuals and apparently school by size, at least in coastal Japan (Nakamura 1985, Beardsley et al. 1975).

The only habitat feature consistently mentioned in the literature that affects abundance and density of population (indicating preferred habitat) is the sailfish’s preference for continental coasts.

As with other billfish, the age of individual sailfish is difficult to determine by analysis of hard parts. They apparently grow rapidly; Beardsley et al. (1975) give the following lengths at age: 1 year—183 cm, 2 years—216 cm and 3 years—233.7 cm. Prince et al. (1986) suggest a revision of the maximum age of sailfish based on a tag recapture. They estimate a maximum age of 13–15 years or more in contrast to earlier estimates in the range of 7 years.

Sailfish are heterosexual and do not exhibit sexual dimorphism.

De Sylva and Breder (1997), discussing Atlantic billfish, note that sailfish can spawn up to four times in a single season and males year around. They found that the sailfish spawning season of the US southeast Atlantic coast spanned April to October. They also state sailfish are largely coastal spawners. Nakamura (1985) states that in the Pacific sailfish spawn year around in the tropics with summer spawning at higher latitudes.

Most of the sailfish landings in the Pacific fisheries are made in the northwest and eastern central Pacific, mainly by Japanese and Korean vessels (Nakamura 1985). Longliners are undoubtedly the major gear type reflected in this description.

Hawaii commercial catch statistics do not separate out sailfish. The total for the “other billfish” category was 400,000 lb in 1996, the most recent published statistics (WPRFMC 1997). From the same source Guam reported no landings of sailfish; American Samoa reported 5,535 lb landed; and the Northern Marina Islands 545 lb. It can be seen that sailfish are a minor commercial species. Looking only at American Samoa, Guam and the Northern Mariana Islands, where landings for sailfish are reported separately, they represent less than half a percent of total PMUS landings. If this rate were applied to total Hawaii PMUS landings, 1996 sailfish landings would be about 130,000 lb. However, sailfish are an esteemed gamefish and is valuable to the charter boat fishery.

Egg and Larval Distribution

De Sylva and Breder (1997) give a recent detailed description of gonadal development based on Atlantic samples. Eggs are described as about 0.85 mm in diameter with a single oil globule surrounded by a pale yellow indefinite nimbus (Nakamura 1985, Beardsley et al. 1975). Duration of the egg phase is not stated in these sources but is probably similar to other billfishes.

Beardsley et al. (1975) summarize larval and juvenile development, stating that the transformation from larval to adolescent phase is without distinct break so the two phases are described together. Post et al. (1997) were able to capture larval sailfish and keep them alive in the laboratory for a maximum of 72 hours. However, they provide little information on larval behavior beyond noting that the larvae exhibited “extremely rapid swimming that led to contact wit the tank sides and bottom. Typically, fish maintained this pattern until their death.” The larvae successfully fed on *Artemia* in the laboratory tanks. Summarizing other studies, Beardsley et al. (1975) state that larvae feed on copepods and fish larvae. The authors reproduce a table from Gehringer (1956) detailing larval stomach contents. Based on drawing reproduced in Beardsley et al. (1975), the transition from larval to adolescent phase occurs between 30 mm and 100 mm.

Little can be said about the distribution or habitat of larval sailfish beyond what has already been summarized about distribution of spawning activity. Post et al. (1997) noted a higher CPUE for larval sailfish during the first quarter of the moon phase.

Juvenile

No information was found on juvenile distribution, behavior or preferred habitat beyond the aforementioned observation that sailfish tend to school by size.

Adult

Nakamura (1985) gives a maximum size of 340 cm and 100 kg. De Sylva and Breder (1997) give the weight at first maturity for females as 13–18 kg and males at 10 kg. This accords with an age of 12–18 months.

Beardsley et al. (1975) give a summary of the sailfish diet based on stomach content analysis.

They suggest that there is "a general consensus that although fish and squid form the major portion of their diet, adult sailfish are fairly opportunistic feeders and eat whatever happens to be present."

No additional habitat features affecting density and abundance can be described for adults that differ significantly from that of the species as a whole.

Essential Fish Habitat: Tropical species complex

In the western Pacific region, sailfish occur as a minor incidental catch in commercial fisheries. A few habitat parameters have been noted. This species seems to prefer continental margin areas. The description of EFH for sailfish has been based on the best available scientific information and the requirements of ecologically related managed species. Beardsley et al. (1975) reproduce a distribution map.

Habitat description for sailfish (*Istiophorus platypterus*)

	Egg	**Larvae**	**Juvenile**	**Adult**
Duration	unknown, hours or days	unknown, weeks	to 12–18 months	female: 13–18 kg, male: 10 kg, 12-18 months
Diet	NA	copepods and fish larvae	unknown	fish, especially scombrids, squid
Distribution: General and Seasonal	unknown, sailfish spawn year around in tropics, seasonally in cooler waters	unknown, probably similar to eggs	unknown, probably generally similar to adults	Range in western Pacific: 27ºS–40ºN; 5ºS–25ºN in east
Location	higher density in coastal waters	higher density in coastal waters	unknown, probably similar to adults	marked preference for continental margins
Water Column	epipelagic	epipelagic	epipelagic	epipelagic
Bottom Type	NA	NA	NA	NA
Oceanic Features	unknown	unknown	unknown	unknown

Bibliography

Beardsley GL, Merrett NR, Richards WJ. 1975. Synopsis of the biology of the sailfish *Istiophorus platypterus* (Shaw and Nodder, 1791). In: Shomura RS, Williams F, editors. Proceedings of the International Billfish Symposium; 1972 Aug 9–12; Kailua Kona, HI. Seattle (WA): NMFS (NOAA). Part 3, Species synopses, p 95–120. NOAA technical report nr NMFS SSRF-675.

De Sylva DP, Breder PR. 1997. Reproduction, gonad histology and spawning cycles of North Atlantic billfishes (Istiophoridae). Bull Mar Sci 60(3):668–97.

Gehringer JW. 1956. Observations on the development of the Atlantic sailfish *Istiophorus americanus* (Cuvier) with notes on an unidentified species of istiophorid. Fish Bull 57:139–71.

Graves JE, McDowell JR. 1995. Inter-ocean genetic divergence of istiophorid billfishes. Mar Biol 122(2):193–203.

Howard JK, Ueyanagi S. 1965. Distribution and relative abundance of billfishes (Istiophoridae) of the Pacific Ocean. Univ Miami Inst Mar Sci, Stud Trop Oceanogr 2:1–134.

Kuwahara A, Washio K, Suzuki S. 1982. Relationship between fishing conditions of sailfish and dolphin fish and fluctuation of hydrographic condition in the sea off Kyoto Prefecture. Bull Jap Soc Oceanogr 40:3–8.

Nakamura I. 1985. Billfishes of the world, an annotated and illustrated catalogue of marlins, sailfishes, spearfishes and swordfishes known to date. Rome: Food and Agriculture Organization of the United Nations. FAO Fish Synop 5(125). 58 p.

Post JT,. Serafy JE,. Ault JS, et al. 1997. Field and laboratory observations on larval Atlantic sailfish (*Istiophorus platypterus*) and swordfish (Xiphias gladius). Bull Mar Sci 60(3):1026–34.

Prince ED, Lee DW, Wilson CA, et al. 1986. Longevity and age validation of a tag-recaptured Atlantic sailfish, *Istiophorus platypterus,* using dorsal spines and otoliths. Fish Bull 84(3):493–502.

[WPRFMC] Western Pacific Regional Fishery Management Council. 1997. Pelagic Fisheries of the Western Pacific Region 1996 Annual Report. Western Pacific Regional Fishery Management Council. 26 pp. + appendices.

6.9 Habitat description for blue shark (*Prionace glauca*)

Management Plan and Area
American Samoa, Guam, MHI, NWHI, Northern Mariana Islands, Johnston Atoll, Kingman Reef, Palmyra Atoll, Jarvis Island, Howland and Baker Islands, Midway Island and Wake Island.

Blue shark within the jurisdiction of the Western Pacific Regional Fishery Management Council (Council) are managed within the requium shark category (family Carcharhinidae) under the Fishery Management Plan (FMP) for the Pelagic Fisheries of the Western Pacific Region. Blue sharks occur throughout the entire region of the Council's jurisdiction and in all neighboring states, territories and adjacent high seas zones.

Life History and General Description

Several studies have examined the life history, distribution and behavior of blue sharks at different locations worldwide (e.g., Strasburg 1958, Hazin et al. 1994, Gruber 1991, Nakano 1994). For a general review of blue shark life history and distribution see Compagno (1984). Information on elasmobranch fisheries and bycatch is given in Pepperell (1992) and Bonfil (1994).

The blue shark is an oceanic-epipelagic and fringe littoral species with a circumglobal distribution. The species is relatively fecund for a requium shark. It is found in all temperate and tropical oceans and is thought to be the most wide ranging shark species. The basic environmental conditions favorable for survival include oceanic waters between 6°C and 28°C, but it prefers cooler water temperatures between 7°C and 16°C (Strasburg 1958, Compagno 1984). In tropical waters, blue shark exhibit submergence and are typically found at greater depths. In temperate waters, blue sharks are caught within the mixed layer and generally range between the surface and upper layer of the thermocline (Strasburg 1958, Nakano et al. 1985), but have been documented as deep as 650 m (Carey and Scharold 1990). In the Pacific blue sharks are most predominant between 35°N and 45°N (Nakano 1994, Stasburg 1958).

Age and growth studies of blue sharks indicate that they may reach maturity in 6 to 7 years (Compagno 1984, Nakano 1994), although there may be regional differences in growth rate (Tanaka et al. 1990, Cailliet and Bedford 1983). They are believed to be opportunistic feeders at all life stages and prey primary on small pelagic fishes, crustaceans and cephalopods (Strasburg 1958, Stevens 1973, Tricas 1979). Blue sharks have also demonstrated seasonal shifts in diet when prey such as squid become abundant during mass spawning events (Tricas 1979).

The blue shark is viviparous with a yolk-sac placenta. Litter size is relatively large but variable ranging from 4 to 135 pups and may be dependent on the size of female (Gubanov and Grigor'yev 1975, Pratt 1979, Nakano 1994). In the Pacific it is thought that mating occurs during the summer months in the equatorial region from May to August (Nakano 1994). Gestation period is thought to range from 9 to 12 months and may vary depending on location (Suda 1953, Nakano 1994). Females have been demonstrated to store sperm, which may also explain variability in gestation period estimates (Pratt 1979). Late term pregnant females are found in the northern Pacific in summer months where they give birth to large, well-developed pups averaging 36 cm FL. The lengthy gestation period and geographic separation of mating and birthing grounds suggests that mature females in the Pacific may reproduce every other year (Nakano 1994).

Seasonal migrations are thought to occur in the Atlantic, Pacific and Indian Ocean populations with seasonal periods of sexual segregation (Casey 1985, Stevens 1992, Nakano 1994). A large-scale shark tag and recapture program has confirmed a clockwise migrations pattern in the North

Atlantic population suggesting blue sharks may follow the Gulf Stream (Casey 1985). However, migratory behavior in the Pacific and Indian Oceans is not known but has been proposed from length frequency and sex ration analysis of shark catch. A shark tagging program has recently been initiated by California Fish and Game further elucidate the migratory movements of blue sharks in the eastern Pacific (Laughlin 1997). However, only limited blue shark tagging has been conducted in the central Pacific, and thus, the extent of blue shark migrations in the central Pacific are still unconfirmed. Currently, the NMFS Honolulu Laboratory is collaborating with the National Research Institute of Far Seas Fisheries (Japan) to tag blue sharks in the north Pacific.

Blue sharks appear to aggregate in loose schools and are generally caught more frequently over depths greater than 1,000 m (Hazin et al. 1993, Ito and Machado 1997). They exhibit diel diving behavior similar to that of other pelagic teleosts and sharks (Sciarrota and Nelson 1977, Carey and Scharold 1990) and appear to show a fair degree of niche overlap with swordfish (C. Boggs, pers. comm.). Blue sharks are a bycatch of pelagic longline fisheries for tuna and swordfish in the Pacific and can seasonally comprise the largest percentage of the catch in some fisheries. In recent years there has been an increase in the number of blue sharks retained for their fins in the tuna and swordfish longline fishery in Hawaii (Ito and Machado 1997). The meat is seldom landed and sold at market because it has a low commercial value. Approximately 95% of shark fins landed in Honolulu by the pelagic longline fishery are from blue shark (WPRFMC 1997).

Neonate and Juvenile Distribution

Little is known about neonatal and juvenile blue sharks in the Pacific other than their general distribution. Young-of-the-year blue sharks (< 50 cm FL) were more frequently caught in large mesh drift-net fishery in the northern Pacific (35°N to 45°N), which is believed to be a parturition (birthing) area. It has been suggested that the separation of the parturition area from the adults habitats may serve to reduce predation on pups from adult sharks (Nakano 1994). Unfortunately, there is little known about the feeding habits or depth preferences of juveniles in their nursery grounds, although it has been speculated that nursery grounds are located in the more productive subarctic boundary where there may be more food for the young sharks (Nakano 1994).

Subadult

Subadult blue sharks appear to segregate according to sex in the Pacific. After leaving their parturition area, 2- to 5-year-old females are more frequently caught further northward (40°N to 50°N), while 2- to 4-year-old males move southward (30°N to 40°N) (Nakano 1994). Little is known about the feeding habits and depth preferences of subadults due to lack of study.

Adult

Adult blue sharks exhibit seasonal sexual segregation as well as possible migratory behavior. In the Pacific, adults range from equatorial waters to 40°N. In Nakano’s study (1994), adult females were predominant in waters off Japan throughout the year and in areas near the subarctic boundary in the summer, while males were most common in waters south of the subarctic boundary. In early summer reproductively ready females reportedly move to southern waters to mate with males. Large numbers of females exhibiting bite marks associated with recent matings were seen at equatorial latitudes. After mating, pregnant females reportedly migrate north where they give birth the following year (Nakano 1994).

Based on spatial and temporal changes in blue shark abundance in the Pacific, it is suspected that the north-south difference in catch rates of blue sharks is mediated by the transition zone. This is the area of water between the cooler Aleutian Current and the warmer water from the North Pacific Current. This transition zone shifts from 31°N and 36°N in the winter to 41°N and 36°N in the fall. Most of the larger catches of blue sharks have been made in or just south of this zone (Strasburg 1958).

Diel movements of blue sharks acoustically tracked off Southern California and in the North Atlantic indicate that adult blue sharks increase their activity at night and make shallower dives than during the day. Sharks tracked off Southern California ventured inshore at night, presumably to feed on seasonally available spawning squid (Sciarrota and Nelson 1977). The cyclical diving behavior is thought to serve as either a hunting, orientation and/or thermoregulatory function (Carey and Scharold 1990).

Although adult blue sharks are opportunistic feeders and prey mainly on small pelagic fishes, cephalopods and crustacean, they have also been observed scavenging on marine mammal carcasses at sea. Unfortunately, there are little data on the diet composition of blue sharks in the central Pacific.

Habitat description for blue shark (*Prionace glauca*)

	Gestation	**Juvenile**	**Subadult**	**Adult**
Duration	9-12 months	~ 1–2 years	~ 2–6 years	~ 6–20 years
Diet	NA	small fishes, cephalopods, crustaceans	small fishes, cephalopods, crustaceans	small fishes, cephalopods, crustaceans
Season/Time	throughout year	between 35°N and 45°N	females: between 40°N and 50°N males: between 30°N and 40°N	females: in equatorial latitudes in summer or high latitude nursery grounds males: equatorial latitudes
Location	offshore	offshore	offshore	offshore
Water Column	NA	epipelagic	epipelagic	epipelagic with tropical submergence
Bottom type	NA	NA	NA	NA
Oceanic Features	NA	subarctic boundary	females: cooler waters males: warmer waters	transition zone between Aleutian Current and North Pacific Current

Bibliography

Bonfil R. 1994. Overview of world elasmobranch fisheries. Rome: FAO. Fish technical paper nr 341.

Cailliet GM,. Bedford DW. 1983. The biology of three pelagic sharks from California waters and their emerging fisheries: A review. Cal COFI Rep 24:57–60.

Carey FG, Scharold JV. 1990. Movements of blue sharks (*Prionace glauca*) in depth and course. Mar Biol 106:329–42.

Casey JG. 1985. Transatlantic migrations of the blue shark: A case history of cooperative shark tagging. In*:* Stroud RH, editor. World angling resources and challenges. Proceedings of the First World Angling Conference; 1984; Cap d'Adge, France. Ft. Lauderdale, FL: International Game Fishing Association. p 253–268.

Compagno LJV. 1984. Sharks of the world. FAO species catalog, volume 4, part 2, Carcharhiniformes. Rome: Food and Agricultural Organization of the United Nations. p 655. Fisheries synopsis nr 125.

Gruber SH, editor. 1991. Discovering sharks. Highlands, NJ: American Littoral Society. 122 p.

Gubanov, YP, Grigor'yev VN. 1975. Observations of the distribution and biology of the blue shark *Prionace glauca* (Carcharhinidae) of the Indian Ocean. J Ichthyol 15:37–43.

Hazin FHV, Boeckman CE, Leal EC, Lessa RPT, Kihara K, Otsuka K. 1993. Distribution and relative abundance of the blue shark, *Prionace glauca*, in the southwestern equatorial Atlantic Ocean. Fish Bull US 92:474–80.

Ito RY,. Machado WA. 1997. Annual report of the Hawaii-based longline fishery for 1996. Southwest Fisheries Center admininstrative report nr H-97-12.

Laughlin LM. 1997. Shark tagging news 1997. Newslet CGFG Shark Tag Prog 2.

Nakano H. 1994. Age, reproduction and migration of blue shark in the North Pacific Ocean. Bull Nat Res Inst Far Seas Fish 31:141–256.

Pepperell JG, editor. 1992. Sharks: biology and fisheries. Australia: CSIRO. 349 p.

Pratt HL. 1979. Reproduction in the blue shark, *Prionace glauca.* Fish Bull US 77(2): 445–70.

Sciarrota TC, Nelson DR. 1977. Diel behavior of the blue shark, *Prionace glauca*, near Santa Catalina Island, California. Fish Bull US 75(3):519–28.

Stevens JD. 1973. Stomach contents of the blue shark (*Prionace glauca* L.) off south-west England. J Mar Biol Assoc UK 53:357–61.

Stevens JD. 1992. Blue and mako shark by-catch in the Japanese longline fishery off south-eastern Australia. Aust J Mar Freshwater Res 43:227–36.

Strasburg DW. 1958. Distribution, abundance, and habits of pelagic sharks in the central Pacific Ocean. Fish Bull 138:335–61.

Suda A. 1953. Ecological study on the blue shark (*Prionace glauca* Linn.) South Seas Area Fish Res Lab Rep 26(1):1–11.

Tanaka S, Cailliet GM, Yudin KG. 1990. Differences in growth of the blue shark, *Prionace glauca*: technique or population. In: Pratt et al, editors. Elasmobranchs as living resources: advances in the biology, ecology, systematics, and the status of the fisheries. p 177–87 NOAA technical report nr 90.

Tricas TC. 1979. Relationships of the blue shark, Prionace glauca, and its prey near Santa Catalina Island. Calif Fish Bull 77(1):175–82.

[WPRFMC] Western Pacific Regional Fishery Management Council. 1997. Pelagic Fisheries of the Western Pacific Region 1996 Annual Report. Honolulu: WPRFMC.

6.10 Habitat description for pelagic sharks (Alopiidae, Carcharinidae, Lamnidae, Sphynidae)

Management Plan and Area

American Samoa, Guam, MHI, NWHI, Northern Mariana Islands, Johnston Atoll, Kingman Reef, Palmyra Atoll, Jarvis Island, Midway Island, Howland and Baker Islands and Wake Islands.

Life History and General Description

Sharks are only identified at the family level for the purpose of management. The four families identified comprise some 65 species, although the vast majority (48 species) are Carcharinids. Table 1, derived from Compagno (1984), lists all species in these families occurring in FAO Fishing Areas 71 and 77, which cover the management area. However, of this total many do not or may not occur in the management area. The table below summarizes this information.

Family	Total Species	Number of species in FAO Area 71 and 77	Possibly in Management Area	Definitely in Management Area
Alopiidae	3	3	-	3
Lamnidae	5	4	1	3
Carcharinidae	48	38	9	12
Sphyrnidae	9	7	1	2

Table 1: Summary of species occurring in management area

According to logbook data from the Hawaii-based longline fishery about 93% of sharks landed are blue sharks (*Prionace glauca*). Of the remainder, about 1.5% are mako sharks (family Lamnidae) and about 3% are thresher sharks (family Alopiidae). This leaves a remainder of about 3% in the “other” category. Table 2 below is based on observer “raw” data, representing total sharks recorded between 1994–1997. Since observer coverage is low and there may be uncorrected biases in the data it should be treated with caution. Nonetheless, it gives some indication of the relative frequency of capture for various sharks. Because of their predominance in the fishery, a separate habitat description has been prepared for the blue shark. Since the remainder of the species are caught in relatively small numbers, habitat and life history will only be discussed at a general or family level.

Strasburg (1958) reports shark landings during the fishery assessment cruises that were part of the Pacific Oceanic Fishery Investigations carried out by the US Fish and Wildlife Service from 1952 to 1955. Twelve species are mentioned in the text. One of these, *Galcorhinus zypterus* (the “soupfin shark”) now classed as *G. galeus* (the tope shark) (Compagno 1984), is in family Triakidae and therefore not a MUS. Of the remainder three were considered common, *Prionace glauca*, *Carcharinus longimanus* (oceanic whitetip) and *Carcharinus falciformus* (the silky shark) Uncommon sharks were *Isurus oxyrinchus* (shortfin mako), the three species of threshers (family Alopiidae) and *Lamna ditropis*, the salmon shark. Eight *G. galeus*, four hammerheads (the two species in family Sphyrnidae that occur in the management area, *Sphyrna lewini* and *S. zygaena*) and two *Carcharinus melanopterus* (blacktip reef shark) were also landed.

Crow et al. (1996) give life history information on 11 species of shark caught in Hawaii during control programs carried out between 1959 and 1980. A total of 15 different species were caught in these programs. Three species, *Hexanchus griseus* (bluntnose six gill), *Echinorhinus cookei* (prickly shark) and *Pseudotriakis microdon* (false cat shark) are deepwater forms. None of these species fall into the four MUS families. Commonly caught species include *Carcharhinus altimus*, *C. limbatus* (blacktip reef shark), *C. plumbeus*, *C. amblyrynchos* (gray reef shark), *C. galapagensis*, *Sphyrna lewini* and *Galeocerdo cuvier*. The pelagic sharks *Isurus oxyrinchus, C. falciformis* and *Prionace glauca* were caught in very small numbers as was the great white, *Carcharodon carcharias*, an occasional visitor to the region. Kato (1964) describes seven Carcharhinid sharks caught by purse seiners in the eastern tropical Pacific: *C limbatus,* an inshore species; *C. azureus* (*now C. leucas,* the bull shark), a

Species	**Number**	**Percent**
Alopiidae		
Pelagic thresher (*Alopias pelagicus*)	19	0.08%
Bigeye thresher (*A. superciliosus*)	356	1.46%
Common thresher (*A. vulpinus*)	35	0.14%
Unidentified thresher (*Alopias sp.*)	38	0.16%
Subtotal	448	**1.84%**
Lamnidae		
Great white (*Charcharodon carcharias*)1	0.00%	
Shortfin mako (*Isurus oxyrinchus*)	312	1.28%
Longfin mako (*I. paucus*)	5	0.02%
Unidentifed mako shark (*Isurus sp.*)	8	0.03%
Salmon shark (*Lamna ditropis*)	57	0.23%
Subtotal	383	**1.57%**
Charcharhinidae		
Bignose shark (*Carcharhinus altimus*)	9	0.04%
Silky shark (*C. falciformis*)	56	0.23%
Galapagoes shark (*C. galapagensis*)	4	0.02%
Oceanic whitetip (*C. longimanus*)	629	2.58%
Dusky shark (*C. obscurus*)	2	0.01%
Sandbar shark (*C. plumbeus*)	27	0.11%
Tiger shark (*Galeocerdo cuvier*)	5	0.02%

Blue shark (*Prionace glauca*)	21,917	89.90%
Subtotal	22,649	**92.90%**
Sphyrnidae		
Scalloped hammerhead (*Sphyrna lewini*)2	0.01%	
Smooth hammerhead (*S. zygaena*)	8	0.03%
Unidentified hammerhead (*Sphyrna sp*.)5	0.02%	
Subtotal	15	**0.06%**
Unidentified sharks	885	3.63%
Total	24,380	100.00

Table 2: Observer data on sharks caught in the longline fishery

rarely caught shallow water and estuarine species*;* *C. galapagensis*; *C. platyrhyncus* (now *C. albimarginatus*), the silvertip, which aggregates near offshore islands; *C. lamiella* (now *C. obscurus*), a rarely caught coastal species; *C. malpeloensis*, the "net eater" (probably *C. falciformis*, which has *Eulamia malpeloensis* as a synonym), the most abundant species; and *C. altimus*, not common in the fishery and first reported in 1962.

The above information suggests that the fishery is dominated by a few species: *Prionace glauca*, *C. longimanus*, *A. superciliosus*, *Isurus oxyrinchus* and to a lesser extent *C. falciformis* and *Lamna ditropis*. However, numerous other Carcharhinid and Sphyrnid species are caught in low numbers. Many of the Carcharhinid species are coastal or reef dwelling but may on occasion venture far enough offshore to be captured by longliners operating near islands. In addition, seamounts and submerged banks outside of territorial waters may be habitat for some of these species. For example, Branstetter (1987) notes that female scalloped hammerheads are more oceanic and known to form offshore aggregations on seamounts.

The habitat, distribution and biology descriptions given in Compagno (1984) for each family are quoted below, supplemented by material from Strasburg (1958), and with information for specific species from various sources.

Family Alopiidae

Threshers are large, active, strong-swimming sharks, ranging in habitat from coastal to epipelagic and deepwater epibenthic. They are found worldwide in tropical, subtropical and cold-temperate waters. These sharks are apparently specialized for feeding on small to moderately large schooling fishes and squids. Threshers swim in circles around a school of prey, narrowing the radius and bunching the school with their long, strap-like caudal fins. The caudal fin is also used as a whip to stun and kill prey, and threshers are commonly tail-hooked on longlines after striking the bait with the caudal tip. The three species of this family broadly overlap in habitat and range, but differences in their structure, feeding habits and spatial and distribution suggest that they reduce interspecific competition by partitioning their habitat and available prey to some extent. *Alopias superciliosus*, with its huge eyes, relatively large teeth, broad caudal fin, and preference for deeper water (coastally near the bottom), take somewhat larger pelagic fishes (including billfishes and lancetfishes) as well as bottom fishes; *A. vulpinus*, with smaller eyes and teeth, a narrower caudal fin, and preference for the surface, takes small pelagic fishes (including clupeids, needlefishes and mackerels) and squids, but also bonitos and bluefishes. The oceanic *A. pelagicus* is poorly known, but its even smaller teeth and very slender caudal fin suggest that it may take smaller prey than *A. vulpinus* or *A. superciliosus* (Compagno 1984).

Strasburg (1958) reports that the three members of this family were uncommon so little about their distribution could be stated with confidence. He does, however, note a higher catch rate close to land, describing them as "definitely neritic [with] their abundance falling close to zero 40 miles from shore." He is uncertain about depth distribution except to say that they are possibly eurythermal and were most common at intermediate depths (49–85 m based on longline depth). Compagno (1984) gives the following depth distributions*:* *A. pelagicus* 0–152 m, *A. superciliosus* 0 to at least 500 m, *A. vulpinus* 0 to at least 366m.

Family Lamnidae

Lamnids are tropical to cold-temperate, littoral to epipelagic sharks with a broad geographic distribution in virtually all seas, in continental and insular waters from the surf line to the outer shelves and rarely down the slopes to at least 1,280 m. All the living species are of large size, with a maximum length of 3 to at least 6.4 m.

These sharks are fast-swimming, active pelagic and epibenthic swimmers, some of which are capable of swift dashes and spectacular jumps when chasing their prey. Mackerel sharks are partially warm-blooded and have a modified circulatory system that enables them to retain a body temperature warmer than the surrounding water. This permits a higher level of activity and increases the power of their muscles. They feed on a wide variety of bony fishes, other sharks, rays, marine birds and reptiles, marine mammals, squids, bottom crustaceans and carrion. Development is ovoviviparous, with a yolk-sac placenta. (Compagno 1984).

The two species mentioned by Strasburg (1958) are *Isurus oxyrinchus*, the shortfin mako and *Lamna ditropis*, the salmon shark, both considered uncommon. He notes that the shortfin mako has "almost the same range as the great blue shark" (i.e., *Prionace glauca*) and their depth distribution is also eurythermal. Compagno (1984) notes that this shark is seldom found in waters below 16ºC and is "the peregrine falcon of the shark world," the fastest shark and famed jumper. The salmon shark, as its name implies, is a temperate to boreal shark; according to Strasburg (1958), almost all were caught north of 35ºN. This shark may rarely occur at the northern margin of the Hawaii EEZ but are more likely occasionally caught by Hawaii-based vessels ranging outside the EEZ. There are two other species in the family. The longfin mako (*Isurus peucus*), which was first named fairly recently, in 1966. This suggests that it is a fairly rare species, or at least rarely caught. The great white shark (*Carcharodon carcharias*) is an infamous top level predator. It tends to be more common on continental margins, although Campagno (1984) notes that "the occurrence of large individuals off oceanic islands far from land where breeding populations of the species apparently do not exist suggests that it can and does make occasional epipelagic excursions into the ocean basins, even though it has never been taken in longline catches there (unlike its relatives in the genera *Isurus* and *Lamna*)." It may therefore be considered an occasional visitor to or vagrant in the management area.

Pratt and Casey (1983) provide growth and age estimates for *I. oxyrinchus* based on specimens captured in the northeast Atlantic. They estimate a one-year gestation period. Growth is considered fast but the species exhibits low fecundity. Size at birth is about 60 cm. Males mature at about 180 cm or 2.5 years, and females, 260 cm or 6–7 years. Theoretical maximum size, based on the von Bertalanffy growth curve is 302 cm for males and 345 cm for females, suggesting a maximum age in excess of 15 years. Size dimorphism between sexes, with females being larger, is common in many shark species.

Family Carcharhinidae

This is one of the largest and most important families of sharks, with many common and wide-ranging species found in all warm and temperate seas. These are the dominant sharks in tropical waters, often both in variety and in abundance and biomass. Most species inhabit tropical continental coastal and offshore waters; several species prefer coral reefs and oceanic islands while a few, including the blue, silky and oceanic whitetip sharks, are truly oceanic and range far into the great ocean basins. Requiem sharks are active strong swimmers, occurring singly or in small to large schools. Some species are continually active while others are capable of resting motionless for extended periods on the bottom. All are voracious predators, feeding heavily on bony fishes, other sharks, rays, squid, octopi, cuttlefishes, crabs, lobsters, and shrimp, but also sea birds, turtles, sea snakes, marine mammals, gastropods, bivalves, carrion, and garbage. (Compagno 1984)

The oceanic species mentioned above are also the three identified as common by Strasburg. The blue shark won't be discussed here as a separate species description has been prepared. The silky (*Carcharinus falciformis*) and oceanic whitetip (*C. longimanus*) are described by Strasburg (1958) as equatorial species with a range practically restricted to within 10 degrees on either side of the equator. According to him, the whitetip is the more abundant of the two species and may be more abundant than the blue shark, even if it is caught less frequently. The whitetip is considered more oceanic while the silky shark was more abundant around the Line Islands (0ºN–10º N and 155ºW–165ºW). The oceanic nature of the whitetip may be due to a lower salinity preference or avoidance of competition with faster moving neritic species. Strasburg (1958) states, "In common with other species occurring in the equatorial area, neither the whitetip nor the silky shark shows much latitudinal change in vertical distribution. The whitetip appears to be principally a surface dweller north of the equator and more bathypelagic to the south, whereas the silky is almost uniformly distributed in depth to the north and is more deep-swimming in the south." Compagno (1984) gives a depth distribution for the silky of 0 to at least 500 m and preferring water temperatures of 23º–24ºC. The whitetip is described as occurring from 0 to at least 152 m and generally found in waters deeper than 184 m. It regularly occurs in waters 18º–20ºC but prefers 20ºC. Strasburg also notes the capture of two blacktips (*C. melanopterus*), but these were caught near shore and are unlikely to caught with any frequency in EEZ waters.

Branstetter (1987) discusses age and growth of *C. falciformis,* one of the more commonly caught species. Based on centrum annuli taken from sharks in the Gulf of Mexico he developed a growth curve for this species. Back calculated size at birth is 55–85 cm with probably a one-year gestation period. Males mature at 210–220 cm or 6–7 years while females mature at greater than 225 cm or more than 9 years. Theoretical maximum size is 290.5 cm or perhaps 20 years old or more, although a more typical maximum age is 10–15 years. Examination of stomach contents suggests that tuna, mackerel, mullet and squid are common prey items in the Gulf of Mexico.

Wetherbee et al. (1996) reviews the biology of the Galapagos shark based on specimens caught in Hawaii shark control programs. This species is essentially limited to oceanic islands and is common on around islands off the American coast but is also commonly found in Hawaii. It prefers rugged bottom terrain and strong currents. There is evidence of sex segregation by depth based on capture records with females preferring shallower water. In Hawaii it is not typically found in shallow water nursery areas, nor does it school, as is common elsewhere. Females are estimated to mature at 6.5–9 years and males at 6–8 years. Mating occurs in winter and spring and pupping in spring and summer of the following year. This species may give birth only once every two to three years, suggesting overall low fecundity.

Tricas et al. (1981) studied the diel behavior of the tiger shark (*Galeocerdo cuvier*) using a tracking device. They found that the shark they studied (at French Frigate Shoals in the NWHI) spent daylight hours on the outer leeward reef, especially near steep drop-offs. At night the shark would move off the reef into deep water, frequently diving but in general following the contour of the reef front slope. They suggest that this behavior is associated with foraging.

Family Sphyrnidae

The hammerheads are a small but common family of wide-ranging, warm-temperate and tropical sharks found in continental and insular waters on or adjacent to their shelves but with none being truly oceanic. Depths range from the surface, surf-line and intertidal region down to at least 275 m depth. Hammerheads are very active swimmers, ranging from the surface to the bottom, and occur in all warm seas. Several species occur in schools, sometimes with hundreds of individuals. Some of the large species seem to find fish baits on longlines quicker than other sharks and expire more swiftly than most other species after being caught. Hammerheads are versatile feeders that take a wide variety of bony fishes, elasmobranchs, cephalopods, crustaceans and other prey; some habitually feed on other elasmobranchs. (Compagno 1984)

Hammerheads were caught very incidentally according to Strasburg (1958), so no distribution information is provided by him. Two species were caught, *Sphyrna lewini* and *S. zygaena*. Compagno (1984) describes the scalloped hammerhead (*S. lewini*) as probably the most abundant hammerhead, remaining close into shore, even ranging into enclosed bays and estuaries, and occurring along insular shelves. They are also reported over seamounts. The depth range is given from intertidal to at least 275 m. They are viviparous with a yolk-sac placenta and adults apparently move inshore to mate and young primarily occur close inshore. The habitat for the smooth hammerhead (*S. zygaena*) is essentially similar; however, Compagno gives the depth distribution as “the surface down to at least 20 m and probably much more.” Both species are omnivorous, feeding on a variety of inshore and reef species of fish, crustaceans and cephalopods. This information indicates that these are predominately inshore species and probably rarely caught in offshore fisheries.

Branstetter (1987) provides information on age and growth of *S. lewini* from the Gulf of Mexico. Size at birth is estimated 49 cm. Males mature at about 180 cm or 9–10 years and females at 250 cm or about 15 years. Theoretical maximum size is 329 cm, close to the largest known specimen, 309 cm, taken in Hawaii. The author estimates a maximum age for females of about 35 years and of males of 22–30 years.

Crow et al. (1996) provide information on *S. lewini* and *S. zygaena* captured around Hawaii during control programs. Juveniles of *S. zygaena* are common in coastal waters while adults may prefer offshore areas. Stomach content analysis from this and other studies suggest that teleost fish, crustaceans and pelagic cephalopods are common in the dies of *S. lewini*. *S. zygaena* apparently prefers cephalopods. Clarke (1971) and Holland et al. (1993) studied scalloped hammerhead (*S. lewini*) pups in Kaneohe Bay, Oahu, Hawaii. The southern part of the bay is a major breeding and pupping ground for this species. Pups apparently tend to avoid light, preferring more turgid waters. Pups school in a core refuge area during the day and then disperse at night, foraging along the base of patch reefs. Juveniles may move out of the bay somewhat inadvertently during foraging activities. As the move out of turgid water they may seek deeper water offshore where light intensity is lower.

Life History Notes on Sharks

Readers are referred to the habitat description for the blue shark as representative of life history aspects of the most commonly caught pelagic species. A very general and brief life history description for the group as a whole is given here.

Sharks are notable in that they produce relatively small numbers of young, which are either oviparous (egg laying, where the young develop inside an egg case) or viviparous (where pups are hatched or are born fully developed). This method of reproduction reduces the susceptibility of young to predation but also makes them more vulnerable to overfishing. Hoenig and Gruber (1990) state that, unlike teleost fish, they can be characterized as “K-selected species” and “the relationship between stock and recruitment in the elasmobranchs is quite direct, owing to the reproductive strategy of low fecundity combined with few, well-formed offspring.” The authors further point out that this strategy is similar to marine turtles and baleen whales, other marine species that have been overfished. Most sharks, except for the exclusively pelagic, reproduce at specific nursery grounds, which are usually inshore and ideally represent a habitat different from likely predators. The main predators on juveniles appear to be other larger sharks (Castro 1987). Thus the availability of predator-free nursery grounds may be an important factor in regulating population (Springer 1967).

Branstetter (1990) describes Atlantic Carcharhinoid and Lamnoid sharks reproductive growth in terms of size at birth and growth rate. These strategies can be divided into various categories. There are slow growing types with large neonates that occupy coastal and surf areas and are exposed to predators. Slow growing species with smaller young use bays and estuarine areas as nursery grounds, where predators are absent. Among fast growing species are small and large sized coastal sharks and pelagic sharks, including species significant in the management area. The silky shark (*C. falciformis*) depends on rapid neonate growth for survival and also has relatively large neonates. According to Springer (1967) neonates are found on deep reef areas and move into the pelagic environment at about six months of age. Alopiids and Lamnids have similar strategies. Young tend to be large, although *Isurus oxyrinchus* has smaller neonates but compensates with large litter sizes. Alopiids produce two to four young of intermediate size. Rapid growth in the young of these species allows greater swimming efficiency and speed in order to escape predators. For truly pelagic species, nursery grounds are probably not used; thus the importance of large neonate size and rapid growth.

Sexual segregation in schools is often observed in sharks and is probably related to reproduction. Strasburg (1958) discusses sexual segregation in blue sharks based on longline data (refer to the blue shark habitat description).

Wetherbee et al., (1990) discuss feeding habits of sharks. Sharks are generally portrayed as opportunistic feeders but the authors wish to qualify this somewhat. First, in most species teleosts tend to dominate in stomach content. Diet also changes with ontogenetic development; juveniles, especially when they are at inshore nursery areas have a different diet, eating more crustaceans for example. There may also be seasonal variation due to changes in prey availability. Similarly prey may vary due to habitat; the authors cite a study (Clarke 1971) showing that scalloped hammerhead diet varied from one location to another in Kaneohe Bay, Oahu, Hawaii. Among their conclusions, Wetherbee et al. (1990) state that feeding occurs in short bouts followed by longer periods of digestion and there is not well established periodicity for feeding. Sharks’s daily ration is apparently lower than for teleosts.

Pacific fisheries

Determination of total catch for sharks is difficult since they are bycatch in Pacific region fisheries. In the Hawaii-based longline fishery there has been an increasing trend towards cutting off the dorsal fins as these may be dried and are valued in Asian markets. Mako and thresher shark carcasses are sometimes retained because their meat has some market value. (For a full discussion of the bycatch issue refer to section 4.1 of this amendment.) The total number of sharks caught in the longline and purse seine fisheries is thought to be large (Heberer and McCoy 1997). Pacific-wide, blue sharks are the most significant component of catches, as they are in the region's fisheries. Bonfil (1984) gives a regional summary but relies on Strasburg's report (1958) to derive a breakdown by species based on estimates of the total number of sharks hooked. For 1989, he estimates 19,897 mt of silky sharks (*C. falciformis*), 10,799 mt of whitetips (*C. longimanus*), 8,193 of blue shark and 1,545 mt of other species for South Pacific longline fisheries. For North Pacific (above 20°N) longline fisheries estimated catch is 39,059 mt of blue shark, 145 mt of whitetip and 1,789 of other species. The author is unable to make similar estimates for the purse-seine fishery but cites Au (1991) who describes the nature of associations in different types of tuna schools.

As noted above, the bycatch discussion in this amendment provides some data on shark catches in the Hawaii-based longline fishery. From Table 4.1.b the following numbers and percentages can be derived for 1997: blue sharks 79,712 (93.21%), mako sharks 1,164 (1.36%), thresher sharks 2,321 (2.71%), other sharks 2,326 (2.72%). Published data (WPRFMC 1997) does not break down shark landings by species. In addition, landings data does not account for discards. In 1996 (the most recent data available) an estimated 4.5 million lb (2,041 mt) were landed in Hawaii. (Shark landings represent an estimate of whole weight based on the number of fins landed in addition to any carcasses.) American Samoa estimated landings were 12,747 lb (5.78 mt), and 3,348 lb (1.52 mt) were estimated for Guam. The regional total is thus 4,516,095 lb (2,048 mt). Total landings for the western Pacific region are about 2.5% of the estimated Pacific regional total of 80,927 mt.

Essential Fish Habitat: Shark species complex

If all sharks in the four MUS families are used as a basis for delineating EFH then it will necessarily be large because the families contain both offshore and inshore species occupying a wide variety of habitats. It is probably more realistic to base the delineation only on the more commonly caught pelagic species. Even so, the designation will encompass all epipelagic and mesopelagic EEZ waters. This broad designation results from the wide-ranging nature of many species (taken together covering tropical, temperate and even boreal seas) and lack of knowledge about relative density, although for all species taken together densities are higher in neritic and inshore waters. Very small-scale distribution maps are found in Compagno (1984); Strasburg (1958) has two distribution maps for "common" and "uncommon" species based on hooking rates.

Habitat description for pelagic sharks (Alopiidae, Carcharinidae, Lamnidae, Sphynidae)

	Gestation	**Juvenile / Sub-Adult**	**Adult**
Duration		to 5–10 years or more	to 20 years or more
Diet	NA	omnivorous, fish, squid	omnivorous, teleost fish, notably scombrids, in some cases billfish, other elasmobranchs, squid, crustaceans, molluscs
Distribution: General and Seasonal	Major pelagic species gestation and parturition is probably wholly pelagic. Some species, such as Sphyrnids and probably many Carcharhinids have inshore nursery grounds	highly variable/unknown, see adult distribution	• Alopiidae: 20ºN– 20º S to 50º N–40º S for *A. vulpinus* • Lamnidae: 50ºN-–45ºS *for I. oxyrinchus*, *I paucus* uncertain but more restricted subtropical tropical; *L. ditropis* boreal-temperate (above 35º) in North Pacific • Carcharhinidae: 10º N - 10º S. for *C. falciformis* and *C. longmanus*, other species highly variable
Location	variable, depends on adults	highly variable/unknown, see adult distribution	• Alopiidae: neritic to offshore, but not truly pelagic • Lamnidae: epipelagic to mesopelagic • Carcharinidae: highly variable, major captured species epipelagic • Sphyrnidae: *S. lewini*- circumglobal in coastal warm temperate and tropical seas; *S. zygaena*- amphitemperate and tropical
Water Column	NA	inshore benthic, neritic to epipelagic	inshore benthic, neritic to epipelagic, mesopelagic

Bottom Type	NA	highly variable	highly variable for inshore species
Oceanic Features	NA	unknown	unknown, captured species associate with tuna schools

Bibliography

Au DW. 1991. Polyspecific nature of tuna schools: shark, dolphin and seabird associates. US Nat Mar Fish Serv Fish Bull 89(3):343–54.

Bonfil R. 1884. Overview of world Elasmobranch fisheries. Rome: Food and Agriculture Organization. 119 p. FAO Fish Tech Paper nr 341.

Branstetter S. 1987. Age, growth and reproductive biology of the silky shark, *Carcharrhinus falciformis*, and the scalloped hammerhead, *Sphyrna lewini*, from the northwestern Gulf of Mexico. Environ Biol 19:161–74.

Branstetter S. 1990. Early life-history implications of selected Carcharinoid and Lamnoid sharks of the northwest Atlantic. In: Pratt HL, Gruber SH,. Taniuchi T, editors. Elasmobranchs as living resources: advances in the biology, ecology, systematics, and the status of the fisheries. p 17–24. NOAA technical report NMFS 90.

Castro JI. 1987. The position of sharks in marine biological communities, an overview. In: Cook S, editor. Sharks, an inquiry into biology, behavior, fisheries, and use. Corvallis (OR): Oregon State University Extension Service. p 11–7.

Clarke, TA. 1971. The ecology of the scalloped hammerhead shark, *Sphyrna lewini*, in Hawaii. Pac Sci 25:133–44.

Compagno LJV. 1984. FAO Species Catalogue. Volume 4, Parts 1–2, Sharks of the world: an annoted and illustrated catalogue of shark species known to date. Rome: Food and Agriculture Organization. 655 p. Report nr FIR/S125.

Crow GL, Lowe CG, Wetherbee BM. 1996. Shark records from longline fishing programs in Hawai'i with comments on Pacific Ocean distributions. Pac Sci, 50(4):382–92.

Heberer CF, McCoy MA. 1997. Overview of Pacific fisheries agencies and institutions collecting shark catch data. Honolulu: WPRFMC. 108 p.

Hoenig JM, Gruber SH. 1990. Life-history patterns in the Elasmobranchs: implications for fisheries management. In: Pratt HL, Gruber SH, Taniuchi T, editors. Elasmobranchs as living resources: advances in the biology, ecology, systematics, and the status of the fisheries. p 1–16. NOAA technical report nr NMFS 90.

Holland KN, Wetherbee BM , Peterson JD, et al. 1993. Movements and distribution of hammerhead shark pups on their natal grounds. Copeia, 2(3):495–502.

Kato S. 1964. Sharks of the genus *Carcharhinus* associated with the tuna fishery in the eastern tropical Pacific Ocean. 22 p. US Fish and Wildlife circular nr 172.

Pratt HL, Casey JG. 1983. Age and growth of the shortfin mako, *Isurus oxyrinchus*, using four methods. Can J Fish Aquat. Sci. 40:1944–57.

Springer S. 1967. Social organization of shark populations. In: Gilbert PW, Mathewson RF, Rall DP, editors. Sharks, skates and rays. Baltimore: Johns Hopkins Univ Pr. p 149–74.

Strasburg DW. 1958. Distribution, abundance and habits of pelagic sharks in the central Pacific Ocean. Fish Bull 58:335–61.

Tricas TC, Taylor LR, Naftel G. 1981. Diel behaviour of the tiger shark, *Galeocerdo cuvier*, at French Frigate Shoals, Hawaiian Islands. Copeia 4:904–8.

[WPRFMC] Western Pacific Regional Fishery Management Council. 1997. Pelagic Fisheries of the Western Pacific Region 1996 Annual Report. Honolulu: Western Pacific Regional Fishery Management Council. 26 pp. + appendices.

Wetherbee BM, Crow GL, Lowe CG. 1996. Biology of the Galapagos shark, *Carcharhinus galapagensis*, in Hawai'i. Environ Biol Fish 45(3):299–310.

Wetherbee BM, Gruber SH, Cortes E . 1990. Diet, feeding habits, digestion and consumption in sharks, with special reference to the lemon shark, *Negaprion brevirostris*. In: Pratt HL, Gruber SH, Taniuchi T, editors. Elasmobranchs as living resources: advances in the biology, ecology and systematics, and the status of the fisheries. p 29–47. NOAA technical report nr NMFS 90.

Name (Order, Family, Genus, species)	Occur in FAO Fishing Areas 71 or 77	Habitat/Range	Common name
ORDER LAMNIFORMES (Mackerel Sharks)			
Family Alopiidae (Thresher Sharks) (Strasburg 1958)			
Alopias pelagicus	71, 77	Oceanic and wide ranging in the Indo-Pacific, Hawaii	Pelagic thresher
superciliosus	71, 77	Oceanic and coastal, virtually cirumtropical, N and S of Hawaii	Bigeye thresher
vulpinus	71, 77	Oceanic and coastal, virtually cricumglobal in warm seas, Fanning Is., Hawaii	Thresher
Family Lamnidae (Porkbeagles, White Sharks			
Carcharodon carcharias	71, 77	Coastal and mostly amphitemperate, Marshall Is., Hawaii	Great white
Isurus oxyrinchus (Strasburg 1958, *I. glaucus*-bonito sh.)	71, 77	Coastal and oceanic, temperate and tropical, 50ºN–40º S	Shortfin mako
	71, 77	Oceanic and tropical, Near Phoenix and north	Longin mako

paucus		of Hawaii	
Lamna ditropis (Strasburg 1951, mackerel shark)	77	Coastal-liitoral and epipelagic in boreal and cool temperate waters, not in management area?	Salmon shark
ORDER CARCHARINIFORMES (Ground Sharks)			
Family Carcharhinidae (Requiem Sharks)			
Carcharinus albimarginatus	71, 77	Coastal-pelagic tropical, Guam	Silvertip
altimus	77	Offshore, bottom-dwelling warm-temperate and tropical, Hawaii	Bignose
amblyrhynchoides	71	Little known, common tropical inshore and offshore	Graceful
amblyrhynchos	71, 77	Coastal pelagic frequenting continental and insular shelves, common on coral reefs, coastal areas throughout management area	Grey reef
amboinensis	71	Inshore, Indo-West Pacific, not in management area	Pigeye
borneensis	71	Rare coastal, inshore, tropical shark of Indo-West Pacific, probably not found in management area	Borneo

brachyurus	71, 77	Inshore to offshore warm temperate shark, possibly confined to continental margins? Not found in management area?	Copper
brevipinna	71	Common coastal-pelagic, warm-temperate and tropical shark of continental and insular shelves, not in management area?	Spinner shark
cautus	71	Little known South Pacific reef shark of shallow water on continental and insular shelves. not in management area?	Nervous shark
dussumieri	71	Common inshore shark of continental shelves, not in management area?	Whitecheek
falciformis (Strasburg 1951, *Eulamia floridanus*)	71, 77	Abundant offshore, oceanic and epipelagic and littoral, tropical, near the edge of continental and insular shelves and in open sea, Caroline, Hawaiian, Phoenix and Line Islands	Silky
fitzroyensis	71	Little known, Australian littoral. Not found in management area	Creek whaler
galapagensis	71	Common but habitat limited tropical shark inshore and offshore, Marianas, to Marshalls, Hawaiian group including NWHI	Galapagos
hemiodon	71	Little known Indo-West Pacific. Not in management area	Pondicherry
leucas	71	Coastal, estuarine continental. Not in management area?	Bull

limbatus	71, 77	Widespread in all tropical and subtropical shelves; not truly oceanic, Hawaii	Blacktip
longimanus (Strasburg 1951, *Pterolamiops longimanus*)	71, 77	Common oceanic-epipelagic, occasionally coastal, tropical and warm temperate, throughout management area	Oceanic whitetip
macloti	71,	Little known Indo-West Pacific, not in management area	Hardnose shark
melanopterus (Strasburg 1951)	71, 77	Common shallow water reef shark throughout management area	Blacktip reef
obscurus	71, 77	Common coastal-pelagic shark of continental margins. Not in management area?	Dusky
plumbeus	71, 77	Abundant inshore and offshore, coastal pelagic, temperate and tropical, Hawaii? Not in management area?	Sandbar
porosus	77	Common inshore shark of tropical America, not in management area	Smalltail
sealei	71	Common coastal shark of Indo-West Pacific, not in management area	Blackspot
signatus	77	Atlantic shark with possible extension to Pacific Panama, not in management area	Night
sorrah	71	Coastal, shallow-water shark of Indo-West Pacific, not in management area	Spot-tail

Galeocerdo cuvier	71, 77	Common wide-ranging coastal pelagic, tropical and warm temperate shark with wide habitat tolerance, found throughout management area	Tiger
Glyphis glyphis	71	Little known shark of Bornea, New Guinea and Queensland, not in management area	Speartooth
Lamniopsis temmincki	71	Little known continental shark, not in management area	Broadfin
Loxodon macrohinus	71	Common inshore shark of continental areas, Indo-West Pacific, not in management area	Sliteye
Negaprion acutidena	71, 77	Tropical inshore shark of continental and insular shelves and terraces, Palau Marshall Islands, not in management area?	Sicklefin lemon
brevirostis	77	Abundant inshore shark of tropical Americas and Atlantic, not in management area	Lemon shark
Prionace glauca (Strasburg 1951)	71, 77	Wide ranging, oceanic-epipelagic and fringe littoral to at least 152 m	Blue
Rhzoprionodon acutus	71	Abundant inshore and offshore shark of continental shelves, not in management area	Milk
longurio	77	Abundant on tropical littoral and continental shelf of America, not in management area.	Pacific sharpnose

oligolinx	71	Common but little known littoral, inshore and offshore tropical, Palau?, not in management area?	Grey sharpnose
taylori	71	Australia, not in management area.	Australian sharpnose
Scoliodon laticaudus	71	Common tropical shark of continental and insular shleves, close inshore. Not in management area.	
Triaenodon obesus	71, 77	Common tropical inshore shark of continental shelves and island terraces. Wide ranging from Indo-West Pacific to central Pacific.	Whitetip reef
Family Sphyrnidae (Bonnethead, Hammerhead, Scoopehead Sharks)			
Euphyra blochii	71	Shallow water on continental and insular shelves, Indo-West Pacific, not in management area.	Winghead
Sphyrna corona	77	Little known, tropical America, not in management area	Scalloped bonnethead
lewini (Strasburg, 1958)	71, 77	Abundant coastal-pelagic, warm temperate and tropical, Hawaii	Scalloped hammerhead
media	77	Little known, tropical America, not in management area.	Scoophead
mokarran	71, 77	Coastal pelagic and semi-oceanic tropical, not	Great hammerhead

		in management area?	
tiburo	77	Abundant inshore, tropical America, not in management area	Bonnethead
zygaena (Strasburg, 1958)	77	Common, coastal pelagic, semi-oceanic, Hawaii.	Smooth hammerhead

6.11 Habitat description for albacore tuna (*Thunnus alalunga*)

Management Plan and Area

American Samoa, Guam, MHI, NWHI, Northern Mariana Islands, Johnston Atoll, Kingman Reef, Palmyra Atoll, Jarvis Island, Midway Island, Howland and Baker Islands and Wake Islands.

Life History and General Description

The main sources used in this description are Foreman (1980) and Collette and Nauen (1983). Other reviews include Bartoo and Foreman (1994) and Murray (1994).

The albacore is a member of the Scombridae family mackerels and tunas, composed of 15 genera and 49 species. *Thunnus* is one of four genera in the tribe Thunni, unique among bony fishes in having central and lateral heat exchangers. Separate northern and southern stocks, with separate spawning areas and seasons, are believed to exist in the Pacific. In the North Pacific there may be two sub-stocks, separated due to the influence of bathymetric features on water masses (Laurs and Lynn 1991). Growth rates and migration patterns differ between populations north and south of 40ºN (Laurs and Wetherall 1981, Laurs and Lynn 1991).

In the north Pacific albacore are distributed in a swath centered on 35ºN and as far as 50ºN in the west. In the south Pacific they are concentrated between 10º and 30ºS in the central Pacific (150ºE to 120ºW) and as far south as 50ºS. They are absent from the equatorial eastern Pacific, southeast of Hawaii (which apparently lies near the edge of its range) in an area stretching roughly from 165ºW to the American coast and between 15ºN and the equator. Temperature is recognized as the major determinant of albacore's distribution. Albacore are both surface dwelling and deep-swimming. The distribution maps in Foreman (1980) show the distribution of deep-swimming albacore, which are generally more concentrated in the western Pacific but with eastward extensions along 30ºN and 10ºS. Depth distribution is governed by vertical thermal structures, and they are found to a depth of at least 380 m. The 15.6º to 19.4º C SST isotherms mark the limits of abundant distribution although deep-swimming albacore have been found in waters between 13.5º and 25.2ºC (Saito 1973). Laurs and Lynn (1991) describe North Pacific albacore distribution in terms of the North Pacific Transition Zone, which 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. This band of water, roughly between 40º and 30–35ºN (the Transition Zone is not a perfectly stable feature) also helps to determine migration routes (see below). Telemetry experiments demonstrate that albacore will enter water as cold as 9.5ºC for short periods of time. Laurs and Lynn (1991) argue that acoustic tracking demonstrates that albacore have a wider temperature range than stated previously; their normal habitat is 10º–20ºC with a dissolved oxygen saturation level greater than 60%. The overall thermal structure of water masses, rather than just SST, has to be taken into account in describing total range. Albacore exhibit marked vertical movement and will move into water as cold as 9ºC at depths of 200 m. They move through temperature gradients of up to 10ºC within 20 minutes. This reflects the many advanced adaptations of this fish; it is a thermo-regulating endotherm with a high metabolic rate and advanced cardiovascular system. Albacore have differential temperature preferences according to size, with larger fish preferring cooler water, although the opposite is true in the northeast Pacific. They are considered epi- and mesopelagic in depth range. The minimum oxygen requirement is reckoned to be 2 ml/l.

Albacore are noted for their tendency to concentrate along thermal fronts, particularly the Kuroshio front east of Japan and the North Pacific Transition Zone. Laurs and Lynn (1991) note that they tend to aggregate on the warm side of upwelling fronts. Near continental areas they prefer warm, clear oceanic waters adjacent to fronts with cool turbid coastal water masses. It is not understood why they don't cross these fronts, especially given that they are able to thermo-regulate, but it may be because of water clarity since they are sight-dependent foragers. Further offshore fishing success correlates with biological productivity.

Albacore have a complex migration pattern with the North and South Pacific stocks having their own patterns. Most migration is undertaken by pre-adults, 2–5 years old. A further sub-division of the northern stock, each with separate migration, is also suggested. The model suggested by Otsu and Uchida (1963) shows trans-Pacific migration by year class. Generally speaking, a given year class migrates east to west and then east again in a band between 30º and 45ºN, leaving the northeast Pacific in September–October, reaching waters off Japan the following summer and returning to the east in the summer of the following year. Four- to 6-year-old albacore enter sub-tropical waters south of 30ºN 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 to the eastern Pacific when the Kuroshio takes a large meander path. This also affects the southward extension of the Oyashio Current and may reduce the availability of forage, primarily saury, in the western Pacific.

The aforementioned sub-stocks apparently divide along 40ºN. Albacore tagged off the US West Coast north of 40ºN apparently undertake more westward migration (58% of tag returns come from the western Pacific west of 180º) versus those tagged to the south (only 10% were recovered in the western Pacific, 78% from the tagging area) (Laurs and Lynn 1991).

Murray (1994), summarizing the work of Jones (1991), describes migration in the South Pacific. Juveniles move from the tropics into temperate waters at about 35 cm LCF and then generally eastward along the Sub-Tropical Convergence Zone. They do not return to the tropics until they are about 85 cm LCF. As they move towards the tropics it is presumed they move deeper, probably due to water temperature. Seasonal patterns are similar to the North Pacific. Juveniles prefer cooler water and move south from sub-tropical waters to temperate in the austral spring. Adults occur from the tropics to temperate zone throughout the years.

Young albacore congregate in large, loosely aggregated schools, at least off the West Coast of North America. Larger fish are observed to form more compact schools, but the dense schools common to yellowfin and skipjack tuna are not true of albacore.

As noted above, the most noted habitat feature affecting abundance and density of albacore populations is their preference for oceanic fronts or temperature discontinuities.

Foreman (1980) summarizes estimates of von Bertalanffy equation parameter in tabular form (Table 2). Growth rates for fish below 38ºN are reportedly higher than those taken to the north. Reported age-length relationships are also summarized. Estimates of the size at one year range from 38 to 57.3 cm, about a third of estimates for size at the von Bertalanffy asymptote, 104–145.3 cm. Juvenile growth has been estimated at 3.12 cm per month (Yoshida 1979). Bartoo and Foreman (1994) give the following von Bertalanffy parameter as the most reasonable for assessment purposes: $L_\infty = 135.6$ cm, $K = 0.17$ and $t_o = -0.87$.

Albacore or heterosexual with no external characters to distinguish males from females. Immature fish generally have an even sex ratio but males predominate in catches of mature fish. Table 4 in Foreman (1980) summarizes published information on sex ratios. For mature fish, male-female ratios range from 1.63:1 to 2.66:1. Like many other pelagic fish, it is believed that albacore release their gametes indiscriminately without selecting partners. Ramon and Bailey (1996) report sexual dimorphism in South Pacific stocks, confirming findings by Otsu and Sumida (1968) with the males being larger. Fecundity is estimated at 0.8–2.6 million eggs per spawning.

Albacore spawn in the summer in subtropical waters. There is also some evidence of multiple spawning (Otsu and Uchida 1959). Foreman (1980) provides a map showing distribution of spawning areas. In the North Pacific the area centers on 25ºN and 160ºE and does not extend east of about 150ºW. In the south Pacific the band is narrower, centered at about 25ºS and stretching from the sea east of Queensland, Australia, to about 110ºW. Ramon and Bailey (1996) discuss spawning seasonality in the South Pacific, near New Caledonia and Tonga. October to December was found to be peak spawning season. Maturing albacore were mostly taken between 20º and 23ºS. The same map in Foreman (1980, Figure 4) shows larval distribution, which is more restricted in extent than estimates of total spawning area.

The review articles consulted for this description summarize the main albacore fisheries in the Pacific. They may be distinguished as either surface or deep water. The surface fisheries are trolling operations off the American coast from Baja to Canada, baitboat operations south of Japan at the Kuroshio Front and a fishery in New Zealand waters. A troll fishery has also developed south of Tahiti. Purse-seine is also considered a surface method but apparently is not a major fishery. Albacore are occasionally bycatch in other tuna fisheries. Elsewhere, mainly the northwest and South Pacific, longline gear is used to capture deep-swimming fish. Taiwanese and Japanese high seas drift gillnetters rapidly expanded effort in the South Pacific after 1988, targeting albacore. 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). Foreman (1980) and Bartoo and Foreman (1994) provide maps of the major fishing areas. Generally, surface fisheries occur in cooler waters and target immature fish; the longline fishery, targeting deep-swimming fish, occurs closer to the equator.

The most recent report for pelagic fisheries in the western Pacific region (WPRFMC 1997) notes that albacore landings in Hawaii by longline, handline and other gear types have increased dramatically in the past five years with much of the catch sent to the US West Coast as a fresh frozen product. Hawaii landings have increased from 300,000 lb (136 mt) in 1987 to 3 million lb (1,361 mt) in 1996, a tenfold increase. The only other area reporting landings in 1996 was American Samoa, with 232,721 lb (105.56 mt). American Samoa also reports 44,500 t (40,370 mt) of albacore landed at the canneries there. Albacore represent 10% of total pelagic landings in Hawaii and 11% of total pelagic landings in the region.

Egg and Larval Distribution

Ueyanagi (1955) and Otsu and Uchida (1959) describe the eggs of albacore, taken from maturing fish. Roe is reported to be the same size as cod roe and light reddish-brown in color. The incubation period is estimated at no more than four days (Matsumoto 1958). Foreman (1980) provides references for papers describing larval albacore. They are easily distinguished from other tuna larvae except yellowfin.

Davis et al. (1990) studied diel distribution of tuna larvae, including albacore in the Indian Ocean off of northwest Australia. They found that albacore migrate to the surface in the day and are deeper at night. This diel pattern was much more marked in albacore than southern bluefin tuna (*Thunnus maccoyii*) larvae. Total vertical range was limited by pycnocline depth, which was 16–22 m in the study area. They concluded that the pycnocline acts as a physical barrier to movement. Albacore may forage during daylight hours and simply sink to neutral depth at night when they cease swimming. Other studies indicate that the top boundary of the pycnocline can be an area of concentration for larvae.

Young and Davis (1990) report on larval feeding of albacore in the Indian Ocean. They found *Corycaeus spp*., *Farranula gibbula* (Cyclopoida) and *Calanoid nauplii* to be major prey items. Diet breadth was greatest for larvae less than 5.5 mm. *Calanoid nauplii* were more important in the diet of smaller larvae; Cyclopoids were eaten by larvae of all sizes but more frequently by larger larvae. As noted above, albacore feed only during the day, although there is some evidence of increased activity around dusk.

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 tuna larvae are sparsely distributed in the open ocean, possibly because they congregate 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 a inshore-offshore gradient from the data. They speculate on why larvae might be concentrated inshore and warn that “anthropogenic impact on near-reef waters will be of concern to tuna fishery management.”

As noted above, 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) can be confirmed, it may be that inshore areas represent a habitat feature of special value to larval stage albacore.

Juvenile

Small juvenile albacore range from 12 to 300 mm in length and 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. They have also been reported from Hawaiian waters. Albacore are not mature until about 5 years old. As noted above, immature fish prefer cooler water and enter the tropics as adults.

Adult

The size range of adults has already been discussed. Based on age groups it is believed that maximum longevity is around 10 years. Female albacore reach maturity by about 90 cm, while mature males are somewhat larger. Ueyanagi (1957) postulates that males reach maturity at 97 cm. This length would accord with ages between 5 and 7 years, based on length-at-age estimates.

Based on stomach content analysis, the type of food consumed varies among fisheries. Other fish and squid tend to predominate; crustaceans are the other major constituent, although minor in comparison (Iversen 1962). Iversen (1962) also discusses variation in forage based on age, latitude and distance from land. Smaller (younger) fish had a higher proportion of squid in their diet. Gempylids and Bramids were more prevalent in the diet of fish nearer the equator, sauries predominated in temperate waters. This may be due to differences in vertical distribution. Squid were also more prevalent in the diet of fish further from the equator (outside of 5ºS–5ºN). In the tropics squid increased as a part of the diet with greater distance from land. Foreman’s (1980) summary emphasizes that albacore feed steadily during both night and day, although less so at night since they are dependent on sight for foraging. Species composition of forage varies by area, and there is a direct relationship between the amount of food in stomachs and the biomass of micronektonic animals (Laurs and Nishimoto 1973). Albacore are considered opportunistic feeders.

The habitat features affecting density and abundance of adults are poorly understood. As discussed above, water temperature, D.O, and salinity are of primarily importance

Essential Fish Habitat: Temperate species complex

EFH can be described in terms of the 15.6º and 19.4ºC SST isotherms that circumscribe the areas of major catches. In the North Pacific the transition zone represents an area of preferred habitat. Albacore are described as epi- and mesopelagic so EFH may be depth limited to about 400 m. Albacore occur throughout the EEZ waters of the western Pacific region. Deep-swimming adults are probably more prevalent, although overall albacore are concentrated away from the tropics and outside of the region’s EEZ waters. It is recognized that oceanic fronts are areas where albacore congregate, but it is probably not practical to identify these features, which are not temporally stable with respect to location, as HAPC. Given the findings of Leis et al. (1991), inshore areas, particularly near coral reefs, might be considered of HAPC although findings are still preliminary in this matter. Foreman (1980) provides a wide variety of distribution maps, as noted in this description, for albacore life stages and the location of major fisheries.

Habitat description for albacore tuna (*Thunnus alalunga*)

	Egg	**Larvae**	**Juvenile**	**Adult**
Duration	about 4 days	weeks (?)	to 4–6 years	to about 10 years
Diet	NA	*Corycaeus spp*. and *Farranula gibbula* (Cyclopoida) and Calanoid nauplii (from studies in Indian Ocean)	see adult	fish (sauries away from tropics, Gempylids and Bramids near equator), squid, crustaceans
Distribution: General and Seasonal	based on spawning: sub-tropical, north Pacific area centers on 25ºN and 160ºE to about 150ºW; in south Pacific narrower band centered at about 25ºS from Australia to about 110ºW	somewhat more restricted than spawning area, possible preference for inshore areas	preference for cooler waters in comparison to adult, seasonal movement to temperate waters	in north Pacific centered on 35º N, south Pacific 10º–30ºS, seasonal movement to sub-tropical waters
Location		possibly inshore	offshore	offshore
Water Column	epipelagic	epipelagic above pycnocline	epi- to mesopelagic	epi- to mesopelagic
Bottom Type	NA	NA	NA	NA
Oceanic Features			oceanic fronts	oceanic fronts

Bibliography

Bartoo N, Foreman TJ. 1994. A review of the biology and fisheries for North Pacific albacore (*Thunnus alalunga*). In: Shomura RS, Majkowski J, Langi S, editors. Interactions of Pacific tuna fisheries. Volume 2, Papers on biology and fisheries. Proceedings of the First FAO Expert Consultation on Interactions of Pacific Tuna Fisheries; 1991 Dec 3–11; Noumea, New Caledonia. Rome: Food and Agriculture Organization. p 173–87. FAO fish technical paper nr 336/2.

Collette BB, Nauen CE 1983. An annotated and illustrated catalogue of tunas, mackerels, bonitos and relateds species known to date. FAO species catalogue. Volume 2, Scombrids of the world. Rome: Food and Agriculture Organization. 118 p.

Davis TLO, Jenkins GP, Young JW. 1990. Diel patterns of vertical distribution in larvae of southern bluefin *Thunnus maccoyii* and other tuna in the East Indian Ocean. Mar Ecol Prog Series 59(1–2):63–74.

Foreman TJ. 1980. Synopsis of biological data on the albacore tuna, *Thunnus alalunga* (Bonnaterre, 1788), in the Pacific Ocean. In: Bayliff WH, editor. Synopses of biological data on eight species of Scombrids. La Jolla (CA): Inter-American Tropical Tuna Commission. p 21–70. Special report nr 2.

Iversen RTB. 1962. Food of the albacore, *Thunnus germo* (Lacepede), in the central and northeastern Pacific. Fish Bull 62(214):459–81.

Jones JB. 1991. Movements of albacore tuna (*Thunnus alalunga*) in the South Pacific: evidence from parasites. Mar Biol 111(1):1–10.

Kimura S, Nakai M, Sugimoto T. 1997. Migration of albacore, *Thunnus alalunga*, in the North Pacific Ocean in relation to large oceanic phenomena. Fish Oceanog 6(2):51–7.

Laurs MR, Nishimoto RN. 1973. Food-habits of albacore caught in offshore area. In: Laurs MR, editor. Report of the Joint National Marine Fisheries Service–American Fishermen's Research Foundation albacore studies conducted during 1973. Washington: NMFS (NOAA). p 36–40.

Laurs RM, Wetherall JA. 1981. Growth rates of North Pacific albacore, *Thunnus alalunga*, based on tag returns. Fish Bull 79(2):293–302.

Laurs RM, Lynn RJ. 1991. North Pacific albacore ecology and oceanography. In: Wetherall JA, editor. Biology, oceanography and fisheries of the North Pacific Transition Zone and Subarctic Frontal Zone. Washington: NMFS (NOAA). p 69–87. NOAA technical report nr NMFS 105.

Leis J.M, Trnski T, Harliem-Vivien M, et al. 1991. High concentrations of tuna larvae (Pisces: Scombridae) in near-reef waters of French Polynesia (Society and Tuamotu Islands (South Pacific Ocean). Bull Mar Sci 48(1):150–8.

Matsumoto WM. 1958. Description and distribution of larvae of four species of tuna in central Pacific waters. Fish Bull 58(128):31–72.

Miller JM. 1979. Nearshore abundance of tuna (Pisces: Scombridae) larvae in the Hawaiian Islands. Bull Mar Sci 29:19–26.

Murray T. 1994. A review of the biology and fisheries for albacore, *Thunnus alalunga*, in the South Pacific Ocean. In: Shomura RS, Majkowski J, Langi S, editors. Interactions of Pacific tuna fisheries.Volume 2, Papers on biology and fisheries. Proceedings of the First FAO Expert Consultation on Interactions of Pacific Tuna Fisheries; 1991 Dec 3–11; Noumea, New Caledonia. Rome: Food and Agriculture Organization. p 188–206. FAO fish tech paper nr 336/2.

Otsu T, Sumida RF. 1968. Distribution, apparent abundance and size composition of albacore, *Thunnus alalunga*, taken in the longline fishery based in American Samoa, 1954–65. Fish Bull 67:47–69.

Otsu T, Uchida RN. 1959. Sexual maturity and spawning of albacore in the Pacific Ocean. Fish Bull 59:287–305.

Otsu T, Uchida RN. 1963. Distribution and migration of albacore in the North Pacific Ocean. Fish Bull 63(1):33–44.

Ramon D, Bailey K. 1996. Spawning seasonality of albacore, *Thunnus alalunga*, in the South Pacific Ocean. Fish Bull 94(4):725–733.

Saito S. 1973. Studies on fishing of albacore (*Thunnus alalunga* Bonnaterre) by experimental deep-sea tuna longline. Hokkaido Univ Mem Fac Fish 21(2):107–84.

Ueyanagi S. 1955. On the ripe ovary of the albacore, *Germo germo* (Lacepede), taken from the Indian Ocean. Tokyo Univ Fish Jour 44(1–2):105–29.

Ueyanagi S. 1957. Spawning of the albacore in the western Pacific. Nankai Reg Fish Res Lab 6:113–24.

[WPRFMC] Western Pacific Regional Fishery Management Council. 1997. Pelagic Fisheries of the Western Pacific Region 1996 Annual Report. Honolulu: Western Pacific Regional Fishery Management Council. p 26 + appendices.

Wright A, Doulman DJ. 1991. Drift-net fishing in the South Pacific. Mar Policy 15(5):303–37.

Yoshida HO. 1979. Compilation of published estimates of tuna life history and population dynamics param. NMFS (NOAA). 15 p. NMFS–SWFC administrative report nr H-79-8.

Young JW, Davis TLO. 1990. Feeding ecology of larvae of southern bluefin, albacore and skipjack tunas (Pisces: Scombridae) in the eastern Indian Ocean. Mar Ecol Prog Series 61(1–2):17–30.

6.12 Habitat Description for Bigeye tuna (*Thunnus obesus*)

Management Plan and Area

American Samoa, Guam, MHI, NWHI, Northern Mariana Islands, Johnston Atoll, Kingman Reef, Palmyra Atoll, Jarvis Island, Midway Island, Howland and Baker Islands and Wake Island.

Bigeye tuna occur throughout the entire region of Council jurisdiction and in all neighboring states, territories and adjacent high seas zones.

Life History and General Description

Several studies on the taxonomy, biology, population dynamics and exploitation of bigeye tuna have been carried out, including comprehensive reviews by Alverson and Peterson (1963), Collette and Nauen (1983), Mimura and Staff (1963) and Whitelaw and Unnithan (1997). Calkins (1980), Martinez and Bohm (1983) and Miyabe (1994) provide descriptions of bigeye tuna biology and fisheries specific to the Pacific or Indo-Pacific region. Solov'yev (1970) provides information specific to Indian Ocean bigeye tuna.

During November 1996, the Inter-American Tropical Tuna Commission (IATTC) held the first world meeting on bigeye tuna at their headquarters in La Jolla, California, with participation from the Food and Agriculture Organization of the United Nations (FAO), the Indian Ocean Tuna Commission (IOTC), the Institut Français de Recherche Scientifique pour le Developpement en Coopération (ORSTOM) of France, the Instituto Español de Oceanografía (IEO) of Spain, the National Research Institute of Far Seas Fisheries (NRIFSF) of Japan, the South Pacific Commission (SPC; currently, the Secretariat of the Pacific Community), the US National Marine Fisheries Service (NMFS), the University of the Azores, and the University of Hawaii. The objectives of the meeting were to review and discuss current information on the species and associated fisheries and to make recommendations for necessary areas of research. Review papers on the biology and fisheries for bigeye tuna in the Atlantic, Indian and Pacific Oceans were tabled by Pallarés et al. (1998), Stobberup et al. (1998) and Miyabe and Bayliff (1998) and published in the proceedings to the meeting. Information provided in this document relies heavily on these review papers which represent the latest published information on bigeye tuna worldwide.

Bigeye tuna are trans-Pacific in distribution, occupying epipelagic and mesopelagic waters of the Indian, Pacific and Atlantic Oceans. The distribution of the species within the Pacific 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).

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 have been conducted on bigeye otoliths from nine geographically scattered regions of the Pacific (SPC 1997b). The results of this study are not conclusive but do support a single stock hypothesis for areas of jurisdiction within the Council's jurisdiction. Although there is currently not enough information available to determine the stock structure of bigeye in the Pacific (Miyabe and Bayliff 1998), a single stock hypothesis is generally accepted for Pacific bigeye tuna and, for the purposes of the region of the Council, a single stock is assumed.

Large, mature-sized bigeye tuna are sought by high value sub-surface fisheries, primarily longline fleets landing sashimi grade product. Smaller, juvenile fish are taken in many surface fisheries, either as a targeted catch or as a bycatch with other tuna species (Miyabe and Bayliff 1998). Basic environmental conditions favorable for survival include clean, clear oceanic waters between 13°C and 29°C. Hanamoto (1987) estimated optimum bigeye habitat to exist in water temperatures between 10° to 15°C at salinities ranging between 34.5‰ to 35.5‰ where dissolved oxygen concentrations remain above 1 ml/l. He further suggested that bigeye range from the surface layers to depths of 600 m. However, evidence from archival tagging studies indicates that greater depths and much lower ambient temperatures can be tolerated by the species. Juvenile bigeye occupy an ecological niche similar to juvenile yellowfin of a similar size. Large bigeye generally inhabits greater depths, cooler waters and areas of lower dissolved oxygen compared to skipjack and yellowfin, occupying depth strata at or below the thermocline at water temperatures of 15°C or lower.

The species is a mixture between a tropical and temperate water tuna, characterized by equatorial spawning, high fecundity andrapid growth during the juvenile stage with movements between temperate and tropical waters during the life cycle. It is believed that the species is relatively long lived in comparison to skipjack and yellowfin tuna.

Feeding is opportunistic at all life stages, with prey items consisting primarily of crustaceans, cephalopods and fish (Calkins 1980). There is significant evidence that bigeye feed at greater depths than yellowfin tuna, utilizing higher proportions of cephalopods and mesopelagic fishes in their diet thus reducing niche competition (Whitelaw and Unnithan 1997). Spawning spans broad areas of the Pacific and occurs throughout the year in tropical waters and seasonally at higher latitudes at water temperatures above 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. Sex ratio is commonly accepted to be essentially 1:1 until a length greater than 150 cm after which the proportion of males increases.

There have been far fewer bigeye tagged in the Pacific in comparison to skipjack and yellowfin, and movement data from tagging programs is not conclusive. Miyabe and Bayliff (1998) present summary information of some long distance movements of tagged bigeye in the Pacific. Hampton et al. (1998) describes 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 tag recoveries have been made in the Indian Ocean or eastern tropical Pacific. Conventional tagging projects on bigeye tuna began in Hawaiian waters in 1996 and will continue into the year 2000 (Itano 1998b). The NMFS Honolulu Laboratory is conducting archival tagging of bigeye tuna in the Hawaiian EEZ.

Bigeye are clearly capable of large-scale movements which have been documented by tag and recapture programs, but most recaptures have occurred within 200 miles of the point of release. The tuna appear to move freely within broad regions of favorable water temperature and dissolved oxygen values. If the majority of spawning takes place in equatorial waters, then there must be mass movements of juvenile fish to higher latitudes and return movements of mature fish to spawn. However, the extent to which these are directed movements is unknown and the nature of bigeye migration in the central and western Pacific remains unclear.

Bigeye tuna, especially during the juvenile stages, 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). Major fisheries for bigeye exploit aggregation effects either by targeting biologically productive areas and deep and shallow seamount and ridge features or by utilizing artificial fish aggregation devices (FADs) to aggregate commercial concentrations of bigeye. Bigeye tuna are exploited by purse-seine, longline, handline and troll gear within the Council area of jurisdiction (WPRFMC 1997, SPC 1997a).

Egg and Larval Distribution

The eggs of bigeye tuna resemble those of several scombrid species and can not be differentiated by visual means. Therefore, the distribution of bigeye eggs has not been determined in the Pacific Ocean. However, the duration of the fertilized egg phase is very short and egg distributions can be assumed to be roughly coincident with documented larval distributions. 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, noting egg diameters ranging from 1.03 to 1.08 mm with oil droplets measuring 0.23 to 0.24 mm. Hatching began 21 hours post-fertilization, and larvae measured 1.5 mm in length. Larval development soon after hatching has been described by Kume (1962) and Yasutake et al. (1973). Descriptions of bigeye larvae and keys to their differentiation from other *Thunnus* species are given by Matsumoto et al. (1972) and Nishikawa and Rimmer (1987). However, the early larval stages of bigeye and yellowfin are difficult or impossible to differentiate without allozyme or mitochondrial DNA analyses (Graves et al. 1988). An indexed bibliography of references on the eggs and early life stages of tuna is provided by Richards and Klawe (1972).

The distribution or areas of collection of larval bigeye in the Pacific has been described or estimated by Nishikawa et al. (1978), Strasburg (1960) and Ueyanagi (1969). Bigeye larvae are most common in warm surface waters between 30°N and 20°S in the Pacific. Data compiled by Nishikawa et al. (1978) indicates that bigeye larvae are relatively abundant in the western and eastern Pacific compared to central Pacific areas and are most common in the western Pacific between 10°N and 15°S. The basic environment of bigeye larvae can be characterized as warm, oceanic surface waters at the upper range of temperatures utilized by the species, which is a consequence of preferred spawning habitat. Kume (1967) noted a correlation between mature but sexually inactive bigeye at SSTs below 23° or 24°C which may represent a lower limit to spawning activity. In the eastern Pacific, bigeye spawning occurs between 10°N and 10°S throughout the year and during summer months at higher latitudes (Collette and Nauen 1983). Hisada (1979) noted from a study in the Pacific that a temperature of 24°C and a maximum depth of 50 m were necessary for maturity and spawning, suggesting a similar seasonal pattern of spawning in the western Pacific. The study by Boehlert and Mundy (1994) in Hawaiian waters and McPherson (1991a) in eastern Australian waters supports the concept of equatorial spawning throughout the year and seasonal spawning of bigeye at higher latitudes. Additional information on the maturity and spawning of western and central Pacific bigeye is provided by Kikawa (1953, 1957, 1961, 1962, 1966), Nikaido et al. (1991) and Yuen (1955). Additional information on the maturity and spawning of eastern Pacific and Atlantic bigeye is given in Goldberg and Herring-Dyal (1981), Pereira (1985, 1987) and Rudomiotkina (1983). It can be assumed that bigeye larvae are common at SSTs above 26°C but may occur in some regions with SSTs of approximately 23°C and above.

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

The age and growth of larval, post-larval and early juvenile bigeye is not well known or studied. Yasutake et al. (1973) recorded newly hatched larvae at 2.5 mm in total length, growing to 3.0 and 3.1 mm at 24 and 48 hours. The early post-larval stage was achieved at 86 hours after hatching. However, it is likely that the early development of bigeye tuna is similar to that of yellowfin tuna which is the subject of current land based tank studies by the IATTC (IATTC 1997). The larval stages of bigeye tuna likely extend for approximately two to three weeks after hatching.

The short duration of the larval stage suggests that the distribution of bigeye larvae is nearly coincident with the distribution of bigeye spawning and eggs. It has been suggested that areas of elevated productivity are necessary to support broad spawning events that are characteristic of skipjack, yellowfin and bigeye tuna whose larvae would subsequently benefit from being in areas of high forage densities (Sunc et al. 1981, Miller 1979, Boehlert and Mundy 1994).

Juvenile

The juvenile phase of bigeye is not clearly defined in the literature. Calkins (1980) suggests grouping bigeye into larval, juvenile, adolescent, immature adult and adult stages. For the purposes of defining EFH, this report will utilize the categories of egg, larval, juvenile and adult. The juvenile phase extends from the time of transformation from the post-larval phase into a small tuna up to the onset of sexual maturity at approximately 3 years of age. For the purposes of discussion, the juvenile phase will include sexually immature fish to approximately 60 cm FL; pre-adult, 61 to 99 cm FL; and adult, greater than or equal to 100 cm FL.

The distribution of juvenile bigeye tuna less than 35 cm FL is not known but is assumed to be similar to that of larval bigeye, 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 and pre-adult bigeye of 35 cm to approximately 99 cm are regularly taken as a bycatch in the eastern and western Pacific purse-seine fisheries, usually on sets made in association with floating objects (Hampton and Bailey 1993). Bigeye tuna enter a seamount-associated handline fishery and FAD-based pole-and-line and handline fisheries in Hawaii at approximately 40 cm FL (Boggs and Ito 1993, Itano 1998). Juvenile and pre-adult bigeye of increasing sizes appear in higher latitude fisheries, so one can infer a movement away from equatorial spawning grounds as the fish grow and begin to utilize greater amounts of sub-surface habitat.

Juvenile bigeye form mono-specific schools at or near the surface with similar-sized fish or 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 sounder, 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 beneath the other species (Itano, pers. observ.). It is well known that juvenile bigeye aggregate strongly to drifting or anchored objects or to large, slow-moving marine animals, such as whale sharks and manta rays (Calkins 1980, Hampton and Bailey 1993). This phenomenon has been exploited by surface fisheries to aggregate juvenile yellowfin and bigeye tuna to anchored or drifting FADs (Sharp 1978). Juvenile and adult bigeye tuna are also known to aggregate near seamounts and submarine ridge features where they are exploited by pole-and-line, handline and purse-seine fisheries (Fonteneau 1991, Itano 1998a).

The majority of feeding studies conducted on bigeye tuna have examined large longline-caught fish. However, juvenile bigeye are generally recognized to feed opportunistically during day and night on a wide variety of crustaceans, cephalopods and fish in a manner similar to yellowfin of a similar size (Collette and Nauen 1983). 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 fish and crustaceans. Alverson and Peterson (1963) state that juvenile bigeye less than 100 cm generally feed at the surface during daylight, usually near continental land masses, islands, seamounts, banks or floating objects.

Adult

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 and 91–95 cm for females and select 100 cm as a general size for “potential maturity” for Pacific bigeye. The following description will use 100 cm as a rough definition for adult bigeye.

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 in relation to general distribution and migration (Hanamoto 1986; Kume 1963, 1967, 1969a, 1969b; Kume and Shiohama 1965; Laevastu and Rosa 1963); the oceanic environment (Blackburn 1965, 1969; Hanamoto 1975, 1976, 1983, 1987; Nakamura and Yamanaka 1959; Suda et al. 1969; Sund et al. 1981; Yamanaka et al.1969); the physiology of tunas (Magnuson 1963; Sharp and Dizon 1978; Stretta and Petit 1989); and fish aggregation devices (Holland et al. 1990).

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

According to several authors, bigeye can tolerate dissolved oxygen levels as low as 1 ml/l, which is significantly lower than the dissolved oxygen requirements of skipjack and yellowfin tuna (Sund et al. 1981). Brill (1994) has proposed a physiological basis to explain how bigeye are able to utilize oxygen in a highly efficient manner thereby allowing them to forage in areas that are not utilized by other tuna species. He theorizes that bigeye tuna spend the majority of their time at depth, making short excursions to the surface to warm up. This vertical movement pattern, which has been clearly demonstrated by sonic tracking experiments of bigeye tuna, is exactly the opposite pattern demonstrated by skipjack and yellowfin tuna (Holland et al. 1992). Sonic tracking and archival tagging of bigeye tuna consistently indicate deep foraging during the daytime near or below the thermocline and shallow swimming behavior during at night.

Hanamoto (1987) examines vertical temperature profiles of water masses within the known range of bigeye in the Pacific and proposes that bigeye range from the surface to as deep as 600 m in areas where suitable temperatures exist at that depth. However, evidence from archival tagging experiments (Boggs, pers. comm.) 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). This work is still in progress and currently unpublished.

The fact that large bigeye take longline hooks at greater depths than yellowfin coupled with a rising demand for sashimi-grade tuna and improved storage techniques prompted a shift to deep longline gear to target bigeye tuna during the late 1970s and early 1980s (Sakagawa et al. 1987, Suzuki et al. 1977). This development promoted numerous studies on differential catch rates and gear configurations to define productive hooking depths for bigeye given different oceanographic conditions (Bahar 1985, 1987; Boggs 1992; Gong et al. 1987, 1989; Hanamoto 1974; Nishi 1990; Saito 1975; Shimamura and Soeda 1981; Suzuki and Kume 1981, 1982; Suzuki et al. 1979).

Several investigators have proposed that the greater depth distribution of bigeye is a foraging strategy to exploit regions less utilized by yellowfin or skipjack tuna, thus reducing niche competition. Bigeye tuna are opportunistic feeders like yellowfin, relying on a mix of crustaceans, fish and cephalopods with feeding taking place during the day and night (Calkins 1980; Collette and Nauen 1983). However, several authors support the notion that the composition of bigeye diet differs significantly from that of similar-sized yellowfin (Watanabe 1958, Talbot and Penrith 1963, Kornilova 1980). Adult bigeye appear to forage at significant depths, utilizing a higher proportion of squid and mesopelagic fishes compared to yellowfin. Solov’yev (1970) suggests that the preferred feeding depth of large bigeye is 218–265 m, which is the most productive depth for longline catches. Miyabe and Bayliff (1998) summarize diet items of bigeye in the Pacific in tabular form from studies by Alverson and Peterson (1963), Blunt (1960), Juhl (1955), King and Ikehara (1956) and Watanabe (1958). Bigeye tuna are also known to aggregate to large concentrations of forage, such as the spawning aggregations of lanternfish (*Diaphus* sp.) [MYCTOPHIDAE] that occur seasonally in the Australian Coral Sea (Hisada 1973, McPherson 1991b).

Whitelaw and Unnithan (1997) provide a useful summary of studies on the age and growth of bigeye tuna in the Pacific and Indian Oceans. Pertinent references include Iverson (1955), Kume and Joseph (1966), Marcille and Stequert (1976), Peterson and Bayliff (1985), Tankevich (1982) and Talbot and Penrith (1960). There is some consensus, which is supported by tagging data, that the bigeye’s growth is rapid during the first couple of years similar to yellowfin’s and then slows down and that the bigeye’s lifespan is longer than the yellowfin’s. Age studies of bigeye tuna are not complete and the subject requires further work. A recent study by Matsumoto (1998) analyzing presumed daily otolith increments finds a relationship indicating 200 and 400 increments corresponding to fish 40 and 55 cm FL.

Currently, an age validation study using daily growth increments on otoliths is being conducted by the IATTC and the Commonwealth Scientific & Industrial Research Organization (CSIRO) of Australia. Bigeye age and growth is being investigated by the Offshore Fisheries Programme of the Secretariat of the Pacific Community (SPC) using presumed daily increments on otoliths and tagging data. (Hampton and Leroy 1998, IATTC 1997, SPC 1997b). Preliminary results indicate that bigeye may be relatively slow growing and long lived after year 4.

Estimates of length at maturity for Pacific bigeye vary, and a large-scale study using histological methods is required. Kikawa (1957, 1961) proposed 100 cm as the length for potential to be sexually mature, which appears to be a reasonable estimate. Kume (1962) recorded a length at first maturity of 92 cm, and McPherson (1988) recorded mature bigeye of 100 cm. A 100 cm fish corresponds approximately to a fish of age 3 according to the best available estimates of age and growth reviewed in Whitelaw and Unnithan (1997).

Information on sex ratios of bigeye are inconsistent though there is general agreement that males are more abundant in the larger size classes, > 150 cm. Spawning occurs throughout the year in tropical waters and at higher latitudes when SSTs rise above 23° to 24°C (Kume 1967). Bigeye are serial spawners, capable of near daily spawning periodicity during spawning seasons of unknown length (Nikaido et al. 1991). Spawning takes place during the afternoon or evening hours at or near the surface (McPherson 1991a).

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 where they are targeted by some longline and handline fisheries. Regions of elevated primary productivity and high zooplankton density—such as near regions of upwelling and convergence of surface waters of different densities that are very important to the distribution of skipjack and yellowfin tuna—are less important to the distribution of adult bigeye. This is logical if one assumes skipjack and yellowfin are inhabitants of the upper mixed layer while adult bigeye are sub-surface in nature, more closely tied to the thermocline and organisms of the deep scattering layer. Water temperature, thermocline depth and season appear to have much stronger influences on the distribution of large bigeye (Calkins 1980). Hanamoto (1987) proposes that productive longline fishing grounds for bigeye do not necessarily equate to regions of higher abundance, but "are nothing more than areas where the hook depths happened to coincide with the optimum temperature layer and where the amount of dissolved oxygen happened to be greater than the minimum required for bigeye tuna (1ml/l)." Nakamura (1969) suggests that bigeye 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 reproductively inactive young adults or pre-adults or spent spawners while the fish taken in the equatorial longline fishery are actively spawning adults (Calkins 1980).

<u>Essential Fish Habitat</u>: Temperate species complex

Habitat Description for Bigeye tuna (*Thunnus obesus*)

	Egg	**Larvae**	**Juvenile**	**Adult**
Duration	approximately 24 hours	to approximately 3 weeks	approximately 3 years	approximately 6 years (longevity of 9+ years)
Diet	NA	zooplankton, larval fish	crustaceans, cephalopods, fish	crustaceans, cephalopods, fish
Season/Time	throughout the year in tropics, seasonally where SST is above 23°–24°C	throughout the year in tropics, seasonally where SST is above 23°–24°C	little information available approximately 25°N to 25°S	Pacific-wide, from northern Japan to north island of New Zealand in western Pacific and 40°N to 30°S in eastern Pacific
Location	offshore waters	offshore waters	offshore waters	offshore waters
Water Column	epipelagic	epipelagic	pelagic, surface to region of thermocline	pelagic, surface to below thermocline, optimum water temperature between 10° to 15°C, dissolve oxygen > 1ml/l
Bottom type	NA	NA	NA	NA
Oceanic Features	areas of upwelling, convergence, oceanic gyres, general productivity	areas of upwelling, convergence, oceanic gyres, general productivity	known to concentrate in areas of high productivity, upwelling, convergence including	known to concentrate in areas of high productivity, upwelling, convergence including

			seamount and ridge features	seamount and ridge features

Bibliography

Alverson FG, Peterson CL. 1963. Synopsis of the biological data on bigeye tuna *Parathunnus sibi* (Temminck and Schlegel) 1844. FAO Fish Rep 6(2):482–514.

Bahar S. 1985. Study on deep tuna long line for bigeye tuna (*Thunnus obesus*) fishing. A study on the use of deep tuna longline by employing various number of branchlines per basket to catch bigeye tuna (*Thunnus obesus*) in Banda Sea. Mar Fish Res Rep (32):39–51.

Bahar S. 1987. A study on the deep longlining for bigeye tuna (*Thunnus obesus*) in the waters west off Sumatra. J Mar Fish Res 40: 51–63.

Blackburn M. 1965. Oceanography and ecology of tunas. Oceanogr Mar Biol Annu Rev (3):299–322.

Blackburn M. 1969. Conditions related to upwelling which determine distribution of tropical tunas off western Baja California. Fish Bull US 68:147–76.

Blunt CEJr. 1960. Observations on the food habit of longline caught bigeye and yellowfin tuna from the tropical eastern Pacific 1956–63. Calif Fish and Game 46(1):69–80.

Boehlert GW, Mundy BC. 1994. Vertical and onshore-offshore distributional patterns of tuna larvae in relation to physical habitat features. Mar Ecol Prog Ser 107:1–13.

Boggs CH. 1992. Depth, capture time, and hooked longevity of longline-caught pelagic fish—timing bites of fish with chips. Fish Bull 90(4):642–58.

Boggs CH, Ito RY. 1993. Hawaii’s pelagic fisheries. Mar Fish Rev 55(2):69–82.

Brill RW. 1994. A review of temperature and oxygen tolerance studies of tunas pertinent to fisheries oceanography, movement models and stock assessments. Fish Oceanogr 3(3):204–16.

Calkins TP. 1980. Synopsis of biological data on the bigeye tuna, *Thunnus obesus* (Lowe, 1839), in the Pacific Ocean. In: Bayliff WH, editor. Synopses of biological data on eight species of scombrids. Inter-American Tropical Tuna Commission. p 213–60. Special report nr 2.

Collette BB, Nauen CE. 1983. An annotated and illustrated catalogue of the tunas, mackerels, bonitos and related species known to date. FAO Fish Synopsis, Volume 2, nr 125. Rome: Food and Agriculture Organization. 137 p.

Fonteneau A. 1991. Sea mounts and tuna in the tropical eastern Atlantic. Aquat Living Resour 4(1):13–25.

Goldberg SR, Herring-Dyal H. 1981. Histological gonad analyses of late summer-early winter collections of bigeye tuna, *Thunnus obesus*, and yellowfin tuna, *Thunnus albacares*, from the northwest Atlantic and the Gulf of Mexico. NOAA tech memo.11 p.

Gong Y, Lee JU, Kim YS. 1987. Fishing efficiency of Korean deep longline gear and vertical distribution of tunas in the Indian Ocean. In: Collective volume of working documents. Expert Consultation of Stock Assessment of Tunas in the Indian Ocean; 1986 Dec 4–8; Colombo. p 367–72.

Gong Y, Lee JUK, Kim YS, Yang WS. 1989. Fishing efficiency of Korean regular and deep longline gears and vertical distribution of tunas in the Indian Ocean. Bull Korean Fish Soc 22(2):86–94.

Graves JE, Simovich MA, Schaefer KM. 1988. Electrophoretic identification of early juvenile yellowfin tuna, *Thunnus albacares*. Fish Bull 86(4):835–8.

Hampton J, Leroy B. 1988. Note on preliminary estimates of bigeye growth from presumed daily increments on otoliths and tagging data. Eleventh meeting of the Standing Committee on Tuna and Billfish; 1998 May 28–June 6; Honolulu, HI. 3 p. Working paper nr 18.

Hampton J, Lewis A, Williams P. 1998. Estimates of western and central Pacific Ocean bigeye tuna catch and population parameters. In: Deriso RB, Bayliff WH,.Webb NJ, editors. Proceedings of the First World Meeting on Bigeye Tuna. Inter-American Tropical Tuna Commission. p 212–34. Special report nr 10.

Hanamoto E. 1974. Fishery oceanography of bigeye tuna. Part 1, Depth of capture by tuna longline gear in the eastern tropical Pacific Ocean. La mer 12 (3):10–8.

Hanamoto E. 1975. Fishery oceanography of bigeye tuna. Part 2, Thermocline and dissolved oxygen content in relation to tuna longline fishing grounds in the eastern tropical Pacific Ocean. La mer 13 (2)**:**58–79.

Hanamoto E. 1976. Swimming depth of bigeye tuna. Bull Jap Soc Fish Oceanogr 29:41–4.

Hanamoto E. 1983. Vertical distribution of bigeye tuna. Bull Jap Soc Sci Fish Oceanogr 44:126–7.

Hanamoto, E. 1986. Distribution of bigeye tuna catch in the Pacific Ocean. Bull Jap Soc Fish Oceanogr 51:9–15.

Hanamoto E. 1987. Effect of oceanographic environment on bigeye tuna distribution. Bull Jap Soc Fish Oceanogr 51 (3):203–16.

Hampton J, Bailey K. 1993. Fishing for tunas associated with floating objects: a review of the western Pacific fishery. Noumea, New Caledonia: South Pacific Commission. 48 p. Tuna and Billfish Assessment Programme technical report nr. 31.

Hisada K. 1973. Investigations on tuna handline fishing ground and some biological observations on yellowfin and bigeye tunas caught in the north-western coral sea. Far Seas Fish Res Lab Bull 8:35–69.

Hisada K. 1979. Relationship between water temperature and maturity status of bigeye tuna caught by longline in the central and eastern Pacific ocean. Far Seas Fish Res Lab Bull 17:159–75.

Kikawa S. 1953. Observations on the spawning of bigeye tuna (*Parathunnus mebachi*, Kishinouye) near South Marshall Islands. Con Nankai Reg Fish Res Lab 1.

Holland KN, Brill RW, Chang RKC. 1990. Horizontal and vertical movements of yellowfin and bigeye tuna associated with fish aggregating devices. Fish Bull 88(3):493–507.

Holland KN, Brill RW, Chang RKC. 1992. Physiological and behavioral thermoregulation in bigeye tuna (*Thunnus obesus*). Nature 358(6385):410–2.

Honma M, Warashina Y, Suzuki Z. 1973. Identification of young yellowfin and bigeye tunas in the western Pacific Ocean. Examination of practical standards based on external characteristics and the reliability in field survey. Far Seas Fish Res Lab Bull 8:1–23.

[IATTC] Inter-American Tropical Tuna Commission. 1997. Quarterly report, fourth quarter 1996. La Jolla, CA: IATTC. 58 p.

Itano DG. 1998a. Hawaii offshore handline fishery: a seamount fishery for juvenile bigeye tuna. Eleventh meeting of the Standing Committee on Tuna and Billfish; 1998 May 28–June 6; Honolulu, HI. 13 p. Working paper nr 44.

Itano DG. 1998b. Hawaii tuna tagging project. In: Deriso RB, Bayliff WH, Webb NJ, editors. Proceedings of the First World Meeting on Bigeye Tuna. La Jolla, CA: Inter-American Tropical Tuna Commission. p 235–7. Special report nr 10.

Iverson ES. 1955. Size frequencies and growth of central and western Pacific bigeye tuna. US Fish and Wildlife Service special scientific report on fish nr 162.

Juhl R. 1955. Notes on the feeding habits of subsurface yellowfin and bigeye tunas of the eastern tropical Pacific Ocean. Calif Fish Game 41(1):99–101.

Kikawa S. 1957. The concentrated spawning areas of bigeye tuna in the western Pacific. Rep Nankai Reg Fish Res Lab 5:145–157.

Kikawa S. 1961. The group maturity of bigeye tuna *Parathunnus mebachi* in the spawning area of Pacific. Rep Nankai Reg Fish Res Lab 13:35–46.

Kikawa S. 1962. Studies on the spawning activity of Pacific tunas, *Parathunnus mebachi* and *Neothunnus macropterus,* by gonad index examination. p 43–56. Nankai Reg Fish Res Lab occassional report nr 1.

Kikawa S. 1966. The distribution of maturing bigeye and yellowfin and an evaluation of their spawning potential in different areas in the tuna longline grounds in the Pacific. Nankai Reg Fish Res Lab 23:131–208.

King JE, Ikehara II. 1956. Notes on feeding habits of subsurface yellowfin and bigeye tunas of eastern Pacific Ocean. Fish Bull US Fish Wildlife Serv 57:108.

Kornilova GN.1980. Feeding of yellowfin tuna, *Thunnus albacares,* and bigeye tuna, *Thunnus obesus,* in the equatorial zone of Indian Ocean. J Icthyol 20(6):111–9.

Kume S. 1962. A note on the artificial fertilisation of bigeye tuna, *Parathunnus mebachi* (Kishinouye). Rep Nankai Reg Fish Res Lab 15:79–84.

Kume S. 1963. Ecological studies of bigeye. Part 1, On the distribution of the bigeye tuna in the Pacific. Rep Nankai Reg Fish Res Lab 17:121–31.

Kume S. 1967. Distribution and migration of bigeye tuna in the Pacific ocean. Rep Nankai Reg Fish Res Lab 25:75–80.

Kume S. 1969a. Ecological studies of bigeye tuna. Part 5, A critical review of its distribution, size composition and stock structure of bigeye tuna in the North Pacific Ocean (north of 16°N). Far Seas Fish Res Lab Bull 1:57–75

Kume S. 1969b. Ecological studies of bigeye tuna. Part 6, A review of distribution and size composition in the equatorial and South Pacific Ocean. Far Seas Fish Res Lab Bull 1:77–98.

Kume S, Joseph J. 1966. Size composition, growth and sexual maturity of bigeye tuna, *Thunnus obesus* (Lowe), from Japanese longline fishery in eastern Pacific Ocean. Inter-Amer Trop Tuna Comm Bull 11(2):45–99.

Kume S, Shiohama T. 1965. Ecological studies on bigeye tuna. Part 2, Distribution and size composition of bigeye tuna in the equatorial Pacific. Rep Nankai Reg Fish Res Lab 22:71–83.

Laevastu T, Rosa H. 1963. Distribution and relative abundance of tunas in relation to their environment. FAO Fish Rep (6):1835–51.

Magnuson JJ. 1963. Tuna behaviour and physiology: a review. FAO Fish Rep (6):1057–66.

Marcille J, Stequert B. 1976. Croises des jeunes albacores *Thunnes albacares* et patudo, *Thunnus obesus* de la cote nord-ouest de Madagascar. Cah ORSTOM (Oceanogr) 14(2):152–62.

Martinez FZ, Bohm SG. 1983. Biological synopsis of *Thunnus obesus* (Lowe) with special reference to the eastern Pacific Ocean. Regional seminar on fish resources and their fisheries in the southeast Pacific. Rev Com Perm Pac Sur 13:103–23.

Matsumoto WM. 1961. Identification of larvae of four species of tuna from the Indo-Pacific region. Part 1, The Carlsberg Foundation's oceanic expedition round the world 1928–30 and previous Dana expeditions. Dana Rep 5:16.

Matsumoto T. 1998. Preliminary analyses of age and growth of bigeye tuna (*Thunnus obesus*) in the eastern Pacific Ocean based on otolith increments. In: Deriso RB, Bayliff WH, Webb NJ, editors. Proceedings of the First World Meeting on Bigeye Tuna. La Jolla, CA: Inter-American Tropical Tuna Commission. p 238–42. Special report nr 10.

Matsumoto WA, Alhstrom EH, Jones S, Klawe WJ, Richards WJ, Ueyanagi S. 1972. On the clarification of larval tuna identification, particularly in the genus *Thunnus*. US Fish Bull 70(1):1–12, figs 1–6.

McPherson GR. 1988. Reproductive biology of yellowfin and bigeye tuna in the eastern Australian Fishing Zone with special reference to the north-western Coral Sea. Queensland, Australia: Dept Prim Ind Res Branch. 80 p. Technical report nr FRB 88/10.

McPherson GR. 1991a. Reproductive biology of yellowfin and bigeye tuna in the eastern Australian Fishing Zone, with special reference to the north western Coral Sea. Aust J.Mar Freshwater Res 42:465–77.

McPherson GR. 1991b. A possible mechanism for the aggregation of yellowfin and bigeye tuna in the north-western Coral Sea. Queensland, Australia: Dept Prim Ind Res Branch. 11 p. Information series nr Q191013.

Miller JM. 1979. Nearshore abundance of tuna (Pisces: Scombridae) larvae in the Hawaiian Islands. Bull Mar Sci US 29:19–26.

Mimura K et al. 1963. Synopsis on the biology of bigeye tuna, *Parathunnus mebachi* Kishinouye 1923 (Indian Ocean). p 350–79. In: Rosa H Jr, editor. Proceedings of the World Scientific Meeting on the Biology of Tunas and Related Species;Rome: Food and Agriculture Organization of the United Nations. 2272 p. FAO fish report nr 6(2).

Miyabe N. 1994. A review of the biology and fisheries for bigeye tuna, *Thunnus obesus*, in the Pacific Ocean. In: Shomura RS, Majkowski J, Langi S, editors. Interactions of Pacific tuna fisheries. Proceedings of the First FAO Expert Consultation on Interactions of Pacific Tuna Fisheries; 1991 Dec 3–11; Noumea, New Caledonia. Rome: FAO. Volume 2; p 207–43.

Miyabe N, Bayliff WH. 1998. A review of the biology and fisheries for bigeye tuna, *Thunnus obesus*, in the Pacific Ocean. In: Deriso RB, Bayliff WH , Webb NJ, editors. Proceedings of the First World Meeting on Bigeye Tuna. La Jolla, CA: Inter-American Tropical Tuna Commission. p 129-170. Special report nr 9.

Mohri M, Hanamoto E, Takeuchi S. 1996. Optimum water temperatures for bigeye tuna in the Indian Ocean as seen from tuna longline catches. Nippon Suisan Gakkaishi 62(5):761–4.

Nakamura EL. 1969. A review of field observations on tuna behavior. FAO Fish Rep 62(2):59–68.

Nakamura H, Yamanaka H. 1959. Relation between the distribution of tunas and the ocean structure. Oce Soc Jap J 15:143–9.

Nikaido H, Miyabe N, Ueyanagi S. 1991. Spawning time and frequency of bigeye tuna, *Thunnus obesus*. Bull Nat Res Inst Far Seas Fish 28:47–73.

Nishi T. 1990. The hourly variations of the depth of hooks and the hooking depth of yellowfin tuna (*Thunnus albacares*) and bigeye tuna (*Thunnus obesus*) of tuna longline in the eastern region of the Indian Ocean. Mem Fac Fish Kagoshima Univ (Kagoshimadai Suisangakabu Kiyo) 39:81–98.

Nishikawa Y, Kikawa S, Honma M, Ueyanagi S. 1978. Distribution atlas of larval tunas, billfishes and related species. Results of larval surveys by R/V *Shunyo Maru* and R/V *Shoyo Maru*, 1956–75. Far Seas Fish Res Lab, S Series (9):99 p.

Nishikawa Y, Rimmer DW. 1987. Identification of the larval tunas, billfishes and other Scombroid fishes (Suborder Scombroidei): an illustrated buide. CSIRO Marine Laboratories. 20 p. Report nr 168.

Pallares P, Pereira J, Miyabe N, Fonteneau A. 1998. Atlantic bigeye tuna: overview of present knowledge (November 1996). In: Deriso RB, Bayliff WH, Webb NJ, editors. Proceedings of the First World Meeting on Bigeye Tuna. La Jolla, CA: Inter-American Tropical Tuna Commission. p 20–80. Special report nr 9.

Pereira J. 1985. Observations on the sex ratio of bigeye (*Thunnus obesus*) in the Azores. Collect Vol Sci Pap ICCAT 23 (2):237–41.

Pereira J. 1987. Sexual maturity and sex ratio of bigeye tuna caught in the Azores.Collect Vol Sci Pap ICCAT 26(1):168–73.
Peterson CL, Bayliff WH. 1985. Size composition, growth and sexual maturity of bigeye tuna *Thunnus obesus* (Lowe), from the Japanese longline fishery in the eastern Pacific Ocean. Bull

IATTC 11:45–100.

Richards WJ, Klawe WL. 1972. Indexed bibliography of the eggs and young of tunas and other scombrids (Pisces, Scombridae), 1880–1970. NOAA. 107 p. Tech report nr NMFS SSRF 652.

Rudomiotkina GP. 1983. Areas, periods and conditions of bigeye tuna, *Thunnus obesus* (Lowe), spawning in the tropical part of the Atlantic Ocean. Collect Vol Sci Pap ICCAT 18(2):355–62.

[SPC] South Pacific Commission. 1997a. South Pacific Commission tuna fishery yearbook, 1996. Lawson T, editor. Noumea, New Caledonia: South Pacific Commission. 104 p.

[SPC] South Pacific Commission. 1997b. Oceanic Fisheries Programme work programme review 1996–97 and work plans for 1997–98. Tenth Standing Committee on Tuna and Billfish; 1997 Jun 16–18; Nadi, Fiji. 45 p. Working paper nr 2.

Saito S. 1975. On the depth of capture of bigeye tuna by further improved vertical longline in the tropical Pacific. Bull Jap Soc Sci Fish 41(8):831–41.

Sakagawa GT, Coan AL, Bartoo NW. 1987. Patterns in longline fishery data and catches of bigeye tuna, *Thunnus obesus.* Mar Fish Rev 49 (4):57–66.

Sharp GD. 1978. Behavioral and physiological properties of tunas and their effects on vulnerability to fishing gear. In: Sharp GD, Dizon AE, editors. The physiological ecology of tunas. New York: Academic Pr. p 379–449.

Sharp GD, Dizon AE, editors. 1978. Physiological ecology of tunas. New York: Academic Pr. 485 p.

Shimamura T, Soeda H. 1981. On the catch by deep-layer tuna fishing. Bull Jap Soc Sci Fish 47(12):1559–65.

Solov'yev BS. 1970. Distribution and biology of bigeye tuna in the Indian Ocean. Rybn Khos 3.

Strasburg EW. 1960. Estimates of larval tuna abundance in the central Pacific. Fish Bull US Fish Wildl Serv 60(167):231–55.

Strobberup KA, Marsac F, Anganuzzi AA. 1998. A review of the biology of bigeye tuna, *Thunnus obesus*, and fisheries for this species in the Indian Ocean. In: Deriso RB, Bayliff WH, Webb NJ, editors. Proceedings of the First World Meeting on Bigeye Tuna; La Jolla, CA: Inter-American Tropical Tuna Commission. p 81–128. Special report nr 9.

Stretta JM, Petit M. 1989. In*:* Le Gall JY, editor. Physiological aspects of thermoecology in tunas. 3.2, Catchability/surface temperature relationship. Satellite geosensing and oceanic fisheries: teledetection. p 49–50. FAO document technlogique peches nr 302.

Suda A, Kume S, Shiohama T. 1969. An indicative note on a role of permanent thermocline as a factor controlling the longline fishing ground for bigeye tuna. Bull Far Seas Fish Res Lab 1:99–114.

Sund PN, Blackburn M, Williams F. 1981. Tunas and their environment in the Pacific Ocean: a review. Oceanogr Mar Biol Annu Rev 19:443–512.

Suzuki Z, Kume S. 1981. Fishing efficiency of deep longline for bigeye tuna in the Atlantic as inferred from the operations in the Pacific and Indian Oceans. Document prepared for the SCRS Symposium of the ICCT; 1981 Nov 30 p.

Suzuki Z, Kume S. 1982. Fishing efficiency of deep longline for bigeye tuna in the Atlantic as inferred from the operation in the Indian and Pacific Oceans. Inter Comm Cons Atlan.Tunas, Coll Vol Sci Pap 17(2):471–86.

Suzuki S, Warashina Y, Kishida M. 1977. The comparison of catches by regular and deep tuna longline gears in the western and central Pacific. Bull Far Seas Fish Res Lab 15:51–89.

Suzuki Z, Warashina Y, Kaneko K. 1979. The comparison of length of catches by regular and deep longline gears for bigeye, yellowfin and blue marlin in the western and central equatorial Pacific. Background Paper, Workshop on the Assessment of Selected Tunas and Billfish Stocks in the Pacific and Indian Oceans; 1979 Jun 13–22; Shimizu, Japan. Rome: FAO. Report nr SAWS/BP/16.

Talbot FH, Penrith MJ. 1963. Synopsis on the biological data on species of the genus *Thunnus* of South Africa. FAO Fish Rep 6 (2):609–46.

Tankevich PB. 1982. Age and growth of bigeye tuna *Thunnus obesus* (Scombridae) in the Indian Ocean. J Icthyol 22(4):26–31.

Ueyanagi S. 1969. Observations on the distribution of tuna larvae in the Indo-Pacific Ocean with emphasis on the delineation of spawning areas of albacore, *Thunnus alelunga.* Bull Far Seas Fish Res.Lab 2:177–256.

Uotani I, Matsuzaki K, Makino Y, Noka K, Inamura O, Horikawa M. 1981. Food habits of larvae of tunas and their related species in the area. Bull Jap Soc Sci Fish 47(9):1165–72.

Watanabe H. 1958. On the difference of stomach contents of the yellowfin and bigeye tunas from the western equatorial Pacific. Rep Nankai Reg Fish Res Lab 12:63–74.

[WPRFMC] Western Pacific Regional Fishery Management Council. 1997. Pelagic fisheries of the western Pacific region, 1996 Annual Report. Honolulu: WPRFMC.

Whitelaw AW, Unnithan VK.1997. Synopsis of the distribution, biology and fisheries of the bigeye tuna (Thunnus obesus, Lowe) with a bibliography. CSIRO Marine Laboratory. 62 p. Report nr 228.

Yamanaka H, Morita J, Anraku N. 1969. Relation between the distribution of tunas and water types of the North and South Pacific Ocean. Bull Far Seas Fish Res Lab 2:257–73

Yasutake H, Nishi G, Mori K. 1973. Artificial fertilization and rearing of bigeye tuna (*Thunnus obesus*) on board, with morphological observations on embryonic through to early post-larval stage. Bull Far Seas Fish Res Lab 8:71–8.

Yuen HSH. 1955. Maturity and fecundity of bigeye tuna in the Pacific. US Fish and Wildlife Service. p 1–30. Special report nr 150.

Yuen HSH. 1963. Schooling behavior within aggregations composed of yellowfin and skipjack tuna. FAO Fish Rep 6(3):1419–29.

6.13 Habitat Description for Yellowfin tuna (*Thunnus albacares*)

Management Plan and Area
American Samoa, Guam, MHI, NWHI, Northern Mariana Islands, Johnston Atoll, Kingman Reef, Palmyra Atoll, Jarvis Island, Midway Island, Howland and Baker Islands and Wake Island.

Yellowfin tuna within the jurisdiction of the Council are managed under the FMP for the Pelagic Fisheries of the Western Pacific Region. Yellowfin tuna occur throughout the entire region of council jurisdiction and in all neighboring states, territories and adjacent high seas zones.

Life History and General Description

Several studies on the taxonomy, biology, population dynamics and exploitation of yellowfin tuna have been carried out, including comprehensive reviews by Cole (1980), Collette and Nauen (1983), Wild (1994) and Suzuki (1994). The information in this brief synopsis of yellowfin tuna distribution and habitat relies heavily on these works.

Yellowfin tuna are trans-Pacific in distribution, occupying the surface waters of all warm oceans and form the basis of large surface and sub-surface fisheries. Basic environmental conditions favorable for survival include clean oceanic waters between 18°C and 31°C within salinity ranges normal for the pelagic environment with dissolved oxygen concentrations greater than 1.4 to 2.0 ml/l (Blackburn 1965, Sund et al. 1981). Larval and juvenile yellowfin occupy surface waters with adults increasingly utilizing greater depth strata while remaining within the mixed layer, i.e., generally above the thermocline (Suzuki et al. 1978).
The species is a tropical tuna characterized by a rapid growth rate and development to maturity

and high spawning frequency and fecundity with a high natural mortality and relatively short life span. Feeding is opportunistic at all life stages, with prey items consisting primarily of crustaceans, cephalopods and fish (Cole 1980). 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 (Suzuki, 1994). Yellowfin are serial spawners, capable of repeated spawning at near daily intervals with batch fecundities of millions of ova per spawning event (June 1953, Nikaido 1988, McPherson 1991, Schaefer 1996). 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).

Yellowfin are clearly capable of large-scale movements, which have been documented by tag and recapture programs, but most recaptures occur within a short distance of release. The tuna 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 (Suzuki 1994).

Yellowfin tuna are known to aggregate to drifting flotsam, large marine animals and regions of elevated productivity, such as near seamounts and regions of upwelling (Blackburn 1969, Wild 1994, Suzuki 1994). Major fisheries for yellowfin exploit aggregation effects either by utilizing artificial fish aggregation devices (FADs) or by targeting areas with vulnerable concentrations of tuna (Sharp 1979). Yellowfin are exploited by purse-seine, longline, handline and troll gear within the Council area (WPRFMC 1997, SPC 1996).

Egg and Larval Distribution

The eggs of yellowfin tuna resemble those of several scombrid species and can not be differentiated by visual means. (Cole 1980). Therefore, the distribution of yellowfin eggs has not been determined in the Pacific. However, the duration of the fertilized egg phase is very short, and egg distributions can be assumed to be roughly coincident with documented larval distributions. Eggs are epipelagic, floating at the surface until hatching. The observation of yellowfin spawning and the development of yellowfin egg and early larval stages is now possible at shore-based facilities where yellowfin spawning was first observed during late 1996 (IATTC 1997). Egg diameter ranged from 0.90 to 0.95 mm, and the duration of the egg stage was approximately 24 hours. The notochord lengths of larvae at hatching ranged from 2.2 to 2.5 mm. The duration of the larval stage has been variable in laboratory reared specimens. 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 (Wexler 1997).

The larval development from artificially fertilized eggs has been described by Harada et al. (1971), Mori et al. (1971) and Harada et al. (1980). A review of research on the development, internal anatomy and identification yellowfin larvae and early life stages is available in Wild (1994). The early larval stages of yellowfin and bigeye are difficult or impossible to differentiate without allozyme or mitochondrial DNA analyses. The distribution of larval yellowfin in different regions of the Pacific has been described by several authors (Matsumoto 1958, Strasburg 1960, Sun´ 1960). Studies on the larval distribution of yellowfin by Yabe et al. (1963), Matsumoto (1966), Ueyanagi (1969) and Nishikawa et al. (1985) encompass broad areas of the Pacific.

Yellowfin 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 (Beohlert and Mundy 1994).

The basic environment of yellowfin larvae can be characterized by warm, oceanic surface waters with a preference toward the upper range of temperatures utilized by the species, which may be a reflection of preferred spawning habitat. It can be assumed that yellowfin larvae are common at SST above 26°C (Ueyanagi 1969) but may occur in some regions with SST of approximately 24°C and above. Harada et al. (1980) found the highest occurrence of normally hatched larvae at water temperatures between 26.4°C to 27.8°C with no normal larvae found in water less than 18.7°C or greater than 31.9°C from laboratory observations.

Yellowfin larvae appear to be restricted to surface waters of the mixed layer well above the thermocline and at depths less than 50 to 60 m, with no clear consensus on diurnal preference by depth or patterns of vertical migration (Matsumoto 1958, Strasburg 1960, Ueyanagi 1969). Prey species inhabit this zone, consisting of crustacean zooplankton at early stages of the yellowfin larval phase with some fish larvae at the end of the larval phase.

Age and growth of yellowfin larvae has been investigated under a variety of laboratory conditions and from field collections. Observations from both laboratory raised and wild specimens indicate highly variable growth rates, with wild fish consistently exhibiting higher growth rates compared to laboratory reared specimens (IATTC 1997). It was suggested the differences in growth rates and size at age were due to less than optimal growth conditions in the laboratory environment. Two critical periods of larval mortality have been identified, the first at 4–5 days and the second at about 11 days after hatching; the latter corresponds to the time period when the diet of yellowfin larvae is proposed to shift from crustaceans to fish larvae (FSFRL 1973).

The distribution of yellowfin larvae has been linked to areas of high productivity and islands, but how essential these areas are to the life history of the species is not known. Grimes and Lang (1991) note high concentrations of yellowfin larvae in productive waters on the edge of the Mississippi River discharge plume, and *Thunnus* larvae (most likely yellowfin due to spawning distributions) have been noted to be relatively abundant near the Hawaiian Islands compared to offshore areas (Miller 1979, Boehlert and Mundy 1994).

Juvenile

The distribution of juvenile tuna less than 35 cm FL has not been well documented but is assumed to be similar to that of larval yellowfin. Juveniles occupy warm oceanic surface waters above the thermocline and are found throughout the year in tropical waters. Published accounts on the capture of juvenile tuna have been summarized by Higgins (1967). Juveniles have been reported in the western Pacific between 31°N near the east coast of Japan to 23°S and 23°N near the Hawaiian Islands to 23°S in the central Pacific region. Juvenile yellowfin form single species schools at or near the surface of similar-sized fish or may be mixed with other tuna species 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. Juvenile fish will aggregate beneath drifting objects or with large, slow moving animals such as whale sharks and manta rays (Hampton and Bailey 1993). This characteristic has been exploited by surface fisheries to aggregate yellowfin tuna, most of which are juvenile fish, to anchored or drifting FADs. Juvenile and adult yellowfin tuna are also known to aggregate near seamounts and submarine ridge features (Fonteneau 1991).

Juvenile yellowfin feed primarily during the day and are opportunistic feeders on a wide variety of forage organisms, including various species of crustaceans, cephalopods and fish (Reintjes and King 1953, Watanabe 1958). 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. Significant differences in the composition of prey species of FAD- and non-FAD–associated yellowfin have been noted in Hawaii (Brock 1985), American Samoa (Buckley and Miller 1994) and the southern Philippines (Yesaki 1983).

Adult

The habitat of adult yellowfin can be characterized as warm oceanic waters of low turbidity with a chemical and saline composition typical of tropical and sub-tropical oceanic environments. Adult yellowfin are trans-Pacific in distribution and range to higher latitudes compared to juvenile fish. The adult 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 of yellowfin, 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. Salinity does not appear to play an important role in tuna distribution in comparison to water temperature and clarity.

Estimates of length at maturity for central and western Pacific yellowfin vary widely with some studies supporting an advanced maturity schedule for yellowfin in coastal or archipelagic waters (Cole 1980). However, most estimates suggest that the majority of yellowfin reach maturity between 2 and 3 years of age on the basis of length-age estimates for the species (Ueyanagi 1966). Longevity for the species has not been defined, but a maximum age of 6 to 7 years appears likely based on growth estimates and tag recapture data. Observations of length at first maturity for female yellowfin range widely from 56.7 cm in the Philippines (Buñag 1956) to 112.0 cm for western Pacific yellowfin (Sun and Yang 1983). However, most of these studies were based on macroscopic staging techniques that are far less accurate compared to histological methods for determining maturity in serial spawning fishes. Using histological analysis of yellowfin ovaries, McPherson (1991) estimates that the length at 50% maturity for yellowfin in the Australian Coral Sea is 107.9 cm in the inshore handline fishery and 120.0 cm in the offshore longline fishery. These results are similar to Kikawa (1962) who notes from the central and western tropical Pacific that a few longline caught yellowfin were reproductive at 80–110 cm and estimates a length at 50% maturity between 110 and 120 cm from GI analysis. Itano (1997) notes that 50% of yellowfin sampled form purse-seine and longline gear at 105 cm were histologically classified as mature from a large data set from the western tropical Pacific and predicts a length at 50% maturity of 107.9 cm.

Spawning occurs throughout the year in tropical waters at least within 10 degrees of the equator and seasonally at higher latitudes when SSTs rise above 24°C (Suzuki 1994). 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) report 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. June (1953) notes well-developed ovaries in yellowfin caught by longline close the MHI from mid-May to the end of October. Spawning in Hawaiian waters has been histologically confirmed from April to October, and spawning frequency estimates approach a daily periodicity during the peak spawning period of June to August (Itano 1997).

Adult yellowfin tuna are opportunistic feeders, relying primarily on crustaceans, cephalopods and fish as has been described for juvenile fish. However, the larger size of adult fish allows the exploitation of larger prey items, with large squid and fish species becoming more important diet items. For example, Yesaki (1983) notes a high degree of cannibalism of large FAD-associated yellowfin on juvenile tunas 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.

Yellowfin tuna are known to aggregate to drifting flotsam, anchored buoys, porpoise and 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 to capitalize on the elevated forage available (Blackburn 1969, Cole 1980, Wild 1994, Suzuki 1994). However, the degree to which these regions are essential or simply advantageous to yellowfin is not known.

Essential Fish Habitat: Tropical species complex

Habitat Description for Yellowfin tuna (*Thunnus albacares*)

	Egg	**Larvae**	**Juvenile**	**Adult**
Duration	24 hours	to approximately 3 weeks	approximately 2 years	approximately 4–5 years
Diet	NA	zooplankton, larval fish	crustaceans, cephalopods, fish	crustaceans, cephalopods, fish
Season/Time	throughout the year in tropics, seasonally where SST is above 24°–25°C	throughout the year in tropics, seasonally where SST is above 24°–25°C	31°N near Japan, at least 23°N–23°S in central Pacific	40°N –40°S, within SST range 18°–31°C, abundant between 20°–30°C Spawning throughout the year in tropics, seasonally where SST is above 24°–25°C
Location	offshore waters	offshore waters	offshore waters	offshore waters
Water Column	epipelagic	epipelagic	pelagic, upper mixed layer	pelagic, throughout mixed layer, occasional excursions below thermocline
Bottom type	NA	NA	NA	NA
Oceanic Features	areas of upwelling, convergence, oceanic gyres, general productivity	areas of upwelling, convergence, oceanic gyres, general productivity	known to concentrate in areas of high productivity, upwelling, convergence	known to concentrate in areas of high productivity, upwelling, convergence

Bibliography

Blackburn M. 1965. Oceanography and the ecology of tunas. Oceanogr Mar Biol Ann Rev 3:299–322.

Blackburn M. 1969. Conditions related to upwelling which determine distribution of tropical tunas off western Baja California. Fish Bull US 68(1):147–76.

Boehlert GW, Mundy BC. 1994. Vertical and onshore-offshore distributional patterns of tuna larvae in relation to physical habitat features. Mar Ecol Prog Ser 107:1–13.

Brock RE. 1985. Preliminary study f the feeding habits of pelagic fish around Hawaiian fish aggregation devices, or can fish aggregation devices enhance local fish productivity? Bull Mar Sci 37:40–9.

Buckley TW, Miller BS. 1994. Feeding habits of yellowfin tuna associated with fish aggregation devices in American Samoa. Bull Mar Sci 55(2–3):445–59.

Buñag DM. 1956. Spawning habits of some Philippine tuna based on diameter measurements of the ovarian ova. J Philipp Fish 4(2):145–77.

Cole JS. 1980. Synopsis of biological data on the yellowfin tuna, *Thunnus albacares* (Bonnaterre, 1788), in the Pacific Ocean. In: Bayliff WH, editor. Synopses of biological data on eight species of scombrids. La Jolla, CA: Inter-American Tropical Tuna Commission. p 71–150. Special report nr 2.

Collette BB, Nauen CE. 1983. An annotated and illustrated catalogue of the tunas, mackerels, bonitos and related species known to date. FAO Fish Synop 2(125):137.

Fonteneau A. 1991. Seamounts and tuna in the tropical rastern Atlantic. Aquat Living Resour 4(1):13–25.

[FSFRL] Far Seas Fisheries Research Laboratory. 1973. Report on experiments on the development of tuna culturing techniques (April 1970–March 1973). FSFRL.165 p. S Series nr 8.

Hampton J, Bailey K. 1993. Fishing for tunas associated with floating objects: a review of the western Pacific fishery. Noumea, New Caledonia: South Pacific Commission. 48 p. Tuna and Billfish Assessment Programme technical report nr 31.

Higgins BE. 1970. The distribution of juveniles of four species of tunas in the Pacific Ocean. Proc Indo-Pac Fish Coun 12(2):79–99

Hampton J, Bailey K. 1993. Fishing for tunas associated with floating objects: a review of the western Pacific fishery. Noumea, New Caledonia: South Pacific Commission. 48 p. Tuna and Billfish Assessment Programme technical report nr 31.

Harada T, Murata O, Oda S. 1980. Rearing of and morphological changes in larvae and juveniles of yellowfin tuna. Bull Fac Agric Kinki Univ (13):33–6.

Harada T, Mizuno K, Murata O, Miyashita S, Furutani H. 1971. On the artificial fertilization and rearing of larvae in yellowfin tuna. Bull Fac Agric Kinki Univ (4):145–51

[IATTC] Inter-American Tropical Tuna Commission. 1997 Quarterly report, fourth quarter 1996. La Jolla, CA: IATTC. 58 p.

Itano DG. 1997. Yellowfin tuna biology and fisheries in the Pacific. Honolulu: Pelag Fish Res Prog Newslet 2(4):6–8.

June FC. 1953. Spawning of yellowfin tuna in Hawaiian waters. US Dept Interior, Fish Wildl Serv Fish Bull 77(54):47–64.

Kikawa S. 1962. Studies on the spawning activity of the Pacific tunas, *Parathunnus mebachi* and *Neothunnus macropterus,* by the gonad index examination. Nankai Reg Fish Res Lab, Occas Rep 1:43–56.

Kikawa S. 1966. The distribution of maturing bigeye and yellowfin and an evaluation of their spawning potential in different areas in the tuna longline grounds in the Pacific. Rep Nankai Reg Fish Res Lab 23:131–208.

Koido T, Suzuki Z. 1989. Main spawning season of yellowfin tuna, *Thunnus albacares,* in the western tropical Pacific Ocean based on the gonad index. Bull Far Seas Fish Res Lab 26:153–64.

Matsumoto WM. 1958. Description and distribution of larvae of four species of tuna in central Pacific waters. Fish Bull US Fish Wildl Serv 59(128):31–72.

Matsumoto WM. 1966. Distribution and abundance of tuna larvae in the Pacific Ocean. In: Manar TA, editor. Proceedings of the Governor’s Conference on Central Pacific Fishery Resources; . p 221–30.

McPherson GR. 1991. Reproductive biology of yellowfin and bigeye tuna in the eastern Australian Fishing Zone, with special reference to the north western Coral Sea. Aust J Mar Freshwater Res 42:465–77.

Miller JM. 1979. Nearshore abundance of tuna (Pisces: Scombridae) larvae in the Hawaiian Islands. Bull Mar Sci US 29:19–26.

Mori K, Ueyanagi S, Nishikawa Y. 1971. The development of artificially fertilized reared larvae of the yellowfin tuna, *Thunnus albacares*. [In Jpn;Engl Synop.] Bull Far Seas Fish Res Lab (5):219–32.

Nishikawa Y, M Honma Y, Ueyanagi S, Kikawa S. 1985. Average distribution of larvae of oceanic species of scombroid fishes, 1956–1981. Far Seas Fish Res Lab. 99 p. S Series nr 12.

Reintjes JW, King JE. 1953. Food of yellowfin tuna in the central Pacific. US Fish Wildl Serv, FishBull 54(81):91–110.

Schaefer KM. 1996. Spawning time, frequency, and batch fecundity of yellowfin tuna, *Thunnus albacares*, near Clipperton Atoll in the eastern Pacific Ocean. Fish Bull 94:98–112.

Sharp GD. 1978. Behavioral and physiological properties of tunas and their effects on vulnerability to fishing gear. In: Sharp GD, Dizon AE, editors. The physiological ecology of tunas. New York: Academic Pr. p 379–449.

[SPC] South Pacific Commission. 1996. South Pacific Commission tuna fishery yearbook, 1995. Lawson T, editor. Noumea, New Caledonia: SPC. 92 p.

Strasburg EW. 1960. Estimates of larval tuna abundance in the central Pacific. Fish Bull US Fish Wildl Serv 60(167):231–55.

Sun' Tszi-Dzen'. 1960. Larvae and juveniles of tunas, sailfishes and swordfish (Thunnidae, Istiophoridae, Xiphiidae) from the central and western part of the Pacific Ocean. Trudy Inst Okeanol 41:175–91.

Sun CL, Yang RT. 1983. The inshore tuna longline fishery of Taiwan—fishing ground, fishing seasons, fishing conditions and a biological study of the major species, yellowfin tuna, 1981–82. J Fish Soc Taiwan 10(2):11–41.

Sund PN, Blackburn M, Williams F. 1981.Tunas and their environment in the Pacific Ocean: a review. Ocenaogr Mar Biol Ann Rev 19:443–512.

Suzuki Z, Tomlinson PK, Honma M. 1978. Population structure of Pacific yellowfin tuna. Inter-Am Trop Tuna Comm Bull 19(2):169–260.

Ueyanagi S. 1966. Biology of tunas and bill fishes. Jap Soc Sci Fish Bull 32(9):739–55, 828.

Ueyanagi S. 1969. Observations on the distribution of tuna larvae in the Indo-Pacific Ocean with emphasis on the delineation of the spawning areas of albacore, *Thunnus alalunga*. Bull Far Seas Fish Res Lab (2):177–256.

Watanabe, H. 1958. On the difference of the stomach contents of the yellowfin and bigeye tunas from the western equatorial Pacific. *Nankai Reg.Fish.Res.Lab., Rep.*, 7:72-81.

[WPRFMC] Western Pacific Regional Fishery Management Council. 1997. Pelagic fisheries of the western Pacific region, 1996 Annual Report. Honolulu: WPRFMC.

Wexler JB, Margulies D, Chow S. 1997. Laboratory and *in situ* growth rates of yellowfin tuna, *Thunnus albacares*, larvae and early-stage juveniles. In: Scott M, Olson R, editors. Proceedings of the 48th annual Tuna Conference; 73 p.

Yabe H, Yabuta Y, Ueyanagi S. 1963. Comparative distribution of eggs, larvae and adults in relation to biotic and abiotic environmental factors. FAO Fish Rep 6(3):979–1009.

Yesaki M. 1983. Observations on the biology of yellowfin (*Thunnus albacares*) and skipjack (*Katsuwonus pelamis*) tunas in Philippine waters. FAO/UNDP Indo-Pac Tuna Dev Mgt Programme. 66 p. Report nr IPTP/83/WP/7.

Yuen HSH. 1963. Schooling behavior within aggregations composed of yellowfin and skipjack tuna. FAO Fish Rep 6(3):1419–29.

6.14 Habitat description for northern bluefin tuna (*Thunnus thynnus*)

Management Plan and Area
American Samoa, Guam, MHI, NWHI, Northern Mariana Islands, Johnston Atoll, Kingman Reef, Palmyra Atoll, Jarvis Island, Midway Island, Howland and Baker Islands and Wake Islands.

Life History and General Description

Material for this habitat description is drawn from Bayliff (1994) and Collette and Nauen (1983). Bayliff provides an extensive list of references which are not, in general, re-cited here.

There are seven species in the genus *Thunnus*, a member of the Thunnini tribe of the subfamily Scombrinae. Three of these species, *T. thynnus*, *T. alabacares* (yellowfin tuna) and *T. obsesus* (bigeye tuna) are PMUS. Tunas of this genus are unique in their high metabolic rate and vascular heat exchanger systems allowing thermo-regulation and endothermy. The Pacific northern bluefin is considered a sub-species. *T. thunnus orientalis* (Temminck and Schlegel) along with an Atlantic sub-species, *T. thynnus thynnus* (Linnaeus). The Pacific population is considered a single stock but with a long range, complex migratory pattern (see below).

The range of the species is between about 20º and 40º N in the eastern and central Pacific, but with a northern extension to the Gulf of Alaska in the east. In the western Pacific they are found as far south as 5º N and north to Sakhalin Island near the Asian mainland. This represents the limits of distribution; based on historic fish landings they are concentrated between about 25º and 40ºN in the central and western Pacific. In the eastern Pacific bluefin are caught mostly between Cabo San Lucas, Baja California, Mexico and Point Conception, California. They are occasionally caught further north along the California coast, in Oregon and Washington and to Shelikoff Straight in Alaska. This probably represents an occasional range extension due to elevated SST. In the eastern and central Pacific preferred habitat as defined by temperature is between 17º and 22º or 23ºC. In the western Pacific off Japan optimal temperature is reported as between 14º and 19º or 15º and 17º. Juvenile fish are caught by Japanese coastal fishermen in warmer water, as high as 29ºC for fish 15 to 31 cm. Temperature range reportedly increases with size. Bayliff (1994) provides maps of the areas of the North Pacific bounded by the 17º and 23ºC isotherm by season. Roughly, in winter it is a band centered on 30ºN latitude and in summer on 40ºN.

In addition to the review article cited earlier, migration is described in Bayliff, et al. (1991) and Bayliff (1993). Bluefin spawn in the western Pacific, off of the Philippines (April–June) and Japan (July–August). Larvae, postlarvae and juveniles are transported northward in the Kuroshio Current. Some fish remain in the western Pacific while others migrate eastward after their first winter. Bayliff suggests that the isotherm band described above, which coincides roughly with the North Pacific Subarctic-Subtropical Transition Zone (see the habitat description for albacore tuna for more discussion of this oceanographic feature), bounds their migration path. The migration time is relatively brief, seven months or less. It is unclear how long fish remain in the eastern Pacific or whether they make multiple migrations back and forth, although this seems unlikely. Eventually fish return to the western Pacific to spawn; the return journey takes longer, around two years, as the minimum time based on tag returns is 674 days. Some juvenile fish also move southward from the spawning areas off the Philippines and Japan. Northern bluefin have been caught as far south as New Zealand and are occasionally caught off of Papua New Guinea, the Solomon Islands and the Marshall Islands. However, there is no evidence of spawning in these areas.

In addition to the temperature ranges discussed above, habitat features mentioned by Bayliff that may affect population abundance and density include the California Current in the eastern Pacific, the aforementioned Pacific Transition Zone and the Kuroshio Current off of Japan.

The papers by Bayliff cited above discuss age and growth. 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 and linear growth for fish greater than 564 mm. The parameters are also presented in Bayliff (1994) but will not be reproduced here. Estimates for size at age for 1-year-old fish range from 43 to 76.3 cm and for 4-year-old fish, 113.1 to 178 cm (see Table 1 in Bayliff (1991)). Bayliff (1993) presents age at length—by month—for bluefin in the eastern Pacific. The maximum size fish caught in the North Pacific is reported as 300 cm. Using the growth equations presented by Bayliff this corresponds to an age of about 9.5 years, but bluefin from the Pacific have lived as long as 16 years in captivity. Bayliff (1993) discusses the coefficient of natural mortality and arrives at a range of 0.161–0.471 for the 90% confidence interval. Using these figures, at 10 years about 79% and 99%+ mortality is achieved respectively.

Bluefin may be sexually dimorphic with respect to size as is common in other tunas; fish raised in captivity reached a size of 1,190 mm for males and 1,353 mm for females at 3 years of age (Hirota et al. 1976). Male-female sex ratios reported in Bayliff (1993) range from 45:0 for fish caught in the eastern Pacific by purse seine to 28:47 (1:1.68) for longline caught fish landed off of Taiwan. Fecundity has been estimated at 10 million eggs for fish 270–300 kg.

Spawning areas and seasons were discussed above. Larvae were reported off of Oahu, Hawaii, by (Miller,1979) but other unpublished sampling data (from 1984–85) reported by Bayliff (1993) found no bluefin larvae off of Oahu.

The major fisheries for bluefin in the eastern Pacific are a sport fishery and commercial purse seining off the US West Coast; foreign longliners also catch a small number of fish in this region. In the western Pacific a variety of gear is used, primarily in coastal fisheries but also by purse seiners in an area about 30º–42ºN and 140º–152ºE. Bayliff (1993) discusses landing trends; CPUE trend is only available for the eastern Pacific. There both CPUE and effort declined during the 1980s and early 1990s.

In the western Pacific region only Hawaii reported commercial bluefin tuna landings in 1996. All of this total of 100,000 lbs (45.36 mt) was landed by the longline fleet (WPRFMC 1997). No information is given on catch areas, but they are most likely north and west of the Hawaiian Islands and mostly in international waters. Total landings in managed fisheries is small in comparison to total catch in the Pacific. For example Bayliff (1993) reports 13,183 mt landed in 1986 by all Japanese vessels, almost 300 times 1996 Hawaii landings.

Egg and Larval Distribution

Eggs and larvae are probably confined to known spawning areas in the western Pacific, outside of the management area. As noted above, Miller (1979) reports larvae from Hawaiian waters but later more extensive sampling in Hawaii failed to turn up larvae. Given the distance from known spawning areas it would seem unlikely the bluefin larvae normally occur in Hawaiian waters. Larvae reportedly feed on small zooplankton, mainly copepods (Uotani et al. 1990).

Bayliff (1994) provides no details on larval growth and habitat. More information may be found in Yabe and Ueyanagi (1962) and Yabe et al. (1966).

Juvenile

Bluefin are estimated to reach maturity at 3–5 years, with the latter age more likely according to Bayliff and equivalent to a size of about 150 cm. As already noted, some juvenile fish migrate across the Pacific, probably within the Transition Zone, and remain off the American West Coast from Baja to southern California. Juvenile fish migrate seasonally (November to April) offshore, perhaps into the central Pacific but probably not returning all the way to the western Pacific. Fish stay in the eastern Pacific for several years, up until 5 or 6 years of age, but return to the western Pacific at or before sexual maturity, eventually to spawn.

Feeding habits of bluefin in the eastern Pacific would represent juvenile food preferences. These are reviewed by Bayliff (1994). Major prey items include anchovies, red crabs (*Pleurocodes planipes*), sauries (*Cololabis saira*), squid (*Loligo opalescens*) and hake (*Merluccius productus*); anchovies make up 80% of stomach contents by volume. Anchovies, crustaceans and squid are also reported as the main prey items for immature fish caught in the western Pacific.

The distribution and preferred habitat of juveniles has already been discussed in connection with migration.

Adult

As already noted, bluefin reach maturity at about 5 years of age or possibly somewhat earlier. Their distribution and habitat preferences have already been discussed. Prey items are squid and a variety of fish including anchovies (*Engraulis japonica* and *Stolephorus zollingeri*), herring (*Etrumeus teres*), pampanos (Carangidae), mackerel (*Scomber spp*.) and other tunas (*Auxis spp*. and *Katsuwonus pelamis*). In the western Pacific, Bluefin are also reported to associate with schools of sardine (*Sardinops melanosticta*), which are probably also an important prey item.

Essential Fish Habitat: Temperate species complex

Bluefin is caught in significant quantifies by the Hawaii-based longline fleet. The North Pacific Transition Zone, areas off the west coast of America and off of east Asia are all important habitat areas outside of the region.

Habitat description for northern bluefin tuna (*Thunnus thynnus*)

	Egg	**Larvae**	**Juvenile**	**Adult**
Duration	days	weeks	to 5 years or somewhat less	to about 10 years
Diet	NA	copepods	fish, squid, crustaceans, especially anchovies	fish and squid, especially anchovies, mackerels, other tunas and sardines
Distribution: General and Seasonal	western Pacific, Philippines to Japan	western Pacific, Philippines to Japan	western Pacific off of Japan and north, North Pacific Transition Zone and off the American coast Baja to southern California	north and west Pacific and south in west Pacific to spawning areas
Location	offshore?	offshore?	offshore and inshore outside management area	offshore and inshore outside management area
Water Column	epipelagic	epipelagic	epipelagic	epipelagic
Bottom Type	NA	NA	NA	NA
Oceanic Features	Kuroshio Current	Kuroshio Current	Kuroshio Current, North Pacific Transition Zone, California Current	Kuroshio Current, North Pacific Transition Zone

Bibliography

Bayliff WH. 1993. Growth and age composition of northern bluefin tuna, *Thunnus thynnus*, caught in the eastern Pacific Ocean, as estimated from length-frequency data, with comments on trans-Pacific migrations. Inter Am Trop Tuna Comm Bull 20(9):503–40.

Bayliff WH. 1994. A review of the biology and fisheries for northern bluefin tuna (*Thunnus thunnus*) in the Pacific Ocean. In: Shomura RS, Majkowski J, Langi S, editors. Interactions of Pacific Tuna Fisheries. Volume 2, Papers on biology and fisheries. Proceedings of the First FAO Expert Consultation on Interactions of Pacific Tuna Fisheries; 1991 Dec 3–11; Noumea, New Caledonia. Rome: FAO. p 244–95. Fish Tech Pap nr 336/2.

Bayliff,WH, Ishizuka Y, Deriso RB. 1991. Growth, movement and attrition of northern bluefin tuna, *Thunnus thynnus*, in the Pacific Ocean, as determined by tagging. Inter Am Trop Tuna Comm Bull 20(1):1–94.

Collette BB, Nauen CE. 1983. An annotated and illustrated catalogue of tunas, mackerels, bonitos, and related species known to sate. FAO Species Catalogue. Volume 2, Scombrids of the World. Rome: Food and Agriculture Organization. 118 pp.

Hirota H, Morita M, Taniguchi N. 1976. An instance of the maturation of 3 full years old bluefin cultured in the floating net. Bull Jap Soc Sci Fish 42(8):939.

Miller JM. 1979. Nearshore abundance of tuna (Pisces: Scombridae) larvae in the Hawaiian Islands. Bull Mar Sci 29:19–26.

Uotani I, Saiot T, Hiranuma K, et al. 1990. Feeding habit of bluefin tuna *Thunnus thynnus* larvae in the western North Pacific Ocean. Nippon Suisan Gakkaishi 56(5):713–7.

[WPRFMC] Western Pacific Regional Fishery Management Council. 1997. Pelagic Fisheries of the Western Pacific Region 1996 Annual Report. Honolulu: WPRFMC. 26 p + appendices

Yabe H, Ueyanagi S. 1962. Contributions to the study of the early life history of the tunas. Location: Nankai Reg Fish Res Lab. p 57–72. Occasional report nr 1.

Yabe H, Ueyanagi S, Watanabe H. 1966. Studies on the early life history of bluefin tuna *Thunnus thynnus* and on the larvae of the southern bluefin tuna *T. maccoyii*. Rep Nankai Reg Fish Res Lab 23:95–129.

6.15 Habitat description for skipjack tuna (*Katsuwonus pelamis*)

Management Plan and Area
American Samoa, Guam, MHI, NWHI, Northern Mariana Islands, Johnston Atoll, Kingman Reff, Palmyra Atoll, Jarvis Island, Howland and Baker Islands Midway Island and Wake Island.

Life History and General Description

Major reviews of skipjack tuna life history and distribution used in the preparation of this description include Matsumoto et al. (1984), Forsburgh (1980) and Wild and Hampton (1991).

Morphological and genetic research indicate that *Katsuwonis pelamis* is one worldwide species, and no subspecies are recognized. Serological and genetic analysis of Pacific populations has not conclusively determined the sub-population structure. The species is genetically heterogeneous across the Pacific. A longitudinal variation in the esterase Est 1 gene was argued to be discontinuous, at least in the southern hemisphere, supporting the argument that there are at least two sub-populations in the eastern and western Pacific (Fujino 1972, 1976). A longitudinal cline has also been detected in Est 2 gene frequency between 140ºE and 130ºW (SPC 1981). Sharp (1978) argued that there are at least five sub-populations, but Ianelli (1993) consider this improbable. Richardson (1983) argues that skipjack exist in a series of semi-isolated "genetic neighborhoods" enclosing a group of randomly breeding adults. However, it is difficult to reliably delimit the size and location of these neighborhoods. In sum, two hypotheses are currently considered: an isolation by distance model where the probability of two individuals mating is inversely proportional to the distance between them at birth and a discrete sub-population model where breeding groups are relatively distinct. Wild and Hampton (1991) state that "the difficulties that are encountered in applying either the isolation-by-distance or discrete–sub-population hypotheses prevent the choice of a single, descriptive model of the skipjack population at this time."

Skipjack tuna are found in large schools across the tropical Pacific. They prefer warm, well-mixed surface waters. Barkley (1969) and Barkley et al. (1978) describe 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: "1) a lower temperature limit around 18ºC, 2) a lower dissolved O_2 level of around 3.5 p/m, and 3) a speculative upper temperature limit, ranging from 33ºC for the smallest skipjack tuna caught in the fishery to 20ºC or less for the largest." These limits represent constraints on activity based on available dissolved oxygen and water temperature. Wild and Hampton (1991) suggest a minimum 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.) A maximum range is proposed as an area bounded by the 15ºC or roughly between 45ºN and S in the western Pacific and 30ºN and S in the east. This range is more restricted in the eastern Pacific due to the basin-wide current regime, which brings cooler water close to the equator in the east. (See Figure 10 in Matsumoto et al. (1984) for a map of skipjack distribution.)

Wild and Hampton (1991) note the a variety of other oceanographic and biological features influence distribution, including thermocline structure, bottom topography, water transparency, current systems, water masses and biological productivity. In the tropics these factors may be more important in determining distribution than temperature. Temperature change in sub-tropical regions affects seasonal abundance. Large-scale climatic features, of which El Niño is the most well known, also affect distribution. This primarily affects localized distribution in the eastern tropical Pacific.

Vertical distribution is generally limited by the depth profile of the temperature and oxygen concentrations given as minimums above. Dizon et al. (1978) found that skipjack move between the surface and 263 m during the day but remain within 75 m of the surface at night.

Although skipjack form large schools, these are not stable and often break up at night. Tagging data indicate that school membership is not stable over time (Bayliff 1988, Hilborn 1991). From analysis of parasite fauna, Lester et al. (1985) determine that school half-life is likely to be only a few weeks.

Pre-recruits disperse from the central Pacific, arriving in the eastern Pacific at 1 to 1 ½ years old and return to the central Pacific at 2 to 2 ½ years old (Wild and Hampton 1991). Migrants to the eastern Pacific split between a northern and southern group off of Mexico and Central and South America respectively. Ianelli (1993) reviews three possible migration models that might account for this north-south distribution. These models are based on large-scale current patterns in the region.

In the western Pacific substantial work has been carried out, although Wild and Hampton (1991) note that many issues have not been resolved. In some cases data indicate that there is relatively little movement, particularly in the Papua New Guinea and Solomon Islands area. There is also evidence of an eastward migration in the Micronesian region (Mullen 1989, Polacheck 1990).

A reliable means for establishing an age-length relationship does not exist. Matsumoto et al. (1984) estimate a maximum age for skipjack of 8–12 years based on the largest individual documented in the literature (Miyake 1968) as in 106.5–108.4 cm size class. Matsumoto et. al. (1984) provide an extensive review of growth estimates. Estimates for a 1-year-old are 26–41 cm and 54–91 cm for 4-year-olds.

Skipjack are heterosexual with a few instances of hermaphroditism being recorded. Sex ratio is variable: young fish have ratios dominated by females, and older fish have a higher proportion of males (Wild and Hampton 1991). Observations by Iversen et al. (1970) suggest courtship behavior between pairs of tuna. Mating is most likely promiscuous (Matsumoto et al. 1984). 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, but the frequency is not known. They spawn year-round in tropical waters and seasonally, spring to early fall, in sub-tropical areas.

Historically bait boats (pole-and-line) were the main gear used in catching skipjack. Since the 1950s purse seiners have come to dominate the fishery. (Some skipjack are also caught incidentally by longliners targeting on yellowfin tuna.)

There are two major fisheries in the eastern Pacific. The most important is located east of 100ºW off of Central and South America. The northern fishery, separated by a region of low abundance (described above) occurs near Baja California, the Revillagigedo Islands and Clipperton Island. In the western Pacific the fishery is diverse, occurring in the waters of a number of island nations and carried out by both small domestic fleets and distant water fleets from developed nations, primarily Japan and the US. Fishing effort is concentrated in the waters around Micronesia and northern Melanesia.

	1995	1996
American Samoa	179,104	75,967
Guam	192,218	21,5944
Hawaii	1,700,000	2,300,000
Northern Mariana Islands	105,423	132,155
Total	2,178,740	2,726,062

Skipjack tuna are caught throughout the management plan area by a variety of methods. The largest fishery is in Hawaii utilizing bait boats. The other principle method of capture is by trolling. Skipjack are also caught by longliners although they are usually not the target species. For comparison, 666,834 mt of skipjack tuna were caught in the SPC statistical area in 1995. The management plan area landings represent about 0.2% of this amount. A significant amount of tuna caught outside of the management plan area is delivered to canneries in American Samoa.

Egg and Larval Distribution

Matsumoto et al. (1984) summarize larval development; Ueyanagi et al. (1974) is the primary source. Ripe eggs are described as spherical smooth, transparent and usually containing a single yellow oil droplet. Diameter range from 0.80 to 1.135 mm. They are comparable in appearance to the eggs of other tunas and thus difficult to distinguish in plankton tows. Therefore, distribution cannot be determined although it is assumed to be coincident with larval distribution since eggs hatch rapidly. Spawned eggs are buoyant and thus epipelagic. Once fertilized, eggs hatch in about 1 day, depending on temperature.

Matsumoto et al. (1984) describe the typical characteristics of larvae as “a disproportionately large head which is bent slightly downward in relation to the body axis, the appearance of 2 or 3 melanophores over the forebrain area when the larvae are about 7 mm long (the number of melanophores increase to about 12 in larvae 14.5 mm in length), heavy pigmentation over the midbrain area throughout all sizes, and the appearance of the first dorsal fin spines in larvae about 7 mm long (the number increases to about 12 in larvae about 14.5 mm in length), heavy pigmentation over the mid-brain area throughout all sizes, and the appearance of the first dorsal fin spines in larvae about 7 mm long (the number of spines increase to about 13 in larvae 11 mm TL).”

Matsumoto et al. (1984) state that the onset of the juvenile stage is evidenced by “attainment of the full complement of 15 spines and 15 rays in the first and second dorsal fins, respectively, and 15 rays in the anal fin.…” These developments occur by the time larvae reach about 12 mm, which conflicts somewhat with the earlier description of larvae up to about 14.5 mm. No age for this size is given but it is probably about 2–3 weeks.

No information was given on feeding and food, but likely food are phytoplankton and for larger-sized larvae, zooplankton also.

As noted earlier, skipjack spawn year-round in tropical waters so it would be expected that in tropical waters eggs and larvae would be present much of the time. The distribution of larvae has been documented by Japanese research vessel net tows (Ueyanagi 1969, Nishikawa et al. 1985). (See Matsumoto et al., 1984, Fig. 11 for a map of larval distribution.) Like adults, larvae have a wider latitudinal distribution in the western Pacific than in the east. Kawasaki (1965) suggests that the center of abundance of skipjack tuna larvae in the Pacific Ocean lies between 5ºN and 4ºS and 160ºE and 140ºW. Matsumoto (1975) later reports the center of abundance between 160ºE and 140ºW but moderate between 100ºW and 140ºW and 120ºE and 160ºE. Areas above 20ºN with relatively high larval abundance include the Hawaiian Islands. Klawe (1963) did not find any larvae below the mixed layer. Larvae apparently migrate to the surface at night while staying deeper at night (Wild and Hampton 1991).

Wild and Hampton (1991) state that skipjack larval distribution is strongly influenced by temperature. Forsbergh (1989) demonstrates that the concentration of larvae in the Pacific approximately doubles with each 1ºC increase in SST between 24º–29ºC and then begins to decrease above 30ºC. Matsumoto et al. (1984) present a limit for larval distribution based on the 25ºC isotherm. As noted above, larvae remain in the mixed layer.

Leis et al. (1991) found particularly high concentrations of skipjack larvae near coral reefs of islands in French Polynesia. It may be that the more productive waters around oceanic islands and reefs provide preferred habitat for larval development.

Juvenile

Mori (1972) defines juveniles as smaller than 15 cm (but above 12–15 mm as the upper limit for larvae as defined by Matsumoto et al. (1984)) while young are 15–35 cm. Skipjack first spawn at about 40 cm length (see below). Relatively little is known about the juvenile phase (especially the adolescent or pre-adult stage) since they do not turn up 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 1991).

Skipjack have closely spaced gillrakers, allowing them to consume a variety of prey (Ianelli 1993). Matsumoto et al. (1984) note that smaller skipjack tuna mainly rely on crustaceans for food, presumably zooplankton.
No information on juvenile habitat is available although the range appears to be similar to that of larvae. Matsumoto et al (1984) note that the distribution in the Pacific Ocean is generally from 35ºN to 35ºS in the west and between 10ºN and 5ºS in the east. (See figure 13 in this publication for a distribution map based on captures.)

No information is available on special habitat features that affect density and abundance.

Adult

Matsumoto et al. (1984), reviewing a variety of sources, argue that the minimum size for female skipjack at maturity is 40 cm and initial spawning occurs between 40–45 cm. Based on growth estimates, skipjack are about 1-year-old at this size.

Skipjack are opportunistic foragers, and an extensive range of species have been found in their stomachs. Matsumoto et al. (1984) 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, followed by molluscs and crustaceans. Scombrids are the most important group of fish consumed by skipjack.

Experiments with captive skipjack indicate that a intense feeding period occurs in the early morning (Magnuson 1969). Despite intense feeding these fish did not immediately fill their stomachs; apparently they ate slowly over the entire 2-hour feeding. Fish ate about 15% of their body weight per day. In another experiment it was observed that fish feed intensively at first and then in smaller amounts throughout the day; they could not feed effectively at night; introduced fish learned feeding methods from other fish that had been in the experimental tanks for some time; and fish never fed off the bottom of the tank (Nakamura 1965).

In the wild skipjack exhibit feeding peaks in the early morning and late afternoon.

The hypothetical habitat for skipjack tuna has already been described and the adult range encompasses all of the areas where earlier life stages are concentrated. Figures 56–60 in Matsumoto et al. (1984) provide information on the distribution of this habitat.

<u>Essential Fish Habitat</u>: Tropical species complex

EFH encompasses the whole EEZ of the management plan area in the near surface waters of the mixed layer. Figure 57 in Matsumoto et al. (1984) suggests that the deepest habitat depth attained in the Pacific is around 300 m but in the management plan areas is probably half that or less. Since skipjack occur in schools, they are not distributed uniformly across the EEZ at any given time. However, all of these waters meet habitat criteria, and it is not possible to determine what part of this habitat is occupied at any given time, except perhaps for seasonal variations in sub-tropical areas.

Waters close to islands, banks and reefs may be areas of larval concentration and could be considered as HAPC.

Habitat description for skipjack tuna (*Katsuwonus pelamis*)

	Egg	**Larvae**	**Juvenile**	**Adult**
Duration		to 12–15 mm (2–3 weeks?)	15 mm–40 cm	above 40 cm
Diet	NA	zooplankton	similar to adult diet?	highly variable, fish, molluscs, crustaceans
Distribution: General and Seasonal	Center of spawning abundance: 5ºN-4º S and 160º E–140ºW.	From 24º to 29ºC with preference at higher temperatures but decreasing above 29ºC.	35ºN–35ºS in the west and 10ºN–5ºS in the east	Warm well mixed oceanic waters. 15º–33ºC maximum range. Above 3.5 p/m dissolved O_2. 45ºN–45ºS in the west and 30ºN and 30ºS in the east. Warm well mixed upper oceanic waters. 15º–33ºC maximum range. Above 3.5 p/m dissolved O_2. 45ºN–45ºS in the west and 30ºN–30ºS in the east.
Location	offshore waters	offshore waters	offshore waters	offshore waters
Water Column	epipelagic	pelagic, upper mixed layer	pelagic, mixed layer	pelagic, mixed layer
Bottom Type	NA	NA	NA	NA
Oceanic Features	depends on adult preferences	depends on adult preferences	eddies, upwelling, oceanic fronts and other areas of high productivity	eddies, upwelling, oceanic fronts and other areas of high productivity

Bibliography

[SPC] South Pacific Commission. 1981. Report of the second Skipjack Survey and Assessment Programme workshop to review the results from genetic analysis of skipjack blood samples. Noumea, New Caledonia: South Pacific Commission. Technical report nr 6.

Barkley RA. 1969. Salinity maxima and the skipjack tuna, *Katsuwonus pelamis*. Bull Soc Oceangr Special Issue:243–6.

Barkley RA, Neill WH, Gooding RM. 1978. Skipjack tuna, *Katsuwonus pelamis*, habitat based on temperature and oxygen requirements. US Fish Wildl Serv Fish Bull 76(3):653–62.

Bayliff WH. 1988. Integrity of schools of skipjack tuna, *Katsuwonus pelamis,* in the eastern Pacific Ocean, as determined from tagging data. Fish Bull 86(4):631-43.

Dizon AE, Brill RE, Yuen HSH. 1978. Correlations between environment, physiology, and activity and the effects of thermoregulation in skipjack tuna. In: Sharp GD, Dizon AE, editors. The physiological ecology of tunas. New York:Academic Pr. p 233–59.

Forsbergh ED. 1980. Synopsis of biological data on the skipjack tuna, *Katsuwonus pelamis* (Linnaeus 1758), in the Pacific Ocean. In: Bayliff WH, editor. Synopses of biological data on eight species of scombrids. La Jolla, CA: Inter-American Tropical Tuna Commission. Special report nr. 2.

Forsbergh ED. 1989. The influence of some environmental variables on the apparent abundance of skipjack tuna, *Katsuwonus pelamis*, in the eastern Pacific Ocean. Inter-Am Trop Tuna Comm Bull 19(6):433–569.

Fujino K. 1972. Range of the skipjack tuna subpopulation in the western Pacific Ocean. In: Proceedings of the Second Symposium on the Results of the Cooperative Study of the Kuroshio and Adjacent Regions, The Kurshio II; 1970 Sep 28–Oct 1; Tokyo. Tokyo: Saikon Publ. p 373–84.

Fujino K. 1976. Subpopulation identification of skipjack tuna specimens from the southwestern Pacific Ocean. Bull Jpn Soc Sci Fish 42:1229–35. (In Japanese.)

Hilborn R. 1991. Modeling the stability of fish schools—exchange of individual fish between schools of skipjack tuna (*Katsuwonus pelamis*). Can J Fish Aquat Sci 48(6):1081–91.

Ianelli JN. 1993. Studies on the population structure of skipjack tuna, *Katsuwonus pelamis*, in the central and eastern Pacific Ocean [dissertation]. Seattle: University of Washington.213 p.

Iversen RTB, Nakamura EL, Gooding RM. 1970. Courting behavior in skipjack tuna, *Katusownus pelamis*. FAO Fish Rep 62(3):849–59.

Kawasaki T. 1965. Ecology and dynamics of the skipjack population. Part I, Classification, distribution and ecology. Jpn Fish Resour Prot Assoc Stud Ser 8:1–48. (In Japanese.)

Klawe WL. 1963. Observations on the spawning of four species of tuna, *Neothunnus macropterus*, *Katsuwonus pelamis*, *Auxis thazard* and *Euthynnus lineatus*, in the eastern Pacific Ocean, based on the distribution of their larvae and juveniles. Inter-Am TropTuna Comm Bull 6(9):447–540.

Leis JM, Trnski T, Harmelin-Vivien M, Renon JP, Dufour V, El Moudni MK, Galzin R. 1991. High concentrations of tuna larvae (Pisces- Scombridae) in near-reef waters of French Polynesia (Society and Tuamotu Islands). Bull Mar Sci 48(1):150–8.

Lester RJG, Barnes A, Habib G. 1985. Parasites of skipjack tuna, *Katsuwonus pelamis*—fishery implications. Fish Bull 83(3):343–56.

Magnuson JJ. 1969. Digestion and food consumption by skipjack tuna (*Katsuwonus pelamis*). Trans Am Fish Soc 98:379–92.

Matsumoto WM. 1975. Distribution, relative abundance and movement of skipjack tuna, *Katsuwonus pelamis*, in the Pacific Ocean based on Japanese tuna longline catches, 1964–67. Washington: NOAA. Technical report nr NMFS SSRF.

Matsumoto WM, Skillman RA, Dizon AE. 1984. Synopsis of biological data on skipjack tuna, *Katsuwonus pelamis*. Washington: NOAA. Technical report nr NMFS circular 451 and FAO fisheries synopsis nr 136.

Miyake MP. 1968. Distribution of skipjack in the Pacific Ocean, based on records of incidental catches by the Japanese longline tuna fishery. Inter-Am Trop Tuna Comm Bull 12:509–608. (In English and Spanish.)

Mori K. 1972. Geographical distribution and relative apparent abundance of some scombrid fishes based on the occurrences in the stomachs of apex predators caught on tuna longline. Part I, Juvenile and young of skipjack tuna (*Katsuwonus pelamis*). Far Seas Fish Res Lab Bull 6:111–57. (In Japanese.)

Mullen AJ. 1989. Mobility of Tuna. Mar Policy 13(1):77–8.

Nakamura IL. 1965. Food and feeding habits of skipjack tuna (*Katsuwonus pelamis*) from the Marquesas and Tuamotu Islands. Trans Am Fish Soc 94:236–42.

Nishikawa Y, Honna M, Ueyanagi S, Kikawa S. 1985. Average distribution of larvae of oceanic species of scombroid fishes, 1956–1981. Far Sas Fish Res Lab. 99 p. S series nr 12.
Polacheck T. 1990. Another perspective on the need for international skipjack and yellowfin tuna management. Mar Policy 14(6):526–9.

Richardson BJ. 1983. Distribution of protein variation in skipjack tuna (*Katsuwonus pelamis*) from the central and south-western Pacific. Aust J Mar Freshwat Res 34(2):231–51.

Sharp GD. 1978. Behavioral and physiological properties of tuna and their effects on vulnerability to fishing gear. In: Sharp GD, Dizon AE, editors. The physiological ecology of tunas. New York: Academic Pr. p 397–449.

Ueyanagi S. 1969. Observations on the distribution of tuna larvae in the Indo-Pacific Ocean with emphasis on the delineation of the spawning areas of albacore, *Thunnus alalunga*. Far Seas Fish Res Lab Bull 2:177–256.

Ueyanagi S, Nishikawa Y, Matsuokoa T. 1974. Artificial fertilization and larval development of skipjack tuna, *Katsuwonus pelamis*. Bull Far Seas Fish Res Lab Shimizu 10:179–88. (In Japanese.)

Wild A, Hampton J. 1991. A review of the biology and fisheries for skipjack tuna, *Katsuwonus pelamis,* in the Pacific Ocean. In: Papers on biology and fisheries. Proceedings of the First FAO Expert Consultation on Interactions of Pacific Tuna Fisheries; 1991 Dec 3–11; Noumea, New Caledonia. Rome: FAO.

6.16 Habitat Description for kawakawa (*Euthynnus affinis*)

Management Plan and Area

American Samoa, Guam, MHI, NWHI, Northern Mariana Islands, Johnston Atoll, Kingman Reef, Palmyra Atoll, Jarvis Island, Midway Island, Howland and Baker Islands and Wake Islands.

Life History and General Description

The main sources for this description were the review documents Yesaki (1994), Collette and Nauen (1983) and Yoshida (1979). Both Yesaki and Yoshida contain extensive reference lists; in general those references are not re-cited here.

The genus *Euthynnus* is a member of the Thunni tribe of the subfamily Scombrinae. There are three species in the genus. Of the other two species, *Euthynnus lineatus* is reported from the American west coast from southern California to Peru and Hawaii but is not a management unit species. For kawakawa no sub-species are recognized and no information is reported on stock separation.

Kawakawa is an epipelagic neritic species, mainly of the west and south Asian and east African continental margin. It is found throughout the archepelagic waters of Southeast Asia to northern Australia. Most reports emphasize its association with continental margins, but it also occurs around oceanic islands and island archipelagoes. Strays have also been reported from the American continental margin. Generally, its distribution is tropical-subtropical between 35ºN and 35ºS. In Hawaiian waters, kawakawa are reportedly confined to the 20–30 fm (36.5–54.8 m) contour. Trolling studies in Thailand indicate that kawakawa are most commonly taken in the outer neritic zone (50–200 m depth) with almost none caught in deeper waters. Fish of 20–40 cm are more common in the inner neritic zone (less than 50 m depth) and apparently move into deeper water after 50 cm (Yesaki 1982). In Japan and Hong Kong favorable habitat characteristics include relatively low salinity (31.22 to 33.80 ppt in Japan, as low as 26 ppt during the monsoon in Hong Kong) and higher productivity either due to upwelling or estuarine influence. However, kawakawa are not found in brackish (i.e., very low salinity) water. The species has a relatively wide temperature range, 18º–29ºC according to Collette and Nauen (1983) or 14º–29ºC for Hong Kong waters as reported by Williamson (1970).

Seasonality in landings is reported throughout the kawakawa's range, although generally it is not strong. However, no definitive migration pattern is reported. Kawakawa tend to form mixed schools, co-occurring with other tunas including yellowfin (*Thunnus albacares*), skipjack (*Katsuwonus pelamis*) and the frigate tuna (*Auxis thazard*). It also schools with the carangid *Megalaspis cordyla*. Juveniles are commonly preyed upon by yellowfin and skipjack, and Yesaki (1994) suggests that all these species are probably competitors.

Yesaki (1994) reviews age and growth studies for kawakawa and concludes that "studies of kawakawa completed to date give conflicting results" (p 392). Lengths at age based on these studies rang from 19–47 cm for 1-year-olds, 41–65 cm for 2-year-olds and 41–72 cm for 3-year-olds. The range in growth parameters given are K 0.37–0.96 (with an outlier of 2.23), $L_{\rangle}$ 59.5–81.0 cm and t_o -0.15 and -0.344 (only two studies reported this parameter). Yesaki (1994) emphasizes that all studies suggest rapid growth during the juvenile stage. Maximum age for the species is 5 or 6 years. The largest specimen reported by Yoshida (1979) is 87 cm and 8.6 kg although specimens over 100 cm have reportedly been taken from Japanese waters.

Kawakawa are heterosexual, and sexual dimorphism is not reported. Fecundity estimates range from .202 to 2.5 million eggs. Kawakawa apparently spawn inshore based on captures of larval fish. Yesaki (1994) states that they are widely but very patchily distributed and generally taken close to land masses. Larvae are reported from Hawaii and French Polynesia, indicating spawning around oceanic islands where they occur, but the highest concentrations of larvae are found off of Australia, Java, Papua New Guinea, the Solomon Islands and the Ryukyu Islands of southern Japan. According to Yesaki (1994) there are two spawning seasons in the tropics, a main season in the first half of the year and a secondary season in the latter half.

Total landings for kawakawa throughout its range are reported at 122,893 mt in 1989. The Philippines generally reports the highest landings, and in 1989 they were 57,899 mt, or close to half total landings. Kawakawa are captured by a variety of gear in coastal fisheries including troll, gillnet, purse seine and ringnet. In general they are part of multi-species, small-pelagic coastal fisheries that are most intense in the Southeast Asian Indo-Pacific.
Kawakawa is not an important commercial species in the western Pacific region. In Hawaii, landings of kawakawa are lumped in the "miscellaneous pelagics" category based on longline logbook reports. However, it is likely that kawakawa are more commonly caught by inshore small boat fishermen. However, these landings do not appear in the Council's annual report. Guam reported 1996 landings of 4,043 lb (1,833.87 kg), but gear type is not specified; American Samoa reported 225 lb (102.10 kg), all troll caught (WPRFMC 1997). In comparison to total commercial landings in the western Pacific region or total landings of kawakawa throughout its

range it can be seen that landings of kawakawa in the Council's management area are negligible.

Egg and Larval Distribution

The distribution of eggs and larvae has already been discussed in connection with spawning. There is little information about kawakawa eggs. Reported egg diameter from one study are 0.85–0.95 mm. Yoshida (1979) provides an extensive treatment of egg and larval development. Eggs take less than 24 hours to hatch.

The key descriptive paper on kawakawa larvae is Matsumoto (1958). The transition from larval to juvenile stage occurs between 10 and 20 mm. No information on larval diet is given in the literature. As already noted, eggs and larvae are found close inshore. At the end of the juvenile stage fish move offshore, although adults are still found in the neritic environment.

Juvenile

Yenagi (1994), summarizing various studies, states that kawakawa reach maturity at about 38 cm. Based at length at age estimates this would correspond to about a 1-year-old fish. As already noted, adult and juvenile kawakawa do not differ markedly in habitat.

Adult

Age and growth have already been discussed. Kawakawa are opportunistic feeders; according to Yoshida (1979) "these fishes feed primarily on whatever is available at any particular place and time." He gives an extensive list of prey items, based on earlier studies. In excess of 17 kinds of fish, some only identified to family or genus, are listed as well as various cephalopods (squid) and crustaceans.

Habitat has already been discussed. As Yoshida (1979) points out for the genus as a whole, they "are generally coastal fishes and judging from the distribution of the various life stages of these species, the entire life cycle is completed within the coastal province."

Essential Fish Habitat: Tropical species complex

The neritic environment can be considered EFH for this species. All of the review articles used in preparing this description contain a variety of distribution maps.

Habitat Description for kawakawa (*Euthynnus affinis*)

	Egg	**Larvae**	**Juvenile**	**Adult**
Duration	24 hours	weeks	to about 1 year	5–6 years
Diet	NA	unknown	similar to adult	highly opportunistic
Distribution: General and Seasonal	coastal-neritic	coastal-neritic	coastal-neritic	coastal-neritic
Location	inshore	inshore	inshore	inshore
Water Column	epipelagic	epipelagic	epipelagic	epipelagic
Bottom Type	NA	NA	NA	NA
Oceanic Features	unknown/coastal	unknown/coastal	unknown/coastal	unknown/coastal

Bibliography

Collette BB, Nauen CE. 1983. An annotated and illustrated catalogue of bonitos, and Related Species known to date. FAO Species Catalogue, Vol. 2 Scombrids of the world. Rome: Food and Agriculture Organization. 118 p.

Matsumoto WM. 1958. Description and distribution of larvae of four species of tuna in central Pacific waters. Fish Bull 58(128):31–72.

[WPRFMC] Western Pacific Regional Fishery Management Council. 1997. Pelagic Fisheries of the Western Pacific Region 1996 Annual Report. Honolulu: WPRFMC. 26 p + appendices.

Williamson GR. 1970. Little tuna *Euthynnus affinis* in the Hong Kong area. Bull Jap Soc Sci Fish 36:9–18.

Yesaki M. 1982. Thailand. Biological and environmental observations. A report prepared for the Pole-and-Line Tuna Fishing in Southern Thailand Project. Rome: Food and Agriculture Organization. 46 p. Report nr FI:DP/THA/77/008.

Yesaki M. 1994. A review of the biology and fisheries for kawakawa (*Euthynnus affinis*) in the Indo-Pacific region. In: Shomura RS, Majkowski J, Langi S, editors. Interactions of Pacific Tuna Fisheries. Volume 2, Papers on biology and fisheries. Proceedings of the First FAO Expert Consultation on Interactions of Pacific Tuna Fisheries; 1991 Dec 3–11; Noumea, New Caledonia. Rome: Food and Agriculture Association. p 409–39. FAO fisheries technical paper nr 336/2.

Yoshida HO. 1979. Synopsis of biological data on tunas of the genus *Euthynnus*. Washington: NOAA (NMFS). 57 p. NOAA technical report nr NMFS Circular 429 (FAO Fisheries Synopsis nr 122).

6.17 Habitat description for dogtooth tuna (*Gymnosarda unicolor*)

Management Plan and Area

American Samoa, Guam, MHI, NWHI, Northern Mariana Islands, Johnston Atoll, Kingman Reef, Palmyra Atoll, Jarvis Island, Midway Island, Howland and Baker Islands and Wake Islands.

Life History and General Description

Very little is known about the biology of dogtooth tuna (*Gymnosarda unicolor*), although it is widely distributed throughout much of the Indo-Pacific faunal region, from the Red Sea eastward to French Polynesia (Collette and Nauen 1983). This species is not found in the Hawaiian Islands, although fishermen do refer to catches of the meso-pelagic snake mackerel (Gempylidae) as “dogtooths.”

G. unicolor is an epipelagic species, usually found individually or in small schools of six or less

(Lewis et al. 1983). Dogtooth tuna are found in deep lagoons and passes, shallow pinnacles and off outer-reef slopes (Collette and Nauen, 1983). It occurs in mid-water, from the surface to depths of approximately 100 m, and has a preference for water temperatures ranging from 20° to 28°C.

G. unicolor is one of the few species of tuna that is found primarily in association with coral reefs (Amesbury and Myers 1982) and probably occupies a niche similar to other reef-associated pelagic predators such as Spanish mackerel (*Scomberomorus* spp) and queenfish (*Scomberoides* spp). Like the Spanish mackerels, large dogtooth tunas can become ciguatoxic from preying on coral reef herbivores, which themselves have become toxic through ingestion of the dinoflagellate, *Gambierdiscus toxicus* (Myers 1989*).*

A positive correlation between size and depth has been observed in the distribution of this species based on limited information from Tuvalu, with larger individuals being found at progressively greater depths (Haight 1998). This species reportedly reaches a maximum size of 150 cm FL and 80 kg (Lewis et al. 1983).

Observations from Fiji suggest that dogtooth tuna obtain sexual maturity at approximately 65 cm (Lewis et al. 1983), while Silas (1963) reported a partially spent 68.5-cm male dogtooth tuna from the Andaman Islands. Females outnumbered males by nearly 2:1 in Fiji, and all fish larger than 100 cm were females, suggesting sexual size dimorphism in this species (Lewis et al. 1983). Lewis et al (1983) suggest that the vulnerability of female dogtooth tuna to trolling declines as the fish approach spawning condition.

In Fiji, spawning reportedly occurs during the summer months, i.e., between October and March (Lewis et al. 1983). Dunstan (1961) observed spawning dogtooth tuna in Papua New Guinea during March, August and December, and various other authors (Silas 1963) have provided some evidence of summer spawning for this species. Okiyama and Ueyangi (1977) note that the larvae of dogtooth tuna occurs over a wide area of the tropical and subtropical Pacific Ocean, between 10°N and 20°S, with concentrations along the shallow coastal waters of islands, such as the Caroline Islands, Solomon Islands and Vanuatu. Dogtooth larvae were collected in surface and subsurface tows, with greater numbers in the sub-surface tows at depths between 20–30m. Older, better-developed larvae appear to make diurnal vertical migrations, rising to the surface during the night. On the basis of larval occurrence throughout the year, Okiyama and Ueyangi (1977) postulate year round spawning in tropical areas.

There are no fisheries specifically directed at dogtooth tuna in the western Pacific region. The primary means of capture include pole and line, handlines and surface trolling (Severance 1998, pers. comm; Collette and Nauen 1983). Dogtooth tuna have been sold in local markets in American Samoa and the Northern Mariana Islands, but currently has little market value (Severance 1998, pers. comm.).

Dogtooth tuna are voracious predators, feeding on a variety of squids, reef herbivores such as tangs and unicorn fish (Acanthuridae), small schooling pelagic species including fusiliers (*Caesio* spp) and roundscads (*Decapterus*) (Myers 1989).
<u>Essential Fish Habitat</u>: Tropical species complex

Dogtooth tuna are unique among the family Scombridae in having a such a close association with coral reefs, although they are also found around rocky reefs in higher latitudes such as in Korea and Japan (Myers 1989). Within the western Pacific region, waters on and adjacent to coral reefs down to a depth of about 100 m should designated EFH for this species.

Habitat Description for Dogtooth Tuna (*Gymnosarda unicolor*)

	Egg	**Larvae**	**Juvenile**	**Adult**
Duration			Dogtooth tuna obtain sexual maturity at approximately 65 cm	Unknown
Diet	N/A	Unknown	Unknown, unlikely to be different from adult	Dogtooth tuna are voracious predators, feeding on a variety of squids, reef herbivores such as tangs and unicorn fish (Acanthuridae), small schooling pelagic species including fusiliers (*Caesio* spp) and roundscads (*Decapterus*)
Distribution: General and Seasonal	Unknown	The larvae of dogtooth tuna occurs over a wide area of the tropical and subtropical Pacific Ocean, between 10°N and 20°S, with concentrations along the shallow coastal waters of islands, such as the Caroline Islands, Solomon Islands and Vanuatu. Dogtooth larvae were collected in surface and subsurface tows, with greater numbers in the sub-surface tows at depths between 20–30m	Unknown, unlikely to be different from adult	Dogtooth tuna (*Gymnosarda unicolor*) is widely distributed throughout much of the Indo-Pacific region, from the Red Sea eastward to French Polynesia. This species is not found in the Hawaiian Islands. Dogtooth tuna are unique among the family Scombridae in having a such a close association with coral reefs, although they are also found around rocky reefs in higher latitudes

	Egg	**Larvae**	**Juvenile**	**Adult**
Water Column	epipelagic	epipelagic	epipelagic	*G. unicolor* is an epipelagic species. Dogtooth tuna are found in deep lagoons and passes, shallow pinnacles and off outer-reef slopes.It occurs in mid-water, from the surface to depths of approximately 100 m, and has a preference for water temperatures ranging from 20° to 28°C.
Bottom Type	N/A	N/A	N/A	N/A
Oceanic Features	Eggs subject to advection by prevailing currents	Larvae subject to advection by prevailing currents	Unknown	Unknown

Bibliography

Amesbury SS, Myers RF. 1982. Guide to the Coastal Resources of Guam. Volume 1, The fishes. University of Guam Marine Laboratory. Contribution nr 173.

Collette BB, Nauen CE. 1983. An annotated and illustrated catalogue of tunas, mackerels, bonitos, and related species known to date. FAO Species Catalogue. Volume 2, Scombrids of the world. Rome: Food and Agriculture Organization. 118 p.

Dunstan DJ. 1961. Trolling results of F/RV *Tagula* in Papua waters. Papua New Guin Agric J 13 (4):148–56

Haight WR. 1998. NMFS/JIMAR, Honolulu Laboratory. Unpublished data.

Lewis AD, Chapman LB, Sesewa A. 1983. Biological notes on coastal pelagics fishes in Fiji. Suva, Fiji: Fisheries Division (MAF). Technical report nr 4.

Myers RF. 1989. Micronesian reef fishes. Coral Graphics. 298 p.

Okiyama M, Ueyangi S. 1977. Larvae and juvenile of the Indo-Pacific dogtooth tuna, *Gymnodarda unicolor* (Ruppell). Bull Far Seas Fish Lab 15:35–49.

6.18 Habitat Description for Moonfish (*Lampris guttatus*): Opah or Moonfish

Management Plan and Area
American Samoa, Guam, MHI, NWHI, Northern Mariana Islands, Johnston Atoll, Kingman Reef, Palmyra Atoll, Jarvis Island, Midway Island, Howland and Baker Islands and Wake Islands.

American Samoa, Guam, Main Hawaiian Islands (MHI), Northwestern Hawaiian Islands (NWHI), Commonwealth of the Northern Mariana Islands (NMI), Johnston Atoll, Kingman Reef, Palmyra Atoll, Jarvis Island, Howland and Baker Islands and Wake Islands.

For management purposes, opah are generally classified under the miscellaneous pelagics. In the Hawaii-based longline fishery, miscellaneous pelagics make up only a small portion of total revenue; however, revenue from this group (led by moonfish) has increased for the three most consecutive years of data (1994-96). Opah landings have increased consistently from 1992 to a high of 760,000 lbs in 1996 averaging 0.52 fish/1000 hooks set; mean ex-vessel price 1987-96 (based on whole weight) was $1.07/lb (Ito and Machado 1997).

Life History and General Description:

The opah, also commonly known as moonfish, are not a target species in any fishery and as a result, very limited biological and ecological information pertaining to the species is currently available in the published literature. Opah was, however, a common incidental take in the now defunct Asian high-seas driftnet fisheries and is a common bycatch in pelagic longline fisheries targeting tunas and swordfish and to a lesser degree in U.S. coastal albacore and salmon fisheries. On Japanese research cruises to waters east of Hawaii and to the equatorial eastern Pacific, mean catch rate for opah was 0.98 and 0.57 fish/hooks, respectively.

Opah are typically found well offshore in temperate and tropical waters of all the world's oceans, including the Mediterranean and Caribbean Seas (Russo 1981, Heemstra 1986). In the Hawaii-based longline fishery where nearly 5000 opah are landed each year, catches and catch rates for the species tend to be highest within the 200 mile EEZ around the main Hawaiian Islands as compared to more distant waters offshore (outside the EEZ) or in the EEZ around the atolls and islets that comprise the Northwestern Hawaiian Islands (Ito and Machado 1997). Off the coast of Europe, Orkin (1950) reported opah to be often taken in 183 m (100 fathoms) near the edge of the Continental Shelf.

Through the water column, opah reportedly inhabit waters from the surface to the lower epipelagial-mesopelagic in excess of 500 m (Miller and Lea 1972, Nakano et al. 1997). On longlines set in the morning and retrieved during the afternoon-evening, opah were among species that are caught more frequently as the depth of the fished hooks increased; i.e., higher catch rates at deeper depths (Nakano et al. 1997). Regular captures in high seas driftnets set in the evening and retrieved in the morning provide evidence that opah frequent waters within 10 m of the surface at night (Seki, in prep). Because captures in driftnets took place exclusively in the northern Transition Zone, it is still not clear whether this species exhibits diel vertical migration or more likely exhibit broad horizontal migrations and/or distributions within a preferential temperature range. In the northeast Atlantic, opah move northward into the waters of the North Sea and off Norway in the summer (Muus and Dahlstrom 1974). Opah catch around Hawaii is usually highest in the fourth quarter of the calendar year (Ito and Machado 1987).

Opah are generally solitary fish (Orkin 1950, Palmer 1986) and attains 185 cm in length and reportedly reach 227-282 kg in weight (Eschmeyer et al. 1983, Palmer 1986). Mean whole weight of opah taken in the Hawaii-based longline fishing fleet (1991-96) was 47.4 kg (104.5 lbs) (Ito and Machado 1997). Little to no information is available on spawning habits, age, or growth or migrations. A single large female caught in the early spring off the west coast of North America appeared to be nearly ready to spawn suggesting that spawning probably takes place during the spring months (Fitch and Lavenberg 1968). Off Scotland, ovaries in a 137 cm (4.5 ft) gravid female measured 290x70 mm and 240x70 mm and weighed 276 and 255 grams, respectively. The largest ova measured 0.82 mm in diameter (Herald 1939). Opah eggs and larvae are pelagic; larvae range from less that 4.7 mm to 10.5 mm at which size fin ray development is complete and juveniles resemble miniature adults in form (Olney 1984). Size at maturity is not known.

As adults, opah are midwater predators that feed on cephalopods (particularly oceanic squid), bony fishes (small pelagics) and to a lesser extent, crustaceans (Orkin 1950, Fitch 1951, McKenzie and Tibbo 1963, Eschmeyer et al. 1983, Heemstra 1986). Predators of opah are not known; no information is available on the diet and trophic relationships of larvae or juveniles.

Habitat Description for Moonfish (*Lampris guttatus*): Opah or Moonfish

	Egg	**Larvae**	**Juvenile**	**Adult**
Duration	Not known	Not known	Size at maturity is not known	Size at maturity is not known
Diet	Not known	Not known	Not known	As adults, opah are midwater predators that feed on cephalopods (particularly oceanic squid), bony fishes (small pelagics) and to a lesser extent, crustaceans
Distribution: General and Seasonal	Not known	Not known	Not known, unlikely differnet from adults	Opah are typically found well offshore in temperate and tropical waters of all the world's oceans, including the Mediterranean and Caribbean Seas. Orkin (1950) reported opah to be often taken in 183 m (100 fathoms) near the edge of the Continental Shelf.
Water Column	epipelagic	epipelagic	epipelagic	epipelagic
Bottom Type	N/A	N/A	N/A	N/A

Oceanic Features	Eggs subject to advection by prevailing currents	Larvae subject to advection by prevailing currents	Not known	Not known

Bibliography

Fitch, J. E. 1951. Studies and notes on some California marine fishes. Calif. Fish Game 37(2):111-120.

Heemstra, P. C. 1986. Family No. 117. Lampridae. In M. M. Smith and P. C. Heemstra (editors). Smiths’ Sea Fishes, p. 398, Springer-Verlag.

Ito, R. Y. and W. A. Machado. 1997. Annual report of the Hawaii-based longline fishery for 1996. Natl. Mar. Fish. Serv., NOAA, SW Fish. Sci. Ctr. Honolulu Lab. Admin. Rep. H-97-12, 48p.

McKenzie, R. A. and S. N. Tibbo. 1963. An occurrence of opah, *Lampris regius* (Bonnaterre), in the Northwest Atlantic. J. Fish. Res. Bd. Canada 20(4):1097-1099.

Miller, D. J. and R. N. Lea. 1972. Guide to the coastal marine fishes of California. Calif. Dep. Fish Game, Fish Bull. 157. 249 p. (addendum added 1976).

Muus, B. J. and P. Dahlstrom. 1974. Collins guide to the sea fishes of Britain and northwestern Europe. Collins, St. James Place, London, U.K. 244 p.

Nakano, H., M. Okazaki, and H. Okamoto. 1997. Analysis of catch depth by species for tuna longline fishery based on catch by branch lines. Bull. Nat. Res. Inst. Far Seas Fish. 34:43-62.

Olney, J. E. 1984. Lampriformes: development and relationships. In H. G. Moser, W. J. Richards, D. M. Cohen, M. P. Fahay, A. W. Kendall, Jr., and S. L. Richardson (editors), Ontogeny and systematics of fishes. pp. 368-379. Am. Soc. Ichthyol. Herpetol., Spec. Publ. 1.

Orkin, P. A. 1950. A history of the opah, *Lampris guttatus* (Brünnich). Scottish Naturalist 62(3):129-141.

Palmer, G. 1986. Lampridae. In P. J. P. Whitehead, M.-L. Bauchot, J.-C. Hureau, J. Nielson, and E. Tortonese (editors), Fishes of the western North Atlantic and the Mediterranean, Vol. 2, pp. 725-726, UNESCO, Paris, France.

Russo, J. L. 1981. Field guide to fishes commonly taken in longline operations in the western North Atlantic. NOAA Tech. Rep. NMFS Circular 435, 50 p.

Seki, M. P., Manuscr. in prep. Fishery atlas of the North Pacific high seas driftnet fisheries. National Marine Fisheries Service, NOAA, Southwest Fish. Sci. Center Honolulu Laboratory, 2570 Dole Street, Honolulu, HI 96822-2396.

6.19 Habitat Description for Oilfish Family (Gempylidae): the escolar (*Lepidocybium flavobrunneum*) and the oilfish (*Ruvettus pretiosus*)

Management Plan and Area

American Samoa, Guam, Main Hawaiian Islands (MHI), Northwestern Hawaiian Islands (NWHI), Commonwealth of the Northern Mariana Islands (NMI), Johnston Atoll, Kingman Reef, Palmyra Atoll, Jarvis Island, Midway Island, Howland and Baker Islands and Wake Islands.

In the Pacific, several species of snake mackerels (Family Gempylidae) are caught in pelagic fisheries. Of particular interest are the two most commonly taken in western Pacific longline fisheries: the escolar, *Lepidocybium flavobrunneum*, and the oilfish, *Ruvettus pretiosus*. For management purposes, the escolor and oilfish are generally classified under the miscellaneous pelagics.

Life History and General Description:

Neither species of snake mackerel is a target species in any fishery and as a result, very limited biological and ecological information pertaining to the species is currently available in the published literature. Both species were, however, among the more common incidental takes in the now defunct Asian high-seas driftnet fisheries and are a common bycatch in pelagic longline fisheries targeting tunas and swordfish. On Japanese research cruises to waters east of Hawaii, mean catch rate for escolar was 0.98 fish/1000 hooks; no oilfish were caught (Nakano et al. 1997). In two areas off the west coast of Africa, escolar catches were 0.20 and 0.17 fish/1000 hooks (Maksimov 1970). Between the two snake mackerel species, the escolar is more frequently caught and possesses the greater commercial value. Excessively high oil content in the flesh of the oilfish renders the species unpalatable as a food fish but historically has possessed value as a laxative (Fitch and Schultz 1978).

Both the escolar and the oilfish are widely distributed, typically found over the continental slope and offshore in all tropical and subtropical waters of the world's oceans but is apparently nowhere abundant (Parin 1986). In a commercial scale fishing effort conducted in the western Pacific, catch rates were highest where topographic relief was steepest, namely in the vicinity of shoals, reefs, and seamounts (Nishikawa and Warashina 1988).

Through the water column, escolar inhabit epipelagic waters from the surface to about 200 m, oilfish to the lower epipelagial-mesopelagic in excess of 700 m (Parin 1978, Nakano et al. 1997). In the vicinity of New Caledonia and New Hebrides, Fourmanoir (1970) reported catching escolar (74.3 to 91.8 cm SL) while fishing at depths of 110 to 195 m. Nakano et al. (1997) found similar catch rates for escolar throughout the water column and concluded no clear trend in escolar depth of capture. Escolar are also believed to vertically migrate upward at night to feed on pelagic fishes, crustaceans and especially squids (Nakamura and Parin 1993). Captures in high seas driftnets set in the evening and retrieved in the morning provide evidence that both the escolar and oilfish frequent waters within 10 m of the surface at night (Seki, in prep). Oilfish are typically solitary or in pairs when near the bottom. Like the escolar, oilfish feed predominantly on squids, also fishes and crustaceans (Parin 1986, Nakamura and Parin 1993).

Predators of juvenile escolar include yellowfin and albacore tuna, swordfish, and other escolars (Fourmanoir 1970, Maksimov 1970). Predators of adult escolar and oilfish are not known.

Little information is available on other life history aspects. From length frequencies, Maksimov (1970) concluded that escolar females grew faster than males but no ages were assigned. Based on the capture of larvae and juvenile stages of escolar, spawning seems to take place in the vicinity of oceanic islands or the coasts of large islands (Nishikawa 1982, 1987). Nishikawa (1982) also found all postlarvae forms of escolar were taken in horizontal subsurface net tows while all juveniles were caught at the surface suggesting differential ontogenetic habitats. In a similar pattern, oilfish were collected near topography particularly in warm waters of the western Pacific (Nishikawa 1987).

Escolar attain about 200 cm SL , most commonly to 150 cm (Nakamura and Parin 1993). Nakamura and Parin (1993) reports escolar weigh 6.5 kg at 77 cm SL (89 cm TL) and 13 kg at 91 cm SL (105 cm TL). Nishikawa and Warashina (1988) reported the relationship between body (fork) length (FL) and weight (in kg) for escolar as:

$W = 1.46 \times 10^{-5} \cdot FL^{2.96}$ (n=46, 59-95 cm FL).

Habitat Description for Oilfish Family (Gempylidae)

	Egg	**Larvae**	**Juvenile**	**Adult**
Duration	Not known	Not known	Not known	Not known
Diet	Not known	Not known	Not known, unlikely different than adults	Feed predominantly on squids, also fishes and crustaceans.
Distribution: General and Seasonal	Not known	Not known	Not known	Both the escolar and the oilfish are widely distributed, typically found over the continental slope and offshore in all tropical and subtropical waters of the world's oceans but is apparently nowhere abundant
Water Column	epipelagic	epipelagic, based on the capture of larvae and juvenile stages of escolar, spawning seems to take place in the vicinity of oceanic islands or the coasts of large islands	epipelagic, juveniles are caught at the surface suggesting differential ontogenetic habitats.	epipelagic, Through the water column, escolar inhabit epipelagic waters from the surface to about 200 m, oilfish to the lower epipelagial-mesopelagic in excess of 700
Bottom Type	N/A	N/A	N/A	N/A

Oceanic Features	Eggs are subject to advection be prevailing currents	Larvae are subject to advection be prevailing currents	Not known	Not known

Bibliography

Fitch, J. E. and S. A. Schultz. 1978. Some rare and unusual occurrences of fishes off California and Baja California. Calif. Fish and Game 64(2):74-92.

Fourmanoir, P. 1970. Notes ichtyologiques (II). 3. Distribution de *Lepidocybium flavobrunneum* Smith (1849) prés de la Nouvelle-Calédonie: (Gempylidae). O.R.S.T.O.M., sér. Océnogr., 8(3):43-45.

Maksimov, V. P. 1970. Some data on the biology of *Lepidocybium blavobrunneum* (Smith) in the eastern Atlantic. Voprosy Ikhtiologii, Acad. Sci. USSR, 10(1):40-45. [English translation, Scripta Technica, Inc.]

Nakamura, I., and N. V. Parin. 1993. FAO species catalogue. Vol. 15. Snake mackerels and cutlassfishes of the world (Families Gempylidaeand Trichiuridae). FAO Fish. Synopsis (125), vol. 15, 136 p.

Nakano, H., M. Okazaki, and H. Okamoto. 1997. Analysis of catch depth by species for tuna longline fishery based on catch by branch lines. Bull. Nat. Res. Inst. Far Seas Fish. 34:43-62.

Nishikawa, Y. 1982. Early development of the fishes of the family Gempylidae. I. Larvae and juveniles of escolar, *Lepidocybium flavobrunneum* (Smith). Bull. Far Seas Fish. Res. Lab., (19):1-14.

Nishikawa, Y. and I. Warashina. 1988. Escolar, *Lepidocybium flavobrunneum* (Smith), commercially fished in waters adjacent to the Pacific coast of Japan. Bull. Fra Seas Fish. Res. Lab., (25):145-162.

Parin, N. V. 1986. Gempylidae. In P. J. P. Whitehead, M.-L. Bauchot, J.-C. Hureau, J. Nielson, and E. Tortonese (editors), Fishes of the western North Atlantic and the Mediterranean, Vol. 2, pp. 967-973, UNESCO, Paris, France.

Seki, M. P., Manuscr. in prep. Fishery atlas of the North Pacific high seas driftnet fisheries. National Marine Fisheries Service, NOAA, Southwest Fish. Sci. Center Honolulu Laboratory, 2570 Dole Street, Honolulu, HI 96822-2396.

6.20 Habitat Description for Pomfret (family Bramidae): the sickle pomfret (*Taractichthys steindachneri*) and the lustrous pomfret (*Eumegistus illustris*)

Management Plan and Area
American Samoa, Guam, Main Hawaiian Islands (MHI), Northwestern Hawaiian Islands (NWHI), Commonwealth of the Northern Mariana Islands (NMI), Johnston Atoll, Kingman Reef, Palmyra Atoll, Jarvis Island, Howland and Baker Islands, Midway Island, and Wake Islands.

In the Pacific, several species of pomfret (Family Bramidae) are caught in pelagic fisheries. Of particular interest is the sickle pomfret, *Taractichthys steindachneri*, the species most commonly taken in western Pacific longline fisheries and the lustrous pomfret, *Eumegistus illustris*, caught both in the longline fishery and in the deep bottomfish snapper fishery. For management purposes, both the sickle and lustrous pomfret are generally classified under the miscellaneous pelagics and marketed commercially as "monchong".

Life History and General Description:

Neither species of pomfret is a target species in any fishery and as a result, very limited biological and ecological information pertaining to the species is currently available. Both species, as mentioned above however, are common incidental bycatch in western Pacific fisheries.

Adult and juvenile (30-150 mm SL) sickle pomfret are widely distributed in the tropical waters of the Pacific and Indian Oceans (Mead 1972). Lustrous pomfret are also known from the tropical Pacific and eastern Indian Ocean but unlike other bramids, are typically found in association with topography (e.g., near islands and over seamounts or submarine ridges) (Mead 1972, Prut'ko 1986, Chave and Mundy 1994).

Through the water column, sickle pomfret inhabit epipelagic waters to at least 300 m (Nakano et al. 1997). On longlines set in the morning and retrieved during the afternoon-evening, sickle pomfret were among the species that are caught more frequently as the depth of the fished hooks increased; i.e., higher catch rates at deeper depths (Nakano et al. 1997). Most of the lustrous pomfrets caught in exploratory deep water bottomfishing at seamounts off Hawaii were taken in depths less than 549 m (300 fathoms); no pomfret were caught at seamounts when the summit exceeded 457 m (250 fathoms) (Okamoto 1982).

There are no descriptions of food or feeding habits of the sickle pomfret. A single stomach collected by a NMFS research cruise contained a pelagic squid, *Moroteuthis* spp. (NMFS, unpubl.) Lustrous pomfret taken on bottom handline rigs off Hawaii (Okamoto 1982) as well as those caught in the Indian Ocean with trawl nets (Prut'ko 1986) fed on midwater fishes such as lanternfishes, crustaceans and some squid . Predators of juvenile pomfrets (both species) include tunas and swordfish (NMFS, unpubl.).

Sickle pomfret attain about 80 cm TL (Dotsu 1980). No maximum size for lustrous pomfret has been reported but a single 70 cm FL individual was taken bottomfishing at Johnston Atoll (Ralston et al. 1986). The range of pomfret weights in Okamoto's (1982) exploratory study off Hawaii was 2.2 - 9.6 kg and averaged 5.5 kg. He further reported the relationship between body (fork) length (FL) and weight (in kg) for escolar as:

$W = 3.0 \times 10^{-6} \cdot FL^{3.442}$ (n=75, 59-95 cm FL).

Trawl caught lustrous pomfret (n=100) in the Indian Ocean ranged from 44.0 to 67.0 cm SL and 2.36 to 7.05 kg in weight (Prut'ko 1986).

Little information is available on other life history aspects. A 60 cm sickle pomfret weighing 11 kg was estimated to be 8 years old (Smith 1986). A 78 cm TL mature female (originally identified as *T. longipinnis* but now considered a misidentified *T. steindachneri),* taken in the Southeast Pacific possessed ova spherical in shape and 1.2 mm in diameter (Dotsu 1980). The mature varies were small and about 90 g in weight, the gonadosomatic index (GSI) was less than 1 and the ovaries contained about 7.0 x 10^5 eggs (Dotsu 1980). The male to female ratio in the Indian Ocean collection of lustrous pomfrets was 1:1 and judging from the advanced maturation stages observed in the gonads, the school was in spawning condition (Prut'ko 1986).

Habitat Description for Pomfret (family Bramidae)

	Egg	**Larvae**	**Juvenile**	**Adult**
Duration	Not known	Not known	Not known	A 60 cm sickle pomfret weighing 11 kg was estimated to be 8 years old
Diet	N/A	Not known	There are no descriptions of food or feeding habits of the sickle pomfret.	There are no descriptions of food or feeding habits of the sickle pomfret. A single stomach collected by a NMFS research cruise contained a pelagic squid, *Moroteuthis* spp.
Distribution: General and Seasonal	Not known	Not known	Not known	Adult and juvenile (30-150 mm SL) sickle pomfret are widely distributed in the tropical waters of the Pacific and Indian Oceans. Lustrous pomfret are also known from the tropical Pacific and eastern Indian Ocean but unlike other bramids, are typically found in association with topography (e.g., near islands and over seamounts or submarine ridges)
Water Column	epipelagic	epipelagic	epipelagic	Through the water column, sickle pomfret inhabit

				epipelagic waters to at least 300 m. Most of the lustrous pomfrets caught in exploratory deep water bottomfishing at seamounts off Hawaii were taken in depths less than 549 m (300 fathoms); no pomfret were caught at seamounts when the summit exceeded 457 m (250 fathoms.
Bottom Type	N/A	N/A	N/A	N/A
Oceanic Features	Eggs are subject to advection by prevailing ocean currents	Larvae are subject to advection by prevailing ocean currents	Not known	Not known

Bibliography

Chave, E. H. and B. C. Mundy. Deep-sea benthic fish of the Hawaiian Archipelago, Cross Seamount, and Johnston Atoll. Pac. Sci. 48:367-409.

Dotsu, Y. 1980. A mature female of the bigscale pomfret, *Taractichthys longipinnis* (Bramidae) with notes on the ripe eggs. Jpn. J. Ichthyol. 27(1):88-89.

Mead, G. W. 1972. Bramidae. Dana Rep. (81), 166 p.

Nakano, H., M. Okazaki, and H. Okamoto. 1997. Analysis of catch depth by species for tuna longline fishery based on catch by branch lines. Bull. Nat. Res. Inst. Far Seas Fish. 34:43-62.

Okamoto, H. 1982. Deep bottomfish surveys - Hawaii. Completion report prepared for the Pacific Tuna Development Foundation under Project no. 35, Deep Bottom Fishing Surveys - Hawaii Div. Aquat. Resour., Dep. Land Natur. Resour., Honolulu, 21 p.

Prut'ko, V. G. 1986. Collection of pomfret, *Eumegistus illustris* (Bramidae), in the Indian Ocean. J. Ichthyol. 25(5):151-154.

Smith, M. M. 1986. Family No. 207. Bramidae. In M. M. Smith and P. C. Heemstra (editors). Smiths' Sea Fishes, p. 633-636, Springer-Verlag.

6.21 Habitat description for bullet tuna (*Auxis rochei*) and frigate tuna (*A. thazard*)

Management Plan and Area

American Samoa, Guam, MHI, NWHI, Northern Mariana Islands, Johnston Atoll, Kingman Reef, Palmyra Atoll, Jarvis Island, Midway Island, Howland and Baker Islands and Wake Islands.

Life History and General Description

This description is based on the following summary documents: Yesaki and Arce (1994), Collette and Nauen (1983) and Uchida (1981).

The genus *Auxis* is a member of the Thunni tribe and the subfamily Scombrinae. For management purposes, regulations identify these fish only to the generic level, but only two cosmopolitan species are currently recognized in this genus. However, there has been a lot of synonymy in scientific names for the species; the two species are very similar in appearance and usually only reported to the generic level in landings reports. *Auxis* are considered both the most primitive and the smallest of tunas in the Thunni tribe. No sub-species are recognized. No information on stock separation is given in the review articles. Hybrids of the two species have been produced under artificial rearing conditions, but none lived beyond a month.

The genus is distributed worldwide in tropical and subtropical waters. Because of their similar appearance, differential distribution is hard to determine. They are confined to neritic waters of continental margins but have also been reported from coastal waters of oceanic islands in the Pacific including Hawaii. Total latitudinal range extends from northern Japan (about 45ºN) to southern New Zealand (almost 50ºS) in the west and from northern California to northern Chile along the American coast. The 20ºC isotherm has been suggested as a range limit, but optimal temperature is probably higher. In any case, it seems clear that they have a fairly wide temperature tolerance. Preference for high fertility coastal waters has been reported from East Africa.

There is little information on migration. Studies conducted in Japan suggest seasonal migration with northward movement in summer and southward movement in winter. *Auxis* have a strong schooling instinct and form dense schools segregated by size. The two species often form mixed schools and have also been reported to school with other tunas and tuna-like fishes.

The largest reported frigate tuna (*A. thazard*) is 53 cm; bullet tuna (*A. rochei*) rarely exceed 30 cm. Maximum ages are estimated to be 2 years and 1 year, respectively.

Auxis are heterosexual and do not exhibit sexual dimorphism. Fecundity estimates are 78,000–717,900 eggs for frigate tuna and 52,000–162,00 for bullet tuna. They generally spawn inshore, although (Klawe 1963) found that while spawning occurred inshore at Baja, California, it occurred in oceanic waters further south. *Auxis* also spawn around oceanic islands, including Hawaii, based on larval distribution and the occurrence of males of both species with freely flowing milt caught at Oahu. In general is appears that these tunas spawn in the warmer regions of their total range, but the precise distribution is unknown.

Yesaki and Arce (1994) state that "there are two spawning seasons for bullet tuna, and most probably frigate tuna, at least in the equatorial regions of their distributions."

Worldwide most *Auxis* are caught in the Philippines; in 1988, total of 107,000 mt were landed there, 61% of the world total. Yesaki and Arce (1994) provide a detailed review of the Philippine fishery. These authors also state that "the world catch is low considering it is generally acknowledged that *Auxis* is the most abundant tuna, in numerical terms, in the world's oceans." The landings for these species are not reported separately in the western Pacific region; however, total "miscellaneous tunas" reported for the region in 1996 is 12,558 lbs (5.70 mt) (WPRFMC 1997). Clearly commercial landings of *Auxis* are negligible both in terms of total western Pacific region landings and for *Auxis* in the Pacific.

Egg and Larval Distribution

Eggs are pelagic and described by (Uchida 1981) as "perfectly spherical, [having] a colorless homogeneous yolk mass and an average diameter of 0.87 mm (range of 0.88–1.09 mm." The eggs of both species hatch within 2 days. Larval/post-larval stages last to about 2 weeks. Uchida (1981) provides a comprehensive description of larval morphological characteristics, including differentiation among the species and larval and juvenile development.

Uchida (1981) states that temperature "is clearly a highly important variable in explaining the distribution of *Auxis* larvae." Optimum temperature is reported as 27.0º–27.9ºC. The larvae are reported as only occurring above the thermocline. Salinity may also affect distribution, and larvae are reported for a relatively narrow range, 33.2–35.4 ppt. They may also undergo diel migration, being more common near the surface at night. Larval habitat is generally coastal, as with adults.

Juvenile

No information is provided in the review papers on juvenile distribution, but as a neritic epipelagic species juveniles probably occur in the same coastal habitat as adults. Planktonic crustaceans and fishes are the main prey items of juveniles, including larval copepods and decapods.

Adult

Frigate tuna reach maturity at about 30–35 cm. In one study all fish measured were mature by 42.1 cm. Bullet tuna were found to reach first maturity in the Philippines 17.0 cm. A study from India indicated that 50% maturity was 24.0 cm for males and 23.8 cm for females.

Adults feed on a wide variety of organisms with fish the most common item, followed by crustaceans. Common prey fishes include herring and herring-like fish, anchovies and other small fishes. Adults also cannibalize their young and are reported to feed on plankton in Japanese waters. In a study from Indian waters fish formed the major constituent of the juvenile diet, while crustaceans were prevalent in the diet of adults. Frigate tuna also are known to occasionally prey on squid.

Essential Fish Habitat: Tropical species complex

There is relatively little information on the habitat preferences of these two species. They are also not important to managed fisheries in the western Pacific region. Nonetheless, given that they are cosmopolitan neritic epipelagic species, the inshore waters may be considered EFH, although it cannot be defined with any precision.

Habitat description for bullet tuna (*Auxis rochei*) and frigate tuna (*A. thazard*)

	Egg	**Larvae**	**Juvenile**	**Adult**
Duration	about 40 hours	2 weeks	1 year or less	*A. thazard*—2 years, *A. rochei*—1 year
Diet	NA	not reported	planktonic crustaceans and fish	opportunistic feeders: fish, crustaceans
Distribution: General and Seasonal	neritic, coastal areas in the warmer waters throughout range	as with eggs	differential distribution not known	cosmopolitan in tropical and subtropical neritic / coastal waters, Pacific latitudinal range roughly 45ºN–45ºS in west, somewhat less in east
Location	nereitc/inshore ? also found offshore but generally not mid-ocean	as with eggs	neritic / inshore	neritic
Water Column	epipelagic	epipelagic	epipelagic	epipelagic
Bottom Type	NA or unknown	NA or unknown	NA or unknown	NA or unknown
Oceanic Features	unknown	unknown	unknown	unknown

Bibliography

Collette BB, Nauen CE. 1983. An annotated and illustrated catalogue of tunas, mackerels, bonitos and related species known to date. FAO species catalogue. Volume 2, Scombrids of the world. Rome: Food and Agriculture Organization. 118 p.

Klawe WL. 1963. Observations on the spawning of four species of tuna (*Neothunnus macropterus, Katsuwonus pelamis*, *Auxis thazard* and *Euthynnus lineatus*) in the eastern Pacific Ocean, based on the distribution of their larvae and juveniles. Inter-Am Trop Tuna Comm Bull 6:447–540.

Uchida RN. 1981. Synopsis of biological data on frigate tuna, *Auxis thazard,* and bullet tuna, *A. rochei.* Washington: NOAA (NMFS). 67 p. NOAA technical report nr NMFS Circular 436 (FAO fisheries synopsis nr 124).

[WPRFMC] Western Pacific Regional Fishery Management Council. 1997. Pelagic Fisheries of the Western Pacific Region 1996 Annual Report. Honolulu: WPRFMC. 26 p + appendices.

Yesaki M, Arce F. 1994. A review of the *Auxis* fisheries of the Philippines and some aspects of the biology of frigate (*A. thazard*) and bullet (*A. rochei*) tunas in the Indo-Pacific region. In: Shomura RS, Majkowski J, Langi S, editors. Interactions of Pacific tuna fisheries. Volume 2, Papers on biology and fisheries. Proceedings of the First FAO Expert Consultation on Interactions of Pacific Tuna Fisheries; 1991 Dec 3–11; Noumea, New Caledonia. Rome: Fisheries and Agriculture Organization. p 409–39. FAO fisheries technical paper nr 336/2.