MARINE VERTEBRATES AND LOW FREQUENCY SOUND

TECHNICAL REPORT FOR LFA EIS

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TABLE OF CONTENTS:

TABLE OF CONTENTS

TABLE OF CONTENTS

TABLE OF CONTENTS

TABLE OF CONTENTS

TABLE OF CONTENTS

TABLE OF CONTENTS

TABLE OF CONTENTS

TABLE OF CONTENTS

TABLE OF CONTENTS

TABLE OF CONTENTS

TABLE OF CONTENTS

EXECUTIVE SUMMARY

INTRODUCTION

Over the past 50 years, economic and technological developments have dramatically increased the human contribution to ambient noise in the ocean. The dominant frequencies of most human-made noise in the ocean is in the low-frequency range (defined as sound energy below 1000Hz), and low-frequency sound (LFS) may travel great distances in the ocean due to the unique propagation characteristics of the deep ocean (Munk et al. 1989). For example, in the Northern Hemisphere oceans low-frequency ambient noise levels have increased by as much as 10 dB during the period from 1950 to 1975 (Urick 1986; review by NRC 1994). Shipping is the overwhelmingly dominant source of low-frequency manmade noise in the ocean, but other sources of manmade LFS including sounds from oil and gas industrial development and production activities (seismic exploration, construction work, drilling, production platforms), and scientific research (e.g., acoustic tomography and thermography, underwater communication). The SURTASS LFA system is an additional source of human-produced LFS in the ocean, contributing sound energy in the 100-500 Hz band.

When considering a document that addresses the potential effects of a low-frequency sound source on the marine environment, it is important to focus upon those species that are the most likely to be affected. Important criteria are: 1) the physics of sound as it relates to biological organisms; 2) the nature of the exposure (i.e. duration, frequency, and intensity); and 3) the geographic region in which the sound source will be operated (which, when considered with the distribution of the organisms will determine which species will be exposed). The goal in this section of the LFA/EIS is to examine the status, distribution, abundance, reproduction, foraging behavior, vocal behavior, and known impacts of human activity of those species may be impacted by LFA operations. To focus our efforts, we have examined species that may be physically affected and are found in the region where the LFA source will be operated. The large-scale geographic location of species in relation to the sound source can be determined from the distribution of each species. However, the physical ability for the organism to be impacted depends upon the nature of the sound source (i.e. explosive, impulsive, or non-impulsive); and the acoustic properties of the medium (i.e. seawater) and the organism.

Non-impulsive sound is comprised of the movement of particles in a medium. Motion is imparted by a vibrating object (diaphragm of a speaker, vocal chords, etc.). Due to the proximity of the particles in the medium, this motion is transmitted from particle to particle in waves away from the sound source. Because the particle motion is along the same axis as the propagating wave, the waves are longitudinal. Particles move away from then back towards the vibrating source, creating areas of compression (high pressure) and areas of rarefaction (low pressure). As the motion is transferred from one particle to the next, the sound propagates away from the sound source. Wavelength is the distance from one pressure peak to the next. Frequency is the number of waves passing per unit time (Hz). Sound velocity (not to be confused with particle velocity) is the product of wavelength and velocity, and is approximately 1500 m/sec in seawater. Sound impedance is loosely equivalent to the resistance of a medium to the passage of sound waves (technically it is the ratio of acoustic pressure to particle velocity). A high impedance means that acoustic particle velocity is small for a given pressure (low impedance the opposite). When a sound strikes a boundary between media of different impedances, both reflection and refraction, and a transfer of energy can occur. The intensity of the reflection is a function of the intensity of the sound wave and the impedances of the two media. Two key factors in determining the potential for damage due to a sound source are the intensity of the sound wave and the impedance difference between the two media (impedance mis-match). The bodies of the vast majority of organisms in the ocean (particularly phytoplankton and zooplankton) have similar sound impedence values to that of seawater. As a result, the potential for sound damage is low; organisms are effectively transparent to the sound – it passes through them without transferring damage-causing energy.

Due to the considerations above, we have undertaken a detailed analysis of species which met the following criteria:

1) Is the species capable of being physically affected by LFS? Are acoustic impedence mis-matches large enough to enable LFS to have a physical affect or allow the species to sense LFS?
2) Does the proposed SURTASS LFA geographical sphere of acoustic influence overlap the distribution of the species?

Species that did not meet the above criteria were excluded from consideration. For example, phytoplankton and zooplankton species lack acoustic impedance mis-matches at low frequencies to expect them to be physically affected SURTASS LFA.

Vertebrates are the organisms that fit these criteria and we have accordingly focused our analysis of the affected environment on these vertebrate groups in the world's oceans: fishes, reptiles, seabirds, pinnipeds, cetaceans, pinnipeds, mustelids, sirenians (Table 1).

SEA TURTLES

Summary

There are eight species of extant sea turtles in two families Dermochelyidae (one species) and Cheloniidae (seven species). All marine turtles are listed as CITES Appendix I species. The green turtle (*Chelonia mydas*) and loggerhead turtle (*Caretta caretta*) are listed as Threatened Species under the U. S. Endangered Species Act. The hawksbill (*Eretmochelys imbricata*), olive ridley (*Lepidochelys olivacea*), Kemp's ridley (*L. kempi*), and leatherback (*Dermochelys coriacea*) are listed as Endangered Species. The flatback turtle *Natator depressus* is unlisted, perhaps due to lack of data, but is a shallow near shore species endemic to Australia and is therefore not likely to be exposed to LFA sounds.

All sea turtles come ashore on specific beaches to lay eggs in holes dug in the sand. Adults are vulnerable predation, disturbance, and pollution when concentrated off shore of these nesting beaches and, for females, when on the beach laying eggs.

The leatherback is primarily pelagic, but the other marine turtles spend most of their time in relatively shallow waters where they feed close to or on the bottom. However, all but the flatback turtle have a pelagic juvenile stage, and as adults migrate across pelagic waters between feeding and breeding grounds. They are capable of relatively deep dives and can spend more than 75% of their time underwater.

Data on vocalization and hearing are few. Leatherbacks, and perhaps other species, make low frequency sounds, but their functional significance, if any, is unknown. It is likely that all species hear low frequency sound as adults. It has been hypothesized that females use the low frequency sound of surf to orient towards nesting beaches, however, this has not been tested.

In a pen experiment, sub-adult loggerhead turtles avoided a loud low frequency sound source. This study has not been followed up in the wild or with other species.

Low frequency sound can impact animals by causing tissue damage; short-term behavioral changes; and, long-term behavioral changes. Tissue damage occurs only at very high dB levels that can be estimated by modeling and measured in laboratory experiments. These have not been determined for marine turtles, but it is unlikely that marine turtles are more sensitive to sound induced tissue damage than are marine mammals.

The paucity of data make it difficult to determine if there are any potential short-term or long-term behavioral impacts of low frequency sound on sea turtles. It is possible that loud low frequency sound could impact turtle populations if it caused them to avoid an area of highly concentrated prey for long periods of time. However, because the LFA source moves continuously this is unlikely. A more likely, but only theoretical, impact of low frequency sound is its possible impacts on movements on and off the breeding beaches of both females and hatchlings. This potential problem could be easily resolved with play back experiments in the field and laboratory.

SEABIRDS

Summary

There are more than 270 species of seabirds in five orders: Sphenisciformes (penguins); Podicipediformes (loons and greebes); Procellariformes (shearwaters, albatrosses and petrels); Pelecaniformes (pelicans, boobies, cormorants, and frigatebirds); and, Charadriiformes (gulls, terns, puffins and auklets). They are can be important top level marine predators and have tremendous impacts on the ecology of their nesting islands. Seabirds are almost exclusively socially monogamous and nest on islands, offshore rocks, isolated areas of the mainland or other predator free sites where they can form huge colonies. Relative to terrestrial birds they tend to have low reproductive potentials; many species only laying one egg per year. The main threat to seabird populations is introduced mammalian predators on breeding islands. Hunting and egging have been problems in the past and continue to threaten seabirds in some areas. Fisheries interactions (competition and entanglement) and pollution have also had dramatic impacts on seabird populations.

Each order has species that dive to more than 25m depth, and occur in the zone of LFA activities. There are few data on hearing in seabirds, and even less on underwater hearing. However, studies with other species have shown that birds are highly sensitive to low frequency sounds in air. Thus, it is likely that many diving seabirds can hear low frequency sound. However, seabirds which occur in areas where LFA may operate are generally shallow divers. In addition, seabirds spend a very small fraction of their time submerged, and they can rapidly disperse to other areas if disturbed. For these reasons, seabirds will be excluded from further evaluation.

Large numbers of seabirds concentrate on breeding colonies during the breeding season. In some cases close to 100% of breeding adults can be on just one or a few islands during the peak of the breeding season. These concentrations combined with their generally low potential reproductive rate make some seabird populations particularly susceptible to negative human impacts. Significant seabird colonies are often also important breeding areas for pinnipeds and sea turtles, and may also have concentrations of cetaceans in near-shore waters

MUSTELIDAE (OTTERS)

Summary

There are 6 species of otters that enter marine waters, but only 2 that are primarily marine; the Sea otter (*Enhydra lutris*) and the Chungungo (*Lontra felina).* These two species, and the river otters that occasionally enter marine waters, are almost exclusively shallow water feeders on fish and benthic invertebrates. Therefore, they are unlikely to be impacted by LFA activities and are not discussed in the full report.

PINNIPEDS

Summary

The natural history of pinnipeds is summarized in Gentry (1998). In the United States, all marine mammals (common, threatened, and endangered) are protected under the Marine Mammal Protection Act (MMPA). In addition, some species are protected by the endangered species act (ESA) and are internationally protected as CITES-designated species. Human activities which may influence marine mammal behavior or cause physiological damage is considered to constitute harassment, a violation of the MMPA and ESA.

Pinnipeds are globally distributed aquatic mammals with some specializations for terrestrial life. The suborder includes the true seals (family Phocidae), eared seals (family Otariidae), and the walrus (family Odobenidae). True seals and walruses swim with undulating motions of the rear flippers driven by back muscles, and move caterpillar-like on land. Otariids swim with their foreflippers and move on all fours on land. On average, pinnipeds are larger than other mammals (range 50-2,000kg). The otariids retain more extensive ties with land: otariids suckle and mate on land while phocids suckle on land but mate at sea.

The otariids include 14 extant species in 7 genera. Most otariids are found in temperate or sub-polar waters. Tropical species are generally located in regions of locally high productivity. Many otariids spend the majority of their time in coastal regions unlikely impacted by LFA operations. The general biology of extant otariids is presented in Table 1. Several species that are listed as special status are discussed in more detail (northern sea lion (*Eumetopias jubata*), northern fur seal (*Calorhinus ursinus*), Guadalupe fur seal *Arctocephalus townsendii*)).

The phocids include 17 extant species in 10 genera. Most phocids are confined to Arctic and Antarctic waters and so would not be impacted by LFA operations. Eight species occur in non polar waters and are discussed below. They are the Hawaiian and Mediterranean monk seals (*Monochas monachus* and *M. shauinslandi*), the northern and southern elephant seals (*Mirounga angustirostris* and *M. leonina*), the grey seal (*Halichoerus grypus*), and three species in the genus *Phoca*: the ribbon, harbor, and spotted seals (*P. fasciata, P. vitulina,* and *P. largha*).

All pinnipeds produce single, precocious young on land and males play no role in raising offspring. While otariid females feed during lactation (making regular trips to sea to forage), phocid females generally fast while suckling. Because of this strategy, otariids can only rear young in limited sites near extremely productive marine areas. Due to the limited number of such sites, a situation arises where males can monopolize mates by defending the few pupping sites. This leads to the polygynous breeding system found in most pinnipeds. Generally, the restriction for otariids in finding productive offshore foraging areas adjacent to pupping sites leads to more extreme polygyny in otariids than phocids. Most pinnipeds gather to bear young and breed once a year. This is facilitated by delayed implantation.

Pinnipeds are generally high-level consumers taking fish, cephalopods and crustaceans. Phocids are often benthic feeders; fur seals tend to feed on small surface-schooling fish; sea lions tend to specialize on large or adult stages of higher-trophic-level species found over continental shelves. While a few species (e.g. monk seals, Galápagos fur seals, Galápagos sea lion) are found at low latitudes in tropical or sub-tropical waters, most species are found in temperate or polar waters. Foraging regions are often associated with fronts or upwelling zones.

Pinniped visual systems are adapted to low light levels, consistent with feeding at depth or at night. However, the eye structure also allows for visual acuity in air. The ears of otariids are similar to carnivore ears while phocid ears are more water-adapted. Individuals of both groups produce aerial sounds, and many also produce underwater sounds. Airborne vocalizations have been associated with territoriality and dominance displays, and mother-pup recognition. The context and function of subsurface vocalizations is not clear. Many appear to be socially important as they are often produced during the breeding season (e.g. harbor seals). Thus, many species must be able to hear well both above and below the water. Sensitivity to sounds at frequencies above 1 kHz has been well established. Fewer studies have examined sensitivity to LFS. However, several generalizations may be made: 1) the dominant frequencies in the vocalizations of walruses and hooded seals are below 1000 Hz (Schevill et al. 1966; Ray and Watkins 1975). 2) Audiograms for ringed, harbor, and harp seals demonstrate hearing to at least as low as 760 Hz, the hearing threshold is flat from 1-50 kHz between 65 and 85 dB re 1 µPa (Møhl 1968; Terhune and Ronald 1972, 1975; Terhune 1991). In a recent study, Kastak (1996) found that in pinniped species (California sea lion, harbor seal, elephant seal) hearing sensitivity is decreased at frequencies below 6400 Hz in sea lions and harbor seals, but the animals are still able to hear low frequency sounds below 100 Hz. While elephant seals have not been recorded to produce underwater LFS (LeBoeuf pers comm.), they were found to be the most sensitive to underwater LFS (Kastak 1996). The mean frequencies of airborne calls of northern elephant seals range from 147-334 Hz for adult males (LeBoeuf and Peterson 1969; LeBoeuf and Petrinovich 1974) and 500-1000 Hz for adult females (Bartholomew and Collias 1962). Because elephant seal hearing sensitivity has been shown to be greater underwater (Kastak 1996), it is logical to infer this species to be most sensitive to human-produced LFS.

All of the phocid species discussed below occur in pelagic waters, dive for their food, and breed on land or pack ice. The monk seals are rare and protected as endangered species. The Mediterranean monk seal is the most endangered of all pinnipeds; it is on the verge of extinction due to competition with commercial fisheries, habitat destruction, pollution, human disturbance, and harassment by fishermen. The other six species have large, in some cases expanding, populations. All eight species of true seals discussed here are likely capable of producing and hearing low frequency sound. There is no strong evidence that loud low frequency sound causes seals to avoid particular areas or alter their behavior. Loud, low frequency noise around breeding colonies could interfere with social signals including contact calls between mothers and pups, however, most aquatic social signals are above 1kHz

CETACEANS

Summary

In the United States, all marine mammals (common, threatened, and endangered) are protected under the Marine Mammal Protection Act (MMPA). In addition all *Balaenoptera* whales are protected by the endangered species act (ESA). Many animals are also internationally protected as CITES-designated species. Human activities that can influence marine mammal behavior or cause physiological damage are considered to constitute harassment, a violation of the MMPA and ESA.

A general description of the order Cetacea can be found in Leatherwood et al. (1983a) and Simmonds and Hutchinson (1996). The order includes two living suborders: Mysticeti (baleen whales) and Odontoceti (toothed whales). Cetaceans are highly modified marine mammals that have secondarily returned to the ocean. Unlike other groups, cetaceans have forsaken terrestrial phases in their life history. The order includes a diverse group with a wide range in body size. All species have lost their hind limbs and have developed flukes, flippers and blubber to cope with the high density and high heat conductance of seawater. Cetaceans have evolved to exploit virtually all productive marine, estuarine, and many river habitats. Some (e.g. blue, beaked, and pygmy and dwarf sperm whales) occur individually or in small groups while others (e.g. killer and sperm whales) are found in larger groups of related individuals. Some (e.g. many of the pelagic dolphins) form large, groups with functional sub-units. Most major cetacean groups feed upon fish, squid or crustaceans over pelagic waters within the LFA operating area. While most species feed in waters less than 200m, a few species (e.g. sperm whales, bottlenosed whales) are capable of diving to at least 2,000m. Their distributions are roughly correlated with that of their prey and they are often associated with continental shelves, fronts, upwelling areas, or convergence zones. Generally, cetaceans spend over 90% of their lives below the water surface.

All cetaceans bear a single, precocious young and have generally low reproductive rates. Many populations have been reduced due to prior exploitation. Social systems range from solitary (e.g. blue whales) to highly social (e.g. sperm whales). While some species have well-defined breeding areas (e.g. gray whales, right whales), most species breed at sea in dispersed regions at times which correspond to high productivity. Many species undergo seasonal north-south migrations that track seasonal peaks in prey availability.

The sense of smell in cetaceans appears to be absent, and they lack taste buds. However, the sense of hearing in most cetceans is highly developed. Many cetaceans find prey by passive listening, active echolocation, or other forms of acoustic imaging. Cetaceans can hear a wide range of frequencies, including LFS, and can accurately detect the directions of incoming sounds. Information on sounds produced and hearing thresholds in cetaceans are limited, but some generalizations can be made: 1) the dominant frequencies in the vocalizations of toothed whales range from several hundred Hz to150 kHz (Cummings and Fish 1971; Popper 1980; Richardson et al. 1995). 2) Underwater audiograms of belugas, killer whales, and horbor porpoise demonstrate hearing at frequencies below 1,000 Hz with optimal sensitivity around 10-80 kHz (Andersen 1970a; Hall and Johnson 1972; White et al. 1978; Awbrey et al. 1988; Johnson et al. 1989), 3) most vocalizations of baleen whales contain frequencies below 1,000 Hz and source frequencies above 170 dB (Norris et al. 1977; Thompson et al. 1979; Watkins and Wartzok 1985).

Shock waves, such as those caused by explosions can cause direct tissue damage to cetaceans. Organisms with air cavities such as fish with swim bladders, and air-breathing vertebrates are particularly vulnerable to underwater explosions (Gordon and Moscrop 1996). Because ears are adapted to be highly sensitive to sound, they are vulnerable to physical damage from high sound levels and rapid pressure changes (as occurs with explosions). In humans, sounds become uncomfortably loud at 100-120 dB above threshold at 1 kHz (126-146 dB). A sound 155 dB above threshold (176-196 dB) is high enough to cause immediate damage and permanent threshold shift (PTS) (Kryter 1985). Richardson et al. (1991) found that belugas have an auditory threshold of 40 dB. This suggests, by analogy, that belugas experience discomfort at sounds of 140-160 dB (Gordon and Moscrop 1996). If cetaceans such as baleen whales have similarly low auditory thresholds for LFS, then sound levels of 195-210 dB could result in immediate damage and PTS. Such levels could be experienced close to seismic arrays and other powerful sound sources such as supertankers and SURTASS LFA.

Following explosions for excavation off Newfoundland two humpback whales which were trapped in fishing nets were found to have badly damaged ear structures likely cause by explosive shock waves (Ketten et al. 1993). It is important to note that cetologists studying this population noted no changes in residency, resight patterns, or movements (Lien et al. 1993). Exposure to high sound levels may not result in acute damage but lead to an increasing in the hearing threshold (temporary threshold shift – TTS). The cumulative impacts of repeated incidents of TTS is not clear, but may lead to gradual hearing loss and eventual PTS. In humans, sound intensity of 80-100 dB above threshold at peak sensitivity can cause TTS. If we again assume that baleen whales have a threshold of around 40 dB re 1 µPa, then noise levels of 120-140 dB re 1 µPa could cause TTS. If the ability to detect faint sounds is important to the life history of the cetacean, loss of sensitivity could affect survival or reproductive success.

In acoustically oriented animals many biologically important sounds can be masked by increased levels of background noise. These include passive cues for foraging, sounds important in navigation, and social sounds important in coordinating movement and breeding. Au et al. (1985) found that belugas shifted the frequency and increased the intensity of their echolocation signals in response to elevated background noise levels. Such shifts may reduce the efficiency of vocal signaling in cetaceans (Gordon and Moscrop 1996).

Because all species of mysticete whale recorded to date produce loud, species-specific signals in the low-frequency band, they are particularly at risk from manmade LFS. It is unclear whether low-frequency signals produced by most mysticetes are used for communication, orientation, navigation, or detection of predators and prey. However, disruption of any of these functions could interfere with normal activities and behavior, and potentially impact the reproductive success of individuals and eventually the size of a population. Thus, it is difficult to accurately predict the potential impact of manmade LFS on important social and ecological functions.

The beaked whales (e.g. *Ziphius*, *Mesoplodon*) are believed to be pelagic, deep-diving cetaceans that feed primarily upon squid. The beaked whales are poorly understood– new species are regularly encountered and described– making it difficult to assess the potential impacts of human-produced LFS on their reproduction and ecology. It is clear, however, that sound plays an important role in their life history and thus is of particular concern.

Anthropogenic sounds in the ocean that mask sounds associated with foraging can decrease these animals' ability to find and capture food. This can decrease population growth rates if: 1) population growth is limited by food rather than predation or disease; and, 2) the species in question does not regulate the population size of its prey. In addition, many marine animals use sound to maintain contact between group members (e.g. females and their offspring), or for other forms of communication. Again, anthropogenic noise in the ocean that masks these communication sounds can decrease the ability of individuals to maintain contact with group members. For example, Payne and Webb (1971) estimated that for blue and fin whales, the increase in ambient noise levels generated by human activities may have reduced the area over which animals could communicate several orders of magnitude from ca. 6×10^5 nmi^2 under pre-shipping conditions to ca. 6×10^3 nmi^2 under present shipping conditions. Examples of the potential effects of such reductions could include: increased calf mortality or changes in group spacing to closer than optimal spacing. Consequently, the most serious potential impacts of LFA are likely its potential contribution to a long-term decrease in the foraging efficiency or communication efficiency of marine animals. Because some marine animals (e.g. large social odontocete cetaceans such as *Pyseter, Hyperoodon*, and *Berardius*) have extremely low potential population growth rates, are poorly known, and difficult to study, small decreases in their reproductive rate could have serious impacts on population size yet be undetected by any known monitoring system.

The most endangered cetaceans are the river dolphins (*Lipotes vexelifer, Platanista* sp.) and the Gulf of California harbor porpoise (*Phocoena sinus).* They are not found in the area of LFA operations.

Recently, considerable progress has been made in understanding the potential mechanisms by which LFS could cause physical damage to a marine mammal's auditory system (Ketten 1992, 1994), and a predictive body of literature exists based upon human subjects. Some progress has also been made in understanding some of the potential short-term impacts of human-produced LFS on marine mammals (review by Richardson et al.

1995). Observed short-term responses include silencing, disruption of activity, and movement away from the source (e.g. Watkins and Schevill 1975; Watkins et al. 1985; Finley et al. 1990).

It is useful to note that studies on the effects of boat traffic on cetacean behavior have found: 1) belugas avoided ships at ranges of 45-60 km, were displaced by as much as 80 km, and took up to 48 hours to resume normal activity (Cosens and Dueck 1988; Finley et al. 1990). 2) Narwhals exposed to approaching ships exhibited a "freeze" response and formed tight pods (Finley et al. 1990). 3) Belugas did not react to oil-industry-related noise up to 60 dB re 1 µPa above ambient (Finley et al. 1990). 4) Humpback whales avoid approaching vessels when noise was strong or rapidly changing (Watkins 1986; Beach and Weinrich 1989). 5) Many species (especially calves) of cetacean approach ships (e.g. Bryde's whales, bottlenosed whales). 6) Gray whales, humpback whales, fin whales, and blue whales exhibit short-term flight when approached by boats (Reeves 1977; Swartz and Cummings 1978; Swartz and Jones 1978, 1981; Jurasz and Jurasz 1979; Baker et al. 1982, 1983; Edds and Macfarlane 1987). 7) Sperm whales appeared to habituate to the presence of whale-watching boats with powerful motors (Gordon et al. 1992).

Studies of the effects of industrial noise on cetaceans have found: 1) migrating gray whales exhibited an 80% avoidance reaction to oil exploration sounds played at 130 dB re 1 µPa (Malme et al. 1983). 2) Migrating gray whales exhibited a 10% avoidance response to airgun sounds played at 164 dB re 1 µPa (Malme et al. 1983). 3) Bowhead whales avoided full seismic arrays (broadband received level at 115 dB) at a range of 2 km (Richardson et al. 1986). 4) Mate et al. (1994a) found that sperm whales moved out of areas in response to seismic surveys. 5) Bowles et al. (1994) reported that sperm whales stopped vocalizing in response to weak seismic pulses from a distant ship (>200 km distant).

Reactions of cetaceans to sonar sounds include: 1) cessation of activities and scattering away from sonar signals between 3.25 and 8.4. 2) Increased strandings of dead beaked whales correlated with the times of naval operations (Simmonds and López-Jurado 1991) found. 3) Twelve Cuvier's beaked whales stranded alive along the coast of Greece after tests of naval sonar systems (Frantzis 1998). 4) Cessation of sperm whale echolocation clicks in reaction to an acoustic thermography sound source (Bowles et al. 1994).

Longer-term studies have inferred that: 1) increased human activities in gray whale calving lagoons led to abandonment of Laguna Guerrero Negro (Bryant et al. 1984). 2) Decreased abundance of breeding humpback whales resulted from increases in human activities (review by Norris and Reeves 1978). 3) Increased tour ship traffic led to a reduction in humpback whale numbers in Glacier Bay, Alaska (Baker et al. 1983), but it is not clear if this is food related (Dean et al. 1985). 4) Bowhead whales decreased their utilization of areas associated with intense offshore oil activity (Richardson et al. 1985a,b,c).

Recent experiments funded by the Office of Naval Research and SPAWAR have made progress in understanding the short-term behavioral impacts of the SURTASS LFA sound source on marine mammals over time scales of minutes to a few weeks and spatial scales of 1-100 nmi2 (Clark et al. 1998; Frankel and Clark 1998; Tyack and Clark 1998).

It is possible (perhaps likely) that brief interruptions of normal behavior or short-term physiological responses to LFS have few serious welfare implications and no serious effects on survival and reproductive success in cetacean populations. However, long-term impacts (e.g. displacement, masking of biologically important signals), while more difficult to identify and quantify, may be biologically significant through reductions in foraging efficiency, survival, or reproductive success. In many cases the basic information needed to understand the long-term consequences of human-produced sound is missing. As a result, completely different conclusions may be drawn from the same sparse data set (Gordon and Moscrop 1996).

SIRENIDAE (MANATEES AND DUGONGS)

Summary

The Sirinidae are the only herbivorous marine mammals. There are 4 extant species (3 manatees and 1 dugong) all of which are confined to the tropics and sub-tropics. The manatees are primarily fresh water and estuary species, one is exclusively fresh water. The dugong is exclusively marine. All species produce and likely receive low frequency sound. The shallow water distribution of manatees make them unlikely to be impacted by LFA activities, so they are not included in the full report.

MARINE FISHES (By Phil Levin)

Summary

Taxonomic Coverage

In general, the term fish refers to members of the superclass Agnatha (jawless fishes), and the classes Chondrichthyes (cartilaginous fishes including sharks and rays) and Osteichthyes (bony fishes) (Nelson 1984). The bony fishes comprise the largest of all vertebrate groups with over 25,000 extant species (Nelson 1984). There is immense diversity among members of this class and this is reflected in their ears and structures associated with the ear (Platt and Popper 1981). Thus, these fish species undoubtedly detect sound and process sound in a variety of ways. The bony fishes are further subdivided into four subclasses and of these, most information on bioacoustics is from the Actinopterygii. The superorder Ostophysi includes 6,000 species which have specializations which enhance their ability to hear (described below). Additionally, several species of non-otophysans have anatomical specializations for hearing. Fishes (both otophysans and non-otophysans) that have specializations that enhance hearing are referred to by the non-taxonomic term, "hearing specialists". Similarly, fishes without such specializations are called "nonspecialists". In general, hearing specialists appear to have greater sensitivity and perceive a broader bandwidth than nonspecialists (Fay 1988).

There are hearing specialists among many taxonomic groups; these same taxonomic groups also contain nonspecialists (Popper and Fay 1993).

Hearing Capabilities and Sound Production in Fish

Of the approximately 25,000 extant fish species, detailed knowledge of hearing abilities exists for 50 species (Fay 1988) of which 34 occur in marine waters. Much more data are available on sound production in fishes; however, much of this data is of poor quality because of the means used to elicit sound production. Although the diversity of morphology and physiology associated with hearing in fishes is immense, hearing capabilities of fishes within orders is relatively homogenous (Popper and Fay 1993). Consequently, in the fish section of the EIS, hearing abilities along with known and potential impacts of low frequency sound, and means to reduce or mitigate such impacts are summarized by fish order. Because hearing abilities are similar within order, it is likely that that limited data available are generalizable to other members of the order. The order perciformes is the most diverse of all vertebrate orders, and dominates marine habitats; therefore, summaries are provided for each perciform family for which hearing or sound production data are available. Appendix 1 lists the orders and families that are included in this report.

In general, fish perceive sound in the 50 - 2000 Hz range, with greatest sensitivity generally less than 800 Hz. Many fish appear adapted to perceive sound in the same general frequencies that they produce sound (Myrberg 1980). Other species appear to use sound to detect potential prey or predators.

Many fishes produce low frequency vocalizations. Sounds are frequently produced when fish are alarmed or harassed in some way (Fish and Mowbray 1970; Myrberg 1981), and are also associated with spawning and territorial activities.

Known and potential impacts of low frequency sound in marine fishes:

Extraneous low frequency sound has rarely been demonstrated to impact marine fish populations; however, very few rigorous studies have been conducted that have the power to test the impacts of loud, low frequency sound on fishes. Because various species of fish use sound to maintain the cohesiveness of schools, detect predators, communicate with mates or competitors, and potentially to navigate, the addition of low frequency sound could, potentially, have dire consequences for fishes. Moreover, it is possible that loud low frequency sound could physically harm the swimbladder or lateral line of fish.

Reducing and mitigating impacts of SURTASS LFA on marine fishes

Because the proposed protocol of SURTASS LFA operations calls for a moving vessel to produce relatively short blasts of sound with several minutes between blasts, the effects of this operation are likely to be minimal on most species of fish. Because many fish that use sound in reproduction and territorial interactions occur in nearshore, shallow waters and especially on coral reefs, operations that are conducted distant from shore will have little effect on the behavior of these species. Moreover, many fishes appear to habituate to extraneous sound; thus, where operations occur in locations where behavioral impacts are possible, fish may be impacted less than expected if they did not habituate. Pelagic species that occur distant from shore are likely to interact with SURTASS LFA operations. This is especially problematic for species such as tunas that are listed by the IUCN as vulnerable or endangered since it will be difficult to simply avoid locations where these highly mobile species occur. Schooling fishes and pelagic predators may suffer from higher predation rates and reduced foraging efficiency, respectively in locations subjected to loud low frequency sound. However, the mobile nature of the project reduces this impact since only a small proportion of any population will be affected and only for a short time. It would be prudent for SURTASS LFA operations to avoid areas were concentrations of fish occur. Atlantic Herring, for example, congregate in well known spawning locations at specific times of the year, and thus, impacts on the spawning population can be reduced by avoided these time / places. Pelagic species that do not congregate present a mitigation problem that may be solved with more research detailing how fish respond to noise. Some evidence is presented below suggesting that coastal species of fish (e.g. salmonids) are repelled by loud low frequency sound. If this is true for species such as tuna, then simply the sound of the vessel may repel fish enough that they are outside of the range where physical damage from the sound could occur.

Based on an exhaustive literature survey, Hastings (1991) concluded that sound levels greater than or equal to 180 dB at 50-2000 Hz would be physically harmful to fish. Levels less than 150 dB should not cause physical harm to fish. Similar loud low frequency sound may damage the neuromasts of the lateral line. As long as SURTASS LFA operations are conducted away from nearshore habitats and distant from known aggregations of pelagic fishes, the direct physical effects on fish stocks of operations should be minimal.

General Research Recommendations

Very few rigorous, experimental data are available that would allow firm conclusions on the effects of loud low frequency sound on fishes. While it is clear that some fish use low frequency sound in behavioral interactions, it is not clear that extraneous low frequency noise in the environment will impact the normal behavior of the fish. Explicit test of the effects of low frequency noise on behavior need to be performed before we really understand how operations such as SURTASS LFA will impact fish. Moreover, no work has been performed that tests the effects of low frequency noise on ecological processes. It is possible that low frequency noise masks the approach of predators and shifts the importance of various demographic processes in the dynamics of fish populations.

CHAPTER 1: MARINE FISHES (BY Phil Levin)

INTRODUCTION - EFFECTS OF LOW FREQUENCY SOUND ON FISHES

Taxonomic Coverage of this Report

In general, the term fish refers to members of the superclass Agnatha (jawless fishes), and the classes Chondrichthyes (cartilaginous fishes including sharks and rays) and Osteichthyes (bony fishes) (Nelson 1984). The bony fishes comprise the largest of all vertebrate groups with over 25,000 extant species (Nelson 1984). There is immense diversity among members of this class and this is reflected in their ears and structures associated with the ear (Platt and Popper 1981). Thus, these fish species undoubtedly detect sound and process sound in a variety of ways. The bony fishes are further subdivided into four subclasses and of these, most information on bioacoustics is from the Actinopterygii. The superorder Ostophysi includes 6,000 species which have specializations which enhance their ability to hear (described below). Additionally, several species of non-otophysans have anatomical specializations for hearing. Fishes (both otophysans and non-otophysans) that have specializations that enhance hearing are referred to by the non-taxonomic term, "hearing specialists". Similarly, fishes without such specializations are called "nonspecialists". In general, hearing specialists appear to have greater sensitivity and perceive a broader bandwidth than nonspecialists (Fay 1988). There are hearing specialists among many taxonomic groups; these same taxonomic groups also contain nonspecialists (Popper and Fay 1993).

The Acoustico-lateralis system in Fishes

The acoustico-lateralis system of fishes senses sound, vibrations and other forms of water displacement in their environment. This system is comprised of two main components: (1) the inner ear and (2) the neuromast/lateral line system. In addition to detecting sound and vibration, this system is used for orientation in three dimensional space. The ear, lateral line and their central pathways functionally interact in terms of the signals detected (Combs et al. 1989), peripheral mechanics (Baxter et al. 1981) and central processing areas of the brain (Striedter 1991). Both the ear and lateral line are hair cell based systems. In this brief overview of the acoustico-lateralis system in fishes, I will first describe inner ear structure followed by a summary of the lateral line and other structures involved in hearing.

The inner ear

The dorsal portion of the inner ear is referred to as the pars superior and includes three semicircular canals and associated ampullae, fluid-filled chambers that sense changes in inertia. Also included in the pars superior is the utriculus with its utricular otolith. This otolith, or earstone, plays a role in the detection of gravity and in maintaining equilibrium. The ventral portion or the inner ear, the pars inferior, consists of the sacculus and lagena. These structures also contain otoliths, although unlike the utriculus, they function primarily in sound detection. These structures function to detect sound as follows. As sound vibrations encroach upon on a fish, the entire fish moves with the particle displacement of the water. Because the otoliths are three times denser than the total fish, they lag behind the movements of the fish. The otoliths are suspended in a fluid filled chamber surrounded by bundles of cilia from sensory hair cells. The differential motions of otoliths result in the mechanical bending of some of the hair cells which stimulates neural transmissions to the auditory center of the brain.

Interspecific diversity in the structure of fish ears is extensive (Popper and Fay 1993). Otolith size and shape vary greatly among species; thus, different acoustic signals may result in different motions of the otoliths relative to the sensory epithelium (Popper 1983). There is also extensive diversity in the hair cell orientation which impacts the detection of sound pressure (Schellart and Popper 1992). Specializations in hair cell orientation appear to be associated with enhanced hearing (Schellart and Popper 1992).

Getting sound to the ear

It is clear that sound is transduced by the otoliths; however, our understanding of the pathways of acoustic input to the ear is limited (Popper and Fay 1993). Fishes that are hearing specialists appear to have one or more otoliths that respond to sound pressure as will as to acoustic particle motion (Popper and Fay 1993). This response may be facilitated by a mechanical coupling of the swimbladder and the inner ear. The gas bubble in the swimbladder provides the means to covert sound pressure into displacement movements because it is more compressible than water. It thus pulsates in response to sound and the pulsating surface acts to vibrate the tissues of the fish associated with it. In many species, there is a close association of the swimbladder with the pars inferior. Members several families (Holocentridae, Elopedae, Notopteridae, Moridae, Sparidae) have a forked forward extension of the swimbladder which ends close to the ear. Clupeids (herrings) have a swimbladder extension that actually enters the cranial auditory capsule (Moyle and Cech 1996). Members of the superorder Ostariophysi (includes the orders Gonorynchiformes (the milkfish, beaked sandfishes), Cypriniformes (minnows and carps, suckers, loaches, river loaches), Characiformes (characins, hatchetfishes) Siluriformes (catfishes) and Gymnotiformes (knifefishes)) have a small chain of bones called the Weberian ossicles that connect the swimbladder with the auditory system. In these species, it is thought that the loss of the Weberian ossicles results in a decrease in sensitivity and bandwidth, although this had only been experimentally demonstrated in one species of catfish (Popper and Fay 1993).

In fishes that are not hearing specialists, the lack a swimbladder or the lack of a mechanical link between the swimbladder and the ear probably results in substantial attenuation and therefore little stimulation to the inner ear.

The lateral line

The lateral line of fish uses mechanoreceptors similar to those in the ear to detect water movements around the fish (Moyle and Cech 1996). These receptors are called neuromasts and consists of individual hair cells with attached cupula. Water movements bend the protruding capulae which stimulates the hair cells be bending the attached cilia. All fishes have at least some free neuromasts and most teleosts and elasmobranchs have lateral line canals in which the neuromasts lie between canal pores that open up to the environment (Moyle and Cech 1996).

Interactions between the ear and lateral line

Both the ear and the lateral line detect water motions with the lateral line being responsive to relative movement between the animal and the surrounding water and the ear being responsive to the relative motion between the otolith and the body of the fish. The ear and lateral line overlap in the frequency range to which they respond with the lateral line responding from several Hz - 200Hz, while the ear responds from several Hz to several thousand Hz in some species (Popper and Fay 1993). The lateral line system is responsive over a distance of 1-2 body lengths, while ears may respond to sources much further away (Popper and Fay 1993). The functional relationship between the lateral line and the ear has not been fully investigated. In several species an extension of the ear actually enters the lateral line canals (Blaxter et al. 1981), but the significance of this relationship is not known (Popper and Fay 1993).

Hearing Capabilities and Sound Production in Fish

Overview

Of the approximately 25,000 extant fish species, detailed knowledge of hearing abilities exists for 50 species (Fay 1988) of which 34 occur in marine waters. Much more data are available on sound production in fishes; however, much of this data is of poor quality because of the means used to elicit sound production. Although the diversity of morphology and physiology associated with hearing in fishes is immense, hearing capabilities of fishes within orders is relatively homogenous (Popper and Fay 1993). Consequently, in the sections that follow, hearing abilities along with known and potential impacts of low frequency sound, and means to reduce or mitigate such impacts are summarized by fish order. Because hearing abilities are similar within order, it is likely that that limited data available are generalizable to other members of the order. The order perciformes is the most diverse of all vertebrate orders, and dominates marine habitats; therefore, summaries are provided for each perciform family for which hearing or sound production data are available. Appendix 1 lists the orders and families that are included in this report.

Hearing range and sound production in marine fishes: a summary

In general, fish perceive sound in the 50 - 2000 Hz range, with greatest sensitivity generally less than 800 Hz. Available audiograms for marine species are provided in Appendix 2. Many fish appear adapted to perceive sound in the same general frequencies that they produce sound (Myrberg 1980). Other species appear to use sound to detect potential prey or predators.

Many fishes produce low frequency vocalizations (summarized in Appendix 3). Sounds are frequently produced when fish are alarmed or harassed in some way (Fish and Mowbray 1970, Myrberg 1981). Vocalizations are frequently associated with spawning and territorial activities.

Known and potential impacts of low frequency sound in marine fishes: a summary

Extraneous low frequency sound has rarely been demonstrated to impact marine fish populations; however, very few rigorous studies have been conducted that have the power to test the impacts of loud, low frequency sound on fishes. Because various species of fish use sound to maintain the cohesiveness of schools, detect predators, communicate with mates or competitors, and potentially to navigate, the addition of low frequency sound could, potentially, have dire consequences for fishes. Moreover, it is possible that loud low frequency sound could physically harm the swimbladder or lateral line of fish.

Reducing and mitigating impacts of SURTASS LFA on marine fishes: a summary

Because the proposed protocol of SURTASS LFA operations calls for a moving vessel to produce relatively short blasts of sound with several minutes between blasts, the effects of this operation are likely to be minimal on most species of fish. Because many fish that use sound in reproduction and territorial interactions occur in nearshore, shallow waters and especially on coral reefs (see summaries below), operations that are conducted distant from shore will have little effect on the behavior of these species. Moreover, many fishes appear to habituate to extraneous sound; thus, where operations occur in locations where behavioral impacts are possible, fish may be impacted less than expected if they did not habituate. Pelagic species that occur distant from shore are likely to interact with SURTASS LFA operations. This is especially problematic for species such as tunas that are listed by the IUCN as vulnerable or endangered since it will be difficult to simply avoid locations where these highly mobile species occur. Schooling fishes and pelagic predators may suffer from higher predation rates and reduced foraging efficiency, respectively in locations subjected to loud low frequency sound. However, the mobile nature of the project reduces this impact since only a small proportion of any population will be affected and only for a short time. It would be prudent for SURTASS LFA operations to avoid areas were concentrations of fish occur. Atlantic Herring, for example, congregate in well known spawning locations at specific times of the year (see section on clupeids below), and thus, impacts on the spawning population can be reduced by avoided these time / places. Pelagic species that do not congregate present a mitigation problem that may be solved with more research detailing how fish respond to noise. Some evidence is presented below suggesting that coastal species of fish (e.g. salmonids) are repelled by loud low frequency sound. If this is true for species such as tuna, then simply the sound of the vessel may repel fish enough that they are outside of the range where physical damage from the sound could occur.

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Very few rigorous, experimental data are available that would allow firm conclusions on the effects of loud low frequency sound on fishes. While it is clear that some fish use low frequency sound in behavioral interactions, it is not clear that extraneous low frequency noise in the environment will impact the normal behavior of the fish. Explicit test of the effects of low frequency noise on behavior need to be performed before we really understand how operations such as SURTASS LFA will impact fish. Moreover, no work has been performed that tests the effects of low frequency noise on ecological processes. It is possible that low frequency noise masks the approach of predators and shifts the importance of various demographic processes in the dynamics of fish populations.

ORDER HETERDONTIDAE

This order contains 6 species in one genus.

U.S. Fish and Wildlife or IUCN Status

No members of this order are listed as Endangered or Threatened by the U.S. Fish and Wildlife Service or the IUCN

Distribution

Heterodontids are found worldwide in shallow, littoral waters. Heterodontus portusjacksonii is found along the Australian coast, H. francisci from California, H. quoyi from the coasts of Equador, Peru and the Galapagos and H. ramalheira from Mozambique and South Africa.

These are bottom-dwelling fish, usually living on or near the substrate. Juveniles generally occur in shallow water, while adults live deeper. Juveniles of H. franscisci, for example, occur on sand near reefs sometimes in the intertidal zone, while adults may be found in the intertidal to depths of more than 150m (Love 1991)

Natural History Notes

Members of this order are primarily nocturnal living in caves, crevices or within algae. They prey on a variety of small fish and invertebrates. Hererodontids lay eggs that are enclosed in a spiral capsule. After laying eggs, females place them in rock crevices, and after 10-12 months they hatch (Ellis 1976). H. franscisci spawn from February - April.

Hearing Range and Sound Production

H. franscisci respond to 20 - 160 Hz with the lowest pressure threshold at 40 Hz (12 dB) and the lowest particle-motion threshold at 80 Hz with a displacement of 1.4 x 10^{-6} cm and a velocity of 7 x 10^{-4} (104 μvar) (Kelly and Nelson 1975).

Known and potential impacts of low frequency sound

There are no data on the impacts of low frequency sound specifically on heterodontids. Members of other shark orders are known to detect sound at similar frequencies (i.e. < 1000 Hz), and certain sound signals in the 20-80 Hz range may attract sharks (see section on Lamniformes below) (Nelson and Gruber 1963, Nelson 1967, Myrberg et al. 1972, Nelson and Johnson, 1972). Heterodonitids were not among the species included in these studies, thus it is unknown if these species would respond in a similar manner. Relative to other shark and fish species, H. francisci has a high threshold level, and therefore, members of this order may be less responsive to sound. Sharks also use sound to detect prey (Banner 1972, Myrberg et al. 1972, Nelson and Johnson 1972); however, this has not been detected in heterodontids. Given the frequency of slow moving invertebrate prey in the diet of heterodontids (Love 1991), it seems unlikely that sound would be critical for prey detection in this taxa.

Further research needs to be conducted that examines the use of sound by members of this order before conclusive statements can be made about the impacts or potential impacts of low frequency sound for this taxa.

Reducing and mitigating impacts of SURTASS LFA

The limited data available at present, indicate that impacts of the SURTASS LFA are likely to be greater on other taxa than on the heterodontids. Thus, measures suggested for other species that overlap in their distribution should reduce or mitigate impacts on heterodontids.

ORDER LAMNIFORMES

The order Lamniformes contains 199 species in 56 genera.

U.S. Fish and Wildlife or IUCN Status

No members of this order are listed as Endangered or Threatened by the U.S. Fish and Wildlife Service. Several species in this order (Carcharias taurus, Carcharodon carcharias, Cetorhinus maximus, Glyphis gangeticus) are considered endangered by the IUCN.

Distribution

Members of this order are found in marine waters worldwide. The following table summarizes the distribution of this order by family.

Table: The distribution of families of the order Lamniformes.

Family	**Distribution**
Rhincodontidae - whale shark	Marine, pelagic, mostly tropical
Orectolobidae - carpet, nurse sharks	Marine, all oceans
Odontaspididae - sand tiger sharks	Coastal waters of South Africa, Australia, Northern Africa, southern South America, eastern North America
Alopiidae - thresher sharks	Atlantic Ocean, Pacific Ocean, Indian Ocean: warm and temperate waters worldwide
Cetorhinidae - basking sharks	Oceanic Islands, Atlantic Ocean, Pacific Ocean: North and South Atlantic and Pacific Oceans
Lamnidae - mackerel sharks	All oceans

Family	**Distribution**
Scyliorhinidae - cat sharks	found on or near the bottom in almost all seas from the intertidal to below 2000 m depth on the continental and insular slopes
Carcharhinidae - requiem sharks	primarily in tropical and warm-temperate seas worldwide, both in coastal and open ocean waters.
Sphyrnidae - hammerhead sharks	inshore to semioceanic in all temperate and tropical seas

Carcharodon carcharias is found circumglobally, mostly in amphitemperate waters. In the Western Atlantic it ranges from Newfoundland, Canada to Argentina. In the Eastern Atlantic it ranges from France to South Africa, including the Mediterranean. In the Western Indian Ocean it occurs from the Red Sea to South Africa. In the Western Pacific it ranges from Russia to New Zealand, and it the Eastern Pacific it is found from Alaska to Chile; Hawaii and the Marshall Islands. Coastal and offshore inhabitant of the continental and insular shelves. Often close inshore to the surf line and even penetrates shallow bays (Last and Stevens 1994)

Carcharias taurus occurs in the Western Atlantic from the Gulf of Maine to Argentina. In the Eastern Atlantic it occurs from the Mediterranean to Cameroon, and in the Western Indian Ocean from the Red Sea to South Africa, Pakistan, possibly India. In the Western Pacific it occurs from Japan to Australia; possibly Viet Nam and Indonesia. Ranges from the surf zone, in shallow bays, and around coral and rocky reefs down to at least 191 m depth on outer shelves (Compagno 1984). Often on or near the bottom but also occurs in midwater or at the surface (Compagno 1984). A migratory species in parts of its range, particularly in its northern and southern extremities where pronounced poleward migration occur in the summer and equatorial movements in autumn and winter.

Cetorhinus maximus is Amphitemperate. It ranges in the Western Atlantic from Newfoundland, Canada Florida; also southern Brazil to Argentina. In the Eastern Atlantic from Iceland, Norway and western Barents Sea to the Mediterranean and Senegal; also western Cape Province, South Africa. In the Western Indian Ocean: eastern Cape Province, South Africa. Western Pacific: Japan to New Zealand. In the Eastern Pacific: Gulf of Alaska to Chile. It is found on the continental and insular shelves, offshore and often close to land; also enters enclosed bays.

Glyphis gangeticus occurs in the Indo-West Pacific. It is known from the Hooghly River, Ganges system, West Bengal, India, and likely from the vicinity of Karachi, Pakistan. It has also been observed in Taiwan. It occurs in large tropical rivers and muddy estuaries.

Natural History Notes

Many sharks of this order that have been examined appear to be attracted to specific types of synthesized sounds as well as to a variety of biological sounds (Myrberg 1978). These species (in a table below) are common in both shallow coastal and deep oceanic waters. Most of the species that were attracted to low frequency sound are picsivorous. It appears that sharks use sound to detect prey (Banner 1972, Myrberg et al. 1972, Nelson and Johnson 1972). In order to attract sharks, the sound must be both low frequency, with an upper frequency limit of 800 - 1000 Hz, and pulsed. Continuous sound regardless of frequency does not appear to attract sharks (Myrberg 1978).

After approaching a transducer sharks frequently strike, bite or swallow the apparatus (Myrberg et al 1969, Nelson and Johnson 1972, Myrberg 1978). Additionally, sharks of this order display behavior such as circling the transducer, veering off, hunching, startle, headshaking, gill puffing, spinning, yawning and thrusting while interacting with a transducer. Many behaviors elicit by low frequency sound appear related to feeding or competitive interactions associated with feeding (Myrberg 1978).

Some species may also withdraw from low frequency sound, and some species which are attracted to sound in some instances, may be repulsed in others (Myrberg 1978). The mechanisms producing these differential responses are unknown, but it appears those sounds eliciting withdrawal behavior had longer intervals than those sounds that attracted sharks. Pure tones do not elicit withdrawal responses from any species (Myrberg 1978). Likewise, the intensity of the sound does not seem to impact withdrawal behavior (Myrberg 1978). At present it appears that the manner in which a given intensity is reached relative to some reference intensity is critical. Attraction may be initiated by and maintained by moving toward a given sound whose level increases smoothly, while withdrawal may be initiated by a sound whose structure has sudden increased levels of intensity (Myrberg 1978)

Table. Shark species that were attracted to an underwater transducer during playback of low frequency pulsed sounds.

Family and Species	**Reference**
Alopidae	Nelson and Johnson cited in Myrberg 1978
Alopias sp.	
Carcharhinidae	
Carcharhinus sp.	Nelson and Gruber 1963
C. albimarginatus	Nelson and Johnson 1972
C. falciformis	Myrberg et al. 1972
C. leucas	Nelson and Gruber 1963
C. longimanus	Myrberg et al. 1975
C. melanopterus	Nelson and Johnson 1972
C. menisorrah	Nelson and Johnson 1972
C. springeri	Myrberg et al. 1969
Galeocerdo cuvieri	Nelson and Gruber 1963
Negaprion bvirostris	Nelson and Gruber 1963
N. fosteri	Nelson and Johnson 1972
Prionace glauca	Nelson and Johnson cited in Myrberg 1978
Rhizoprionodon porosus	Myrberg et al. 1969
Triaenodon obesus	Nelson and Johnson 1972
Orectolobidae	
Ginglymostoma cirratum	Myrberg et al. 1969
Sphyrnidae	
Sphyrna sp.	Nelson and Gruber 1963
S. tiburo	Nelson et al. 1969

Hearing Range and Sound Production

Responses of sharks to sound have been noted between 10 and 7000 Hz, with the strongest response of most species < 1000 Hz. The bull shark Carcharhinus leucas was conditioned to approach a submerged transducer for a food reward, and responses were recorded between 100 and 1500 Hz with the greatest sensitivity between 400 and 600 Hz (Kritzler and Wood 1961).

Hammerhead sharks, Sphyrna lewni respond to frequencies between 250 and 750 Hz with the greatest sensitivity between 250 and 750 Hz (Olla 1962). Nelson reported a pressure audiogram for the lemon shark Negaprion brevirostris. Lemon sharks respond to frequencies between 10 and 640 Hz with maximum sensitivity at 40 Hz. These animals could distinguish between frequencies that differed by as little as 20 Hz and showed good directional hearing.

Known and potential impacts of low frequency sound

Because sharks respond to low frequency sound there are potential impacts of extraneous low frequency sound to shark behavior. Some sharks appear to use low frequency sound to detect prey; thus, the addition of loud low frequency sound may disrupt the foraging of some species (Myrberg 1978). In addition, sharks appear to orient to or away from low frequency sound, and thus long-term use of SURTASS LFA in a single location could impact the local density of sharks. However, sharks readily habituate to low frequency sounds (Nelson and Johnson 1972), and thus the attractiveness or repulsiveness of the SURTASS LFA transmissions would wane over a period of time assuming the characteristics of the transmissions do not change substantially

Reducing and mitigating impacts of SURTASS LFA

Impacts to Lamniformes are possible, but do not appear significant because of the ability of sharks to habituate, the short-term nature of the transmissions, and the local nature of the impact. It would be prudent to monitor stock assessments in locations where transmissions occur repeatedly over a long time period to attempt to evaluate any impact from the SURTASS LFA.

ORDER RAJIFORMES - SKATES AND RAYS

There are 49 genera and 315 species in the order Rajiformes

U.S. Fish and Wildlife or IUCN Status

No members of this order are listed as Endangered or Threatened by the U.S. Fish and Wildlife Service or the IUCN

Distribution

Table: The distribution of families of the order Rajiformes.

Family	**Distribution**
Pristidae - sawfishes	Marine; Atlantic, Indian and Pacific; can be freshwater
Rhinobatidae - guitarfishes	Marine; Atlantic, Indian, Pacific
Torpedinidae - electric rays	Marine; Atlantic, Indian, Pacific
Rajidae - skates	All oceans
Dasyatidae	Marine; Atlantic, Indian, Pacific; a few species occasionally occur in brackish and fresh water
Potamotrygonidae - river stingrays	Freshwater; South America, Africa, Laos
Myliobatidae - eagle rays	Marine; Atlantic, Indian, Pacific
Mobulidae - manta and devil rays	Marine; Atlantic, Indian, Pacific

Natural History Notes

Skates and Rays occur worldwide in shallow and deep waters. They are especially abundant in waters less than 1000m deep. Most species are bottom dwellers although some species such as Dastatis violacea are pelagic. Rays are a diverse group and feed an

a variety of food and live in a variety of habitats. Crustaceans and invertebrates dominate the prey of must species, although some eat fish.
One species in this order, the cownose ray Rhinoptera bonasus, is known to produce sound Fish and Mowbray (1970). After being prodded individuals of this species produce one or more sharp clicks accompanied by vigorous evasive behavior. Fish and Mowbray (1970) indicate that sound may have a defensive or aggressive function in this species.

Hearing Range and Sound Production

The use of sound and hearing have been examined in only one member of the order, the cownose ray Rhinoptera bonasus (Fish and Mowbray 1970). Their vocalizations range from near 0 to 3000 Hz with their dominant vocal frequencies from near 0 to 2000 Hz.

Known and potential impacts of low frequency sound

There are no known impacts of low frequency sound and there are to few data to speculate on potential impacts.

Reducing and mitigating impacts of U.S. Navy Low Frequency Active Acoustic System

The limited data available at present, indicate that impacts of the SURTASS LFA are likely to be greater on other taxa than on the skates and rays. Thus, measures suggested for other species that overlap in their distribution should reduce or mitigate impacts on this taxon.

ORDER ELOPIFORMES

Five genera with 11 species are in this order.

U.S. Fish and Wildlife or IUCN Status

No members of this order are listed as Endangered or Threatened by the U.S. Fish and Wildlife Service or the IUCN

Distribution

Table: The distribution of families of the order Elopiformes.

Family	**Distribution**
Elopidae - ten pounders	Mainly marine, rarely in brackish and freshwater. Tropical and subtropical oceans (Nelson 1984)

Family	**Distribution**
Megalopidae - tarpons	primarily inshore fish, although adult fish spawn offshore where the ribbon-like larval stage of the fish can be found. Mainly tropical and subtropical marine. Will enter freshwater (Nelson 1984)
Albulidae	Worldwide distribution in inshore tropical and warm waters

Natural History Notes

Members of the family Elopidae generally occur in schools in shallow inshore areas, although they may penetrate lagoons and estuaries. Some species spawn in the open sea, and they produce transparent larvae that migrate towards coastal areas (Whitehead and Rodriguez-Sanchez 1995). Tarpons, family Megalopidae, are legendary game fish that reach a length of 2.5 m. They inhabit coastal waters, bays, sand and seagrass flats, coral reefs, estuaries, mangrove-lined lagoons and rivers, and large schools may frequent particular spots for years (Helfman et al. 1997). Their swim bladder is attached to their esophagus and therefore can be filled directly with air. This permits the fish to live in oxygen poor waters. Tarpon are slow growers reaching maturity at 7-13 years of age. They feed mainly on fish and large crustaceans. Bonefish, family Albulidae, inhabit mud flats of turbid inner reefs and mangroves and sandy lagoons. They forage by grabbing food from the substratum using their snout. Like tarpons, they can tolerate low oxygen water by inhaling air into a long-like swim bladder (Shaklee 1984). They migrate on a lunar cycle to mass spawning sites located at the mouths of channels (Shaklee 1984).

Hearing Range and Sound Production

Hearing has not been directly investigated in this taxa. Sound production has been investigated in Atlantic Tarpon (Megalops atlantica), and the bonefish Albula vulpes. Tarpon produce a loud low frequency (< 200 Hz) sound when started (Fish and Mowbray 1970). Their vocal range is between near 0 to 400 Hz with their dominant vocal frequencies from a few Hz to 200 Hz (Fish and Mowbray 1970)

Bonefish also emitted similar low frequency sounds when startled (Fish and Mowbray 1970). Additionally, bonefish appear to produce a higher pitched click during competitive feeding bouts (Fish and Mowbray 1970). Their vocal range is from 50 to 500 Hz with the dominant vocal frequencies between 100 and 400 Hz.

Known and potential impacts of low frequency sound

There are no data on the impacts of low frequency sound specifically on members of this order. If members of this order use frequency sound in social interactions, which the very limited data suggest is possible, exogenous low frequency sound could interrupt some social interactions. However, there are no strong data to support this, and much more research needs to be conducted that examines the use of sound by members of this order before conclusive statements can be made about the impacts or potential impacts of low frequency sound for this taxa.

Reducing and mitigating impacts of SURTASS LFA

Because this taxa is primarily a shallow water coastal group, and SURTASS LFA operations will be conducted distant from shore, impacts will likely be minimal. It would be prudent to monitor stock assessments in locations where transmissions occur repeatedly over a long time period to attempt to evaluate any impact from the SURTASS LFA.

ORDER ANGUILLIFORMES

There are 133 genera with about 603 species in this order

U.S. Fish and Wildlife or IUCN Status

No members of this order are listed as Endangered or Threatened by the U.S. Fish and Wildlife Service or the IUCN

Distribution

Table: The distribution of families of the order Anguilloformes.

Family	**Distribution**
Anguillidae - freshwater eels	Usually catadromous fishes in tropical and temperate waters, except eastern Pacific and south Atlantic
Moringuidae	Indo-Pacific and Western Atlantic
Nemichthyidae	Bathypelagic and mesopelagic: Atlantic, Indian, and Pacific Oceans
Xenocongridae	Atlantic and Indo-pacific
Muraenidae	Tropical and temperate seas; Adults benthic, generally in shallow water among rocks and coral heads
Synaphorbranchidae	Atlantic, Indian and Pacific Oceans
Simenchelyidae	Deep Sea Atlantic and Pacific
Dysommidae	Indo-Pacific and Atlantic
Colocongridae	Atlantic, Indian, and Pacific Oceans
Congridae	Atlantic, Indian and Pacific Oceans - shallow coastal waters and deeper continental slope habitats
Muraenesocidae	Atlantic and Indo-Pacific Oceans. From coastal estuaries, shelf and upper bathybenthic habitats

Family	**Distribution**
Serrivomeridae	Atlantic, Indian and Pacific Oceans
Ophichthidae	coastal, estuaries and entering rivers in tropical to warm temperate waters
Derichthyidae	Deep sea Atlantic and Pacific
Saccopharyngidae	Deep sea Atlantic and Indo-pacific

Natural History Notes

The eels are an extremely diverse group that occur in a variety habitats, from freshwater lakes and streams to corals reefs and the deep sea. Most eels live in shallow tropical or subtropical habitats (Moyle and Cech 1996). Anguillids are best known because they live in freshwater and are commercially exploited. Members of this family appear to be important predators in many lakes and streams (Moyle and Cech 1996). Anguillids spend 6-12 years in freshwater habitats before moving to sea. They use deep water to get to their spawning ground in the Sargasso Sea. They appear to spawn at great depths and then die (Moyle and Cech 1996). Moray eels (Muraenidae) are important predators of fish and invertebrates on rocky and coral reefs in tropical and temperate regions. Conger eels (Congridae) are similar to morays although they use their cone shaped (rather than the sharp teeth of the morays) to feed on invertebrates. In temperate regions conger eels are found in shallow rocky areas, while in tropical regions many species construct burrows in shallow soft bottom habitats.

Hearing Range and Sound Production

Little is known about the hearing of members of this order. Hearing in one species of eel Anguilla anguilla has been examined in some detail using an acoustic tube producing sound stimuli with different ratios between sound pressure and particle motion. The upper audible frequency limit of this species is 300 Hz with their best hearing around 100 Hz at 95 dB. (Jerko et al.1989). The swimbladder appeared to improve hearing at the upper frequency limit of the species, but not at the lower end of the frequency limit. Sound has been recorded from the American eel (Aguilla rostrata) with vocalizations ranging from near zero to 2500 Hz with the dominant frequencies at 40 - 400 Hz (Fish and Mowbray 1970). The use of these vocalizations are unknown.

Known and potential impacts of low frequency sound

There are no known impacts of low frequency sound on eels. To my knowledge, there are no data that document how or if eels use sound. Given that at least one species of eel can detect low frequency sound (Jerko et al. 1989) and a congener produces sound, there is some possibility that eels may use sound in some way. Without data that address this point, the potential for impact will remain unknown.

Reducing and mitigating impacts of SURTASS LFA

Most eel species live in coastal nearshore waters or in quite deep water (Moyle and Cech 1996, Helfman et al. 1997); consequently, impacts of SURTASS LFA on this order should be minimal. Additionally, the threshold of hearing for the one species examined was 95 dB suggesting that animals distant from the sound source will not be impacted. Further work is needed to document how or if members of this taxa use sound.

ORDER CLUPEIFORMES

292 species in 72 genera occur in this order.

U.S. Fish and Wildlife or IUCN Status

No members of this order are listed as Endangered or Threatened by the U.S. Fish and Wildlife Service. The ICUN lists two species Alosa alabamae and Tenualosa thibaudeaui as endangered. Only the former occurs in marine waters.

Distribution

Table: The distribution of families of the order Clupeiformes.

Family	**Distribution**
Denticipitidae	Freshwater; southwest Nigeria
Clupeidae	Primarily marine, although some are freshwater and anadromous. They occur in all the world's ocean, primarily in nearshore, shallow pelagic waters; however, some species move to deeper water in winter. One endangered species, Alosa
	Distribution
Family	alabamae, is anadromous. Spawns in the ascending rivers of the Gulf of Mexico. Rare west of the Mississippi River and knot known west of Grand Isle or east of the Florida panhandle (Hoese and Moore1992).
Engraulidae	Atlantic, Indian and Pacific Oceans. Schooling fishes, mostly of shallow coastal waters and estuaries in tropical and temperate regions. Some species enter or live in freshwater
Chirocentridae	Indian Ocean (West to South Africa and the Red Sea) and western Pacific (Japan to New South Wales)

Natural History Notes

Many members of this order support important commercial fisheries worldwide. As examples, about 2 million metric tons of Clupea harengus were landed in 1995. This species has complex schooling behavior (Blaxter et al. 1981) as well as complicated feeding and spawning migrations (Whitehead. 1985). Members of the clupeiformes are generally planktivorous and usually occur in large schools in nearshore waters.

Hearing Range and Sound Production

Hearing in several species of the Clupeidae have been examined relatively well. The swimbladder of clupeids has a rather specialized connection with the inner ear allowing a wide range of sound reception (Blaxter et al. 1981, Sorokin et al. 1988). Additionally, clupeids have a unique connection between the ear and the lateral line. The detection of low frequency sound via the lateral line appears to play an important role in the internal dynamics of fish schools (Partridge 1981) and potentially, the detection of predators (Blaxter and Batty 1985)

Pacific herring (Clupea harengus pallasi) receive acoustic fluctuations from 20 to 4000 Hz with maximal sensitivity between 125-500 Hz. Their optimal capacity for distinguishing signal from noise occurs at frequencies from 20 - 125 Hz (Sorokin et al. 1988). Pacific sardine (Sardinops sagax) detect sound between 20 and 2600 Hz with maximal sensitivity at 63 - 500 Hz. This species also appears to be repelled by very low frequency sounds (< 20 Hz) and from low frequency vocalizations of predators (Sonalysts 1995). The range from 20 -125 Hz appears optimal for detecting signal from noise. Spotted Shad (Clupanodon punctatus) detect frequencies from 20 to 2000 Hz, with maximal sensitivity from 125 to 500 Hz (Sorokin et al 1988). Experiments with the Northern Anchovy (Engraulis mordax) of the family Engraulidae demonstrate that this species detects low and very low frequency sound (10-200 Hz). Very low frequency signals elicited an avoidance response from these species, and they did not appear to habituate to the signal (Sonalysts 1995).

Known and potential impacts of low frequency sound

Members of this order appear to use low frequency sound to maintain the integrity of large schools and to detect the movement of predators. Loud low frequency sound may result in temporary instability of fish schools, which may make them more susceptible to predation. This effect would be enhanced if the addition of low frequency noise masks the sound of approaching predators. While impacts to members of this order are possible, the localized nature of the impact is unlikely to affect a large portion of the population. The IUCN lists Alosa alabamae as an endangered species, although the US Fish and Wildlife Service does not. As long as SURTASS LFA operations remain distant from shore, populations of this species should not be impacted. This fish ascends rivers and streams to spawn in spring and early summer, and juveniles return to marine waters in autumn. Operations that occur where fish are concentrated could have impacts on the persistence of this species.

Reducing and mitigating impacts of SURTASS LFA

Operations which are short-term should have little impact on populations of members of this order. Reduction of continuous SURTASS LFA operations in times and places where concentrations of fish are known to occur would reduce potential impacts. Data are available on peak spawning times and locations for some commercially important members of this order. Pacific anchoveta (Cetengraulis mysticetus) investigated in the Gulf of Panama spawn in shallow water with a peak in November and December (FAO 1998). Brevoortia patronus spawn in April/May in Cape Cod and Long Island Waters and October - November from Long Island to North Carolina. Engraulis capensis spawn in southern African waters with a peak in November - December for the southern populations and February off Namibia. Engraulis ringens peak spawning occurs along the coast of Peru in July - September. Peak spawning times and locations are provided below for Atlantic Herring, Clupea Harengus.

Table: Peak spawning periods and locations of Atlantic Herring (Sinclair 1988)

Spawning Location	**Peak Period**
Clyde Sea	Feb. 20-28
Norwegian	Feb 18 - Mar 18
Minch	March
Blackwater estuary	April
Schlei Fjord - Kiel Bay	April
Magdalen Island	May 9
Southwestern Gulf of St. Lawerence	May 14-18
Chedabucto Bay	May
Southeastern Gulf of St. Lawerence	May 29 - June 6
Southwestern Nova Scotia	August
Coastal Eastern Gulf of Maine	Sept 15 - Oct 17
Spawning Location	**Peak Period**
Coastal Western Gulf of Maine	Oct 1 - 21
Jeffrey's Ledge Gulf of Maine	Sept 29 - Oct 25
Georges Bank	Oct 5 - 23
Nantucket Shoals	Oct 12 - Nov 2
Dunmore, UK	September - October
Downs, UK	December
Plymouth, UK	January

ORDER SALMONIFORMES

This order includes 5 suborders, 24 families, 145 genera and 508 species. Of the 24 families, 7 occur in marine waters. Only marine members of this order are considered here.

U.S. Fish and Wildlife or IUCN Status

The winter run Sacramento River populations of Chinook Salmon (Oncorhynchus tshawytscha) is considered endangered by the US Fish and Wildlife Service. Snake River populations of Chinook Salmon are considered Threatened. Coho Salmon (Oncorhynchus kisutch) in streams between Punta Gorda, Humboldt Co. California and the San Lorenzo River, Santa Cruz, Co., CA and between Cape Blanco in Curry County, OR and Punta Gorda are considered Threatened. Snake River Sockeye Salmon (Oncorhynchus nerka) are endangered. Steelhead trout (Oncorhynchus mykiss) spawning in rivers from the Santa Maria river, San Luis Obispo Co., CA to Malibu Creek Los Angeles County, CA and in the upper Columbia River Basin upstream from the Yakima River are endangered.

Plecoglossus altivelis, the Ayu fish, is considered endangered by the IUCN.

Distribution and species notes

Table: The distribution of families of the order Salmoniformes.

Family	**Distribution**
Salmonidae	Anadromous and freshwater in the Northern Hemisphere
Oncorhynchus clarki	Gulf of Alaska to the Eel River in N. California
Oncorhynchus gorbuscha	Honshu Island, Japan north to E. Siberian Sea and Beaufort Sea S. to La Jolla California. Spawning peaks August - October and migrating fish are concentrated outside of riverine spawning grounds (Love 1996)
Oncorhynchus keta	Japan and Korea N. to Laptev Sea and Beaufort Sea S. to San Diego. Spawning occurs from the Naktong River, Korea and Kyushu Island, Japan across the Pacific to the San Lorenzo River, California. Most spawning occurs within 50 miles of shore (Love 1996)
Oncorhynchus kisutch	Korea and Japan to the Chukchi Sea and SE to Punta Camalu, Mexico. Center of Abundance is from Oregon to SE Alaska. Spawning occurs from Peter the Great Bay, Sea of Japan to the San Lorenzo River, California. Spawning occurs from early September - March in California peaking in November - January. In British Columbia fish spawn in October and November (Love 1996)
Oncorhynchus mykiss	Japan to the Bering Sea and south to N. Baja California. At sea, most abundant from Oregon to the Gulf of Alaska. Some move upstream to spawn in May -August while others move in November - April. Spawning takes place from March - May.
Oncorhynchus nerka	Northern Japan and the Sea of Okhotsk northward to Beaufort Sea and south to Los Angeles. Not common south of the Columbia River. Most important spawning locations are the Bristol Bay, Alaska watershed, and the Fraser River drainage, British Columbia. Other important areas include the Chignek, Karluk, and Cooper Rivers and tributaries of Cook Inlet in Alaska and the Skena, Nass and Somass Rivers of British Columbia (Love 1996). At sea this species travels long distances. Spawning runs occur at discrete times of the year with those in Bristol Bay usually spawning within 6 days of July 4.
	Japan to the Beaufort Sea and south to San Diego. Usually occur close to the coast. They ascend rivers to

Oncorhynchus tshawytscha	spawn during much of the year and some rivers have distinct runs. Winter run Sacramento populations move up from December to February.
Osmeridae	Anadromous, freshwater (coastal) and marine in Northern Atlantic and Pacific Oceans
Plecoglossidae	Anadromous in Japan, Korea and China. Spawning occurs in spring in the lower reaches of rivers.
Argentinidae	Atlantic and Indo-Pacific. Usually occurs in schools in close association with the bottom or in mesopelagic waters.
Bathylagidae	Deep-sea Atlantic and Indo-Pacific
Opisthiproctdae	Atlantic and Indo-pacific most species in several 100 meters of water
Alepocephalidae	Deep sea of all oceans

Natural History Notes

The life history of nearshore salmonids, particularly members of the family Salmonidae, is well known. The interest in members of this family appears to be their mystique as a sport fish, their commercial value, and recently their endangered status. Most species are anadromous or are derived from anadromous forms. In the ocean, juvenile salmon grow quickly and roam far at sea before returning to their natal streams to spawn. Some salmon migrate several thousand miles from the time they leave rivers as juveniles until they return as adults (Cech and Moyle 1996).

There has been a long standing interest in the effects of sound on salmonids because workers have viewed low frequency sound as a potential tool to steer smolt from the turbine inlets of power plants. Recent work suggests that infrasound effectively deters salmon from entering turbine intakes (VanDerwalker, 1967,Knudsen et al. 1992, 1994)

Hearing Range and Sound Production

One species, Salmo salar has been examined in detail. S. salar detects sound between 25 and 600 Hz` with the best hearing at 170 Hz at 95 dB (Hawkins and Johnstone 1978). Particle motion rather than sound pressure appears to be the relevant stimulus to this fish (Hawkins and Johnstone 1978). Hearing in salmon is poor relative to cod and carp (Hawkins and Johnstone 1978). Very low frequency sounds (< 30 Hz) appear to elicit avoidance responses by salmon (Knudsen et al. 1992, 1994, Enger et al. 1993). By contrast sound at 150 Hz has no observable effect on salmon smolt even at intensities 114 dB above the hearing threshold at this frequency (Knudsen et al. 1994).

Known and potential impacts of low frequency sound

Intense low frequency sounds repel salmon (Knudsen et al. 1992, 1994, Enger et al. 1993). Consequently, as adults concentrate in nearshore waters before moving up streams and rivers to spawn (Love 1996), loud low frequency sound could interfere with reproductive behavior. In addition, higher levels of sound at 125 and 250 Hz may decrease smolting rates in Atlantic Salmon (Terhune et al. 1990).

Reducing and mitigating impacts of SURTASS LFA

Because SURTASS LFA operations will not be in nearshore waters, the impacts on salmon are likely to be minimal. However, it would be prudent to adjust operations near locations and during the time of year when salmon spawn. The available data indicate that frequencies above 150 Hz are not likely to impact salmon while lower frequencies may repel them. Thus, avoiding the use of very low frequencies near salmon spawning grounds may reduce the impact of SURTASS LFA greatly. The mechanisms by which low frequency sound may impact smolting rates are unknown. While SURTASS LFA will not impact smolting (because smolting occurs in freshwater), it is possible that low frequency sound might affect other life history or demographic parameters in salmon. Monitoring the demography of salmon populations through stock assessments in regions where SURTASS LFA operations are extensive would be prudent.

ORDER SILUIFORMES

There are about 2000 species in 400-500 genera in 34 families in this order; the taxonomy of this order is under much debate. Of the 34 families, only one, Ariidae, is marine. Therefore, the discussion of this order focuses solely on this marine family.

U.S. Fish and Wildlife or IUCN Status

No species in the family Ariidae are considered threatened or endangered by the US Fish and Wildlife Service. One species, Arius bonillai, is considered endangered by the IUCN.

Distribution

Members of the family Ariidae occur in tropical and subtropical waters over much of the world, but are particularly common in estuarine waters.
Arius bonillai is found in turbid water over muddy bottoms in the lower portions of streams, estuaries and mangrove-lined lagoons in the western central Atlantic and the eastern central Pacific.

Natural History Notes

Ariidae, the Sea Catfishes, are unspecialized looking catfishes found throughout the world, particularly in inshore waters. They feed on benthic invertebrates often in noisy schools. Sound in this group is created by the clicking of pectoral spines and the vibration of the swimbladder. Fecundity is low in this family, and the males incubate the eggs in their mouths (Moyle and Cech 1996).

Hearing Range and Sound Production

Members of this order are members of the Otophysi, and the Ariidae are the only marine fishes in the Otophysi. Members of the Otophysi are united by a number of features, but the most obvious of these features is the Weberian apparatus. This is a chain of bones that connects the swimbladder to the inner ear giving fishes in this group a sensitive sound reception system. It is presumed that an acute sense of hearing is useful in turbid water or at night (when most catfish are active). Although members of Ariidids should have acute hearing, sound reception has not been explicitly examined in this family. Sound production has been examined in three species: Barge marinus, Arius felis, and Galeichthys felis. Arius. felis produces vocalizations from 100 to 1600 Hz (Dobrin 1947). G. felis produces sound from 100 to 700 Hz with dominant frequencies from 200-700 Hz (Fish and Mowbray 1970). Other members of the otophysi appear to hear from 20-1200 Hz with optimal hearing near 150 Hz with a threshold sound pressure of about 65 dB: 1 μPa (Popper and Fay 1993). Thus, it is likely that the sounds produced by Ariidids are perceived by conspecifics and may be used in behavioral interactions.

Known and potential impacts of low frequency sound

There are no known impacts of low frequency sound on Ariidids. Because members of this group are thought to be "hearing specialists" (Popper and Fay 1993), and they are active sound producers (Dobrin 1947), it is possible that low frequency sound may impact behavioral interactions among members of this family. In addition, because these fish are generally found in turbid waters, it is conceivable that catfishes use hearing to locate prey or avoid predators. Thus, sound could impact predator-prey dynamics in Ariidids.

Reducing and mitigating impacts of SURTASS LFA

Because members of this family are generally found inshore in shallow waters, the impacts of SURTASS LFA should be minimal. Research determining how catfishes use sound will be critical in determining if any speculation about potential impacts are realized. Avoiding operations in waters off the coast of Columbia where the endangered species, Arius bonillai, occurs would reduce any possibility of impacting this species. However, since this is an inshore species, offshore operations should not harm Arius bonillai.

ORDER GADIFORMES

This order has 684 species in 168 genera.

U.S. Fish and Wildlife or IUCN Status

No species in this order is considered endangered or threatened by the US Fish and Wildlife Service. Physiculus helenaensis is considered critically endangered and cod Gadus morhua and haddock Melanogrammus aeglefinus are considered vulnerable by the IUCN.

Distribution

Table: The distribution of families of the order Gadiformes.

Family	**Distribution**
Muraenolepididae	Marine Southern Hemisphere
Moridae	Marine deep-water, all seas
Physiculus helenaensis	Southeast Atlantic, St. Helena
Melanonidae	Meso- to bathypelagic in southern Atlantic and southern Pacific oceans
Bregmacerotidae	Tropical and subtropical seas

Gadidae	Arctic, Atlantic and Pacific Oceans
cod Gadus morhua	Cod are widely distributed in a variety of habitats from the shoreline to well down the continental shelf. Their range is from Cape Hatteras to Ungava Bay along the North American coast; east and west coast of Greenland; around Iceland; coasts of Europe from the Bay of Biscay to the Barents Sea, including the region around Bear Island. Cod feed at dawn or dusk on invertebrates and fish, including young cod. They occur in temperatures ranging from nearly 0 to 20°C. They form schools during the day. They spawn in late winter through the spring and early summer with a peak in spring
haddock Melanogrammus aeglefinus	Haddock are found commonly from 80 to 200 m, over rock, sand, gravel or shells, usually at temperatures between 4° and10°C. They range from the eastern North Atlantic from the Bay of Biscay to Spitzbergen; in the Barents Sea to Novaya Zemlya; around Iceland; rare at the southern Greenland. In the western North Atlantic from Cape May, New Jersey to the Strait of Belle Isle. Spawning peaks in spring. They feed mainly on small crustaceans, mollusks, echinoderms, worms and fishes.
pollack Pollachius pollachius	Pelagic to benthopelagic, mostly close to shore over hard bottoms. They occur in the Northeastern Atlantic from Norway, the Faeroes (rare) and Iceland to the Bay of Biscay. They feed mostly on fish and incidentally on cephalopods and crustaceans
pollock Pollachius virens	Gregarious fish occurring inshore and offshore waters. They occur from Barents Sea and Spitsbergen to Bay of Biscay, around Iceland, southwest Greenland, and in the western Atlantic from Hudson Strait

	to North Carolina. Usually enters coastal waters in spring and returns to deeper waters in winter. Smaller fish in inshore waters feed on small crustaceans and small fish, while larger fish prey predominantly upon fishes.
Merlucciidae	Atlantic, eastern Pacific, Tasmania, and New Zealand
Macrouridae	Arctic to Antarctic in deep water
Ophidiidae	Atlantic, Indo-pacific
Carapidae	Atlantic, Indo-pacific
Zoarcidae	Arctic to Antarctic

Additional Natural History Notes

Members of this order are important members of their communities often playing significant ecological roles in benthic deepwater communities. Many members of this order are commercially exploited and there is considerable interest in developing fisheries for others that are not presently exploited. Many members of the family Gadidae are presently overexploited.

Detailed information is provided below for two species, cod and haddock, which are considered vulnerable by the IUCN. Data for the species descriptions below were extracted from Cohen et al. 1990.

Atlantic cod are considered a demersal fish, although they may become pelagic when spawning or when feeding. Larger fish are food in cooler water, although the species occurs in a wide range of temperature (0-5 °C). They also occur in a wide range of salinities. They are most often found in nearshore waters to a depth of 150-200m. Cod are gregarious during the day; forming compact schools that swim between 30 and 80 m above the bottom, and scatter at night. To the south of its range, cod is found in shallow water only during the winter and there, as elsewhere, it is the younger smaller fish that live close inshore.

Most cod in the eastern and western parts of the Atlantic ocean spawn from December to June, i.e., Norwegian coast, from February to April; Baltic Sea, April to July; North Sea, December to May; Gulf of Maine, November to April; Newfoundland, April to June; West Greenland, March to June; and southwestern Gulf of St. Lawrence, May to September. The major spawning areas of cod are the North Sea in depths of < 50m especially in the Bornholm Basin in Denmark; the eastern half of Georges Bank and the area south of the Grand Banks in Newfoundland; the southwestern part of the Gulf of Main between Nantucket Shoals and the Bay of Fundy.

The haddock, Melanogrammus aeglefinus, ranges from Greenland to Cape Hatteras. Haddock are most common at temperature of 2 - 10 ^{o}C. Haddock prey primarily on small invertebrates, but fish are also consumed by adult haddock. Spawning occurs between January and June, with peak activity during late March and early April. Major spawning concentrations occur on eastern Georges Bank, although some spawning also occurs to the east of Nantucket Shoals and along the Maine coast. Commercial landings of Gulf of Maine haddock declined from about 5,000 mt annually in the mid-1960s to less than 500 mt since 1988. Abundance is at an historic low and recruitment has been insufficient to support landings.

Hearing Range and Sound Production

Gadids appear to have good hearing. They are able to analyze a sound's spectrum using auditory filters and are able to discriminate between pure tones of different frequencies with an acuity of 3-5% (Popper and Fay 1993). Using a conditioning procedure to determine auditory thresholds of cod (Gadus morhua) at different levels of background noise, Buerkle (1968) demonstrated that cod can detect sound from 35 to 400 Hz with the lowest threshold of 50 dB re 1 µPa at 140 Hz. Recent work (Mann et al. 1997) suggests that cod can detect sounds to at least 38 kHz. G. morhua as well as other Gadid species also vocalize extensively (Hawkins and Rasmussen 1978), apparently associated with agonistic behavior (Almada et al. 1996). G. morhua vocalizes between 30 and 650 Hz with the dominant frequencies between 30 and 400 Hz (Almada et al. 1996). The vocal range of other Gadids is as follows: Gadus callarias 0-500 Hz (Brawn 1961) Gaidropsarus mediterraneus 47 and 736 Hz (Hawkins and Rasmussen 1978); Melangrammus aeglefinus 40 and 300 Hz (Hawkins and Rasmussen 1978); Merluccisu bilinearis near 0-100 Hz (Fish and Mowbray 1970); Pollachius pollachius near 0-100 Hz (Hawkins and Rasmussen 1978); Pollachius virens near 0 to 200 (Fish and Mowbray 1970); Raniceps raninus 0-500 Hz (Hawkins and Rasmussen 1978); Urophycis regius 0-800 Hz (Fish and Mowbray 1970); Urophycis chuss 0-800 Hz (Fish and Mowbray 1970).

Known and potential impacts of low frequency sound

There are no known impacts of low frequency sound on members of this order. Because many members of this order, including the commercially exploited and IUCN red listed cod and haddock, are active sound producers (Hawkins and Rasmussen 1978), and the uses of such vocalizations are only beginning to be understood (Almada et al. 1996), there is some potential for impact of low frequency sound. In particular, if gadoid fish use sound for specific behavioral interactions, then low frequency sound could interfere with these behaviors.

Reducing and mitigating impacts of SURTASS LFA

Although gadoids appear to have the ability to discriminate between background noise and pure tone (Buerkle 1968), they appear to use low frequency sound in behavioral interactions (Hawkins and Rasmussen 1978, Almada et al. 1996). SURTASS LFA operations may thus impact the behavior of gadoids. At present, however, there are no data that demonstrate that low frequency sound would impact gadoids, and there is a clear need for data explicitly testing this. Given the transient nature of SURTASS LFA operations, it is unlikely that a population effect on gadoids would occur. However, since both cod and haddock are vulnerable and of considerable commercial importance, it would be judicious to avoid operations in known spawning grounds of these species.

ORDER BATRACHOIDIFORMES

This order contain 69 species

U.S. Fish and Wildlife or IUCN Status

No Batrachoids are listed as endangered or threatened by the US Fish and Wildlife Service. The IUCN lists Batrachoides manglae, Sanopus astrifer, S. greenfieldorum, S. reticulatus, and S. splendidus as vulnerable.

Distribution

Member of this order are chiefly marine found in nearshore coastal and benthic waters. They are rarely in brackish waters and there are a few freshwater species. They occur in the Atlantic, Indian and Pacific Oceans (Froese and Pauly 1997). Batrachoides manglae occurs in the western Atlantic from Columbia to Venezuela; Sanopus astriferm, S. greenfieldorum, S. reticulatus, and S. splendidus all occur in Belize.

Natural History Notes

Batrachoids are commonly encountered in shallow marine waters especially off North America. They are benthic carnivores often associated with structure. Members of this order are known to make loud sounds by vibrating their swimbladder (Dobrin 1947, Fine 1983, Moyle and Cech 1996).

Hearing Range and Sound Production

Hearing thresholds of one species in this order, Opsanus tau, have been investigated. The range of hearing for this species is from 38 to 700 Hz with best hearing at 40-90 Hz with a threshold of 98 dB (Fish and Offutt 1971). Toadfish as well as other members of this order are well-known sound producers (Fish and Mowbray 1970). Sound production of O. tau appears allow short distance communication primarily for mating (Fine and Lenhardt 1983). The courtship vocalization occurs principally in very shallow water (1-2 m), and because of the short distance nature of the communication, ambient noise does not appear to exert a strong selection pressure on the frequency spectrum of the mating call (Fine and Lenhardt 1983)

Known and potential impacts of low frequency sound

Fine and Lendardt (1983) investigated the effects of ambient noise on communication among male toad fish (Opsanus tau) and found no impact of ambient noise. Ambient noise in this study was measured in two estuaries at frequencies most likely to influence toadfish, and was about 23 dB. Fine and Lendardt calculated that an increase of 60 dB would still not affect toadfish.

Reducing and mitigating impacts of SURTASS LFA

Given the available data for Opsanus tau and the shallow, nearshore distribution of members of this order, the possibility of impact by SURTASS LFA operations is negligible. Near the Belize, Columbia and Venezuela where vulnerable species of this order reside, it would be prudent, based on data from O. tau, to adjust operations such that the intensity of the sound reaching the shoreline is < 85 dB to prevent the masking of mating calls.

ORDER LOPHIIFORMES

There are 215 species in 15 Familes in this order

U.S. Fish and Wildlife or IUCN Status

One species, Brachionichthys hirsutus is considered critically endangered by the IUCN.

Distribution

Lophiformes occurs in all oceans. There are two ecological groupings of this order: (1) those that live in shallow water, usually on the bottom or attached to drifting seaweed (families Lophiidae, Brachionichthyidae, Antennariidae, Chaunacidae, Ogcocephalidae); and (2) those that occur in the deep sea (all the remaining families).
Brachionichthys hirsutus is endemic to Tasmania, Australia and occurs in the continental shelf and inshore waters.

Natural History Notes

Members of this order are called angler fishes because most Lophiformes possess a organ which dangles from the head and is used to attract prey. These fish are generally inactive with large mouths and heads.

Hearing Range and Sound Production

Six members of this order have been recorded producing sound when artificially prodded by a researcher; however, the frequencies and intensities of this sound were not investigated (Fish and Mowbray 1970). The species that produced sound were Lophius americanus (Family Lophiidae), Antennarius scaber, Histrio gibba and Histrio histrio (Family Antennariidae), Ogocephalus radiatus and O. vespertillo (Family Ogococephalidae).

Reducing and mitigating impacts of SURTASS LFA

There are insufficient data to suggest means to reduce or mitigate impacts of SURTASS LFA operations. Research documenting hearing range, sound production and the uses of sound is necessary before recommendations can be made.

ORDER ATHERINIFORMES

There are 285+ species in this order occurring in both fresh and marine waters. Only the marine species are considered here.

U.S. Fish and Wildlife or IUCN Status

No members of this order are considered threatened or endangered by the US Fish a d Wildlife Service or the IUCN.

Distribution

Table: The distribution of families of the order Atheriniformes.

Family	**Distribution**
Exocoetidae	Atlantic, Indian, and Pacific Oceans
Belonidae	Tropical and temperate fishes of the surface layer ranging from open ocean to freshwater
Scomberesocidae	Tropical and temperate epipelagic waters of the Atlantic and Pacific
Atherinidae	Tropical to temperate waters; some in freshwater. About 160 sp. that are extremely abundant inshore

Natural History Notes

Atherinformes are common fish in inshore shallow water. They are schooling diurnal planktivores. They are often important prey for larger commercially exploited fishes as well as birds and marine mammals (Robbins and Ray 1986)

Hearing Range and Sound Production

Two species in this order (Menidia berylinna and M. menidia) produce sound (Fish and Mowbray 1970); however, the frequencies or intensity of these vocalizations have not been investigated.

Known and potential impacts of low frequency sound

Because these fish form large schools, low frequency sound may disrupt the integrity of schools (Partridge 1981) or potentially, the detection of predators (Blaxter and Batty 1985) as has been suggested for Clupeids.

Reducing and mitigating impacts of SURTASS LFA

There are insufficient data to suggest means to reduce or mitigate impacts of SURTASS LFA operations. Research documenting hearing range, sound production and the uses of sound is necessary before recommendations can be made.

ORDER BERYCIFORMES

There are 39 genera with 143 species. This order is divisible into five groups (Nelson 1984), and hearing and sound production has only been noted for one of this groups, the Holocentridae. This discussion, therefore, focuses only on this family.

U.S. Fish and Wildlife or IUCN Status

No members of this order are considered threatened or endangered by the US Fish a d Wildlife Service or the IUCN.

Distribution

The Holocentids are tropical and found in Atlantic, Indian, and Pacific Oceans. Most are nocturnal. They are usually cryptic during the day and are found in crevices or beneath ledges of reefs. Most species occur shallow water from shoreline to 100 m depth.

Natural History Notes

Holocentrids are the largest and most widely distributed family in the Beryciformes. They inhabit coral reefs or rocky outcroppings. They emerge at night in large numbers and consume benthic invertebrates and zooplankton (Randall 1967). Members of this family are well-known sound producers using a variety of clicks, croaks and grunts as communication (Moyle and Cech 1996). These vocalizations appeared to be used in territorial conflicts and as alarm calls as predators approach (Winn et al. 1964, Horch and Salmon (1973).

Hearing Range and Sound Production

Auditory thresholds have been determined for several holocentrids. Myripriste kuntee (Coombs and Popper 1979) and Holocentrus ascensionis (Tavolga 1971) have auditory thresholds between 100-3000 Hz, with M. kuntee being most sensitive between 300-2000 Hz at 50 dB re:1 uPa (Coombs and Popper 1979). H. vexillarius can hear between 100-1000 Hz (Tavolga 1971), and Adioryx xantherythrus between 100-800 Hz, with a sensitivity of 72 dB re:1 uPa at 500 Hz (Coombs and Pooper 1979). Sound production has been documented from near zero to 600 Hz in M. jocobus and Holocentrus ascensionis (Fish and Mowbray 1970). M. violanceus and M. pralinus produce and react to vocalization ≤ 1500 Hz, with some sound production as high as 3000 Hz (Horch and Salmon 1973).

Known and potential impacts of low frequency sound

There are no known impacts of LFS on beryciforms; however, some potential impacts exist. Seven species have been reported to produce sound (Fish and Mowbray 1970, Moulton 1958, Horch and Salmon 1973). Members of the Family Holocentridae have been reported to produce and respond to conspecific noise in threat situations and territorial interactions (Horch and Salmon 1973, Salmon 1967, Winn et al. 1964). Based on the reported information and because beryciforms are nocturnally active, low frequency sound could disrupt social interactions and the detection of predators.

Reducing and mitigating impacts of SURTASS LFA

When SURTASS LFA operations are performed distant from shore, shallow members of this species should not be impacted. Reef dwelling species will not be affected as long as operations are conducted away from coral reef habitats. Some open ocean species in this order may be at risk of impact. Research documenting if and how these species are impacted is needed.

ORDER GASTEROSTEIFORMES

This order contains 200 species in 40 genera.

U.S. Fish and Wildlife or IUCN Status

No members of this order are considered threatened or endangered by the US Fish a d Wildlife Service or the IUCN.

Distribution

Table: The distribution of families of the order Gasterosteiformes.

Family	**Distribution**
Aulostomidae	Tropical Atlantic and Indo-Pacific
Fistulariidae	Tropical Atlantic and Indo-Pacific
Macrorhamphosidae	Tropical Atlantic and Indo-Pacific
Centriscidae	Atlantic, Indian, and Pacific Oceans on reefs and over shelf and slope
Solenostomidae	Tropical Indo-pacific
Syngnathidae	Atlantic, Indian, and Pacific Oceans mostly in warm temperate to tropical waters. Some species occur in fresh or brackish waters

Natural History Notes

The Syngnathids (sea horses and pipefish) are the only family in this order demonstrated to produce sound. Sound may be related to mating (Fish and Mowbray (1973). Male Sea horses and pipefishes have a sealed brood pouch on the underside of the tail and females lay eggs in this pouch. Males then incubate the eggs. They feed on small crustaceans. They are successful group in shallow marine waters throughout the world.

Hearing Range and Sound Production

Auditory thresholds have not been determined for the syngnathids. Hippocampus hudsonius has been recorded to produce sound from near zero to 1300 Hz (Fish and Mowbray 1970).

Known and potential impacts of low frequency sound

There are no known impacts of low frequency sound on synbranchiforms. One species (Hippocampus hudsonius) has been reported to produce sounds (Fish and Mowbray 1970), but no information exists on its use, or the hearing ability of this species. If members of this order use sound in mating rituals, then low frequency noise could impact spawning.

Reducing and mitigating impacts of SURTASS LFA

Research determining the use of sound by this taxon should be conducted to reduce the potential of unknown effects of low frequency sound. However, since this is largely a shallow water, nearshore group, impacts of SURTASS LFA are likely to be minimal.

ORDER SCORPAENIFORMES

There are 21 Familes, 260 general and about 1000 species in this order.

U.S. Fish and Wildlife or IUCN Status

The IUCN lists Pontinus nigropunctatus as vulnerable, Sebastes fasciatus as endangered and S. paucispinus as critically endangered. The US Fish and Wildlife Service does not list any marine species in this order as endangered or threatened.

Distribution

Table: The distribution of families of the order Scorpaeniformes.

Family	**Distribution**
Scorpaenidae	All tropical and temperate seas
Triglidae	All tropical and temperate seas
Caracanthidae	Indian and Pacific Oceans on reefs
Aploactinidae	Coastal western Pacific
Pataecidae	Australia, 40-80 m water
Anoplopomatidae	North Pacific from California to Japan one species on mud bottom from 305 to 1,829 m or deeper the other in shallower water from 0-450 m
Hexagrammidae	Endemic to the North Pacific, primarily littoral
Platycephalidae	Indo-Pacific usually in shallow water
Hoplichthyidae	Indo-Pacific shelf slope and bathypelagic waters
Congiopodidae	Southern Hemisphere shelf waters to a depth of 500m
Cottidae	Northern Hemisphere and near New Zealand
Normanichthyidae	Southeastern Pacific: ranges from Chimbote, Peru to Isla Mocha, 38°22' Lat. S., Chile
Psychrolutidae	Atlantic, Indian, and Pacific Oceans from shallow to very deep waters
Agonidae	North Atlantic, North Pacific, and southern South America
Cyclopteridae	Antarctic, Arctic, Atlantic, and Pacific

Pontinus nigropunctatus is endemic to St. Helena and generally occurs in 150-200m of water. Sebastes fasciatus occur in shallow water from the Gulf of St. Lawrence to shelf waters of Nova Scotia in Canada, and in the Northeastern off Iceland and western Greenland. S. paucispinus occur in the Eastern Pacific: from Kodiak Island, Alaska to central Baja California, Mexico. Adults occur over rocky reefs but also common on open bottom from 27-320 m depth. Young live in shallower water.

Natural History Notes

Scorpaenids have large mouths, large eyes and stout bodies, and they support valuable commercial and recreational fisheries. Most are demersal predators, although some species enter the water column to prey on plankton, fish and squid. Many species in this family are long-lived with some rockfishes living as long as 140 years. In addition, they are slow growing, and as a result, overexploitation of members of this family is a problem. The searobbins, family Triglidae, are perhaps the noisiest fish in the sea (Moyle and Cech 1996). They appear to use sound produced by a large swimbladder as part of mating rituals (Myrberg 1978). This widely distributed family lives at moderate depths and feeds on benthic invertebrates. Cottids are a large family of bottom-dwelling fishes with marine representatives occurring in coastal waters. They frequently live in turbulent water, and feed on invertebrates and fish.

Hearing Range and Sound Production

Two species of scorpaenids are known to produce sound. Fish and Mowbray (1970) noted sound production by Sebastes marinus and Scorpaena plumieri; however, frequencies and intensities of the vocalizations were not enumerated. Adverse responses of rockfishes to loud (180dB) low frequency sound has been noted (Pearson et al. 1992), but Klimley and Beavers (1997) failed to detect a response of rockfish to 153 dB low frequency sound.

Known and potential impacts of low frequency sound

There are no known impacts of low frequency sound on scorpaeniforms, however potential impacts exist. Members of this order have been reported to produce sounds in conjunction with spawning, courtship, and territorial defense (Fish and Mowbray 1970, Mouton 1958, Ladich 1994, Whang and Janssen 1994). However, Klimley and Beavers (1997) failed to detect a change in rockfish behavior when they were exposed to loud low frequency sound. Some members of this taxa are nocturnal, and thus hearing may be an important sensory system in these species. Both juvenile (Jones and Janssen 1992) and adult (Hoekstra and Janssen 1985) members of the Family Cottidae use lateral-line senses to detect near-field disturbances of prey. Low frequency sound could disrupt feeding ability and spawning and social interactions in this group.

Reducing and mitigating impacts of SURTASS LFA

There are insufficient data to suggest means to reduce or mitigate impacts of SURTASS LFA operations. The limited data available at present suggest SURTASS LFA impacts should be minimal if intensities are less than about 150 dB where fish concentrations are located; however, research documenting hearing range, sound production and the uses of sound is necessary before recommendations can be made. Because many members of this taxon, particularly rockfishes, are commercially and recreationally important, stocks should be monitored in regions with where SURTASS LFA operations occur frequently.

ORDER DACTYLOPTERIFORMES

U.S. Fish and Wildlife or IUCN Status

No members of this order are considered threatened or endangered by the US Fish a d Wildlife Service or the IUCN.

Distribution

Dactylopteriformes occur in the tropical Atlantic and Indo-Pacific

Natural History Notes

Species in this order are found on sand, mud or over rocks in sandy areas, exploring the bottom with the free part of the pectoral fins. They feed primarily on benthic crustaceans, especially crabs, clams and small fishes (Roux 1986).

Hearing Range and Sound Production

One species, Dactylopterus volitans, is known to produce sounds ranging from near 0 to 1200 Hz (Fish and Mowbray 1970). No data exist documenting the uses of these vocalizations.

Known and potential impacts of low frequency sound

There are no known impacts of low frequency sound on dactylopteriforms. One species has been reported to produce sound (Fish and Mowbray 1970), but the use and their hearing ability have not been reported. There is currently not enough information to provide an educated synopsis of potential impacts.

Reducing and mitigating impacts of SURTASS LFA

Research determining the use of sound should be conducted to reduce the potential of unknown effects of low frequency sound.

ORDER PERCIFORMES

The order perciformes is the most diverse of all vertebrate orders, and dominate marine habitats. There are 18 suborders, 147 families, 1257 genera and 6880 species. Below we discuss those marine perciform families for which hearing or sound production data are available.

Perciformes - Centropomidae

U.S. Fish and Wildlife or IUCN Status

No members of this order are considered threatened or endangered by the US Fish and Wildlife Service or the IUCN.

Distribution

Atlantic, Indian, and Pacific Oceans, often in brackish water. They are often associated with coastal, estuarine or lagoonal waters.

Natural History Notes

Some species in this family congregate at mouths of passes and rivers during the spawning season (Fraser 1978). Centropomids feeds on fish and crustaceans (Faser 1978).

Hearing Range and Sound Production

Auditory thresholds have not been determined for the centropomids. Vocalization has been documented in Centropomus ensiferus at 50-300 Hz (Fish and Mowbray 1970).

Known and potential impacts of low frequency sound

There are no known impacts of LFS on centropomids. Centropomis ensiferus is reported to produce sound (Fish and Mowbray 1970). However, the use and importance of the sound as well as this species hearing ability are unknown. Dara are insufficient to speculate on potential impacts.

Reducing and mitigating impacts of SURTASS LFA

Impacts of SURTASS LFA operations should be minimal as along as operations are distant from the nearshore habitat used by members of this family. Further research is necessary to better define hearing abilities and sound production in this family.

Perciformes - Serranidae

U.S. Fish and Wildlife or IUCN Status

The following serranids are considered vulnerable by the IUCN: Anthias salmopunctatus, Ephinephelus inermis, E. lanceolatus, E. niveatus, Hypoplectrus providencianus, Mycteroperca cidi, M. jordani, M. microlepis, M. olfax, M. prionura, M. rosacea, Plectranthias chungchowensis, and Pseudanthias regalis. E. striatus is considered endangered by the IUCN, and E. drummondhayi, E. itajara, and E. nigritus are considered critically endangered.

Distribution

Serranids are found in tropical and temperate oceans fishes associated with tropical and temperate reefs or other inshore environments. Distributions for IUCN red listed species are below.

Table: The distribution of IUCN listed species of the family Serranidae.

Species	**Distribution**
Anthias salmonpunctatus	Eastern Central Atlantic; Common on rock faces below 30 m
E. drummondhayi	Occurs in Bermuda and the coast of the USA from North Carolina to the Florida Keys and in the northern and eastern Gulf of Mexico; Inhabits offshore rocky bottoms; most common between 60 and 120 m
E. inermis	Western Atlantic: from North Carolina to Rio de Janeiro, including the Gulf of Mexico and the Caribbean; Usually on deep ledges, at depths to 210 m
E. itajara	Western Atlantic: from Florida to southern Brazil, in the Gulf of Mexico and the Caribbean. Eastern Atlantic: from Senegal to Congo Eastern Pacific: from Gulf of California to Peru. Inhabits inshore areas, usually in shallow water
E. lanceolatus	Southeast Atlantic and Indo-Pacific: Red Sea to Algoa Bay, South Africa and eastward to the Hawaiian and Pitcairn Islands; northward to southern Japan and southward to Australia. Common in shallow waters. Found in caves in coral reefs or wrecks; also in estuaries
E. nigritus	Western Atlantic: from Massachusetts to the Gulf of Mexico, Cuba, Trinidad, and Rio de Janeiro. Usually found on rough, rocky bottom; juveniles are occasionally seen on jetties and shallow-water reefs
E. niveatus	Western Atlantic: from Massachusetts to the Gulf of Mexico, Bermuda, the Caribbean, and southern Brazil. Adults occur well offshore on rocky bottoms. Commonly found between depths of 100 and 200 m
E. striatus	Western North Atlantic: Bermuda, Florida, Bahamas, Yucatan Peninsula and throughout the Caribbean to southern Brazil. Occurs from the shoreline to at least 90 m depth. Usually close to caves. Juveniles are common in seagrass beds
Hypoplectrus providencianus	Western central Atlantic on coral reefs
Mycteroperca cidi	Caribbean coast of Venezuela. Common in

	depths of 5 to 8 m; large adults are caught in 20 to 40 m; juveniles in shallow water over sandy bottoms near coral reefs and seagrass beds
M. jordani	Found in rocky reefs and kelp beds from southern La Jolla, California, USA to Mazatlan, Mexico
M. microlepis	Western Atlantic from North Carolina, USA to the Yucatan Peninsula. Juveniles occur in estuaries and seagrass beds; adults are usually found offshore on rocky bottom (rarely to 152 m), occasionally inshore on rocky or grassy bottom. It is the most common grouper on rocky ledges in the eastern Gulf of Mexico
M.olfax	Isla del Coco off Costa Rica and Galapagos Islands. Found among rock walls, underwater lava ridges, and all kinds of well structured vertical rock formation
M. prionura	Rocky reefs from Gulf of California south to Jalisco, Mexico
M. rosacea	Prefers rocky areas in shallow water at depths of about 50 m from the southwest coast of Baja California throughout the Gulf of California to Jalisco, Mexico
Plectranthias chungchowensis	Taiwan
Pseudanthias regalis	East central pacific.

Natural History Notes

Serranids are bottom-dwelling predators and highly prized commercial food fish. They are generally large and eat fish and / or crustaceans. Most species are hermaphroditic with females generally changing to males with age. Some species appear to form large spawning aggregations, where they are susceptible to environmental perturbations. For example, Nassau grouper (Ephinephelus striatus) the most important commercially exploited serranid in the Caribbean (Froese and Pauly 1997), forms spawning aggregations of > 30,000 individuals (Lieske and Myers 1994).

Hearing Range and Sound Production

Sound production is well known in serranids, but auditory thresholds have only been determined for once species. Epinephelus guttatus has an auditory threshold at 100-1000 Hz (Tavolga 1971) and has been recorded to produce sound at 50-240 Hz (Fish and Mowbray 1971). Vocalization has been recorded from near zero to 120 Hz in Epinephelus striatus; up to 140 Hz for Morone saxatilis, E. adscensionis and E. itajara; up to 200 Hz in E. nigritus and Mycteroperca microlepis; up to 220 Hz in E. morio and M. bonaci; up to 240 Hz in M. interstitialis and Petrometopon cruentatum; up to 300 Hz in

Diplectrum formosum; up to 500 Hz in Cephalopholis fulva, M. venenosa, Rypticus saponaceus, and Serranus tigrinus; up to 600 Hz in Alphestes afer; up to 700 Hz in Centropristes striatus (Fish and Mowbray 1970); and from 200 - 3000 Hz (Lobel 1992).

Known and potential impacts of low frequency sound

There are no known impacts of low frequency sound on serranids, however potential impacts exist. The ability to produce sound has been demonstrated for a number of serranids (Fish and Mowbray 1970), and hearing has been demonstrated in Epinephelus guttatus (Talvolga and Wodinsky 1963). Some serranids such as Hypoplectrus unicolor may use sound as a spawning cue (Lobel 1992). Richard (1968) demonstrated that these fish are attracted to sound from 25-200 Hz and suggested that they use sound to localize prey. The introduction of additional low frequency sound could disrupt breeding and foraging behavior.

Reducing and mitigating impacts of SURTASS LFA

Research needs to be conducted to determine if there are any impacts of low frequency sound on serranids. Until research demonstrates no significant impact of low frequency sound on this family, areas where endangered or threatened species congregate, as well as known spawning areas should be avoided to eliminate the possibility of negative impacts.

Perciformes - Pomatomidae

U.S. Fish and Wildlife or IUCN Status

No members of this order are considered threatened or endangered by the US Fish a d Wildlife Service or the IUCN.

Distribution

Pomatomids are found in the Eastern Atlantic from Portugal, Madeira, the Canaries, southward along the African coast to South Africa, also Mediterranean and Black Sea. In the Western Atlantic they are found from Canada and Bermuda to Argentina. They are also in the Indian Ocean.

Natural History Notes

One of two species (Bluefish, Pomatomus saltatrix) in this family has been investigated for its ability to produce sound. Bluefish inhabit coastal waters such as bays, estuaries and beaches (Wilk 1977). Young individuals up to 17 cm may be encountered near the shore, in schools pursuing and attacking small fishes, while the adults are in loose groups, often attacking shoals of mullets or other fishes (Wilk 1977). Migrates to warmer water during winter and to cooler water in summer (Wilk 1977).

Hearing Range and Sound Production

Auditory thresholds have not been determined for the pomatomids. Vocalization is known in Pomatomus saltatrix to occur at few to 240 Hz.

Known and potential impacts of low frequency sound

There are no known impacts of LFS on pomatomids. Pomatomus saltatrix is a reported sound producer (Fish and Mowbray 1970). However, the use and importance of sound is unknown.

Reducing and mitigating impacts of SURTASS LFA

Pomatomids are pelagic hunters present in all ocean waters except the eastern pacific. Known to attack schools of fish, it is possible that they use sound to localize prey. Because they are cosmopolitan pelagic predators they will be subjected to SURTASS LFA operations. Research determining if sound disrupts their foraging or other behavior is necessary to fully understand the impact potential of SURTASS LFA.

Perciformes - Carangidae

U.S. Fish and Wildlife or IUCN Status

No members of this order are considered threatened or endangered by the US Fish and Wildlife Service or the IUCN.

Distribution

Carangids are found in tropical Atlantic and Indo-Pacific waters. They are typically found in shallow water in nearshore and in oceanic habitats.

Natural History Notes

There are over 140 species of Carangids (jacks and pompanos). All are fast swimming predators that school. They feed on small fishes including herring, anchovies, silversides, and juvenile reef fishes.

Hearing Range and Sound Production

Auditory thresholds have been documented for Trachurus japonicus at 70-3000 Hz with the most sensitive region at 100-1500 Hz (Chung et al. 1995). Vocalization has been documented in the carangids, typically while the fish is under duress (Fish and Mowbray 1970). Sound production as low as 50-240 Hz has been recorded in Seroila dumerili and S. zonata; from 50-400 Hz in Caranx bartholomaei and T. glaucus; up to 600 Hz in Oligoplites saurus; up to 1000 Hz in Caranx crysos; up to 1500 Hz in Chloroscombrus chrysurus and Selene vomer; up to 2000 Hz in Alectis crinitus, C. hippos, C. ruber, Selar crumenophthalmus, and Vomer setapinnis; and up to 3000 Hz in C. latus (Fish and Mowbray 1970).

Known and potential impacts of low frequency sound

There are no known impacts of LFS on Carangids. The production of sound has been reported in fourteen species (Fish and Mowbray 1970) and hearing has been examined in Trachurus japonicus (Hawkins and Rasmussen 1978), however its use is unknown. One potential impact is on the cooperative hunting behavior exhibited in some species (Helfman et al. 1997). If sound is used for attack and localization cues low frequency sound could disrupt feeding success and possible social interactions.

Reducing and mitigating impacts of SURTASS LFA

Because some Carrangids are present in pelagic waters they come into contact with SURTASS LFA operations. While the potential impacts will be small because of the short-term and mobile nature of SURTASS LFA, it would be prudent to conduct research to determine the importance of sound in carangids.

Perciformes - Lutjanidae

U.S. Fish and Wildlife or IUCN Status

Two species, Lutjanus cyanopterus, Lutjanus analis are listed as vulnerable by the IUCN.

Distribution

Lutjanids occur in tropical and subtropical waters of Atlantic, Indian and Pacific Oceans. They are generally demersal and occur to depths of 450m. Most species are associated with submerged banks, tropical reefs or other inshore, shallow structured habitats. Lutjanus analis occurs in the Western Atlantic as far north as Massachusetts and southward to southeastern Brazil; including the Caribbean Sea and the Gulf of Mexico. It is most abundant around the Antilles, the Bahamas and off southern Florida. Lutjanus cyanopterus occurs from the eastern USA to mouths of the Amazon, Brazil. Adult L. cyanopterus are found mainly around ledges over rocky bottoms or around reefs while young sometimes inhabit mangrove areas.

Natural History Notes

Most species are carnivorous feeding on both fishes and invertebrates, often at night. These are among the most important food fishes in tropical and subtropical waters. They are usually associated with structure and are common members of fish assemblages on shipwrecks, oil platforms, and artificial reefs (Moyle and Cech 1996)

Hearing Range and Sound Production

The auditory threshold has been documented only in the Lutjanus apodus at 100-1000 Hz (Tavolga 1971). Vocalization below 500 Hz has been recorded in a variety of species. L. jocu has been recorded to produce sound from a few to 200 Hz; L. synagris and Ocyurus chrysurus to 300 Hz; L. griseus to 400 Hz; and L. analis, L. apodus, and Rhomboplites aurorubens to 500 Hz (Fish and Mowbray 1970).

Known and potential impacts of low frequency sound

There are no known impacts of low frequency sound on Lutjanids. However, sound may play a key role in feeding in the many nocturnal or crepuscular feeding species in this family. This is supported by the research of Richard (1968) that suggests that lutjanids use low frequency sound (25-200 Hz) to localize prey.

Reducing and mitigating impacts of SURTASS LFA

Because members of this family are found on coral reefs or other shallow nearshore habitats, as long as SURTASS LFA operations avoid these habitats, impacts on this family should be minimal.

Perciformes - Gerridae

U.S. Fish and Wildlife or IUCN Status

No members of this order are considered threatened or endangered by the US Fish and Wildlife Service or the IUCN.

Distribution

Gerreids are found in most tropical and subtropical seas. This is generally a shallow water, nearshore group.

Natural History Notes

These are generally schooling fishes and may be important forage for larger fish and birds (Froese and Pauly 1997).

Hearing Range and Sound Production

Hearing ranges are unknown for the gerrids. Sound production has been documented when fish were harassed by a researcher. Gerres cinereus produced sound at 50-200 Hz; Eucinostomus gula at 50-400 Hz; and Diapterus rhombeus and E. havana at 50-500 Hz (Fish and Mowbray 1970).

Known and potential impacts of low frequency sound

There are no known impacts of LFS on gerrids. Four species are reported to produce sound, but its use is not known (Fish and Mowbray 1970). Hearing abilities of this group are unknown.

Reducing and mitigating impacts of SURTASS LFA

Because gerrids inhabit shallow waters and silty regions near tropical reefs, impacts should be minimal if SURTASS LFA avoids these areas.

Perciformes - Haemulidae

U.S. Fish and Wildlife or IUCN Status

The IUCN lists one species, Anisotremus moricandi as endangered.

Distribution

Haemulids are conspicuous members of tropical reef communities and are found in Atlantic and Indo-Pacific tropical waters. Anisotremus moricandi is found on reefs near Brazil, Colombia, Panama, Venezuela.

Natural History Notes

Haemulids use their pharyngeal teeth for making sounds that are amplified by the swimbladder. These fish feed on hard-shelled invertebrates that live in the sand flats that surround coral reefs.

Hearing Range and Sound Production

Hearing has been documented in Haemulon sciurus at 50-1000 Hz, with the most sensitive frequencies below 300 Hz (Tavolga and Wodinsky 1965). Although hearing is not well documented, the Haemulids are a vocal group, and sound production is common. The ranges in which sound is produced are: few to 800 Hz for H. album, and H. macrostomum; few to 1000 Hz for Conodon nobilis, H. melanurum; few to 1200 Hz for H. scurus, Orthopistis chrysopterus, and Pomadasys corvinaeformis; and up to 2300 Hz for Anistremus virginicus, H. aurolineatum, H. carbonarium, H. flavolineatum, H. parrai, and H plumieri (Fish and Mowbray 1970). Vocalization is known in A. surinamensis and H. struatum but not recorded (Fish and Mowbray 1970).

Known and potential impacts of low frequency sound

There are no known impacts of low frequency sound on Haemulids; however, the vocal nature of this group as well has their documented ability to hear suggests there could be an impact of low frequency sound on this taxon. The use of sound by Haemulids in social interactions suggests that vocalizations may play an important role in territorial and mating behavior (Fish and Mowbray 1970). Haemulids are attracted to low frequency sound, and may use sound to detect prey (Richards 1968).

Reducing and mitigating impacts of SURTASS LFA

Because Haemulids are reef fish, impacts on this family should be minimal if SURTASS LFA avoids reef areas. In addition, since these fish are nocturnal, day time operations would have less of an impact than night time operations.

Perciformes - Sparidae

U.S. Fish and Wildlife or IUCN Status

Pagrus pagrus is listed as endangered by the IUCN.

Distribution

Sparids are chiefly marine, although they occur very rare in fresh- and brackish water. They occur in tropical and temperate Atlantic, Indian and Pacific Oceans. Most species occur in very shallow water on reefs, rocky outcroppings and in estuaries, although some species occur in depths up to 50m.

Pagrus pagrus inhabits rock and rubble or sandy bottoms with the young frequently found in seagrass beds. They occur commonly to a depth of 80 m, but occur to a depth of 250 m depth. They range in the Eastern Atlantic from the Straits of Gibraltar to 15°N (rare southward 20°N) including Madeira and the Canary Islands; in the Mediterranean and northward to the British Isles. In the Western Atlantic they are found from New York and northern Gulf of Mexico in USA to Argentina.

Natural History Notes

Sparids are grunt like in appearance but are more diversified in their feeding than grunts. Some feed on mollusks while others feed extensively on plants. Many species, especially as juveniles, are important forage species for larger fish and birds.

Hearing Range and Sound Production

Limited auditory range frequencies are known in the sparids. Pagrus major has an audible range from 50-1000 Hz with peak sensitivity of -14.2 dB (0dB=1 mPa) at 200 Hz (Ishioka et al. 1988).
Sound production has been documented when sparids competitively feed, act territorially, and as escape sounds in several species. Diplodus argenteus vocalizes from 50-400 Hz. Archosargus rhomboidalis, Calamus bajonado, C. calamus, and Stenotomus chrysops produce sound at 50-500 Hz. Lagodon rhomboides produces sound at 50-600 Hz (Fish and Mowbray 1970). Sound has been observed, but not recorded, in A. probatocephalus and C. penna (Fish and Mowbray 1970).

Known and potential impacts of low frequency sound

There are no known impacts of low frequency sound on sparids. Because some sparids use sound in behavioral contexts, low frequency sound could disrupt social interactions. However, there are insufficient data to determine potential impacts of low frequency sound.

Reducing and mitigating impacts of SURTASS LFA

Most members of this family occur in shallow nearshore, habitats and avoiding these habitats will reduce most of the impacts of SURTASS LFA on this group. It would be prudent to avoid locations where Pagrus pagrus, listed endangered by the IUCN, is found. Additionally, research documenting the effects of low frequency sound on this species as well as others in the family, is necessary to determine the extent of the potential impact.

Perciformes - Sciaenidae

U.S. Fish and Wildlife or IUCN Status

One sciaenid, Totoaba macdonaldi, is listed as critically endangered by the IUCN.

Distribution

Sciaenids occur in shallow water in the Atlantic, Indian and Pacific Oceans. Totoaba macdonaldi is found in Gulf of California in coastal near river mouths and rocky coasts.

Natural History Notes

The swim bladder of Sciaenids usually has many branches and is used as a resonating chamber for sound. The diet of most species consists of benthic invertebrates and / or small fish. Many scianenids are important food fishes and some species have been severely overexploited.

Hearing Range and Sound Production

Hearing abilities and sound production have been examined extensively in this family. In the genus Corvina several hearing frequencies have been reported. Dijkgraaf (1952) found an upper frequency at 1000 Hz, while Maliukina (1960) found 1500-2000 Hz with thresholds of -45 dB at 320 Hz and -50 dB at 500-600 Hz. Corvina niger responded to frequencies of 340, 480, 640, 770, and 1024 Hz (Dijkgraff 1949).

Sound production is well documented in sciaenids. Most vocal activity recorded relates to courtship behavior and spawning activities, and is primarily produced by males (Saucier 1993, Connaughton and Taylor 1995, Connaughton 1996). Pogonias chromis produces sound at 50-500 Hz (Saucier 1993) while in spawning aggregations. Cynoscion nebulosis (Saucier 1993) and C. regalis (Connaughton 1996, Connaughton and Taylor 1995) also produce sound in spawning aggregations, but the frequencies of these vocalizations is undocumented. Bairdiella chrysura produces sound up to 2500 Hz (Fish and Mowbray 1970). Larimus breviceps and Scianops ocellata vocalize from 200-2000 Hz (Fish and Mowbray 1970, Guest 1978). Micropogonias undulatus and Leiostomus zanthurus vocalize from 100-400Hz (Guest 1978). B. ronchus and Ophioscion adustus produce sound from 200-700 Hz (Fish and Mowbray 1970), and Equetus acuminatus, Odontoscion dentex, and Sciaenops ocellata have been recorded producing sound from 50-500 Hz. Sound production, but no documented ranges, have been observed in Menticirrhus saxatillis, Stellifer lanceolatus, and Umbrina caroides (Fish and Mowbray 1970).

Known and potential impacts of low frequency sound

There are no known impacts of low frequency sound on sciaenids, however potential impacts exist. The vocal and hearing ability of sciaenids, along with a highly developed lateral line demonstrate the importance of sound in their life history. Sciaenids use sound for both spawning and territorial behavior (Connaughton 1996, Connaughton and Taylor 1995, Connaughton and Taylor 1994, Saucier and Baltz 1993, Guest 1978, Fish and Cummings 1972, Pilleri et al. 1982, Dobrin 1947). Low frequency sound can potentially disrupt breeding activity and social interactions. They also school, and low frequency sound may be important in maintaining school integrity as well for group interactions and predator detection and avoidance.

Reducing and mitigating impacts of SURTASS LFA

Sciaenids generally occur in nearshore coastal waters, and thus SURTASS LFA operations that avoid this habitat will reduce the impact on this family. Sciaenids often form spawning aggregations and operations should avoid known locations where aggregations occur. In locations where frequent SURTASS LFA operations and spawning sciaenids occur, it would be prudent to monitor stock assessments in an attempt to determine impacts of SURTASS LFA.

Perciformes - Mullidae

U.S. Fish and Wildlife or IUCN Status

No members of this order are considered threatened or endangered by the US Fish and Wildlife Service or the IUCN.

Distribution

Mullids are found in Atlantic, Indian, and Pacific Oceans and generally occur in shallow, nearshore waters. Many species are associated with coral reefs.

Natural History Notes

The chin of mullids has 2 long barbels which contain chemosensory organs and are used to probe the sand or holes in the reef for benthic invertebrates or small fish. Many mullids are brightly colored. They grow to 60 cm maximum length, and are valued as food fish.

Hearing Range and Sound Production

The auditory range has not been thoroughly documented for the mullids. Maliukina (1960) reported the threshold for <u>Mullus</u> to be 450-900 Hz at below -30 dB. <u>Mulloidichthys martinicus</u> and <u>Pseudopeneus maculatus</u> both make escape sounds, knocks, thumps, and clicks at 0-500 Hz (Fish and Mowbray 1970).

Known and potential impacts of low frequency sound

There are no known impacts of LFS on mullids. Two species have been reported to produce sound (Fish and Mowbray 1970) and one reported to hear (Maliukina 1960). However, the use of sound remains uninvestigated. Mullids use chemosensory structures to locate prey reducing the importance of sound for feeding. There is currently too little information to provide an educated synopsis of potential impacts.

Reducing and mitigating impacts of SURTASS LFA

Research needs to be conducted to determine if potential impacts exist. However, it appears unlikely that SURTASS LFA operations will impact this family as long as operations avoid coral reef and associated habitats.

Perciformes - Kyphosidae

U.S. Fish and Wildlife or IUCN Status

No members of this order are considered threatened or endangered by the US Fish and Wildlife Service or the IUCN.

Distribution

Kyphosids occur in the Atlantic, Indian and Pacific Oceans and usually are found near shore in shallow water

Natural History Notes

Many Kyphosids are herbivores feeding on a variety of benthic algae, while others are carnivores consuming benthic invertebrates.

Hearing Range and Sound Production

No hearing range is known for the kyphosids. Sound production has been documented in <u>Kyphosus sectatrix</u> at 50-400 Hz as alarm sounds that increased in intensity with mechanical and electrical stimulation (Fish and Mowbray 1970).

Known and potential impacts of low frequency sound

There is no known impact of LFS on Kyphosids. Although one species, Kyphosus sectatrix is reported to produce sound, but its use and importance is not known (Fish and Mowbray 1970).

Reducing and mitigating impacts of SURTASS LFA

Because kyphosids are occur on coral reefs, impacts will be minimal if SURTASS LFA avoids tropical reef habitats.

Perciformes - Ephippidae

U.S. Fish and Wildlife or IUCN Status

No members of this order are considered threatened or endangered by the US Fish and Wildlife Service or the IUCN.

Distribution

Atlantic and Indo-Pacific shallow water. Frequently found on coral reefs, mangroves or other nearshore tropical habitats.

Natural History Notes

Most species are omnivorous with some species consuming plankton and others benthic invertebrates and algae.

Hearing Range and Sound Production

No hearing range in known for the ephippids. Vocal production has been observed in Chaetodipterus faber at 50-400 Hz as grunts during competitive feeding, knocks of an alarm sound, and escape sounds (Fish and Mowbray 1970).

Known and potential impacts of low frequency sound

There is no known impact of LFS on ephippids. Only one species has been investigated and found to produce sound (Fish and Mowbray 1970), but its use and importance is not known.

Reducing and mitigating impacts of SURTASS LFA

Ephippids inhabitat shallow tropical habitats, thus impacts of SURTASS LFA operations will be minimized if operations are conducted distant from coral reefs, mangroves and seagrass beds.

Perciformes - Chaetodontidae

U.S. Fish and Wildlife or IUCN Status

Chaetodon flavocoronatus, Chaetodon litus, Chaetodon marleyi, Chaetodon obliquus and Chaetodon robustus are all considered vulnerable by the IUCN.

Distribution

Chaetodontids occur in tropical waters of the Atlantic, Indian, and Pacific Oceans. They generally occur near coral reefs. Chaetodon flavocoronatus occurs in Guam, C. litus is endemic to Easter Island. C. marleyi is known only from Delagoa Bay, Mozambique to Lamberts Bay (western Cape Province), South Africa. C. obliquus occurs in the Eastern Central Atlantic and is known only from St. Paul's Rocks. C robustus ranges in the Eastern Central Atlantic from Mauritania southwards to Gulf of Guinea, extending to Cape Verde Islands.

Natural History Notes

Chaetodontids are often brightly colored with a dark band across the eye and an 'eyespot' dorsally. They are typically diurnal and feed on a combination of coelenterate polyps or tentacles, small invertebrates, fish eggs, and filamentous algae. Most species occur as heterosexual pairs.

Hearing Range and Sound Production

No hearing range is known for the chaetodontids. Thumps, knocks and clicks are reported sounds by Chaetodon ocellatus at 100-500 Hz, and C. striatus at 50-400 Hz when electronically stimulated (Fish and Mowbray 1970).

Known and potential impacts of low frequency sound

There are no known impacts of LFS on chaetodontids, however potential impacts exist. Sound production has been reported in seven species by Fish and Mowbray (1970). Two species have been observed to produce sound during feeding, aggressive interactions, and social interactions (Moulton 1958). The introduction of low frequency sound may disrupt social interactions in this family.

Reducing and mitigating impacts of SURTASS LFA

Chaetodontids are tropical shallow-water species, therefore any impacts should be minimal as long as SURTASS LFA operations are conducted distant from coral reefs. In addition, it would be prudent to avoid locations where IUCN listed species occur.

Perciformes - Pomacanthidae

Legal Status

One species in this family, Centropyge resplendens, is listed as vulnerable by the IUCN.

Distribution

Pomacanthids are found on coral reefs throughout the tropical Atlantic and Indo-Pacific. They usually occur in depths less 20m deep and are rarely found below 50m.

Natural History Notes

Pomacanthids are brightly colored, conspicuous members of coral reef communities. All species studied to date are protogynous hermaphrodites with 'haremic' social system (Froese and Pauly 1997). Species of Centropyge feed primarily on filamentous algae, and species of Genicanthus feed primarily on zooplankton; most Pomacanthids feed on sponges, invertebrates, algae and fish eggs.

Hearing Range and Sound Production

Hearing has not been investigated in the pomacanthids. Escape sounds, thumps, grunts, and knocks are reported with electric stimulation, and feeding noises have been recorded (Fish and Mowbray 1970). Holocanthus cillaris, and H. tricolor produced sounds at 50-500 Hz, and H. isabelita and Pamocanthus arcuatus at 50-400 Hz (Fish and Mowbray 1970).

Known and potential impacts of low frequency sound

There are no known impacts of low frequency sound on pomacanthids. Although these fishes produce sound while feeding, it is unlikely that sound places a critical role in preying upon the sessile species that dominant the diet of this taxa (Froese and Pauly 1997).

Reducing and mitigating impacts of SURTASS LFA

There are too few data to suggest means for reducing or mitigating the impacts of SURTASS LFA operations. However, because pomacanthids occur in shallow water on coral reefs, operations which avoid this habitat will eliminate any impact on this family.

Perciformes - Pomacentridae

U.S. Fish and Wildlife or IUCN Status

Chromis santaehelenae, Stegastes sanctaehelenae, and S. santipaulae are listed as vulnerable by the IUCN.

Distribution

Pomacentrids occur in all tropical seas with the majority of the species in the Indo-Pacific. Most species are associated with coral reef habitats. Chromis santaehelenae is found at St. Helena Island in the Southeastern Atlantic. Stegastes santaehelenae is known only from St. Helena Island, and S santipaulae is found at St. Paul's rocks in the east central Atlantic.

Natural History Notes

Pomacentrids are often highly territorial herbivores or omnivores. They lay elliptical demersal eggs that are guarded by the males. The damselfishes are among the most conspicuous fishes on coral reefs.

Hearing Range

Hearing and acoustic production are well documented in the pomacentrids. Extensive testing has been performed on the Genus Stegastes finding that the audible frequency range is 100-1200 Hz (Myrberg and Spires 1980). The sensitivity in this range is +20 dB at 100 Hz dropping to -5 dB at 500 Hz, then climbing steadily to +30 dB at 1200 Hz. The most sensitive range around 500 Hz, corresponds to the peak amplitude of a

territorial and advertising "chirp" call produced in many species of Stegastes(Myrberg and Spires 1980).
Although hearing is not as well documented in other genera, vocal production is. Abudefduf luridus produce aggressive display or territorial defense sounds at <50 to 800 Hz (Santiago and Castro 1997). Stegastes partitus uses a chirp in territorial interactions (Myrberg 1997), as well as in a courting advertisement signal and a grunt when a female enters the males nest territory (Kenyon 1994). Female S. partitus are acute to the males courtship calls and can distinguish between a similar frequency of ambient sounds on the reef, and between different conspecific males (Myrberg 1986). Some species of Amphiprion are known to make calls above 3000 to 8000 Hz during agonistic displays, and many lower frequency sounds (500-1500 Hz) when fighting or in a defensive position (Pessoa de Amorim 1996). Chromis viridis produces a click sound ranging from 0-3000Hz in agonistic interactions (Pessoa de Amorim 1986).

Known and potential impacts of low frequency sound

There are no known impacts of low frequency sound on pomacentrids; however, there is a strong potential for impacts of low frequency sound on this family.. Sound is used in courting, spawning, and territorial interactions (Myrberg 1997, Santiago and Castro 1997, Myrberg et al. 1986, Myrberg and Spires 1980, Kenyon 1994, Moulton 1958). Myrberg and Riggio (1985) found that Stegastes partitus can recognize individuals by the sound they produce. This information strongly suggests that low frequency sound can disrupt reproduction and social behavior.

Reducing and mitigating impacts of SURTASS LFA

Although there is a great potential of SURTASS LFA operations to disrupt behavioral interactions of pomacentrids, this potential will not be realized if operations are conducted away from shallow water habitats where pomacentrids are common. Most species live on coral reefs, and thus, operations should avoid this habitat. It would be prudent to avoid locations where IUCN listed species occur.

Perciformes - Mugilidae

U.S. Fish and Wildlife or IUCN Status

Liza luciae is listed as endangered by the IUCN.

Distribution

Mugilids occur in all tropical and temperate seas in shallow waters. Liza luciae occurs in southern Mozambique to northern Transkei, South Africa

Natural History Notes

Mugilids are valued as food fish. Species in this family exhibit a diversity of food habitats including omnivory, planktivory and herbivory.

Hearing Range and Sound Production

Limited data on hearing ability exist for Mugilids. Tavolga (1971) reported an upper frequency limit for Mugil at 1600-2500 Hz, and separately published a threshold of -50 dB for 640Hz (Tavolga and Wodinsky 1963). Fish and Mowbray (1970) found no sound production in M. brsiliensis and M. curema.

Known and potential impacts of low frequency sound

There are no known impacts of low frequency sound on mugilids. Although hearing ability has been examined in one species, there are no data demonstrating that members of this taxa use sound.

Reducing and mitigating impacts of SURTASS LFA

There are insufficient data to suggest the means to reduce or mitigate impacts of SURTASS LFA operations. Research examining the use of sound in this taxa is required before recommendations can be made.

Perciformes - Sphyraenidae

U.S. Fish and Wildlife or IUCN Status

No members of this order are considered threatened or endangered by the US Fish and Wildlife Service or the IUCN.

Distribution

Sphyraenids occur in nearshore demersal and pelagic habitats in tropical, subtropical and occasionally temperate waters of the Atlantic, Indian, and Pacific Oceans.

Natural History Notes

Sphyraenids have a well-developed lateral line and are important predators on other fishes. Sphyraenids swim actively in clear water, often in schools searching for prey. Their hunting strategy involves locating a prey patch, using the stealth afforded by their silvery narrow profile to close in on prey, and a quick burst of speed to capture the prey.

Hearing Range and Sound Production

No hearing range is known for the sphyraenids. Thumps and knocks in the frequency range of 0-200 Hz have been recorded for Sphyraena barracuda during swift movements (Fish and Mowbray 1970). Similar sounds have been observed in S. guachancho, but no recordings have been made (Fish and Mowbray 1970).

Known and potential impacts of low frequency sound

There are no known impacts of low frequency sound on sphyraenids; however, there is a potential for impact. These schooling predators have a well developed lateral line which is likely used to maintain the integrity of the school as well as for detecting prey. Loud low frequency sound could impact foraging behavior of this family.

Reducing and mitigating impacts of SURTASS LFA

Sphyraenids are common near coral reefs, thus operations that avoid this habitat will reduce the impact of SURTASS LFA on this family. Pelagic species would still be subjected to sound from SURTASS LFA operations. The status of these species should be monitored for declines in stock size in regions where operations occur frequently. As long as SURTASS LFA operations are short-term and mobile, it appears likely that the impact will be minimal on this family.

Perciformes - Polynemidae

U.S. Fish and Wildlife or IUCN Status

No members of this order are considered threatened or endangered by the US Fish and Wildlife Service or the IUCN.

Distribution

Polynemids are found in all tropical and subtropical seas typically in nearshore soft sediment habitats.

Natural History Notes

Polynemids have highly specialized pectoral fins that are divided into two parts. The upper webbed portion is located laterally and shaped like a typical pectoral fin, while the ventral portion consists of 3-7 long rays that are used to feel for prey along the bottom. They are bottom feeders and their mouth, therefore, is subterminal.

Hearing Range and Sound Production

No hearing range is known for the polynemids. Polydactylus virginicus has been recorded to make knocks and escape sounds at 0-600 Hz when mechanically and/or electronically stimulated (Fish and Mowbray 1970).

Known and potential impacts of low frequency sound

There is no known impact of low frequency sound on polynemids. One species is reported to produce sound (Fish and Mowbray 1970), but research on its use and if they can hear has not been conducted. Food foraging is performed with chemosensory structures, reducing the potential importance of sound for feeding. However, at present data are insufficient to speculate on potential impacts of low frequency sound.

Reducing and mitigating impacts of SURTASS LFA

Data are insufficient to recommend means to reduce or mitigate impacts of SURTASS LFA operations on this family. As this is a nearshore, shallow water group, operations that are distant from shore will reduce any impact. Measures taken to reduce impacts on other taxa will also reduce impacts in this family. Further research demonstrating hearing abilities and sound production is necessary before more detailed mitigating measure can be suggested.

Perciformes - Labridae

U.S. Fish and Wildlife or IUCN Status

Cheilinus undulatus, Lachnolaimus maximus, Thalassoma ascensionis, and Xyrichtys virens are listed as vulnerable by the IUCN.

Distribution

Labrids occur in coastal habitats in tropical and temperate waters in Atlantic, Indian, and Pacific Oceans. Typically labrids are associated with structured habitats such as coral reefs, rock reefs, and macrophytes. Cheilinus undulatus occurs on reefs from the Red Sea to the Tuamotus, north to the Ryukyus, south to New Caledonia and throughout Micronesia. Lachnolaimus maximus is reef associated and occurs in shallow, clear water from Nova Scotia in Canada, to Bermuda and to the northern Gulf of Mexico in USA and to northern South America. Thalassoma ascensionis occurs on rocks and in seagrass in Ascencion and St. Helena in the central tropical Atlantic. Xyrichtys virens occurs in the Eastern central and southwest Pacific.

Natural History Notes

Labrids are a very diverse family with a variety of shapes, colors and sizes. Most species in the family are associated with coral reefs. Many species are sand burrowers and burrow when frightened or at night. Their diet consists of small benthic invertebrates. Some small species remove ectoparasites of larger fishes.

Hearing Range and Sound Production

An auditory threshold was reported for Thalassoma bifasciatum at 100-1300 Hz at 10 to 35 dB (25 dB at 100 Hz, decreasing to 10 dB at 400 Hz, then increasing steadily to 35 dB at 1300 Hz) (Tavolga 1976). Other labrids have been reported to make escape sounds, thumps and knocks upon mechanical and/or electrical stimulation, and feeding noises (Fish and Mowbray 1970). Halichoeres radiatus, Lachnolaimus maximus, Tautoga onitis, Tautogolabrus adspersus, and Thalassoma bifasciatum all produced sound at 0-300 Hz (Fish and Mowbray 1970). H. bivittatus produced sound from near 0-400 Hz (Fish and Mowbray 1970)

Known and potential impacts of low frequency sound

There are no known impacts of low frequency sound on labrids. While many species produce sound and the hearing abilities of one species has been documented, the use of sound in labrids had not been investigated.

Reducing and mitigating impacts of SURTASS LFA

Most labrids occur in nearshore rocky reef, kelp forest or coral reef habitats. Therefore, operations that avoid these habitats will largely reduce any impact on this family. Further research examining the use of sound is clearly necessary before more detailed recommendations can be made.

Perciformes - Scaridae

U.S. Fish and Wildlife or IUCN Status

Scarus guacamaia is considered vulnerable by the IUCN.

Distribution

Scarids are chiefly tropical and found in Atlantic, Indian, and Pacific Oceans. The are important members of coral reef and seagrass communities. Scarus guacamaia is found on coral reefs from Bermuda, Florida in USA and Bahamas to Argentina; it is absent from northern Gulf of Mexico.

Natural History Notes

Scarids are herbivorous, usually scraping algae from dead coral substrates. Some species consume coral as well. At night, some species rest enveloped in their mucoid secretion. Sex change is a common occurrence, in this family with the females either primary or secondary in most species.

Hearing Range and Sound Production

Hearing abilities have no been investigated in scarids. Sound production has been well documented and occurs while the fish are spawning (Lobel 1992) feeding, as escape sounds, and as clicks, rasps and knocks during mechanical and electrical stimulation (Fish and Mowbray 1970). Spawning sounds were recorded at 30-1200 Hz in Scarus iserti and were mostly hydrodynamic noises associated with the rapid swimming behavior during spawning (Lobel 1992). Sounds in the frequency range of 0-700 Hz were produced by Scarus guacmaia and Sparisoma aurofrenatum; up to 3000 Hz by Scarus coelestinus, Sparisoma rubripinne and S. viride; and up to 5000 Hz by Scarus coeruleus, S. croicensis, S. vetula, Sparisoma chrysopterum, and S. radians (Fish and Mowbray 1970).

Known and potential impacts of low frequency sound

There are no known impacts of low frequency sound on scarids. Because some species produce sound associated with spawning there is a potential that extraneous low frequency sound could mask sound important in reproductive behavior. However, at present, there are too few data to determine if sound is critical in the spawning behavior of members of this family.

Reducing and mitigating impacts of SURTASS LFA

Scarids occur on coral reefs, and therefore, SURTASS LFA operations that are conducted distant from this habitat will have minimal impact on scarids. Further research documenting how sound is used and perceived by scarids will help determine means to reduce or mitigate impacts of SURTASS LFA operations.

Perciformes - Uranoscopidae

U.S. Fish and Wildlife or IUCN Status

No members of this order are considered threatened or endangered by the US Fish and Wildlife Service or the IUCN.

Distribution

Uranoscopids occur in Atlantic, Indian, and Pacific Oceans from shallow nearshore waters to depths > 500 m. Many species are common on silty, sandy, or rubble bottoms.

Natural History Notes

Uranoscopids possess electric organs located in a specialized pouch behind the eyes. They can discharge up to 50 volts (Moller 1995). The electric organ discharge (EOD) rate depends on the temperature: about 500 Hz at 35°C and 50 Hz at 15°C (Moller 1995).

Hearing Range and Sound Production

Astroscopus guttatus produced no sound with mechanical or electrical stimulation, and none of the other twenty-five species of uranoscopids are reported to produce sound either (Fish and Mowbray 1970). No hearing ranges are known.

Known and potential impacts of low frequency sound

There are no known impacts of LFS on uranoscopids.

Reducing and mitigating impacts of SURTASS LFA

Hearing and sound production do not appear to be important for this family. . Thus, measures suggested for other species that overlap in their distribution should reduce or mitigate impacts on this family.

Perciformes - Ammodytidae

U.S. Fish and Wildlife or IUCN Status

No members of this order are considered threatened or endangered by the US Fish and Wildlife Service or the IUCN.

Distribution

Ammodytids are found in the Indian, Atlantic and Pacific Oceans. Occur from the intertidal zone to depths of > 50 m. Over deep water they are often found near the surface.

Natural History Notes

Many species occur in large schools near the surface but they also bury themselves in sand. They feed on plankton and are important prey for predatory fishes such as salmon, cod, pollock, halibut, sea birds and marine mammals (Froese and Pauly 1997).

Hearing Range and Sound Production

No hearing ranges are known for the ammodytids. No sound was produced when Ammodytes americanus was examined (Fish and Mowbray 1970).

Known and potential impacts of low frequency sound

There are no known or potential impacts of low frequency sound on ammodytids.

Reducing and mitigating impacts of SURTASS LFA

Impacts of SURTASS LFA operations on Ammodytids are likely to be negligible. Measures suggested for other species that overlap in their distribution should reduce or mitigate impacts on this family. Because of their ecological importance, it would be prudent to conduct research to determine if the apparent lack of importance of low frequency sound is real or simply the result of a lack of data.

Perciformes - Gobiidae

U.S. Fish and Wildlife or IUCN Status

The US Fish and Wildlife service lists Eucyclogobius newberryi as endangered and the IUCN lists this species as vulnerable. Other listed species live in freshwater.

Distribution

Gobiids are mostly tropical and subtropical and chiefly found in shallow coastal regions and near coral reefs. Eucyclogobius newberryi occurs from Del Norte County in northern California, USA to Del Mar in southern California in coastal lagoons and brackish bays.

Natural History Notes

Gobiids are the most species rich group of marine fishes (possibly > 2,000). The smallest fishes (and vertebrates) in the world belong to this family. The cracks and crevices of reefs and other inshore inhabitats provide homes for the majority of goby species. When they occur in soft bottom habitats they usually live in burrows of invertebrates. Many species of gobies clean ectoparasites from larger fishes. Many species are specialists on particular species of sponges, corals or other invertebrates.

Hearing Range and Sound Production

The only report of a hearing range known in gobiids is an upper frequency limit of 800 Hz in Gobius (Dijkgraff 1952). Sound production has been documented in several freshwater and marine gobiid males, usually associated with territorial, prespawning and spawning behaviors. Gobius jozo and Neogobius melanostomus are both reported to produce sounds, but ranges have not been documented (Tavolga 1971). Padogobius nigricans produced spawning sounds at a frequency of 60-100 Hz at 128-137 dB (Lugli, 1996), while P. martensii produced at 0-800 Hz and Knipowitschia punctatissima at 0-2000 Hz both in the range of 113-123 dB (Lugli 1995). Bathygobius soporator produced sound at 100-150 Hz during prespawning behavior (Tavolga 1958). Gobiosoma bosci produced sound at 0-6000 Hz when a ripe female approached the nest, 0-10000 Hz during male-female interactions, and up to 13000 Hz in male-male interactions (Mok 1981).

Known and potential impacts of low frequency sound

There are no known impacts of low frequency sound on gobiids, although there is considerable potential for impacts to occur. Gobiids use sound for courtship and territorial interactions, and thus extraneous low frequency sound may disrupt breeding and social interactions.

Reducing and mitigating impacts of SURTASS LFA

Marine species are mostly present in shallow coastal waters and around coral reefs. Impacts on gobiids present in shallow, coastal waters will thus be minimal as long as SURTASS LFA operations are performed distant from shore. Because gobiids are the largest and most diverse marine fish family, further research should be conducted to determine the use of sound and the impacts of low frequency sound on gobiids.

Perciformes - Acanthuridae

U.S. Fish and Wildlife or IUCN Status

No members of this order are considered threatened or endangered by the US Fish and Wildlife Service or the IUCN.

Distribution

Acanthurids are circumtropical, especially around coral reefs There are five species in the Atlantic, the remaining 67 species occur in the Pacific and Indian ocean

Natural History Notes

Most Acanthurids graze on benthic algae and have a long intestine; some feed mainly on zooplankton or detritus. Acanthurids are able to slash other fishes with their sharp caudal spines by a rapid side sweep of the tail. Many species have bright colors and are popular aquarium fishes.

Hearing Range and Sound Production

There are no data on the hearing abilities of acanthurids. Acanthurus bahianus, A. chirurgus, and A. coeruleus all produced sounds in the frequency range of 0-500 Hz, 0-300 Hz and 0-600 Hz respectfully (Fish and Mowbray 1970). Most sounds were made in response to mechanical and/or electrical stimulation, some as a result of chase behaviors or mild duress (Fish and Mowbray 1970).

Known and potential impacts of low frequency sound

There are no known impacts of low frequency sound on acanthurids. Fish and Mowbray (1970) report the ability of sound production in members of this taxa, but the purpose of the sound production is not known. At present, data are insufficient to speculate on the potential impacts of low frequency sound on this family.

Reducing and mitigating impacts of SURTASS LFA

Because Acanthurids inhabit coral reef habitats, as long as SURTASS LFA operations are conducted distant from this habitat impacts on this family should be negligible.

Perciformes - Scombridae

U.S. Fish and Wildlife or IUCN Status

The IUCN lists the pacific stock of Thunnus alalunga, T. maccoyii, and the western Atlantic stock of T. thynnus, as critically endangered. The eastern Atlantic stock of T. thynnus, Pacific stock of T. obesus, and Scomberomorus concolor are listed as endangered, and the Atlantic stocks of T. obesus and T. alalunga as vulnerable.

Distribution

Scombrids are found in all tropical and subtropical seas. Many species range into temperate waters.

Thunnus thynnus, Northern Bluefin tuna, is found in the Atlantic from Canada through the Gulf of Mexico and the Caribbean Sea to Venezuela and Brazil; and Lofoten Island off Norway to Canary Island including the Mediterranean and the southern part of the Black Sea. There is a subpopulation off South Africa (Collette 1986). They are oceanic but seasonally come close to shore and can tolerate a wide range of temperatures.

Thunnus maccoyii, Southern Bluefin tuna, is found in the Southern Hemisphere in temperate and cold seas, mainly between 30° and 50°S, to nearly 60°S. During spawning in the austral summer, large fish migrate to tropical seas, off the west coast of Australia, up to 10°S (Nakamura 1990). These pelagic fish are encountered in waters with surface temperatures between 20° and 30°C when spawning and larvae,

Thunnus alalunga, Albacore Tuna, is cosmopolitan in tropical and temperate waters of all oceans including the Mediterranean Sea, but they are not at the surface between 10°N and 10°S. In the western Pacific their range extends in a broad band between 40°N and 40°S (Collette 1997). They are found in offshore waters and are known to concentrate along thermal discontinuities. They occur to depths of 600 m (Froese and Pauly 1997). Schools of T. alalunga may be associated with floating objects, including floating Sargassum. In the Atlantic, larger size classes (31 to 50 inches) are associated with cooler water bodies, while smaller individuals tend to occur in warmer waters

Thunnus obesus, Bigeye Tuna is present in tropical and subtropical waters of the Atlantic, Indian and Pacific Oceans but is absent from the Mediterranean. Occurs in areas where water temperatures range from 13°-29°C, but the optimum is between 17° and 22°C. Variation in occurrence is closely related to seasonal and climatic changes in surface temperature and thermocline. Spawning occurs in waters between 10°N and 10°S throughout the year but occurs most often from April up to the end of September (Collette 1997)

Scomberomorus concolor Monterey Spanish Mackerel, is endemic to the northern Gulf of California, Mexico. S. concolor supports a commercial net fishery close inshore, in estuaries and coastal marshes. Its biology is almost completely unknown (Froese and Pauly 1997).

Natural History Notes

Bluefin Tuna school by size, sometimes together with albacore, yellowfin, bigeye, skipjack or other scombrids. They prey on small schooling fishes (anchovies, sauries, hakes) or on squids and red crabs (Froese and Pauly 1997). Both species of Bluefin tuna are relatively slow to mature: about 5-8 years for T. thynnus, 8-9 for T.maccoyii (Collette 1986). Accordingly, they are more vulnerable to over-exploitation than most other fish species. Northern bluefin tuna have declined dramatically in numbers in the western Atlantic and has declined to a lesser degree in the eastern Atlantic and the Pacific. According to some estimates, the population of the species in the western Atlantic has declined by about 87 percent since 1970. Southern bluefin tuna population may have declined by as much as 90 percent. These declines are reflected in dwindling commercial catches (Froese and Pauly 1997).

Albacore feed on fishes, crustaceans and squids. They spawn from January to June between Hawaii and Japan (Hart 1973). Albacore grow quickly and remain near the surface of the ocean for their first three or four years, and survivors of a single spawning often swim and feed together in schools. Young albacore will school with the young of several species of young tuna. In general, young albacore prefer warmer surface waters while the adults are in cooler water at depth.

Yellowfin tuna, Thunnus albacares, school in near-surface waters as well as below the thermocline, primarily by size, either in monospecific or multispecies groups (Froese and Pauly 1997). Larger fish frequently school with porpoises. They are also associated with floating debris and other objects. Yellowfin tuna feeds on fishes, crustaceans and squids (Collette 1997). It is sensitive to low concentrations of oxygen and therefore is often limited to depths of 100 m (Collette 1997). Peak spawning occurs during the summer, in batches (Collette 1997).

The diet of bigeye tuna includes fishes, squid, and crustaceans. Like most other tunas, they feed on what is most abundant in the area. Bigeye tuna are approximately 3 years old at spawning. In the equatorial regions of the Pacific, the peak spawning is between April and September. They live 7 or 8 years

Hearing Range and Sound Production

Hearing has been investigated in one species of scombrid. The hearing range for Thunnus albacares is 50-1100 Hz, and is most sensitive at 300-500 Hz (-10 to -15 dB) (Iversen 1967, Tavolga 1971). A "knock" resulting in school coordination is produced by T. albacares at a frequency of 400-5000 Hz with maximum intensities at 500-700 Hz and 1500-2000 Hz (Iversen 1967).

Known and potential impacts of low frequency sound

There are no known impacts of low frequency sound on scombrids; however, potential impacts exist. Scombrids produce sound and are sensitive to low frequency sounds. They appear to use sound to coordinate their own schools as well as to capture prey. Although hearing and sound production has not been examined in many species in this family, it is likely that many members of this family use sound in their foraging (version 1967). Consequently, extraneous low frequency sound may disrupt feeding and schooling behavior of members of this family. In addition, because of their presence in the open ocean, scombrids may be close enough to SURTASS LFA operations that they are subjected to the physically damaging intensity of loud, close-range low frequency sound.

Reducing and mitigating impacts of SURTASS LFA

Because both SURTASS LFA operations and scombrids are highly mobile, stock-level impacts on scombrids is likely to be minimal. Any disruption in foraging behavior is likely to be very short-term without any demographic consequences. Of some concern is the occurrence of scombrids close to SURTASS LFA operations such that should levels exceed 180 dB. Under such circumstances, physical damage to the scrombrid is possible. Research determining if, how and why different species of scombrids use low frequency sound is necessary in order to develop the means to reduce impacts of SURTASS LFA on scombrids. It is possible that simple the sound of the ship will repel scombrids and prevent physical harm.

Perciformes - Stromateidae

U.S. Fish and Wildlife or IUCN Status

No members of this order are considered threatened or endangered by the US Fish and Wildlife Service or the IUCN.

Distribution

Coastal waters of North and South America, western Africa, and the Indo-Pacific.

Natural History Notes

Stromateids form schools in nearshore coastal and estuarine waters. They are carnivores feeding on jellyfish, ctenophores, saulps, fish and zooplankton.

Hearing Range and Sound Production

No hearing range is known for the stromateids. Faint, but unidentifiable and unmeasurable sounds were made when Palinurichthys perciformis, Peprilus paru and Poronotus triacanthus were mechanically and electronically stimulated (Fish and Mowbray 1970).

Known and potential impacts of low frequency sound

There are no known impacts of low frequency sound on stromateids. Too few data exist to speculate about potential impacts of low frequency sound.

Reducing and mitigating impacts of SURTASS LFA

Stromateids inhabit tropical and warm temperate areas of the open sea, and are likely to co-occur with SURTASS LFA operations. Research determining hearing abilities and determining if fish use sound is required before reasonable suggestions can be made that will reduce or mitigate SURTASS LFA operations.

ORDER PLEURONECTIFORMES

There are 520 species in 117 genera in this order.

U.S. Fish and Wildlife or IUCN Status

Hippoglossus hippoglossus is listed as endangered and Pleuronectes ferrugineus is listed as vulnerable by the IUCN.

Distribution

Family Psettodidae occurs in west Africa; the Citharidae are found in the Mediterranean, Indian Ocean and in the Pacific from Japan to Australia; the Bothidae are found in Atlantic Indian and Pacific Oceans, the Pleuronectidae are found in Arctic, Pacific and Atlantic oceans; Soleidae and Cynoglassidae occur in tropical and temperate seas.

Hippoglossus hippoglossus occurs in the Eastern Atlantic from the Bay of Biscay to Spitsbergen, Barents Sea, Iceland and eastern Greenland and in the Western Atlantic from southwestern Greenland and Labrador in Canada to Virginia in USA.
Pleuronectes ferrugineus occurs in the Northwestern Atlantic from southern Labrador in Canada to Chesapeake Bay in USA.

Natural History Notes

Pleuronectiformes, the flatfishes, lie on the bottom when not moving and stay close to the bottom even while swimming. The swimbladder is absent in adults of this order. Flatfishes are generally found on soft bottoms of continental shelves, although a few species occur in deeper slope waters. On shelves, they have a world wide distribution and often support important commercial fisheries.

Hearing Range and Sound Production

Little is known on the hearing ranges of the Pleuronectiformes. Paralichthys olivaceus can detect sound at a frequency of 70-500 Hz with the average auditory threshold ranging with frequency (and average threshold of 101 dB for 70 Hz, 94 dB for 100 Hz, 98 dB for 150 Hz, 101 dB for 200 Hz, 107 dB for 300 Hz, and 115 dB for 400 and 500 Hz) (Fujieda et al. 1996). Pleuronectes platessa and Limanda limanda responded to sounds in the frequency range from 30-250 Hz, with greatest sensitivity at 110-160 Hz (Chapman and Sand 1974). Both species were also sensitive to particle motion, with displacement amplitude thresholds of 4 x 10^{-9} cm for the 110-160 Hz frequency range, declining sharply either direction of that range to 5 x 10^{-8} cm at 40 and 250 Hz (Chapman and Sand 1974).
Pleuronectiformids lack swim bladders which many fish use in sound production. Accordingly, no sound production could be evoked in Hippoglossoides platessoides, Paralichthys dentatus, or Pseudopleuronectes americanus (Family Pleuronectidae), and in Archirus fasciatus and Scophthalmus aquuosus (Family Bothidae) with mechanical or electrical stimulation (Fish and Mowbray 1970).

Known and potential impacts of low frequency sound

There are no known impacts of low frequency sound on pleuronectiforms. The hearing studies performed on flatfish suggest the primary hearing sensitivity in the near field range. The exact use of this near field detection is unknown. Also, Pleuronectiformes lack swimbladders suggesting less chance of physical damage by intense low frequency sound.

Reducing and mitigating impacts of SURTASS LFA

Impact of SURTASS LFA on this order are likely to be negligible. Measures suggested for other species that overlap in their distribution should reduce or mitigate impacts on this order.

ORDER TETRADONTIFORMES

There are 320 species in 65 genera in this order.

U.S. Fish and Wildlife or IUCN Status

Balistes vetula, Canthigaster rapaensis, and Liosaccus pachygaster are each considered vulnerable by the IUCN.

Distribution

Family Triacanthodidae occur in tropical deepwater benthic habitats in the Atlantic and Indo-pacific; Triacanthidae occur in shallow benthic habitats of the Indo-pacific; Balistidae occur in Atlantic, Indian and Pacific oceans typically in nearshore waters; Ostraciontidae occur in nearshore waters of the Atlantic and Indo-Pacific oceans; Triodontidae occur in the Indo-Pacific; Tetraodontidae occur in tropical and subtropical waters of the Atlantic, Indian and Pacific Oceans; Diodontidae occur inshore in the Atlantic, Indian and Pacific Oceans; Molidae occur in pelagic waters of subtropical and tropical portions of the Atlantic, Indian and Pacific Oceans.

Balistes vetula occurs in the Western Atlantic from Massachusetts and northern Gulf of Mexico in USA to southeastern Brazil. In the Eastern Atlantic it ranges from Ascension, Cape Verde Is. and Azores and ranges south to southern Angola. Canthigaster rapaensis occurs in French Polynesia. Liosaccus pachygaster occurs in Taiwan.

Natural History Notes

All members of this order are slow swimmers and most posses some form of protection from predators such as spines, body armor, stout fin spines, leathery skin or poison. Most tetraodontiform fishes consume primarily invertebrates that have heavy shells or other armor. Most members of this order are associated with coral reefs.

Hearing Range and Sound Production

Auditory thresholds have not been determined for the Tetradontiformes, although, sound production has been documented. In one instance, though not verified, Lobel (1996) reported that Melichthys niger responds to spawning sounds produced by Ostacion meleagris, suggesting M. niger may hear at the 215-270 Hz frequency.

All Tetradontiformes use teeth stridulation, and most use the swim bladder in vocalization (Fish and Mowbray 1970). The following frequencies were recorded while fish were in tanks and being feeding or stimulated mechanically or electrically (Fish and Mowbray 1970). In the family Balistidae: Alutera schoepfi and Monocanthus hispidus produced sound at 0-5000 Hz; Balistes capriscus and B. vetula at 0-3000 Hz; Cathidermes sufflamen at 0-2000 Hz; A. scripta at 0-1500 Hz; and C. pullus and Melichthys radula at 0-400 Hz (Fish and Mowbray 1970).

In the Family Ostraciidae: Lactophrys quadricornis produced sound at 0-400 Hz; L. bicandalis and L. triqueter at 0-500 Hz; and L. trigonus at 0-700 Hz (Fish and Mowbray 1970). The only Tetradontiformes to have sound production recorded in a natural setting was Ostacion meleagris which made three calls: a spawning call at 215-270 Hz with an intensity of -30.4 dB; a fighting "bump" sound at 140-790 Hz (peak at 388 Hz) with an intensity of -34.5 dB; and an aggressive or defensive "buzz" at 198-535 Hz (peak at 431 Hz) with an intensity of -34.5 dB (Lobel 1996).

In the Family Tetradontidae: Sphaeroides maculatus produced sound at 0-6000 Hz; S. testudineus at 0-7000 Hz; Lagocephalus laevigatus at 0-9000 Hz; and Canthigaster rostrata and S. spengleri are know to produce sound, but the frequency has not been recorded (Fish and Mowbray 1970).

In the Family Diodontidae, the porcupinefishes: Chilomycterus schoepfi produced sound at 0-4500 Hz; Diodon hystrix at 0-7000 Hz; and C. atinga at 0-8000 Hz (Fish and Mowbray 1970).

For the Family Modidae, Mola mola is known to produce sound, but the frequency has not been recorded (Fish and Mowbray 1970).

Known and potential impacts of low frequency sound

There are no know impacts of low frequency sound on tetraodontiforms.

however potential impacts exist. Two ostraciids produce spawning, territorial, defensive and aggressive sounds (Lobel 1996). Low frequency sound could potentially disrupt spawning and social interactions.

Reducing and mitigating impacts of SURTASS LFA

Areas inhabited by the three IUCN listed vulnerable species should be avoided to eliminate any possibility of SURTASS LFA impacts. Where this is not possible population monitoring should be conducted to determine the impact of low frequency sound.

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Appendix 1a. Marine fish orders for which some hearing ability or sound production data are available.

Lamniformes, Rajiformes, Elopiformes, Abguilliformes, Clupeformes, Salmoniformes, Siluiformes, Gadiformes, Batrachoidifrs, Lophiformes, Atheriniformes, Beryciformes, Gasterosteiformes, Scorpaeniformes, Dactylopteriformes, Perciformes, Pleuronectiformes, Tetraodontiformes

Appendix 1b. Marine fish orders for which no hearing or sound production data are available.

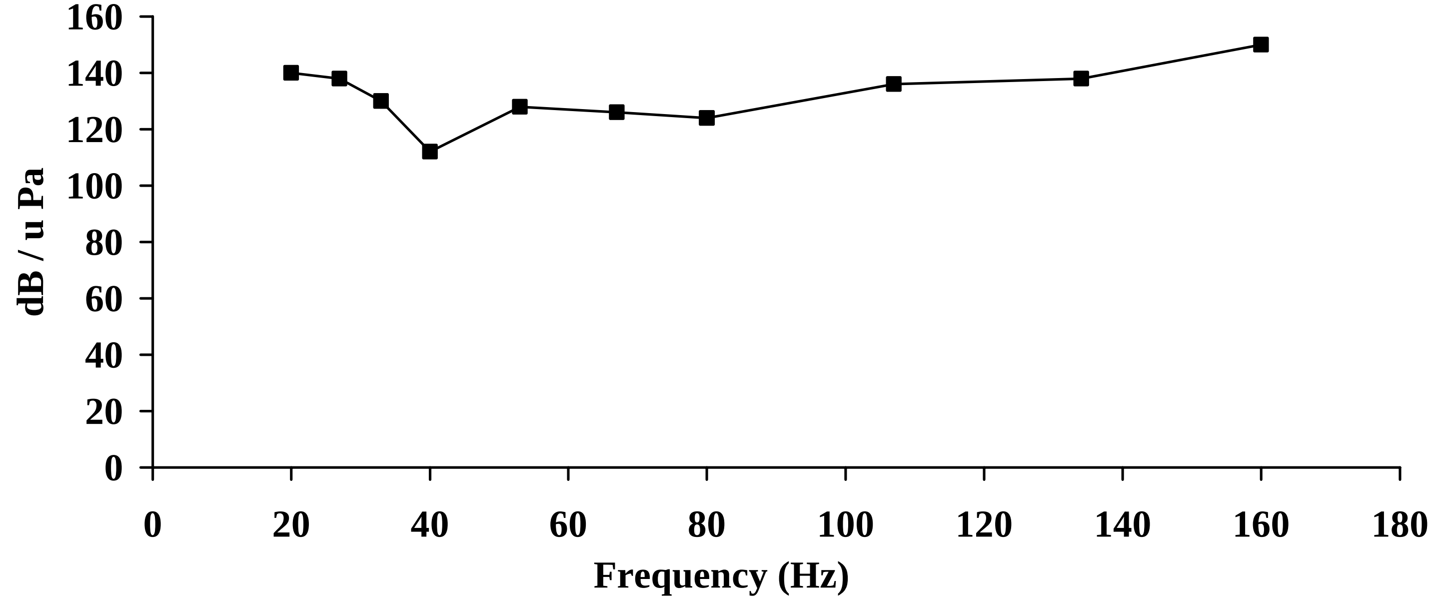
Myxiniformes, Petromyzontiformes, Chimaeriformes, Coelocanthiformes, Acipenseriformes, Notacanthiformes, Gonorynchiformes, Myctophiformes, Polymixiiformes, Percopsiformes, Zeiformes, Lampridiformes, Synbranchiformes, Pegasiformes

Appendix 1c. Marine Perciformes for which some hearing ability or sound production data are available

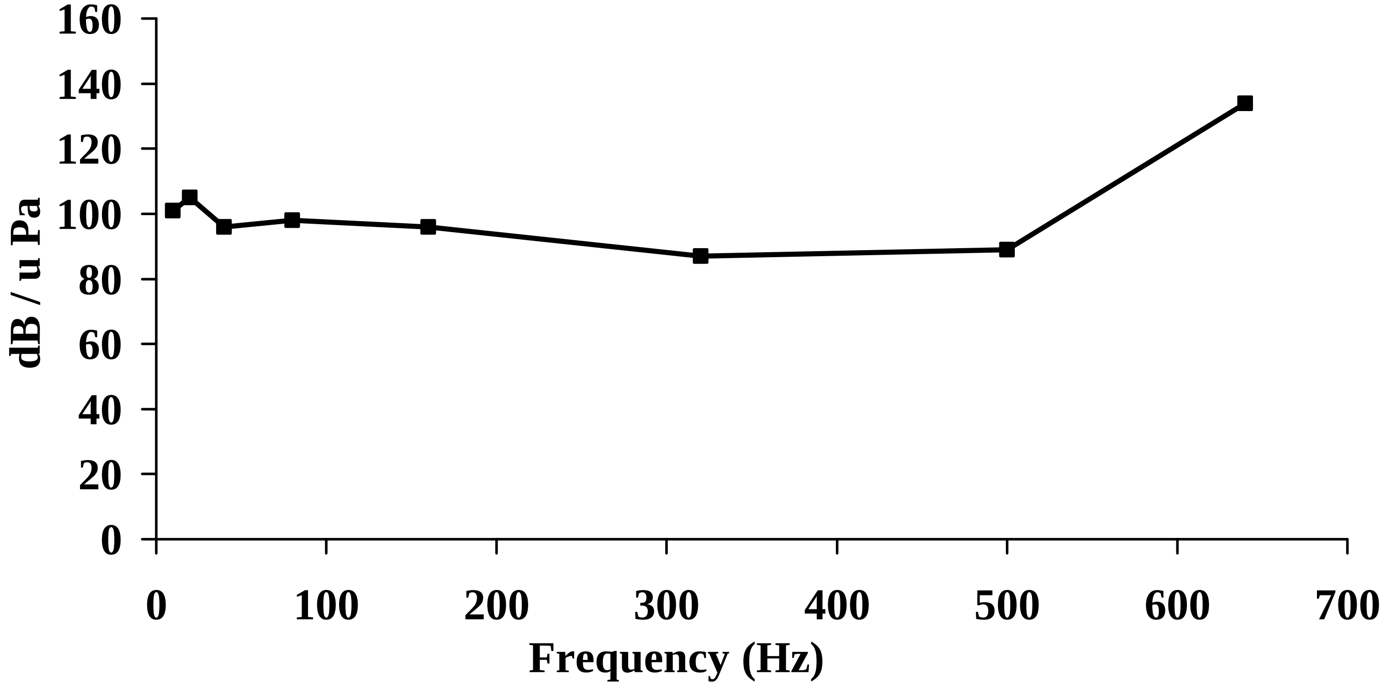
Centropomidae, Serranidae, Pomatomidae, Carangidae, Lutjanidae, Gerridae, Haemulidae, Sparidae, Sciaenidae, Mullidae, Kyphosidae, Ephippidae, Chaetodontidae, Pomacentridae, Mugilidae, Sphyraenidae, Polynemidae, Labridae, Scaridae, Uranoscopidae, Acanthuridae, Stromateidae

Appendix 2. Audiograms of Marine Fishes.

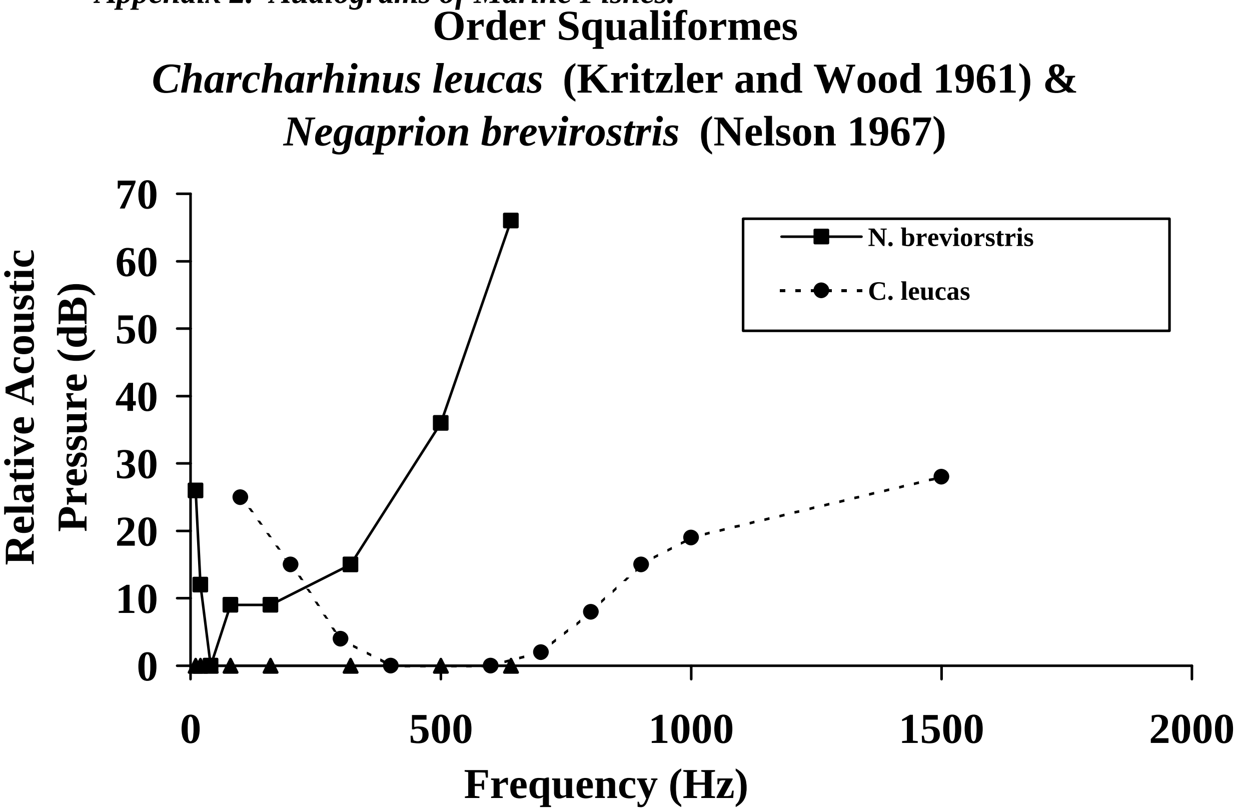
Order Heterodontiformes
Heterodontus francisci **(Kelly and Nelson 1975)**

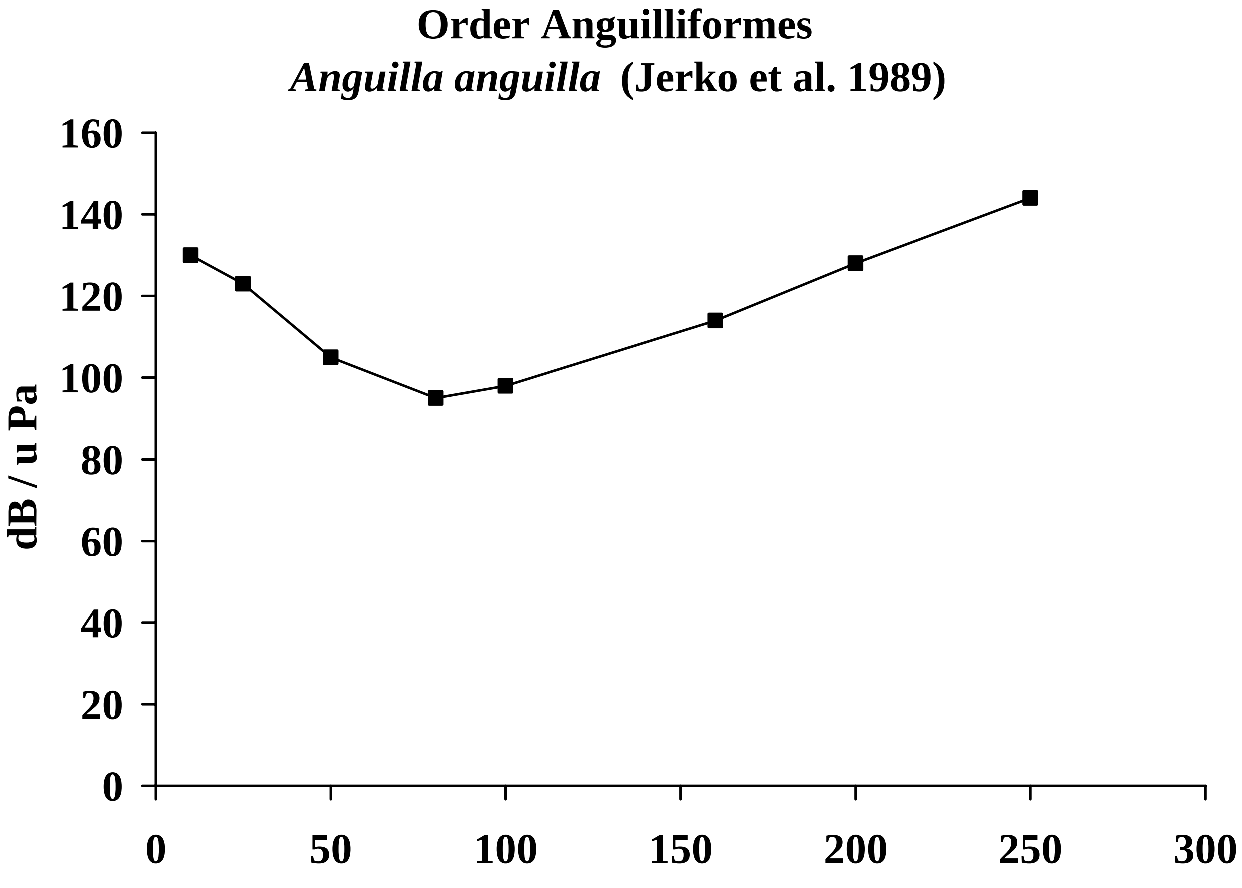


Order Squaliformes
Negaprion brevirostris **(Nelson 1967)**

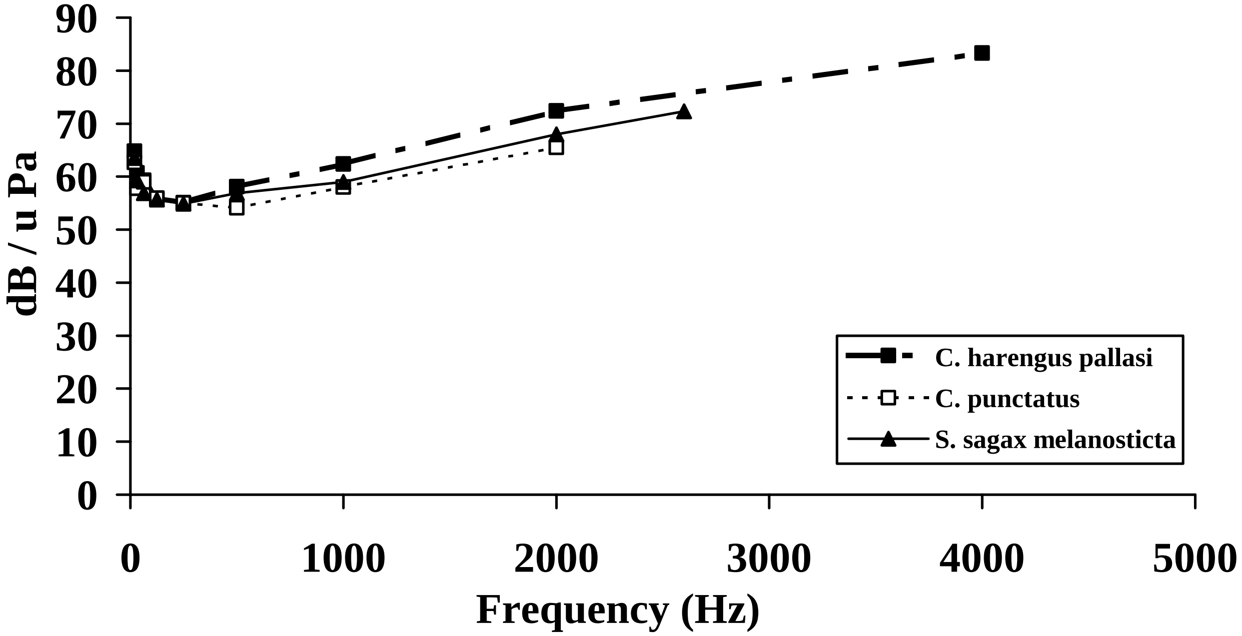


Appendix 2. Audiograms of Marine Fishes.

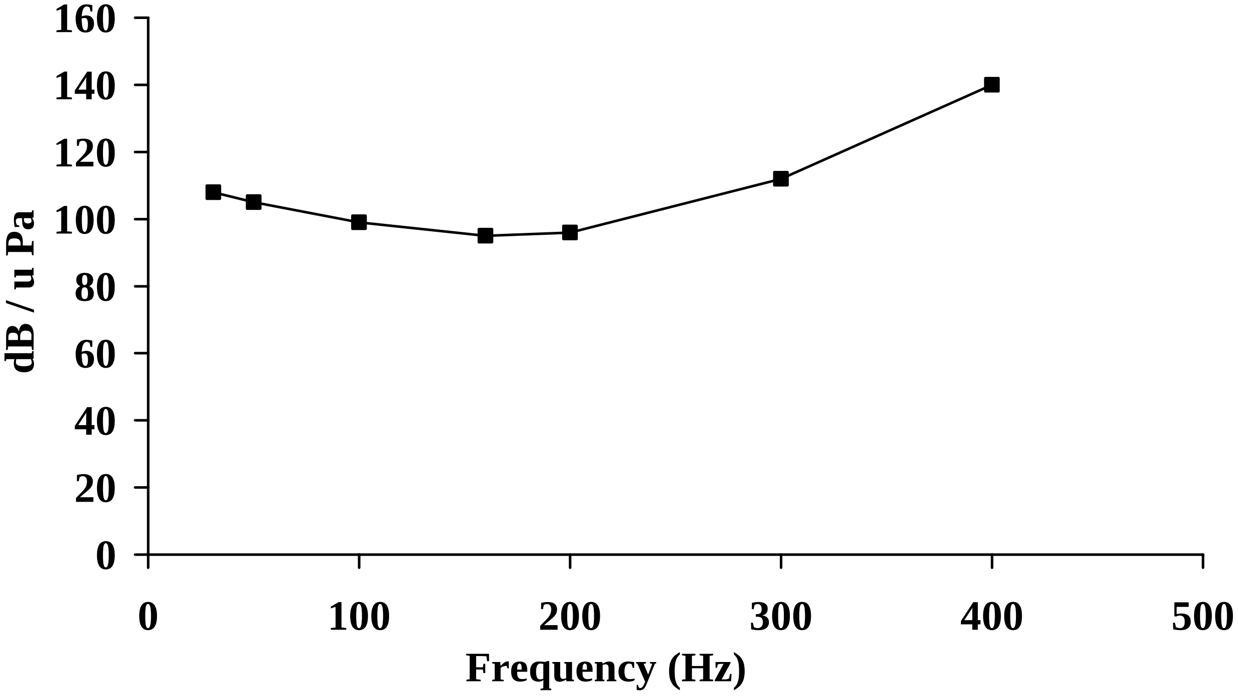




Appendix 2. Audiograms of Marine Fishes.



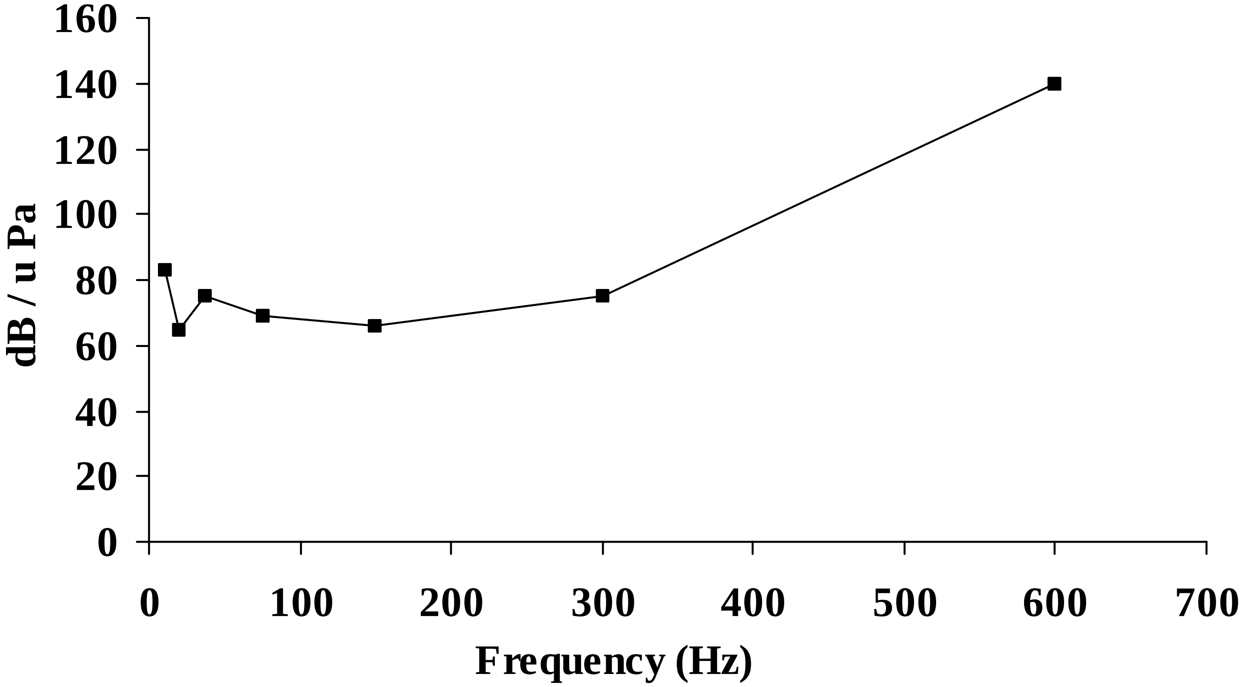
Order Clupeifromes
***Clupea harengus pallasi* , *Clupanodon punctatus* , &**
***Sardinops sagax melanosticta* (Sorokin et al. 1988)**



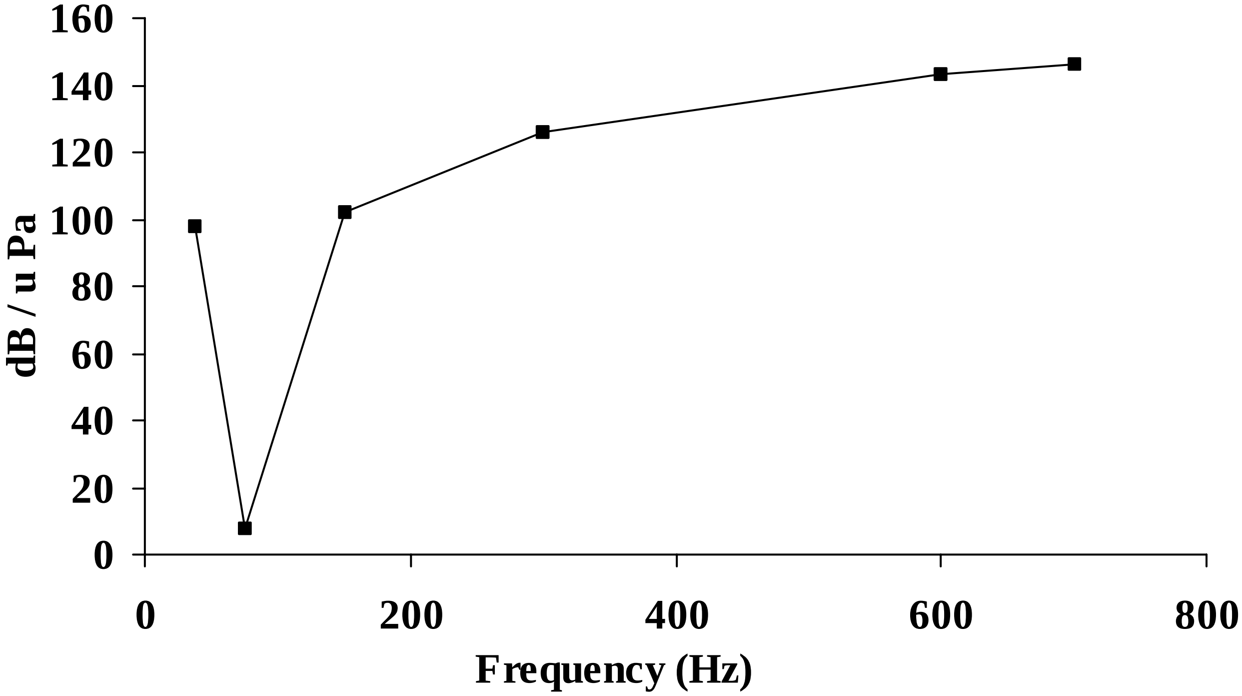
Order Salmoniformes
***Salmo salar* (Hawkins and Johnstone 1978)**

Appendix 2. Audiograms of Marine Fishes.

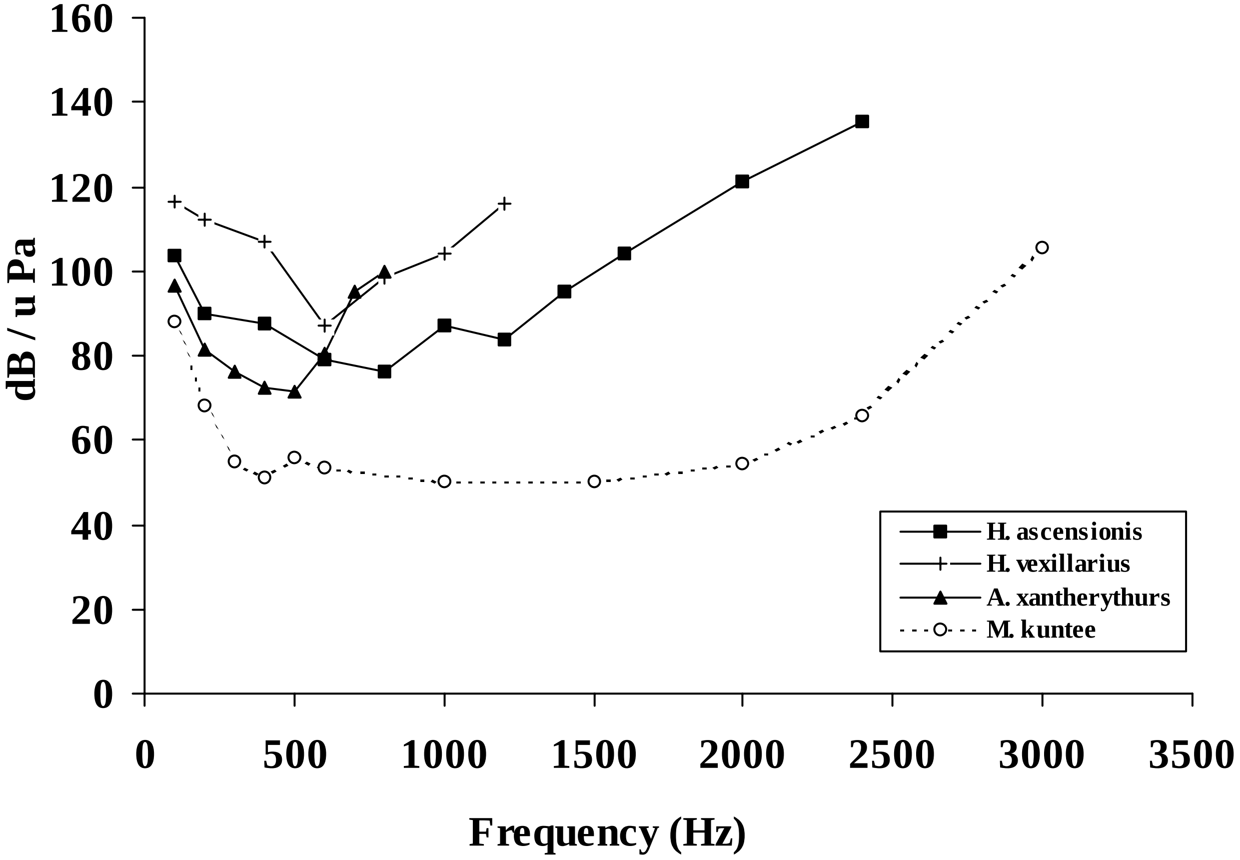
Order Gadiformes
Gadus morhua (Offutt 1974)



Order Batrachoidiformes
Opsanus tau (Fish and Offutt 1971)



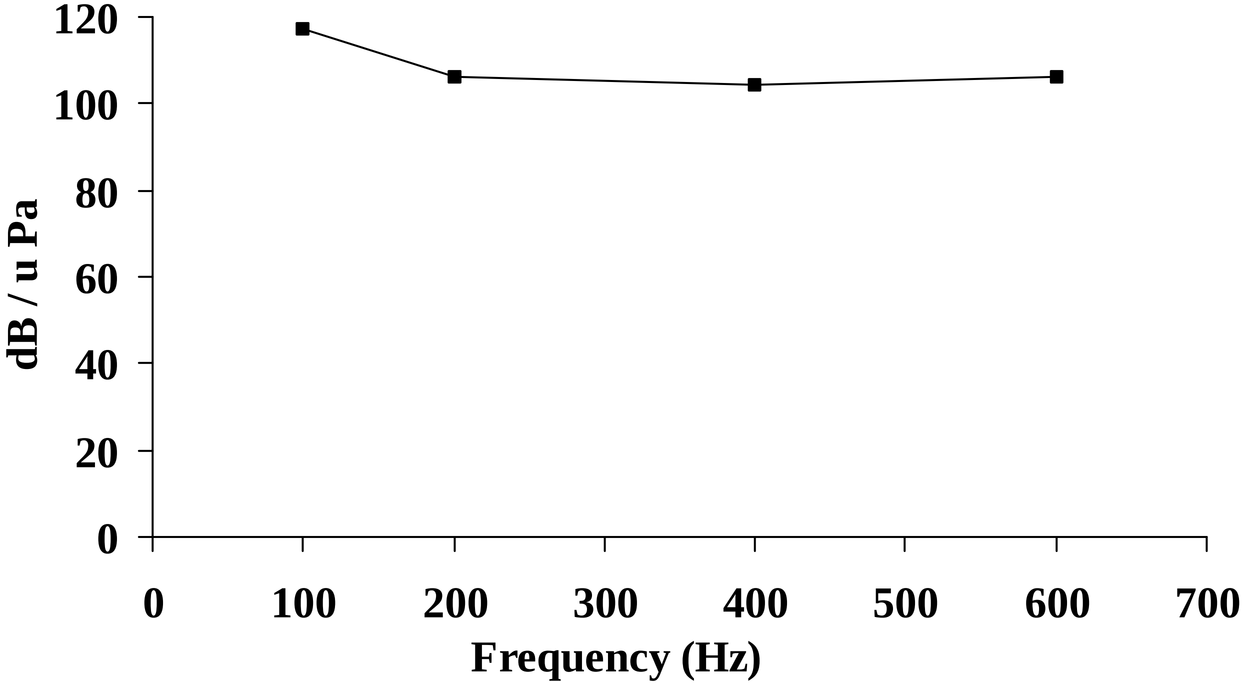
Appendix 2. Audiograms of Marine Fishes.



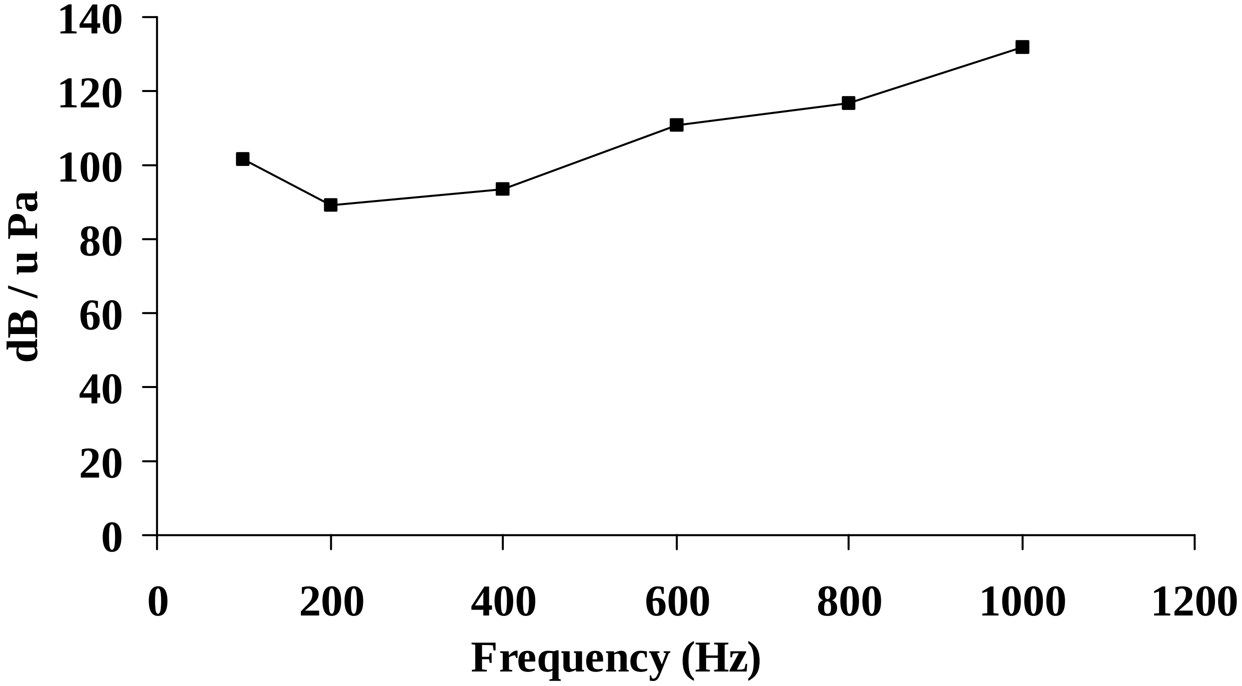
Order Beryciformes
Holocentrus ascensionis*, *Holocentrus vexillarius
(Tavolga and Wodinsky 1963),*Adioryx xantherythrus* ,
& *Myripristis kuntee* (Coombs and Popper 1979)

Appendix 2. Audiograms of Marine Fishes.

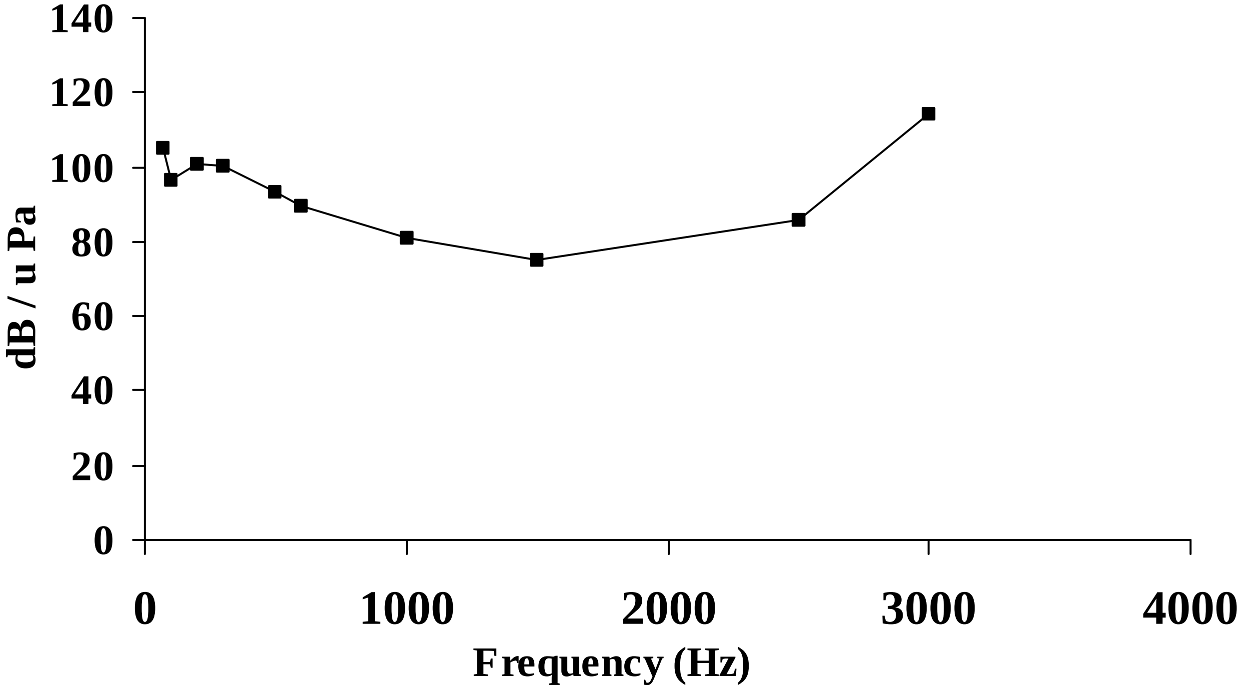
Order Scorpaeniformes
Prionotus scitulus (Tavolga and Wodinsky 1963)



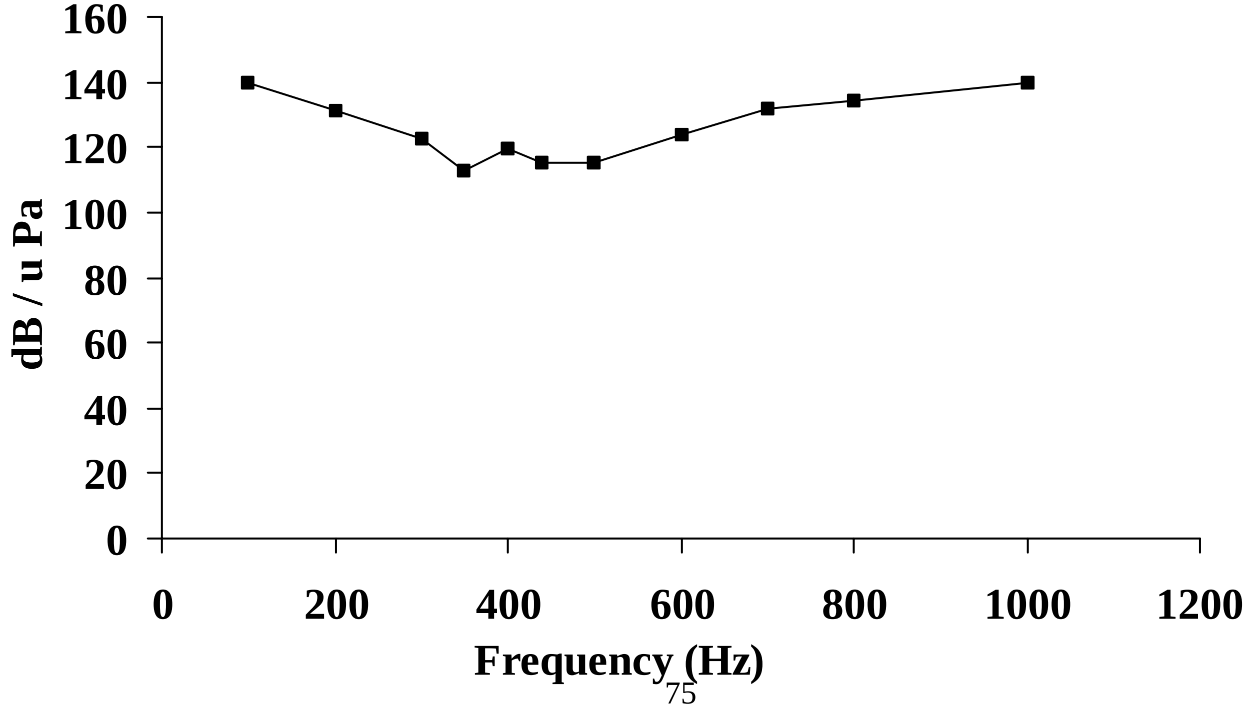
Order Perciformes - Family Serranidae
Epinephelus guttatus (Tavolga and Wodinsky 1963)



Appendix 2. Audiograms of Marine Fishes.



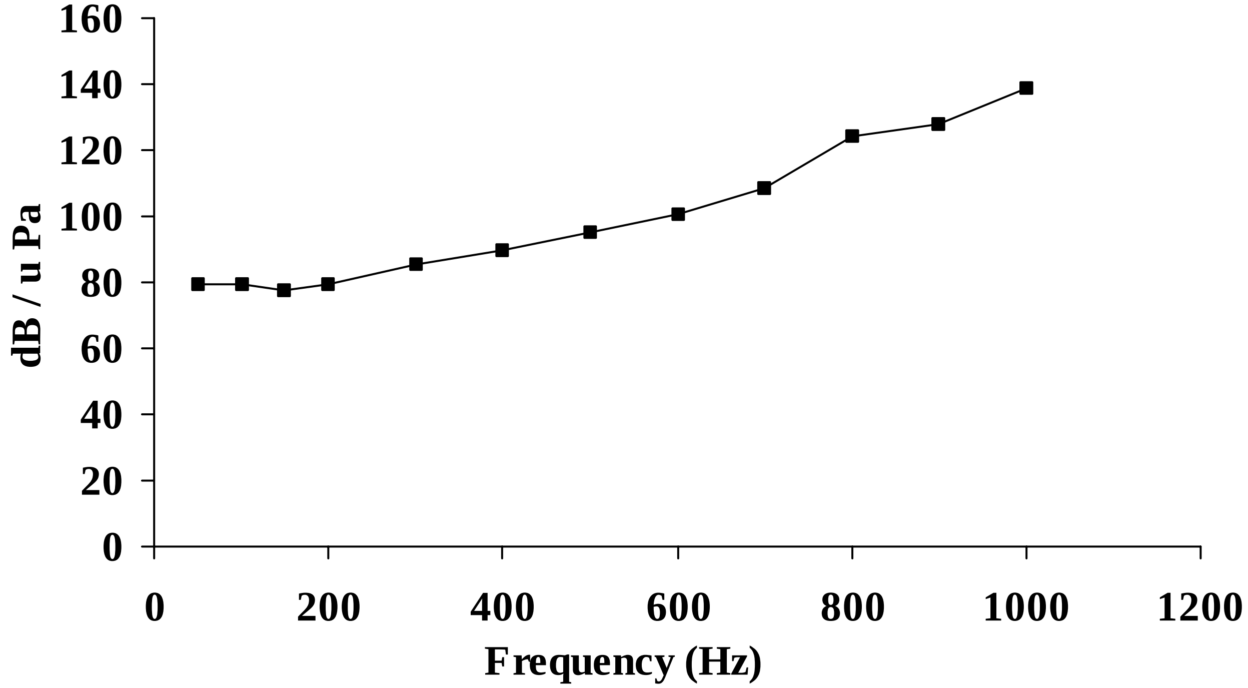
Order Perciformes - Family Carangidae
Trachurus japonicus **(Chung et al. 1995)**



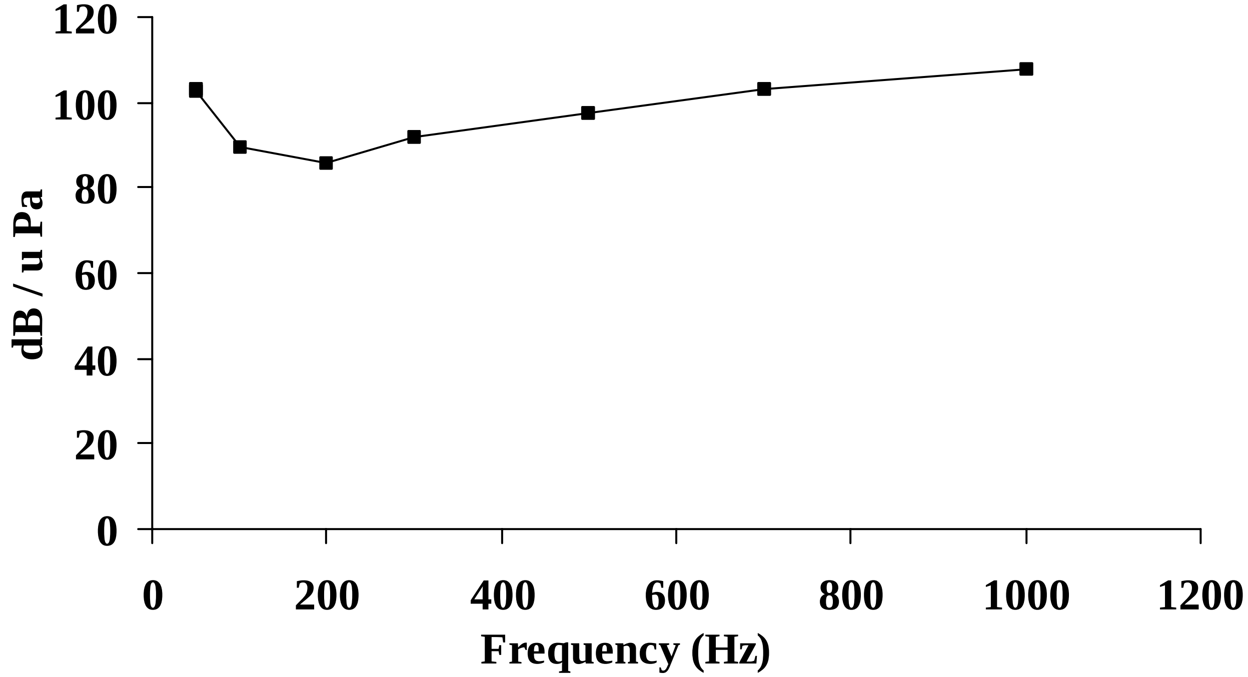
Order Perciformes - Family Lutjanidae
Lutjanus apodus **(Tavolga and Wodinsky 1963)**

Appendix 2. Audiograms of Marine Fishes.

Order Perciformes - Family Pomadasyidae
Haemulon sciurus **(Tavolga and Wodinsky 1965)**

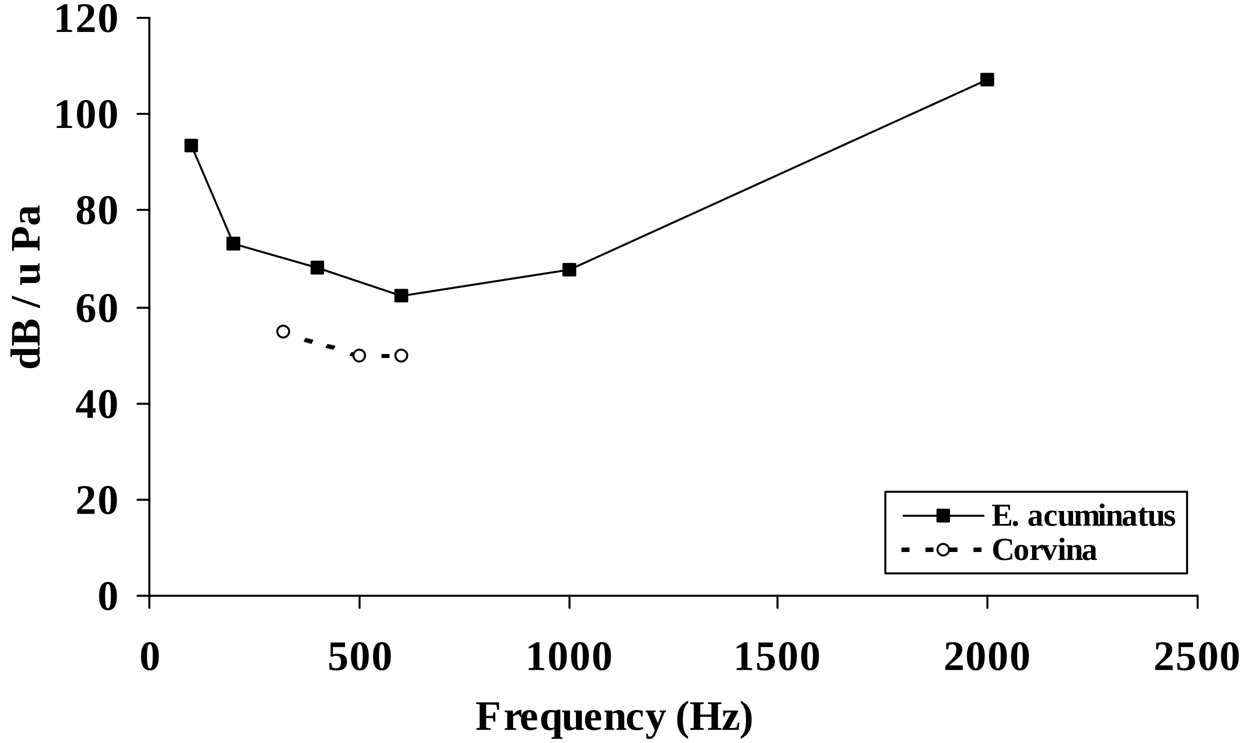


Order Perciformes - Family Sparidae
Pagrus major **(Ishioka et al. 1988)**

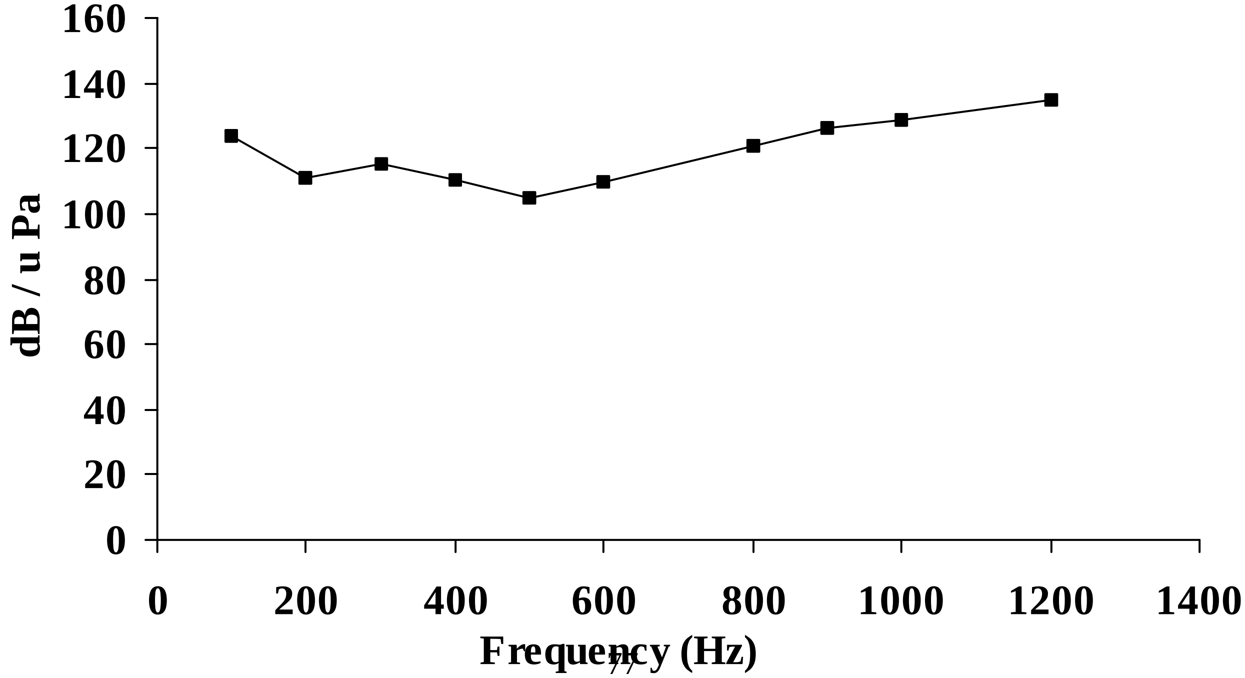


Appendix 2. Audiograms of Marine Fishes.

Order Perciformes - Family Sciaenidae
Equetus acuminatus (Tavolga and Wodinsky 1963) & *Corvina* (Maliukina 1960)

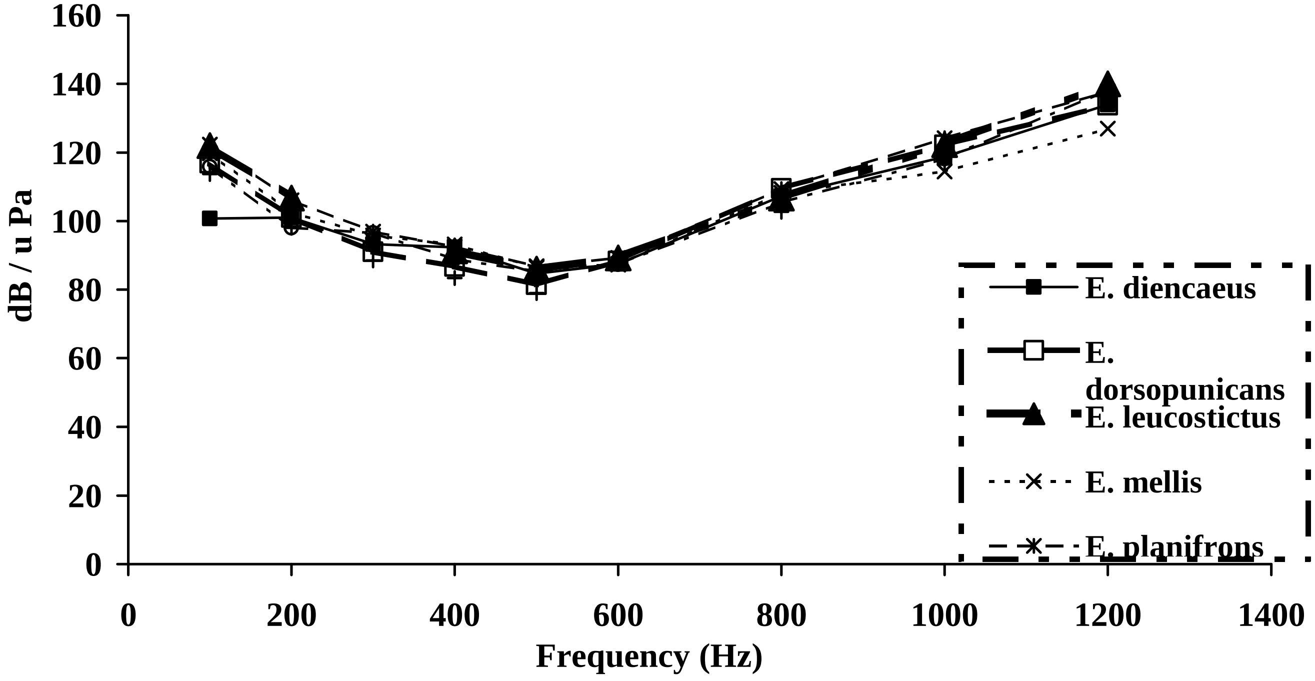


Order Perciformes - Family Labridae
Thalassoma bifasciatum (Tavolga and Wodinsky 1963)

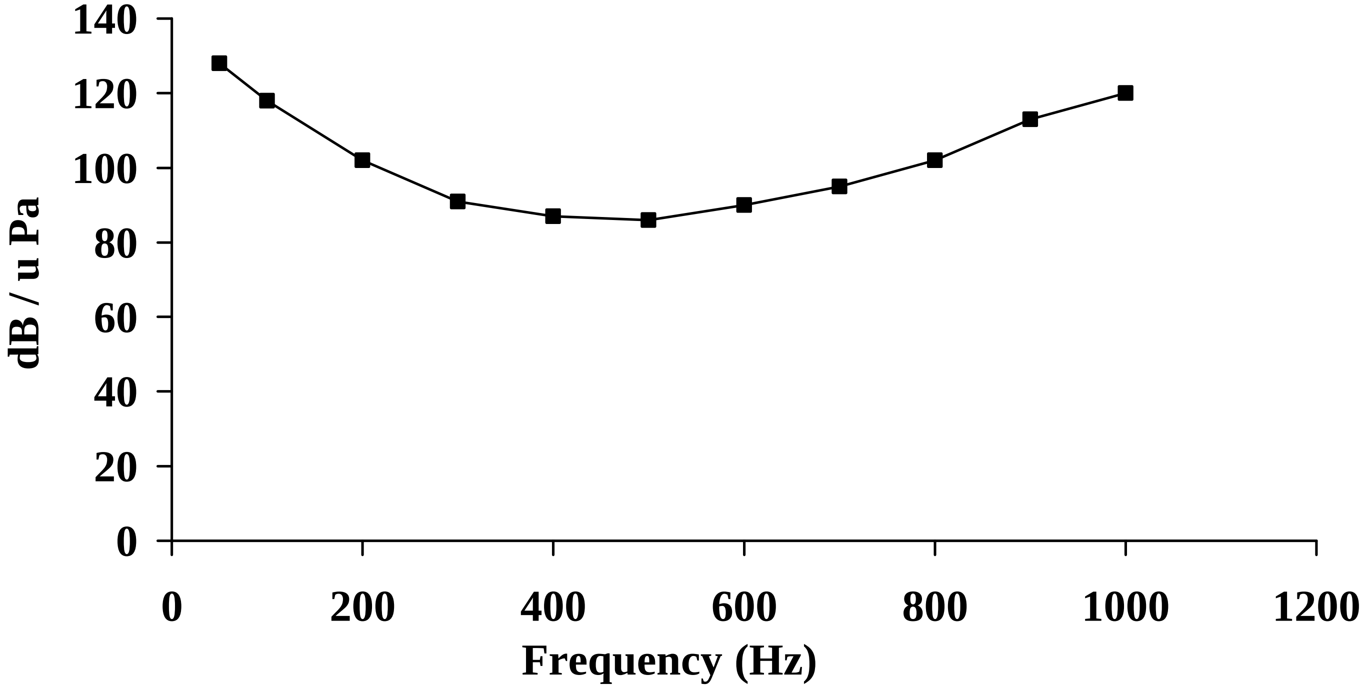


Appendix 2. Audiograms of Marine Fishes.

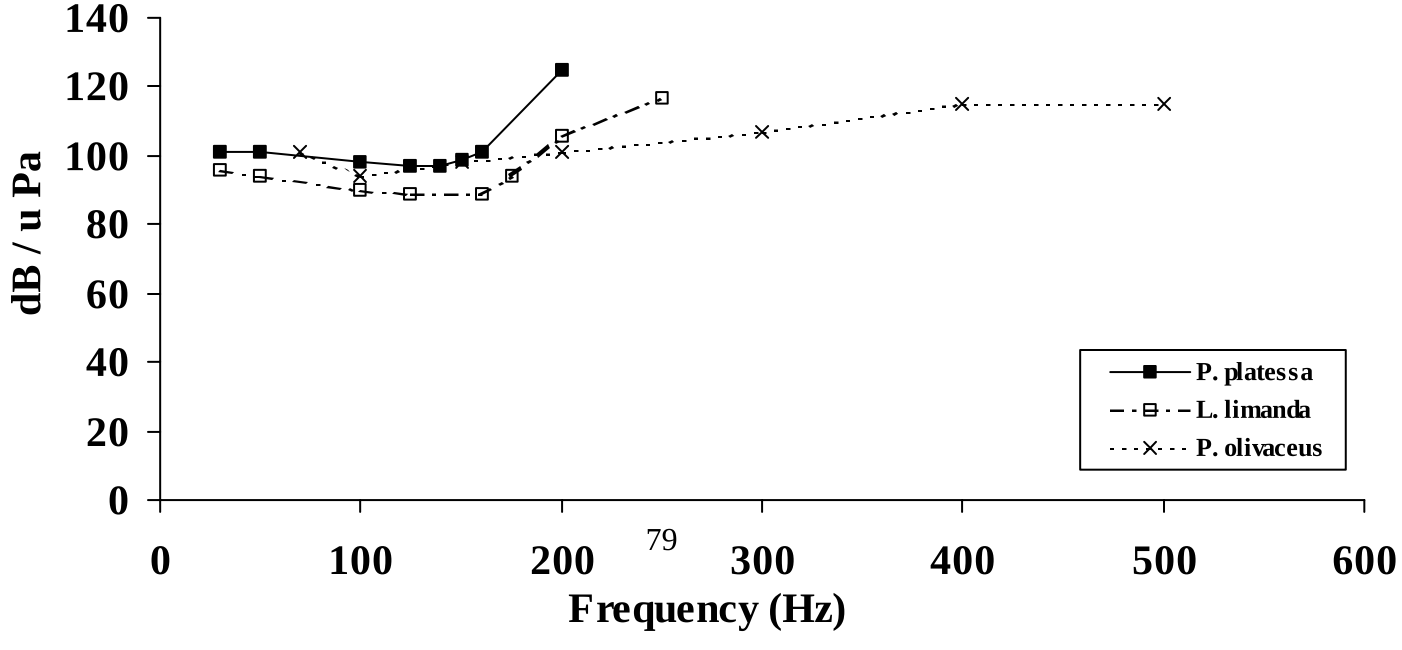
Order Perciformes - Family Pomacentridae
Eupomacentrus diencaeus*, *E. dorsopunicans*, *E. leucostictus*, *E. mellis*, *E. planifrons*, *E. variabilis **(Myrberg and Spires 1980), &**
E. partitus **(Ha 1973)**



Appendix 2. Audiograms of Marine Fishes.



Order Perciformes - Family Scombridae
***Thunnus albacares* (Iversen 1967)**



Order Pleuronectiformes
***Pleuronectes platessa*, *Limanda limanda* (Chapman and Sand 1974), & *Paralichthys olivaceus* (Fujieda et al. 1996)**

Appendix 3. Tabular summary of hearing capabilities and sound production in marine fishes.

ORDER	**FAMILY**	**SPECIES**	**HEARING RANGE (kHz)**	**BEST HEARING (kHz at DB)**	**VOCAL RANGE (kHz)**	**DOMINANT FREQUENCIES VOCAL (kHz)**
HETERODONTIFORMES	HETERODONTIDAE	*Heterodontis francisci*	0.020-0.160	0.04@115		
SQUALIFORMES	CHARCHARHINIDAE	*Charcharhinus leucas*	0.1-1.5	0.4-0.6@<85		
		Negaprion brevirostris	0.01-0.64	0.04@96		
RAJIFORMES		*Rhinoptera bonasus*			0-3	0-2
ELOPIFORMES	ELOPIDAE	*Megalops atlantica*			0-0.4	0-0.2
	ALBULIDAE	*Albula vulpes*			0.5-5	1-4.
ANGUILLIFORMES	ANGUILLIDAE	*Anguilla anguilla*	0.01-0.300	0.08@95		
		Anguilla rostrata			0-2.5	0-0.4
CLUPEIFORMES	CLUPEIDAE	*Alosa aetivalis*				
		Alosa mediocris				
		Alosa pseudoharengus				
		Brevoortia tyrannus			0-0.14	
		Clupea harengus harengus			0-3	0-2
		Clupea harengus pallasi	0.02-4	0.125-0.5@55.1		
		Clupanodon punctatus	0.02-2.6	0.063-0.5@55		
		Dorosoma cepedianum			0-0.3	0-0.2
		Opisthonema oglinum			0.1-0.24	0.15-0.2
		Sardinops sagax	0.02-2	0.125-		

		melanosticta		0.5@54.9		
SALMONIFORMES	SALMONIDAE	*Salmo salar*	0.025-0.6	0.1@95	0.1-0.5	
SILUIFORMES	ARIIDAE	*Bagre marinus*				
		Felichthys felis			0.1-1.6	
		Galeichthys felis			0.1-0.7	0.2-0.7
GADIFORMES	GADIDAE	*Gadus callarias*			<-0.5	
		Gadus morhua	0.01-0.6	0.02-0.15@65	0.03-0.65	0.03-0.4
		Gaidropsarus mediterraneus			0.047-0.736	
		Melanogrammus aeglefinus			0.04-0.3	
		Merluccius bilinearis			0-0.12	0-0.06
		Pollachius pollachius			0-0.1	0.1-0.6
		Pollachius virens			0-0.2	0-0.12
		Raniceps raninus			0-0.5	0-0.4
		Urophycis chuss			0-0.5	0-0.3
		Urophycis regius			0-0.8	
	OPHIDIIDAE	*Ophidion marginatum*			0.4-1.7	
	ZOARCHIDAE	*Macrozoarces americanus*				
BATRACHOIDIFORMES	BATRACHOIDIDAE	*Opsanus phobetron*			0-0.5	
		Opsanus tau	0.0375-0.8	0.04-0.09@98	0.1-0.7	0.15-0.25
		Porichthys notatus			0-1	
LOPHIIFORMES	LOPHIIDAE	*Lophius americanus*				
	ANTENNARIIDAE	*Antennarius scaber*				
		Histrio gibba				
		Histrio histrio				
	OGCOCEPHAL	*Ogcocephalus radiatus*				

	IDAE					
		Ogcocephalus vespertilio				
ATHERINIFORMES	ATHERINIDAE	*Menidia beryllina*				
		Menidia menidia				
BERYCIFORMES	HOLOCENTRIDAE	*Adioryx xantherythrus*	0.1-0.8	0.5@72		
		Holocentrus ascensionis	0.1-3		0-0.6	
		Holocentrus vexillarius	0.1-1			
		Myripristis jacobus			0-0.6	0-0.4
		Myripristis kuntee	0.1-3	0.3-2@50		
		Myripristis violaceus			0-3	
		Myripristis pralinus			0-3	
GASTEROSTEIFORMES	SYNGNATHIDAE	*Hippocampus hudsonius*			0-1.3	0-0.8
SCORPAENIFORMES	SCORPAENIDAE	*Scorpaena plumieri*				
		Sebastes marinus				
	TRIGLIDAE	*Prionotus carolinus*			0.15-2	0.1-0.25
		Prionotus evolans			0-0.7	
		Prionotus scitulus	0.1-0.6		0-0.5	
	COTTIDAE	*Cottus bairdi*			0-1.3	
		Cottus gobio			0.05-0.5	
		Hemitripterus americanus				
		Myoxocephalus aeneus			0.05-0.16	
		Myoxocephalus octodecimspinosus			0.05-0.13	
	CYCLOPTERIDAE	*Cyclopterus lumpus*				

DACTYLOPTERIFORMES	DACTYLOPTERIDAE	*Dactylopterus volitans*		0-1	
PERCIFORMES	CENTROPOMIDAE	*Centropomus ensiferus*		0-0.3	0-0.2
	SERRANIDAE	*Alphestes afer*		0-0.6	0-0.3
		Centropristes striatus		0-0.7	
		Cephalopholis fulva		0-0.5	
		Diplectrum formosum		0-0.3	
		Epinephelus adscensionis		0-0.14	
		Epinephelus guttatus	0.1-1	0-0.24	0-0.18
		Epinephelus itajara		0-0.14	0-0.1
		Epinephelus morio		0-0.22	0-0.12
		Epinephelus nigritus		0-0.2	0-0.06
		Epinephelus striatus		0-0.12	
		Hypoplectrus unicolor		0.2-3	0.2-1
		Mycteroperca bonaci		0-0.22	0-0.12
		Mycteroperca interstitialis		0-0.24	
		Mycteroperca microlepis		0-0.2	
		Mycteroperca venenosa		0-0.5	0-0.3
		Petrometopon cruentatum		0-0.24	
		Roccus saxatilis		0-0.14	
		Rypticus saponaceus		0-0.5	
		Serranus tigrinus		0-0.5	
	POMATOMIDAE	*Pomatomus saltatrix*		0-0.24	
	ECHENEIDAE				
	CARANGIDAE	*Alectis crinitus*		0.1-2.1	0.3-1.5
		Caranx bartholomaei		0-0.4	

	Caranx crysos			0-1	0-0.5
	Caranx hippos			0-2	0-1
	Caranx latus			0-3	0-1
	Caranx ruber			0-2	0-1
	Chloroscombrus chrysurus			0-1.5	0.1-1
	Oligoplites saurus			0-0.6	
	Selar crumenophthalmus			0-2	
	Selene vomer			0-1.5	0-1
	Seriola dumerili			0-0.24	
	Seriola zonata			0-0.24	
	Trachinotus glaucus			0-0.4	
	Trachurus japonicus	0.07 - >3	1.5@75		
	Vomer setapinnis			0.1-2	0.1-1.5
LUTJANIDAE	*Lutjanus analis*			0-0.5	
	Lutjanus apodus	0.1-1		0-0.5	
	Lutjanus griseus			0-0.4	
	Lutjanus jocu			0-0.2	0-0.1
	Lutjanus synagris			0-0.3	
	Rhomboplites aurorubens			0-0.5	
	Ocyurus chrysurus			0-0.3	
GERRIDAE	*Diapterus rhombeus*			0-0.5	
	Eucinostomus gula			0-0.4	0-0.2
	Eucinostomus havana			0-0.5	0-0.4
	Gerres cinereus			0-0.2	
POMADASYIDAE	*Anisotremus surinamensis*				
	Anisotremus virginicus			0-2.3	0-1
	Conodon nobilis			0-1	
	Haemulon album			0-0.8	

	Haemulon aurolineatum			0-2.3	0-1.5
	Haemulon carbonarium			0.1-2.3	
	Haemulon flavolineatum			0-2.3	0-1
	Haemulon macrostomum			0-0.8	0-0.5
	Haemulon melanurum			0-1	
	Haemulon parrai			0-2.3	0-1
	Haemulon plumieri			0-2.3	0-1
	Haemulon sciurus	0.05-1		0-8	1.5-4
	Haemulon striatum				
	Orthopristis chrysopterus			0-1.2	0-1
	Pomadasys corvinaeformis			0-1.2	0-1
SPARIDAE	*Archosargus probatocephalus*				
	Archosargus rhomboidalis			0-0.5	
	Calamus bajonado			0-0.5	
	Calamus calamus			0-0.5	
	Calamus penna				
	Diplodus argenteus			0-0.4	
	Lagodon rhomboides			0-6	0-1
	Pagrus major	0.05-1	0.2@86		
	Stenotomus chrysops			0-0.5	
SCIAENIDAE	*Bairdiella chrysura*			0-2.5	
	Bairdiella ronchus			0-0.8	
	Corvina sp.	0.32-2	0.32@56		
	Cynoscion jamaicensis			0-1	
	Cynoscion nebulosis				
	Cynoscion regalis			0-2.4	0.3-0.5 and >1

	Equetus acuminatus	0.1-2		0-0.5	
	Leiostomus xanthurus			0-1.4	
	Larimus breviceps			0-2	0.5-1.5
	Menticirrhus saxatilis			0.175-1.475	
	Micropogonias undulatus			0.1-1.4	
	Odontoscion dentex			0-0.5	
	Ophioscion adustus			0-0.7	
	Pogonias cromis			0-0.8	0-0.5
	Sciaenops ocellata			0-2.5	0.24-1
	Stellifer lanceolatus				
	Umbrina coroides				
MULLIDAE	*Mullus sp.*		0.45-0.9@70		
	Mulloidichthys martinicus			0-0.5	
	Pseudupeneus maculatus			0-0.5	
KYPHOSIDAE	*Kyphosus sectatrix*			0-0.4	
EPHIPPIDAE	*Chaetodipterus faber*			0-0.4	
CHAETODONTIDAE	*Chaetodon aureus*			0-0.4	
	Chaetodon ocellatus			0-0.5	
	Chaetodon striatus			0-0.4	
	Holacanthus ciliaris			0-0.5	
	Holacanthus isabelita			0-0.4	
	Holacanthus tricolor			0-0.5	
	Pomacanthus arcuatus			0-0.4	
POMACENTRIDAE	*Abudefduf luridus*			0-0.8	
	Abudefduf saxatilis			0-0.7	
	Eupomacentrus	0.1-1.2	0.5@84.7		

	diencaeus				
	Eupomacentrus dorsopunicans	0.1-1.2	0.5@81.4	0.1-0.7	
	Eupomacentrus leucostictus	0.1-1.2			
	Eupomacentrus leucostictus	0.1-1.2	0.5@86	0-6	0-1
	Eupomacentrus mellis	0.1-1.2	0.5@86.4		
	Eupomacentrus partitus	0.1-1.2	0.5@79		
	Eupomacentrus planifrons	0.1-1.2	0.5@86.8		
	Eupomacentrus variabilis	0.1-1.2	0.5@85.3		
	Hypsypops rubicunda			0-0.4	
	Pomacentrus partitus			0.35-1	0.55-0.75
	Pomacentrus viridis			0-3	
MUGILIDAE	*Mugil sp.*		0.64@50		
	Mugil brasiliensis				
	Mugil curema				
SPHYRAENIDAE	*Sphyraena barracuda*			0-0.2	
POLYNEMIDAE	*Polydactylus virginicus*			0-0.6	
LABRIDAE	*Halichoeres bivittatus*			0-0.4	
	Halichoeres radiatus			0-0.3	
	Lachnolaimus maximus			0-0.3	
	Tautoga onitis			0-0.3	
	Tautogolabrus adspersus			0-0.3	
	Thalassoma bifasciatum	0.1-1.2		0-0.3	
SCARIDAE	*Scarus coelestinus*			0-3	
	Scarus coeruleus			0-5	

	Scarus croicensis			0-5	
	Scarus guacamaia			0-0.7	
	Scarus iserti			0-1.2	
	Scarus vetula			0-5	
	Sparisoma aurofrenatum			0-0.7	
	Sparisoma chrysopterum			0-5	
	Sparisoma radians			0-5	
	Sparisoma rubripinne			0-3	0-1
	Sparisoma viride			0-5	0-2
URANOSCOPIDAE	*Astroscopus guttatus*				
AMMODYTIDAE	*Ammodytes americanus*				
GOBIIDAE	*Bathygobius soporator*				0.1-0.15
	Gobiosoma bosci			0-16	0-6
	Gobius jozo				
	Neogobius melanostomus				
	Padogobius martensii			0-0.8	0.2-0.3
	Padogobius nigricans			0-1	
	Knipowitschia punctatissima			0-2	0.24-0.27
ACANTHURIDAE	*Acanthurus bahianus*			0-0.5	
	Acanthurus chirurgus			0-0.3	
	Acanthurus coeruleus			0-0.6	0.1-0.4
SCOMBRIDAE	*Thunnus albacares*	0.05-1.5	0.3-0.5@100	0.4-5	0.5-0.7
STROMATEIDAE	*Palinurichthys perciformis*				
	Peprilus paru				
	Poronotus triacanthus				

	ANABANTIDAE	*Trichopsis vittatus*				
PLEURONECTIFORMES	BOTHIDAE	*Archirus fasciatus*				
	PLEURONECTIDAE	*Hippoglossoides platessoides*				
		Limanda limanda	0.025-0.25	0.1@87		
		Paralichthys dentatus				
		Paralichthys olivaceus	0.07-0.5	0.1@94		
		Pleuronectes platessa	0.025-0.2	0.125@97		
		Pseudopleuronectes americanus				
	SOLEIDAE					
TETRAODONTIFORMES	BALISTIDAE	*Alutera schoeplfi*			0-5	
		Alutera scripta			0-1.5	
		Balistes capriscus			0-3	0-1
		Balistes vetula			0-3	0-0.5
		Cantherines pullus			0-0.4	
		Canthidermis sufflamen			0-2	
		Melichthys radula			0-0.4	
		Monacanthus hispidus			0-5	
	OSTRACIIDAE	*Ostracion meleagris*			0.1-0.8	0.198-0.79
		Lactophrys bicaudalis			0-5	
		Lactophrys quadricornis			0-0.4	
		Lactophrys trigonus			0-9	
		Lactophrys triqueter			0-0.8	
	TETRAODONTIDAE	*Canthigaster rostrata*				
		Lagocephalus laevigatus			0-9	
		Sphaeroides maculatus			0-6	

	Sphaeroides spengleri	
	Sphaeroides testudineus	0-7
DIODONTIDAE	*Chilomycterus atinga*	0-8
	Chilomycterus schoepfi	0-4.5
	Diodon hystrix	0-8
MOLIDAE	*Mola mola*	

CHAPTER 2: OTHER MARINE VERTEBRATES (By Donald Croll, Bernie Tershy And Alejandro Acevedo)

INTRODUCTION

Over the past 50 years, economic and technological developments have dramatically increased the human contribution to ambient noise in the ocean. The dominant frequencies of most human-made noise in the ocean is in the low-frequency range (defined as sound energy below 1000Hz), and low-frequency sound (LFS) may travel great distances in the ocean due to the unique propagation characteristics of the deep ocean (Munk et al. 1989). For example, in the Northern Hemisphere oceans low-frequency ambient noise levels have increased by as much as 10 dB during the period from 1950 to 1975 (Urick 1986; review by NRC 1994). Shipping is the overwhelmingly dominant source of low-frequency manmade noise in the ocean, but other sources of manmade LFS including sounds from oil and gas industrial development and production activities (seismic exploration, construction work, drilling, production platforms), and scientific research (e.g., acoustic tomography and thermography, underwater communication). The SURTASS LFA system is an additional source of human-produced LFS in the ocean, contributing sound energy in the 100-500 Hz band.

When considering a document that addresses the potential effects of a low-frequency sound source on the marine environment, it is important to focus upon those species that are the most likely to be affected. Important criteria are: 1) the physics of sound as it relates to biological organisms; 2) the nature of the exposure (i.e. duration, frequency, and intensity); and 3) the geographic region in which the sound source will be operated (which, when considered with the distribution of the organisms will determine which species will be exposed). The goal in this section of the LFA/EIS is to examine the status, distribution, abundance, reproduction, foraging behavior, vocal behavior, and known impacts of human activity of those species may be impacted by LFA operations. To focus our efforts, we have examined species that may be physically affected and are found in the region where the LFA source will be operated. The large-scale geographic location of species in relation to the sound source can be determined from the distribution of each species. However, the physical ability for the organism to be impacted depends upon the nature of the sound source (i.e. explosive, impulsive, or non-impulsive); and the acoustic properties of the medium (i.e. seawater) and the organism.

Non-impulsive sound is comprised of the movement of particles in a medium. Motion is imparted by a vibrating object (diaphragm of a speaker, vocal chords, etc.). Due to the proximity of the particles in the medium, this motion is transmitted from particle to particle in waves away from the sound source. Because the particle motion is along the same axis as the propagating wave, the waves are longitudinal. Particles move away from then back towards the vibrating source, creating areas of compression (high pressure) and areas of rarefaction (low pressure). As the motion is transferred from one particle to the next, the sound propagates away from the sound source. Wavelength is the distance from one pressure peak to the next. Frequency is the number of waves passing per unit time (Hz). Sound velocity (not to be confused with particle velocity) is the product of wavelength and velocity, and is approximately 1500 m/sec in seawater. Sound impedance is loosely equivalent to the resistance of a medium to the passage of sound waves (technically it is the ratio of acoustic pressure to particle velocity). A high impedance means that acoustic particle velocity is small for a given pressure (low impedance the opposite). When a sound strikes a boundary between media of different impedances, both reflection and refraction, and a transfer of energy can occur. The intensity of the reflection is a function of the intensity of the sound wave and the impedances of the two media. Two key factors in determining the potential for damage due to a sound source are the intensity of the sound wave and the impedance difference between the two media (impedance mis-match). The bodies of the vast majority of organisms in the ocean (particularly phytoplankton and zooplankton) have similar sound impedence values to that of seawater. As a result, the potential for sound damage is low; organisms are effectively transparent to the sound – it passes through them without transferring damage-causing energy.

Due to the considerations above, we have undertaken a detailed analysis of species which met the following criteria:

3) Is the species capable of being physically affected by LFS? Are acoustic impedence mis-matches large enough to enable LFS to have a physical affect or allow the species to sense LFS?
4) Does the proposed SURTASS LFA geographical sphere of acoustic influence overlap the distribution of the species?

Species that did not meet the above criteria were excluded from consideration. For example, phytoplankton and zooplankton species lack acoustic impedance mis-matches at low frequencies to expect them to be physically affected SURTASS LFA.

Vertebrates are the organisms that fit these criteria and we have accordingly focused our analysis of the affected environment on these vertebrate groups in the world's oceans: fishes, reptiles, seabirds, pinnipeds, cetaceans, pinnipeds, mustelids, sirenians (Table 1).

SEA TURTLES

Summary

There are eight species of extant sea turtles in two families Dermochelyidae (one species) and Cheloniidae (seven species). All marine turtles are listed as CITES Appendix I species. The green turtle (*Chelonia mydas*) and loggerhead turtle (*Caretta caretta*) are listed as Threatened Species under the U. S. Endangered Species Act. The hawksbill (*Eretmochelys imbricata*), olive ridley (*Lepidochelys olivacea*), Kemp's ridley (*L. kempi*), and leatherback (*Dermochelys coriacea*) are listed as Endangered Species. The flatback turtle *Natator depressus* is unlisted, perhaps due to lack of data. It is a shallow near shore species endemic to Australia and is not likely to be exposed to LFA sounds.

All sea turtles come ashore on specific beaches to lay eggs in holes dug in the sand. Adults are vulnerable predation, disturbance, and pollution when concentrated off shore of these nesting beaches and, for females, when on the beach laying eggs.

The leatherback is primarily pelagic, but the other marine turtles spend most of their time in relatively shallow waters where they feed close to or on the bottom. However, all but the flatback turtle have a pelagic juvenile stage, and as adults migrate across pelagic waters between feeding and breeding grounds. They are capable of relatively deep dives and can spend more than 75% of their time underwater.

Data on vocalization and hearing are few. Leatherbacks, and perhaps other species, make low frequency sounds, but their functional significance, if any, is unknown. It is likely that all species hear low frequency sound as adults. It has been hypothesized that females use the low frequency sound of surf to orient towards nesting beaches, however, this has not been tested.

In a pen experiment, sub-adult loggerhead turtles avoided a loud low frequency sound source. This study has not been followed up in the wild or with other species.

Low frequency sound can impact animals by causing tissue damage; short-term behavioral changes; and, long-term behavioral changes. Tissue damage occurs only at very high dB levels that can be estimated by modeling and measured in laboratory experiments. These have not been determined for marine turtles, but it is unlikely that marine turtles are more sensitive to sonic tissue damage than are marine mammals.

The paucity of data make it difficult to determine if there are any potential short-term or long-term behavioral impacts of low frequency sound on sea turtles. It is possible that loud low frequency sound could impact turtle populations if it caused them to avoid an area of highly concentrated prey for long periods of time. However, because the LFA source moves continuously this is unlikely. A more likely, but only theoretical, impact of low frequency sound is its possible impacts on movements on and off the breeding beaches of both females and hatchlings. This potential problem could be easily resolved with play back experiments in the field and laboratory.

LEATHERBACK TURTLE (*DERMOCHELYS CORIACEA*).

Summary

The leatherback is the largest, most pelagic, and most temperate of the marine turtles. It feeds primarily on jellyfish and is a deep, nearly continuous diver. It is protected by the U. S. Endangered Species Act and CITES. Although it has not been subject to significant commercial exploitation, population size appears to be declining. Leatherback turtles produce low frequency sound and it has been speculated that females use the low frequency sound of surf to orient towards nesting beaches in turbid water.

Protected Status

The leatherback turtle (*Dermochelys coriacea*) is listed as Endangered Species under the U. S. Endangered Species Act. Like other marine turtles it is protected under CITES Appendix I. Thus, trade in leatherback turtle products or live turtles is prohibited between signatory countries.

Distribution

The leatherback turtle is the most widely distributed and most pelagic marine turtle. They are tropical nesters but much of the foraging is in temperate waters. Overall, their at sea distribution is related to the distribution of their primary prey jellyfish, salps, and other gelatinous species (Bjorndal 1997). It ranges throughout tropical and temperate pelagic, and occasionally coastal waters of the Atlantic, Pacific, and Indian Oceans (Lutz and Musick 1997). They enter the Mediterranean and Gulf of California and likely other marginal seas. Extreme high latitude records for leatherback turtles include Iceland in the North Atlantic; the Bering Sea in the North Pacific; Argentina in the South Atlantic; and New Zealand in the South Pacific (Lutz and Musick 1997). There are three potential subspecies of leatherback turtles in the Atlantic, Pacific and Indian Oceans, and the Eastern Pacific. However, a detailed study is needed to determine if these are actually distinct populations (Lutz and Musick 1997).

There are 19 significant nesting beaches known (Table 3 in Ross 1981), however, most of these are relatively small.

Abundance

Global population estimates for leatherback turtles include 115,000 mature females in 1980 (Pritchard 1982). However, a more recent estimate using similar methods was 26,200 – 42,900 with a best estimate of 34,500 (Spolila et al. 1996). This is indicative of a real decline in population size (Spolila et al. 1996). In the Gulf of Mexico aerial surveys provided a density of 5 leatherback turtles / 1,000km.

Diet and Foraging Behavior

Leatherback turtles feed primarily on jellyfish and other gelatinous invertebrates (Bjorndal 1997). They feed throughout the water column, but much of their feeding is thought to be near the surface. Although leatherback turtles will eat mollusks, fish, and even echinoderms (Lutz and Musick 1997), they lack the jaw muscles and crushing plates in their mouth and throat that are typical of other marine turtles.

Bjorndal (1980) estimated that the typical hatchling leatherback needs to consume 55g. of jellyfish/ day, and estimates for adults range from 2.5 – 10kg/day (Lutz and Musick 1997). To consume these quantities of jellyfish, leatherback turtles tend to forage in concentrations of jellyfish.

Diving Behavior

The maximum recorded dive for a leatherback turtle is 1,300m, with many other dives to 200m (Eckert et al. 1989). Leatherback turtles dive routinely to 50-84m and have a maximum dive time of 37.4 min; routine dive time 10-15 min. ((Lutz and Musick 1997). Leatherback turtles dive throughout the day and night, but dive deeper during the day (Eckert et al. 1996). Females moving between nesting beaches spent 87% of their time beneath the surface. Average surface time was 20.6 sec. and average dive time was 2.3 min (Keinath and Musick 1993).

Social Behavior

Leatherback turtles may aggregate at concentrations of jellyfish (Lutz and Musick 1997). Little is known about courtship and mating (Lutz and Musick 1997).

Reproduction and Population Parameters

Modeling suggests that females mature at 13-24 years and 5-6 years at the absolute youngest. The mean clutch size in 12 populations was 81.5 ± 3.6(sd). Females lay perhaps 6-10 clutches every 9-10 days during the breeding season (Miller 1997). Larger females lay more clutches (Lutz and Musick 1997).

Breeding Areas

It is unclear if copulation takes place primarily on temperate feeding grounds or offshore of tropical breeding grounds. There are at least 28 known nesting beaches (Table 3 in Ross 1979). The most important nesting beaches are in Trengganu, Malaysia; Silebache, Surinam; and, Chacahua and Tierra Colorada, Mexico.

Speed of Travel and Movements

Travel speeds during migration of 40km/day have been recorded from satellite tagged leatherback turtles. A female moving between nesting sites traveled 29 km/day (Keinath and Musick 1993, Wyneken 1997). Maximum swimming speeds for adults was 9.3km/hr (Lutz and Musick 1997). For a sub-adult maximum swimming speeds were 18km/hr and mean swimming speeds were 3.1km/hr (Standora et al. 1984). Hatchlings travel at 30cm/sec. below the surface and 8cm/sec. at the surface (Davenport 1987).

Vocal Behavior

Sound production in turtles may be of minor functional significance, however some anecdotal observations suggest purposeful underwater vocalizations (Mrosovsky 1972).

A nesting female on a beach vocalized at 300-500Hz, just above the sound of the surf (Mrosovsky 1972).

Hearing Range

No data.

Known Impacts of Human Activity

Leatherback turtles have not been subjected to large commercial hunting efforts and in general, their flesh is not highly prized. However, there are a number of subsistence or small-scale commercial hunts (e.g. Suárez and Starbird 1996). Eggs are also collected for human consumption in some areas.

The indirect effects of toxic pollution and plastic pollution are unknown, but potentially significant (Lutz and Musick 1997). Plastic ingestion may be a significant problem for leatherback turtles because floating plastic is apparently mistaken for jellyfish and eaten.

Competition with commercial fisheries is essentially non-existent because there are no commercial fisheries for the main prey of leatherback turtles. However, entanglement in commercial fishing gear may be a significant cause of mortality (C. Starbird, pers. comm.).

Feral pigs, dogs, and other animals consume eggs and likely young on nesting beaches.

GREEN AND BLACK TURTLES (*CHELONIA MYDAS AND C. AGASSIZI*).

Summary

The green turtle (*Chelonia mydas*) is widespread throughout tropic and temperate seas. There are a number of morphologically distinct populations, one of which, *C.m. agassizi* in the Eastern Pacific, is generally accepted as a separate species *C. agassizi*. Hatchlings and young turtles are pelagic and omnivorous, but adults forage on benthic algae and sea-grasses. They are, therefore, primarily coastal, but make long pelagic migrations. Population sizes are not known, but they appear to be declining, at least since the 1950's, and are protected by the U. S. Endangered Species Act.

Protected Status

The green and black turtles (*Chelonia* sp.) are listed as Endangered Species under the U. S. Endangered Species Act. Like other marine turtles it is protected under CITES Appendix I. Thus, trade in green and black turtle products, or live turtles, is prohibited between signatory countries.

Distribution

Green turtles are found throughout the tropics, except in the eastern Pacific where they are replaced by the black turtle (Pritchard 1997). Specific status has also been proposed for populations of the green turtle in the Caribbean (*C. m. viridis*), South Atlantic (*C.m. mydas*), Indo Pacific (*C. m. japonicai*), and Gulf of California (*C. m. carrinegra*). However, these taxonomic divisions have not been widely accepted.

Abundance

Although absolute population estimates are rare, there is a consensus amongst researchers that green turtle numbers have been declining since at least the 1950's (Lutz and Musick 1997).

Diet and Foraging Behavior

Post hatching green turtles are pelagic and likely omnivorous, however, as they mature they switch to feeding on benthic algae and sea-grass (Bjorndal 1997). However, black turtles appear to be somewhat more carnivorous than green turtles (Bjorndal 1997).

Diving Behavior

In Hawaii, 90% of sub-adult green turtle dives were less than 33 min. and none were over 66 min (Brill et al. 1995). In the Gulf of California green turtles hibernate on the seafloor for weeks to months at a time during the cold winter months (Felger et al. 1976). The deepest recorded dive is 110 m and animals routinely dive to 20m (Lutz and Musick 1997). The maximum dive duration is 66 min. for non-hibernating adults and they routinely dive for 9-23min (Lutz and Musick 1997).

Social Behavior

Multiple males appear to compete for access to receptive females and to try to displace each other during copulation by biting (Miller 1997). Copulation may last as long as ten hrs, suggesting considerable mate guarding after sperm transfer (Miller 1997).

Reproduction and Population Parameters

Estimated age at sexual maturity is up to 20-50 years in the wild (Miller 1997), but can be only 6-13 years in some captive individuals (Lutz and Musick 1997). Females lay on average 2.9 clutches per season 12 days apart (Miller 1997). Females do not store sperm between reproductive seasons (Miller 1997).

Breeding Areas

There is evidence of considerable mixing between Caribbean breeding beaches at small spatial scales, but philopatry for both males and females at larger spatial scales (Fitzsimmons et al. 1997).

Speed of Travel and Movements

Adult green turtles are relatively sedentary. However migrations from feeding to nesting areas often exceed 100km (Wyneken 1997), and in some populations 2,000km (Lutz and Musick 1997). They can cover 23km/day and have been measured at 1.4-2.2 km/hr (Wyneken 1997). Satellite tagged green turtles swam 38-89km/day (Papi et al. 1995). Green turtles are the only marine turtle known to leave the water to bask, however, this only occurs in isolated island populations (Lutz and Musick 1997)

Vocal Behavior

No data.

Hearing Range

Maximum sensitivity was measured at 300-400 Hz (Ridgway et al. 1969).

Known Impacts of Human Activity

Green turtles and their eggs are highly valued as food throughout most of their range. Extreme over-harvesting of green turtles combined with, entanglement in fishing gear, habitat destruction on nesting beaches, light pollution, and predation by feral animals (e.g. dogs, fox, pigs) have decimated a number of populations (Lutz and Musick 1997).

Pollution may also have an impact on green turtle populations (Lutz and Musick 1997), but experimental exposure to DDE did not alter sex ratios or hatchability of green turtle eggs (Podreka et al. 1998).

LOGGERHEAD TURTLE (*CARETTA CARETTA*).

Summary

Loggerhead turtles are a large, widespread, primarily benthic invertebrate feeding turtle. They nest primarily outside of the tropics, and in some population they have long cross-basin migrations between feeding and nesting areas. They are listed as Threatened under the U. S. Endangered Species Act and are protected by CITES. The primary threat to their populations is incidental capture by commercial trawlers. They dive to the bottom and spend most of their time in coastal waters. They can receive low frequency sound and may use it to orient towards breeding beaches. Experimental animals avoided areas of loud low frequency sound in captivity.

Protected Status

The loggerhead turtle (*Caretta caretta.*) are listed as a Threatened Species under the U. S. Endangered Species Act. Like other marine turtles it is protected under CITES Appendix I. Thus, trade in loggerhead turtle products, or live turtles, is prohibited between signatory countries.

Distribution

The loggerhead turtle occurs in the tropical and subtropical waters of the Atlantic, Pacific, and Indian Oceans (Lutz and Musick 1997). It strays into temperate waters, especially in warm years (Lutz and Musick 1997). There are no clearly defined subspecies or races of the loggerhead turtle (Lutz and Musick 1997).

Loggerhead turtles appear to prefer shallow coastal waters (Nelson 1988) and will enter bays, lagoons, marshes and even the mouths of large rivers (Lutz and Musick 1997). However, they are found as far out to sea as 240km (Lutz and Musick 1997).

Abundance

Estimated population size for the southeastern USA is 14,150 females (Ehrhart 1989), and perhaps 40,000 worldwide (NMFS/USFWS 1991).

Diet and Foraging Behavior

Loggerhead turtles eat a wide variety of prey items including invertebrates from eight phyla (Dodd 1988). However, adult and subadult turtles specialize on benthic invertebrates including crabs and other crustaceans, horseshoe crabs, mollusks, (NMFS/USFWS 1991; Bjorndal 1997). Juveniles eat pelagic plankton such as crustaceans, isopods, salps, coelenterates, and some algae but switch to benthic feeding when their carapace length is about 40-80cm (Carr and Meylan 1980; Bjorndal 1997).

Diving Behavior

The maximum recorded dive is 233m and they regularly dive from 9-22m (Lutz and Musick 1997). Average dive duration was 17-30min., and they spend 80-94% of their time submerged (Lutz and Musick 1997).

Social Behavior

Little is known about the social behavior of loggerhead turtles at sea. Most indications are that they are relatively solitary except when aggregating on food concentrations or near nesting beaches. Schooling aggregations of loggerheads have been reported (Dodd 1988). In captivity some individuals can be very aggressive, but this is difficult to extrapolate to the wild (Lutz and Musick 1997). As in other sea turtles, copulation can last for several hours (Lutz and Musick 1997) suggesting post sperm transfer mate guarding by males.

Reproduction and Population Parameters

Estimated age at maturity is 12-30 years at a size of 65-87cm. carapace length (Frazer and Ehrhart 1985). Females breed at intervals of 1-7 years with an average of 2.5 years (NMFS/USFWS 1991). They lay several clutches (range 1-7) each season at intervals of 9-28 days. Clutch size is generally 110-130 (Lutz and Musick 1997).

Breeding Areas

The loggerhead is the only marine turtle whose primary nesting sites are north and south of the tropics. Nests are primarily excavated on continental beaches seaward from the dune front or, secondarily on island beaches (Lutz and Musick 1997). About 88% of all nesting occurs on beaches in the southeastern USA, Oman, and Australia (NMFS/USFWS 1991).

Speed of Travel and Movements

Swimming speeds based on mark recapture data average 28 – 40 km/day (Wyneken 1997). But some individuals traveled as fast as 45km/day or even 70km/day (Bolten et al. 1992; Lutz and Musick 1997). Satellite tagged loggerhead turtles swam at an average speed of 0.45km/hr with a range of 0.02 – 3.01km/hr (Tucker et al. 1996). Loggerhead turtles can make cross-ocean migrations between feeding and nesting areas. For example, mark recapture and genetic studies show that individuals move between Western Mexico and Eastern Japan for nesting and feeding (Lutz and Musick 1997; Reséndiz et al. 1998).

Vocal Behavior

No data

Hearing Range

Anatomical studies and stimulation of the skull of a captive loggerhead with sound demonstrate that loggerhead turtles are capable of receiving low frequency sound using their skull and shell and receiving surfaces (Lenhardt et al. 1983, 1985). This may aid in the location of nesting beaches.

Sub adult loggerhead turtles avoided passing through a sound barrier created by an array of air guns with a broad band spectrum of 20-1,000 Hz (O’Hara and Wilcox 1990).

Known Impacts of Human Activity

Loggerhead turtles are not widely taken for food, although eggs are gathered in some regions, thus hunting and egging do not have a significant impact on loggerhead populations (Pritchard 1997). The major threats to loggerhead turtle populations are incidental capture in fishing gear (primarily shrimp and other types of trawlers) and to a lesser extent habitat destruction (NMFS/USFWS 1991; Pritchard 1997). Populations off Australia and the southeastern USA appear to be declining due to incidental fisheries capture, while other populations, without significant incidental capture, appear to be increasing (Pritchard 1997)

Introduced vegetation on nesting beaches can cause excessive shading, or impenetrable root masses thus making successful nesting impossible (NMFS/USFWS 1991). Introduced predators such as pigs, fox, and fire ants are also known to prey on nests (Nelson 1988; NMFS/USFWS 1991).

Underwater explosions associated with the removal of old oil exploration platforms are known to have killed and (in experimental settings) injured loggerhead turtles (Klima et al. 1988). Entrapment in coastal power plants is also significant in some area (NMFS/USFWS 1991).

HAWKSBILL TURTLE (*ERETMOCHELYS IMBRICATA*).

Summary

Hawksbill turtles are tropical, primarily near-shore reef dwelling turtles that feed primarily on benthic sponges as adults. They nest in a number of scattered tropical locations, primarily under coastal vegetation, but there are very few sites where a number of females concentrate for breeding. They show high levels of nesting location site fidelity, but individuals from numerous populations mix on the foraging grounds. Some adults make long migrations between feeding and nesting areas, but juveniles are relatively sedentary on shallow reefs. They are listed as Endangeree under the U. S. Endangered Species Act and are protected by CITES. They have, and continue to be, heavily harvested for their shells which are made into a number of products. Some are also incidentally captured in commercial fishing gear.

Protected Status

The hawksbill turtle (*Eretmochelys imbricata.*) is listed as a Endangered Species under the U. S. Endangered Species Act. Like other marine turtles it is protected under CITES Appendix I. Thus, trade in loggerhead turtle products, or live turtles, is prohibited between signatory countries.

Distribution

Hawksbill turtles are found world wide in tropical waters. Like many other sea turtles, hatchlings are pelagic, but older juveniles (15-25cm SCL) and adults live in clear shallow water over reefs (Witzell 1983). Adults tend to be in waters over 20m, but juveniles are often found in very shallow water (Witzell 1993).

Abundance

Hawksbill turtle population sizes are difficult to estimate because females breeding an a wide variety of beaches, most of which are relatively isolated.

Diet and Foraging Behavior

Hatchling Hawksbill turtles appear to feed primarily on sargassum algae (Pritchard and Trebau 1984). As they grow and move out of pelagic waters and onto the near shore reefs, there appears to be a period of generalized omnivorous feeding on benthic invertebrates (Bjorndal 1997). As adults hawksbill turtles specialize on sponges (Meylen 1988; Bjorndal 1997). Other items found in their stomachs appear to be ingested incidentally during feeding on sponges.

Diving Behavior

Average dive duration for immature hawksbill turtles was 19-26min. during daylight foraging dives, and 7-10min. during night time resting dives (Van Dam and Diez 1997). The duration of daylight foraging dives increased with turtle size. These were all dives in shallow water only 7-10m deep. During they day they spent 92% of time underwater, and during the night 86% of time underwater (Van Dam and Diez 1997). Data from observations of an adult during the day indicate that they routinely dive for 56min; the longest routine dives reported (Lutz and Musick 1997).

Social Behavior

Little is known about the social behavior of hawksbill turtles at sea. Most indications are that they are relatively solitary. As in other sea turtles, copulation can last for several hours (Lutz and Musick 1997) suggesting post sperm transfer mate guarding by males.

Reproduction and Population Parameters

Estimated age at maturity is greater than 31 years, at a size of 65-87cm. carapace length (Frazer and Ehrhart 1985). Females breed at intervals of 2.9 years on average (Miller 1997). They lay several clutches each season at intervals of 11-28 days. Clutch size averages 130 eggs (Miller 1997).

Breeding Areas

Hawksbill turtles nest almost exclusively on vegetated areas adjacent to beaches or to the water's edge (Miller 1997). They are generally a dispersed nester on tropical islands and sparsely inhabited tropcial continental shores around the world. However, small nesting concentrations do exist in some locations. Nesting habitat varies from high energy ocean beaches to tiny pocket beaches only a few meters wide.

Speed of Travel and Movements

Swimming speeds are estimated at 17.8km/day (Wyneken 1997). Adult female hawksbill turtles moved between Australia and Vanuatu, Solomon Islands, Papua New Guinea, and Indonesia; moving 368-2,425kmbetween foraging areas and breeding beaches (Miller et al. 1998). Immature hawksbill turtles, in contrast, were resident to small areas of offshore reefs near Puerto Rico (Van Dam and Diez 1998). Reproductive stocks appear to be genetically isolated over ecological time scales do to relatively strict natal philopatry for nesting females (Bass et al. 1996). However, individuals from a number of breeding populations mix on the feeding grounds (Bowen et al. 1996).

Vocal Behavior

No data.

Hearing Range

No data.

Known Impacts of Human Activity

Hawksbill turtles are the subject of intense national and international trade both in shell products (called beko in Japan) and in stuffed live mounts (Pritchard 1997). This trade has decreased in recent years, due to increased enforcement. This large trade, when compared to the number of known nesting beaches, has led to widespread concern that the species is endangered.

In addition to capture for their shells, hawksbill turtles are capture incidentally in net fisheries (Heppell and Crowder 1996; Poiner and Harris 1996). For example, in the

Australian prawn trawl fishery, capture of hawksbill turtles was estimated as 0.002 individuals per trawl. (Poiner and Harris 1996).

OLIVE RIDLEY TURTLE (*LEPIDOCHELYS OLIVACEA*).

Summary

The olive ridley is the most abundant sea turtle. It is found throughout the tropics, but is most concentrated around several very concentrated nesting beaches in Costa Rica, Mexico, and India. The global population is listed as Threatened under the Endangered Species Act, but the Mexico Pacific population is listed as endangered. They are omnivorous, feeding on a wide variety of animals and algae from diverse marine habitats. They nest in huge concentration on a few beaches which are generally protected. Their main threat is incidental mortality in commercial fishing gear.

Protected Status

The olive ridley turtle (*Lepidochelys olivacea.*) is listed as a Threatened Species under the U. S. Endangered Species Act; however, the Mexican population is listed as Endangered. The global population has declined since listing and may be re-classified as Endangered (NMFS web site). Like other marine turtles it is protected under CITES Appendix I. Thus, trade in olive ridley turtle products, or live turtles, is prohibited between signatory countries.

Distribution

Olive ridley turtles are found world wide in tropical waters. Like many other sea turtles, hatchlings are thought to pelagic (Lutz and Musick 1997). Even adults can be pelagic feeders during the non-breeding season, although they are generally more coastal (Lutz and Musick 1997). Immature olive ridley turtles use both habitats depending on food availability.

Abundance

The olive ridley is the most abundant sea turtle in the world (Pitman 1993; Pritchard 1997).

Diet and Foraging Behavior

Adult olive ridleys use a wide variety of foraging habitats including deep water soft bottom benthic, pelagic, and shallow waters (Bjorndal 1997). Their diet includes salps, fish, molluscs, crustaceans, algae, bryozoans, fish eggs, spiunculids, jelly fish and ascidians (Bjorndal 1997). Thus they feed on a wide variety of prey in different habitats.

Diving Behavior

The maximum recorded dive for an olive ridley turtle is 290m, they regularly dive for 29-54min. (Lutz and Musick 1997).

Social Behavior

Little is known about the social behavior of olive ridley turtles at sea. Most indications are that they are relatively solitary. As in other sea turtles, copulation can last for several hours (Lutz and Musick 1997) suggesting post sperm transfer mate guarding by males.

They form huge aggregations on breeding beaches with considerable competition for nest sites.

Reproduction and Population Parameters

Females nest about 110 eggs twice a year. The interval between nesting within a year is longer than for any other sea turtle (17-30 days), and they nest every 1-2 years (Miller 1997).

Breeding Areas

Olive ridley turtles are known for huge breeding aggregations on a few beaches- two in Pacific Costa Rica, on in Pacific Mexico, and several in Orissa State, northeastern India (Pritchard 1997).

Speed of Travel and Movements

Mark recapture studies estimate migratory speeds at 28-87km/day (Wyneken 1997). The higher swimming speed almost certainly includes considerable assistance by currents.

Vocal Behavior

No data.

Hearing Range

No data.

Known Impacts of Human Activity

The large concentrated nesting aggregations of olive ridley turtles are relatively easy to protect, and in many cases collection of eggs is limited. In fact, most egg loss is due to nests being dug up by subsequent nesting females (Pritchard 1997). The primary source of mortality for olive ridley turtles appears to be incidental capture in fishing gear, especially in fishing gear off of breeding beaches. In Australia’s northern prawn fishery 0.001 olive ridley turtles were captured per 180 min trawl (Poiner and Harris 1996). In Orissa State, India, where there are three important olive ridley nesting beaches, 5,282 dead olive ridley were recorded during 6 months of survey along a 480km stretch of coastline. Most deaths were due to incidental capture in commercial fishing nets (Pandav et al. 1997).

KEMP'S RIDLEY TURTLE (*LEPIDOCHELYS KEMPI*).

Summary

The olive ridley is the rarest and most endangered sea turtle.

Protected Status

The Kemp's ridley turtle (*Lepidochelys kempi*) is listed as an Endangered Species under the U. S. Endangered Species Act. It is the rarest and most endangered marine turtle. Like other marine turtles it is protected under CITES Appendix I. Thus, trade in olive ridley turtle products, or live turtles, is prohibited between signatory countries.

Distribution

Kemp's ridley turtles are found primarily in the Gulf of Mexico and to a lesser extent along the Atlantic coast of the United States as far north as Long Island. Juveniles drift north into the Atlantic in the Gulf current, but adults appear to be almost exclusively found in the Gulf of Mexico (Lutz and Musick 1997).

Abundance

The Kemp's ridley is the most rare and endangered sea turtle in the world (Pritchard 1997).

Diet and Foraging Behavior

During the early pelagic stage Kemp's ridley turtles feed at the surface until they reach about 20cm SCL. They then move to shallow waters less than about 50m depth where they become benthic foragers (Bjorndal 1997). Juvenile and adult Kemp's ridley turtles feed primarily on crabs (Bjorndal 1997; Burke et al. 1997).

Diving Behavior

Kemp's ridley turtles regularly dive for to less than 50m for 13-18 min. the maximum dive time recorded was 300min. (Lutz and Musick 1997). Tagged individuals spent 94-95% of their time submerged (Gitschlag 1996).

Social Behavior

There are persistent reports of large concentrations of mating adults at sea, suggesting breeding aggregations well offshore of the breeding beaches (NRC 1990).

Reproduction and Population Parameters

Kemp's ridley females breed every year (Rostal et al. 1988). They reach sexual maturity at 8-19 years (8-13 years- Schmid and Witzell 1997; 13-19 years- Zug et al. 1997). Females nest about 110 eggs twice a year. The interval between nesting within a year is longer than for any other sea turtle (17-30 days), and they nest every 1-2 years (Miller 1997).

Breeding Areas

Kemp’s ridley turtles nest primarily at Rancho Nuevo Mexico in the Gulf of Mexico (NRC 1990; Pritchard 1997). Only rarely has significant nesting been observed at any other beaches.

Speed of Travel and Movements

Mark recapture studies estimate migratory speeds at 24-29 km/day (Wyneken 1997).

Vocal Behavior

No data.

Hearing Range

No data.

Known Impacts of Human Activity

Development near the primary breeding beach and incidental capture in shrimp trawling nets are the two primary threats to the Kemp’s ridley turtle. Additional significant threats include marine pollution, poaching of eggs, and intentional capture for human consumption (NRC 1990).

SEABIRDS

Summary

There are more than 270 species of seabirds in five orders: Sphenisciformes (penguins); Podicipediformes (loons and greebes); Procellariformes (shearwaters, albatrosses and petrels); Pelecaniformes (pelicans, boobies, cormorants, and frigatebirds); and, Charadriiformes (gulls, terns, puffins and auklets). They are can be important top level marine predators and have tremendous impacts on the ecology of their nesting islands. Seabirds are almost exclusively socially monogamous and nest on islands, offshore rocks, isolated areas of the mainland or other predator free sites where they can form huge colonies. Relative to terrestrial birds they tend to have low reproductive potentials; many species only laying one egg per year. The main threat to seabird populations is introduced mammalian predators on breeding islands. Hunting and egging have been problems in the past and continue to threaten seabirds in some areas. Fisheries interactions (competition and entanglement) and pollution have also had dramatic impacts on seabird populations.

Each order has species that dive to more than 25m depth, and occur in the zone of LFA activities. There are few data on hearing in seabirds, and even less on underwater hearing. However, studies with other species have shown that birds are highly sensitive to low frequency sounds in air. Thus, it is likely that many diving seabirds can hear low frequency sound. However, seabirds which occur in areas where LFA may operate are generally shallow divers. In addition, seabirds spend a very small fraction of their time submerged, and they can rapidly disperse to other areas if disturbed. For these reasons, seabirds will be excluded from further evaluation.

Large numbers of seabirds concentrate on breeding colonies during the breeding season. In some cases close to 100% of breeding adults can be on just one or a few islands during the peak of the breeding season. These concentrations combined with their generally low potential reproductive rate make some seabird populations particularly susceptible to negative human impacts. Significant seabird colonies are often also important breeding areas for pinnipeds and sea turtles, and may also have concentrations of cetaceans in near-shore waters.

PINNIPEDS

Summary

The natural history of pinnipeds is summarized in Gentry (1998). In the United States, all marine mammals (common, threatened, and endangered) are protected under the Marine Mammal Protection Act (MMPA). In addition, some species are protected by the Endangered Species Act (ESA) and are internationally protected as CITES-designated species. Human activities which may influence marine mammal behavior or cause physiological damage is considered to constitute harassment, a violation of the MMPA and ESA.

Pinnipeds are globally distributed aquatic mammals with some specializations for terrestrial life. The suborder includes the true seals (family Phocidae), eared seals (family Otariidae), and the walrus (family Odobenidae). True seals and walruses swim with undulating motions of the rear flippers driven by back muscles, and move caterpillar-like on land. Otariids swim with their foreflippers and move on all fours on land. On average, pinnipeds are larger than other mammals (range 50-2,000kg). The otariids retain more extensive ties with land: otariids suckle and mate on land while phocids suckle on land but mate at sea.

The otariids include 14 extant species in 7 genera. Most otariids are found in temperate or sub-polar waters. Tropical species are generally located in regions of locally high productivity. Many otariids spend the majority of their time in coastal regions unlikely impacted by LFA operations. The general biology of extant otariids is presented in Table 1. Several species that are listed as special status are discussed in more detail (northern sea lion (*Eumetopias jubata*), northern fur seal (*Calorhinus ursinus*), Guadalupe fur seal *Arctocephalus townsendii*)).

The phocids include 17 extant species in 10 genera. Most phocids are confined to Arctic and Antarctic waters and so would not be impacted by LFA operations. Eight species occur in non polar waters and are discussed below. They are the Hawaiian and Mediterranean monk seals (*Monochas monachus* and *M. shauinslandi*), the northern and southern elephant seals (*Mirounga angustirostris* and *M. leonina*), the grey seal (*Halichoerus grypus*), and three species in the genus *Phoca*: the ribbon, harbor, and spotted seals (*P. fasciata, P. vitulina,* and *P. largha*).

All pinnipeds produce single, precocious young on land and males play no role in raising offspring. While otariid females feed during lactation (making regular trips to sea to forage), phocid females generally fast while suckling. Because of this strategy, otariids can only rear young in limited sites near extremely productive marine areas. Due to the limited number of such sites, a situation arises where males can monopolize mates by defending the few pupping sites. This leads to the polygynous breeding system found in most pinnipeds. Generally, the restriction for otariids in finding productive offshore foraging areas adjacent to pupping sites leads to more extreme polygyny in otariids than phocids. Most pinnipeds gather to bear young and breed once a year. This is facilitated by delayed implantation.

Pinnipeds are generally high-level consumers taking fish, cephalopods and crustaceans. Phocids are often benthic feeders; fur seals tend to feed on small surface-schooling fish; sea lions tend to specialize on large or adult stages of higher-trophic-level species found over continental shelves. While a few species (e.g. monk seals, Galapagos fur seals, Galapagos sea lion) are found at low latitudes in tropical or sub-tropical waters, most species are found in temperate or polar waters. Foraging regions are often associated with fronts or upwelling zones.

Pinniped visual systems are adapted to low light levels, consistent with feeding at depth or at night. However, the eye structure also allows for visual acuity in air. The ears of otariids are similar to carnivore ears while phocid ears are more water-adapted. Individuals of both groups produce aerial sounds, and many also produce underwater sounds. Airborne vocalizations have been associated with territoriality and dominance displays, and mother-pup recognition. The context and function of subsurface vocalizations is not clear. Many appear to be socially important as they are often produced during the breeding season (e.g. harbor seals). Thus, many species must be able to hear well both above and below the water. Sensitivity to sounds at frequencies above 1 kHz has been well established. Fewer studies have examined sensitivity to LFS. However, several generalizations may be made: 1) the dominant frequencies in the vocalizations of walruses and hooded seals are below 1000 Hz (Schevill et al. 1966; Terhune and Ronald 1973; Ray and Watkins 1975). 2) Audiograms for ringed, harbor, and harp seals demonstrate hearing to at least as low as 760 Hz, the hearing threshold is flat from 1-50 kHz between 65 and 85 dB re 1 µPa (Møhl 1968; Terhune and Ronald 1972, 1975; Terhune 1991). In a recent study, Kastak (1996) found that in pinniped species (California sea lion, harbor seal, elephant seal) hearing sensitivity is decreased at frequencies below 6400 Hz in sea lions and harbor seals, but the animals are still able to hear low frequency sounds below 100 Hz. While Elephant seals have not been recorded to produce underwater LFS (LeBoeuf pers. comm.), they were found to be the most sensitive to underwater LFS (Kastak 1996). The mean frequencies of airborne calls of northern elephant seals range from 147-334 Hz for adult males (LeBoeuf and Peterson 1969; LeBoeuf and Petrinovich 1974) and 500-1000 Hz for adult females (Bartholomew and Collias 1962). Because elephant seal hearing sensitivity has been shown to be greater underwater (Kastak 1996), it is logical to infer this species to be most sensitive to human-produced LFS.

All of the phocid species discussed below occur in pelagic waters, dive for their food, and breed on land or pack ice. The monk seals are rare and protected as endangered species. The Mediterranean monk seal is the most endangered of all pinnipeds; it is on the verge of extinction due to competition with commercial fisheries, habitat destruction, pollution, human disturbance, and harassment by fishermen. The other six species have large, in some cases expanding, populations. All eight species of true seals discussed here are likely capable of producing and hearing low frequency sound. There is no strong evidence that loud low frequency sound causes seals to avoid particular areas or alter their behavior. Loud, low frequency noise around breeding colonies could interfere with social signals including contact calls between mothers and pups, however, most aquatic social signals are above 1kHz

OTARIDAE (SEA LIONS AND FUR SEALS)

NORTHERN SEA LION (*EUMETOPIAS JUBATA*)

Summary

The northern sea lion is widely distributed throughout the north Pacific. It is the largest of the sea lions, and feeds upon a wide variety of fish and cephalopods. Populations have dramatically declined in recent years, and it is speculated that this is due in part to declines in prey species in the northern portion of its range due to competition with commercial fisheries.

Protected Status

Northern sea lions *(Eumetopias jubata)* are federally protected under the U. S. Marine Mammal Protection Act, listed as threatened under the U. S. Endangered Species Act, and listed as an IUCN endangered species.

Distribution

Northern sea lions are present in both the eastern and western Pacific from Hokkaido in the west to southern California in the eastern Pacific. The center of abundance is in the Aleutian Islands region, but breeding colonies exist on islands in the sea of Okhtosk, the east coast of the Kamchatka Peninsula, Aleutian Islands, Gulf of Alaska, southern Alaska coast, British Columbia, and central California. The northernmost breeding rookery is the Pribilof Islands. They formerly bred as far south as southern California (King 1983).

The non-breeding distribution of northern sea lions is not clear. In colonies off central and southern California it appears that males disperse north while females and young are present throughout the year (Orr and Poulter 1967). Females routinely make 6-week foraging trips to location 550km south of their haulout sites (Merrick et al. unpubl. rep. in Reeves et al. 1992).

Abundance

Trites and Larkin (1996) estimate the northern sea lion population between the mid 1950’s through the mid 1970’s rose from 250,000 to 282,000. Since that time, the population has decreased by over 70% (about 5% per year) to about 76,000 animals. Most of the decline has taken place in the Aleutian Islands and Kodiak reagion. However, since 1989, the decline appears to have slowed within some regions.

The reasons for population decline are not clear, but it has been suggested that declines are due to reduced availability of preferred prey due to competition with commercial fisheries (Merrick et al. 1994), and disease from the pathogen *Leptospira pomona* (Braham et al. 1980a). York (1994) examined Leslie matrix models which were consistent with field observations and accounted for the decline and suggested that the decrease was likely due to a 10-20% decline in the survival of juveniles rather than changes in adult mortality.

Diet and Foraging Behavior

Merrick et al. (1997) examined the diet of northern sea lions from the Aleutians and Gulf of Alaska and found that walleye pollock and Atka mackerel dominated the diet. The remainder of the prey consisted of small schooling fish (e.g. herring and salmon). They also found that population declines were positively correlated to decreases in diet diversity.

In central California, Hood and Ono (1997) found that foraging trip duration of breeding females increased in 1992 compared to measurements made in 1973, and pups spent less time suckling. They speculated that these observations are consistent with offshore prey availability. Hobson (1966) speculated that vision was important in foraging.

Diving Behavior

Detailed diving behavior of northern sea lions has not been published. Kenyon (1952) reported northern sea lions hooked on fishing lines at depth of 183m. Merrick et al. (1994) describe the use of satellite-linked time depth recorders to measure dive duration and depth. Although unpublished, NMFS notes (cited in Reeves et al. 1992) that northern sea lions generally feed in the water column at shallow depths. Maximum-recorded dive depth is 277m.

Social Behavior

Northern sea lions are gregarious on land, and may be found foraging in groups at sea. They often form rafts of several hundred individuals offshore, adjacent to haulouts (King 1983). They exhibit a typical otariid polygynous breeding behavior (Riedman 1990).

Reproduction and Population Parameters

Males arrive at colonies in May, females arrive and pup in May-June. Males are sexually mature at 3-8 years, and physically mature at 10-11 years. Females sexually mature at 2-8 years, average age of first pregnancy 4.9 years (Reeves et al. 1992), and pup each year after. Gestation is 11 months. Pups are generally weaned by the end of their first year (Reeves et al. 1992).

Breeding Areas

See above

Speed of Travel and Movements

Speed of travel and movement patterns have not been published for northern sea lions.

Vocal Behavior

The aerial sounds of northern sea lions have been described (e.g. Sandegren 1970) as “roars”, “rattling” sounds like a “distant two-stroke motor bike”, and “bleats”(Sandegren 1970; Gentry 1970). Underwater vocalizations of captive animals are described by Schusterman et al. (1970) and Poulter and DelCarlo (1971). The function of underwater signals is not clear.

Hearing Range

The hearing range of northern sea lions has not been published.

Known Impacts of Human Activity

Northern sea lions were previously hunted by Aleutian natives. Currently all available data demonstrate that the indirect effects of human overfishing of pollock caused the decline of northern sea lion populations (e.g. Merrick et al. 1997).

GUADALUPE FUR SEAL (*ARCTOCEPHALUS TOWNSENDI*)

Summary

Guadalupe fur seals were once believed extinct from overharvest in the 18th and 19th centuries. Since a remnant population was discovered on Guadalupe Island, Mexico, the species has recovered to over 7,400 individuals in 1993. Currently the species only breeds on Guadalupe Island. Guadalupe fur seals appear to be nocturnal feeders upon squid and myctophids in the California Current south of Guadalupe Island. They are shallow divers, foraging within the upper 30m of the water column. Nothing is known of their vocal behavior or sensitivity to human-produced LFS.

Protected Status

Guadalupe fur seals (*Arctocephalus townsendi*) are federally protected under the U. S. Marine Mammal Protection Act, listed as threatened under the U. S. Endangered Species Act, and listed as an IUCN vulnerable species.

Distribution

Guadalupe fur seals are known only from a small part of the eastern coast of Guadalupe Island, Mexico. A few individuals range to the north to the Sonoma County, California and south to Los Islotes Island, Baja California Sur. Historically they ranged from central California to the Revilla Gigedos Islands, Baja California Sur, Mexico.

Abundance

Pre-exploitation size of the Guadalupe fur seal population is estimated at 30,000 (Hamilton 1951) to 100,000 (Hubbs 1956). Towards the end of the 18th and early 19th centuries the Guadalupe fur seal was intensively harvested. By 1897 the Guadulpe fur seal was believed extinct, until a small population was found on Guadalupe Island in 1926. By 1993 the population had reached over 7,408 individuals. From 1955 to 1993 the intrinsic growth rate was 13.7% (Gallo-Reynoso 1994).

Diet and Foraging Behavior

The diet of Guadalupe fur seals is thought to consist primarily of squid and myctophids (Reeves et al. 1992).

Diving Behavior

Gallo-Reynoso (1994) studied the foraging behavior of lactating Guadalupe fur seals. Mean dive depth of lactating females was 16.9 m, modal dive depth was 3.1 m. Mean and modal dive duration were 2.6 min and 3.6 min, respectively. Mean surface interval between dives was 2 min. Dives were organized as bouts of 3-2.5 hr with a mean of 62 dives/bout. Foraging occurred during the night, and transiting during the day, with a maximum of 168 dives/day. Generally, diving started around 2030 and ended around 0530.

Social Behavior

Gallo-Reynoso (1994) and Pierson (1987) review the social behavior of Guadalupe fur seals. They have a typical otariid polygynous breeding, and the sexes are strongly sexually dimorphic. The operational sex ratio varies from 1:12.7 to 1:3.5, with roughly 33% of males holding territories in sequential years. While on shore animals may aggregate in shady areas, caves, or the water in order to avoid high temperatures.

Reproduction and Population Parameters

Females give birth to single pups in June, and pups are nursed through the following spring (Reeves et al. 1992). It appears that males and females are faithful to the same breeding site from year to year (Reeves et al. 1992). Nothing is known about age at sexual maturity or longevity.

Breeding Areas

Presently Guadalupe fur seals are known to breed only on Guadalupe Island, Mexico. Their historical range is thought to have included central California to the Revillagigedos Islands south of Baja California Sur, Mexico (Gallo-Reynoso 1994).

Speed of Travel and Movements

The population returns to breed on Guadalupe Island during the summer to breed and again in the fall-winter to molt (Gallo-Reynoso 1994). Lactating females were tracked to foraging areas in the California Current South of Guadalupe Island, with a maximum distance from the island of 444 km (Gallo-Reynoso 1994). Mean swimming velocity to foraging areas was 1.97 m/s (range 1.8-2.0).

Vocal Behavior

Aerial sounds of Guadalupe fur seals have been described as barks, roars, and a cough – similar to the sounds produced by *Arctocephalus gazella* (Peterson et al. 1968).

Hearing Range

Nothing is known of the hearing range of Guadalupe fur seals.

Known Impacts of Human Activity

Beyond the devastating effects of direct harvest in the 18th and 19th centuries, no other impacts of human activity have been described. However, Gallo-Reynoso (1994) speculated that populations could be impacted by the introduction of domestic animal disease (e.g. brucellosis) from goats introduced to Guadalupe Island.

NORTHERN FUR SEAL (*CALLORHINUS URSINUS*)

Summary

Northern fur seals have been commercially exploited for over 250 years. In spite of the cessation of commercial harvest, populations continued to decline between 1976 and 1983, perhaps as a result of competition with commercial pollock fisheries. Thus, they are listed as a depleted stock under the MMPA and and IUCN vulnerable species. Since 1984 populations have remained relatively stable. Northern fur seals are generally found associated with the continental shelf break in the north Pacific between Japan and southern California. They feed upon a wide array of prey species, foraging primarily in the upper 100m of the water column. Low frequency sound sensitivity appears to range down to 500 Hz, with best hearing around 5 kHz. No direct or indirect impacts of human-produced low-frequency sound have been documented.

Protected Status

Northern fur seals (*Callorhinus ursinus*) are federally protected as a depleted stock under the U. S. Marine Mammal Protection Act, and listed as an IUCN vulnerable species.

Distribution

Generally the species' distribution is bounded east and west by the continental shelf breaks, south by the transition between subtropic and subarctic waters, and north near 60°N latitude (Gentry 1998). The primary rookeries are on the Pribilof Islands (St. Paul and St. George) in the eastern Bering Sea and on the Commander Islands in the western Bering Sea. Small colonies are also found on Robben Island (Sea of Okhotsk), Kuril Islands, Bogoslof Island (eastern Aleutians), and San Miguel Islands (Channel Islands). Females and pups leave the Bering Sea by late November and migrate as far south as southern California (eastern Pacific) and Japan (western Pacific), remaining offshore along the continental slope until March when they return to the rookeries, following the continental margins (Reeves et al. 1992; Gentry 1998). This gives fur seals access to seasonally predictable prey resources (Gentry 1998). Some juveniles and non-breeding femailes may not return north, remaining in the Pacific to feed in the transition between the Oyashio and Kuroshio currents (Wada 1971). Little is known about the distribution of adult males during the nonbreeding season, but it is believed that they leave the rookeries in late August through early October and overwinter near the Aleutians (Reeves et al. 1992).

Abundance

Northern fur seals are the most abundant and widespread otariid in the Northern Hemisphere. They were intensively exploited during the late 18th through the 19th centuries when the Pribilof population dropped to fewer than 300,000 individuals. This reduction prompted international treaties for the sustainable harvest of fur seals, leading to a recovery (initially at a rate of 8% per year) to approximately 2.1 million indivduals on the Pribilofs by the late 1950's (Reeves et al. 1992; Gentry 1998). Since that time the population declined between the 1950's through the 1960's, increased between 1970 and 1976, and again decreased between 1976 through 1983. Overall the population decreased approximately 57% to 1.25 million between late 1950 and 1984. Since 1984 the population has remained relatively constant (York 1990). The decline between the 50's and 80's is largely blamed on a female harvest (York and Hartley 1981; Trites and York 1993; Gentry 1998). However, there is some evidence that the decline may at least in part be due to environmental changes, perhaps due to overfishing of pollock (Gentry 1998).

Diet and Foraging Behavior

Northern fur seals are top-level consumers with a diverse diet that includes about 75 species of fish, cephalopod, and crustacean (Wada 1971; Kajimura 1984; Perez and Bigg 1986; Sinclair et al. 1994; review by Gentry 1998). Diet differs by season and geographic area (Antonelis et al. 1993; review by Gentry 1998). Myctophid fish and squid are the main dietary items in the broad oceanic areas at the southern end of their range. In coastal areas their diet is more diverse. During the breeding season, the distribution at sea, diving behavior and movements of radio-tagged females suggest that females feed over deep water as the deep-scattering layer rises to the surface (Kenyon and Wilke 1953; Gentry et al. 1986; Goebel et al. 1991). Tracking studies indicate some foraging site fidelity (Goebel et al. 1991; Loughlin et al. 1993). Kajimura (1984) described regional differences in prey: fur seals feeding in the Bering Sea beyond the continental shelf fed on vertically-migrating oceanic squid (Gonatidae) and deep sea smelt (Bathylagidae); animals foraging in the Bering Sea over the continental shelf feed on walleye pollock, Pacific herring, and capelin. Fur seals feeding off southern California feed primarily upon squid (*Loligo opalascens*) and anchovy.

Diving Behavior

Diving records of lactating females indicate that most animals feed in the upper 100m of the water column. Night and day dive depths of females have been recorded to 75-200m (Gentry et al. 1986; Goebel et al. 1991). Maximum recorded dive depths of breeding females are 207m and 230m in the Bering Sea and southern California, respectively, and average dive durations are 2.6 minutes (Reeves et al. 1992). Mean dive depth of lactating females in the Bering Sea ranged from 34-170m, at a dive rate of 1.03-4.88 dives/hour (Goebel 1998). The diving patterns of breeding females have been categorized as shallow nighttime dives less than 30 m, deep dives both day and night in excess of 75m, , and a mixed dive pattern alternating between shallow and deep dives (review by Goebel 1998). Goebel (1998) found that the diving effort of breeding females increases between early and late lactation, and dive pattern shifted from a mixed to deep pattern. Nothing is known of the winter diving behavior. Deep dives are typically followed by surface intervals of 20 minutes, and shallow dives followed by surface intervals of less than 0.5 min (Pierson and Vladimirov 1998).

Social Behavior

Individuals have no group behavior, form no social bonds (except mother/young), join no coalitions, and form no social hierarchies beyond male territorial hierarchy determined by size. Northern fur seals exhibit a typical otariid polygynous breeding behavior (Riedman

1990), and the sexes are strongly sexually dimorphic. Annual arrival at colonies and breeding events are closely timed around the same date each year (Gentry 1998). Males and females are philopatric, females pupping near their natal site. Males defend beach territories where females come to pup, giving rise to a resource defense polygynous breeding system (Emlen and Oring 1977). Non-breeding juvenile males often aggregate on adjacent landing areas near the rookery (Gentry 1998). Males do not assist in pup rearing. Young are precocial and females leave pups on shore while alternating between feeding themselves at sea and feeding the pups on land (Gentry 1998). Fur seals are usually solitary at sea, and during the non-breeding season are mostly nocturnal (Gentry 1998).

Reproduction and Population Parameters

Mating season occurs during the summer and is brief with arrival dates being synchronized and stable from one year to the next. Males arrive at colonies in May-June, females arrive and pup in July-early August. A postpartum estrous allows impregnation soon after parturition. Embryonic implantation is delayed until after lactation ends (Gentry 1998). Males are sexually mature at 4-5 years, and physically mature at 8-9 years. Females sexually mature at 4-5 years (Reeves et al. 1992), and pup each year after. Pups are generally weaned by the end of their first year (Reeves et al. 1992). Natural mortality of 2-3 year-olds is 10-20% per year; 32-38% for adult males; 10-11% for adult females. Maximum longevity for northern fur seals is about 26 years. Males rarely breed for more than one year (Reeves et al. 1992; Gentry 1998).

Breeding Areas

See above.

Speed of Travel and Movements

Post breeding animals head south-east from the Pribilofs through the Aleutian passes and south along the continental margin as far south as central/southern California (33°10’N) in the east and Japan (35°N) in the west (King 1983; Gentry 1998). Between January and April northern fur seals may be found anywhere along their migration rate from Sitka, Alaska to California. The spring movement north begins in April, and between June and October most northern fur seals are in the vicinity of their breeding colonies (King 1983). The San Miguel herd remains near the colony year-round (King 1983).

Vocal Behavior

Males vocalize almost continuously at the colony (Gentry 1998); vocalizations have been described as “trumpeted roars” (Peterson 1965, 1968). Females vocalize to their pups almost immediately after birth, with the pups responding within 4 minutes (Gentry 1998).

Hearing Range

The underwater hearing range of northern fur seals, estimated from audiograms, ranges from 500 Hz to 40 kHz. Underwater hearing threshold is 90-100 dB at 1 kHz; best underwater hearing occurs at 5 kHz with a threshold of 50-60 dB.

Known Impacts of Human Activity

Northern fur seals have been intensively exploited through direct harvest for over 250 years (Gentry 1998). Beyond the direct effects of harvesting, it is believed that the indirect effects of human overfishing of pollock have contributed to recent declines of northern fur seal populations (Gentry 1998).

Table 1. Diet, distribution, abundance, reproductive behavior, and natural history of Otariids.

Species	**Pelagic Distribution**	**Abundance**	**Diet**	**Special Geographic Regions**	**Breeding Distribution and Environment**	**Breeding Period**	**Potential Threats**
Arctocephalus australis South American fur seal	Unknown, but dependent upon coastal upwelling systems	69700	Fish (Sardine, Anchovy, Mackerel), Cephalopods, Crustaceans	Breeding Colonies	South American Islands: Peru to Uruguay	Oct-Dec	Not Identified
A forsteri New Zealand fur seal	Unknown, but animals present on rookery year round. Males move north after breeding	52500	Cephalopods and fish	Breeding Colonies	New Zealand Islands and Mainland, Australian Islands	Nov-Jan	Not Identified
A galapagoensis Galapagos fur seal	Unknown, but likely dependent upon nearshore upwelling	27000	Cephalopods, Fish (myctophids)	Breeding Colonies	Galapagos Islands	Aug-Nov	Not Identified
A philippii Juan Fernandez fur seal	Unknown, but at leat 500km offshore	6300	Myctophids, Cephalapods	Breeding Colonies	Juan Fernandez Islands	Nov-Jan	Restricted breeding distribution

Table 1. Diet, distribution, abundance, reproductive behavior, and natural history of Otariids (continued).

Species	**Pelagic Distribution**	**Abundance**	**Diet**	**Special Geographic Regions**	**Breeding Distribution and Environment**	**Breeding Period**	**Potential Threats**
A pusillus South African fur seal	Coastal resident	1100000 South Africa; 25000 Australia	Fish (pilchard, mackerel, snook, anchovy, hake), cephalopods, crustaceans	Breeding Colonies	SE Australia, Tasmania, South Africa, Namibia	Oct-Dec	Not Identified
A townsendi Guadalupe fur seal	Unknown, as far north as central California	3250	Fish, Cephalopods	Breeding Colonies	Guadalupe Island	Jun-Jul	Restricted breeding distribution
A tropicalis Subantarctic fur seal	Unknown, females may be resident year-round, males disperse widely to the north	2,000,000	Cephalopods, Nototheniid fish, krill	Breeding Colonies	Subantarctic Islands north of Antarctic Convergence	Nov-Jan	Not Identified
Callorhinus ursinus Northern fur seal	Bering Sea, to 35_N in W Pacific, to 33_N in E Pacific; 48-100km offshore	1320000	Fish (pollock), squid	Breeding Colonies; Aleutian passes during migration	Pribilof Islands, Commander Islands	Jun-Oct	Indirect fisheries impacts

Table 1. Diet, distribution, abundance, reproductive behavior, and natural history of Otariids (continued).

Species	**Pelagic Distribution**	**Abundance**	**Diet**	**Special Geographic Regions**	**Breeding Distribution and Environment**	**Breeding Period**	**Potential Threats**
Eumetopias jubata Northern sea lion	North Pacific, Shore to continental slope	7,600	Fish (pollock), squid	Breeding Colonies	North Pacific Islands: Hokkaido-central California	May-Jun	Indirect fisheries impacts, disease
Neophoca cinerea Australian sea lion	Shallow waters off Australia, non-migratory	5000	Benthic fish, squid	Breeding Colonies	Western and Southern Australian islands and mainland between 28_ and 36_ S	Asynchronous 18-month cycle	Net entanglement
Otaria byronia South American sea lion	Coastal resident; Near shore, Near surface	300,000	Fish (Anchovy), Crustaceans, Mollusks	Breeding Colonies	Uruguay around South America to Peru	Dec-Jan	Commercial harvest
Phocarctos hookeri Hooker sea lion	Offshore to 600km	6000	Fish (flatfish), Cephalopods, Crustaceans, Bivalve	Breeding Colonies	New Zealand, Aukland Islands	Dec-Jan	Introduced species; Fishing mortality

Table 1. Diet, distribution, abundance, reproductive behavior, and natural history of Otariids (continued).

Species	**Pelagic Distribution**	**Abundance**	**Diet**	**Special Geographic Regions**	**Breeding Distribution and Environment**	**Breeding Period**	**Potential Threats**
Zalophus californianus California sea lion	Males migrate north near shore; Females disperse near shore	160000	Fish (anchovy, whiting, rockfish), Cephalopods	Breeding Colonies	Islands/remote mainland southern California to Mexico; Galapagos	May-Jun; May-Jan (Galapagos)	Commercial fisheries conflicts

References: King (1983); Ridgway and Harrison (1981); Riedman (1990); Reeves et al. (1992); Gentry (1998).

PHOCIDAE (TRUE SEALS)

MEDITERRANEAN AND HAWAIIAN MONK SEALS (*MONACHUS MONACHUS AND M. SCHAUINSLANDI*)

Summary

The two surviving monk seals are very rare and the Mediterranean monk seal is in immanent danger of extinction. A third species, the Caribbean monk seal (*M. tropicalis*) was driven to extinction some time in the past 25 years. The Mediterranean and Hawaiian monk seals are protected as endangered species throughout their range. There are probably fewer than 500 Mediterranean monk seals and 1,500 Hawaiian monk seals. Mediterranean monk seals are found in several fragmented and now isolated populations throughout their former range in the Mediterranean and Black Seas, and the Atlantic coast and offshore islands of North Africa. Hawaiian monk seals are found almost exclusively on the Leeward Islands. Monk seals tend to stay close to their haul out areas and forage in coastal waters for fish, octopus, and crustaceans. They are less social than other pinnipeds and have a lower potential population growth rate than other pinnipeds. The main conservation problems are past and current exploitation, and interactions with commercial fisheries. They are not known to be negatively impacted by loud low frequency sound, but because both species are in immediate danger of extinction, every precaution must be made to avoid potential disturbance.

Protected Status

Monk seals (*Monachus* sp.) are listed as Endangered under the U. S. Endangered Species Act. They are protected by CITES and by the U. S. Marine Mammal Protection Act.

Distribution

The Mediterranean monk seal was formerly distributed in the southern Black Sea, throughout the Mediterranean Sea, and along the Atlantic Coast of northwestern Africa and offshore islands, South to about 20 degrees latitude (Riedman 1990; Reeves et al. 1992). It is now confined to a number of small, apparently isolated populations. In the Atlantic they occur at Cape Blanc Mauritania, possibly to the north between cape Barbas and Guerguerat, and on Madiera Island (Reeves et al. 1992). In the Mediterranean Sea they occur mainly along the eastern Mediterranean archipelago, the Aegean and northern Ionian seas and to some extent in Greek and Turkish waters. Some probably survive along the Turkish and Bulgarian coasts of the Black Sea and Sea of Marmara (Reeves et al. 1992). Sightings in other areas are sporadic, but do occur. They are generally found close to shore near haul out areas, but have been sighted more than 30km from shore (Reeves et al. 1992). Their presence on offshore islands indicates that they occasionally travel great distances from shore.

The Hawaiian monk seal is found primarily on the Leeward Chain of the Hawaiian Islands, especially Nihoa, Necker, French Frigate Shoals, Pearl and Hermes Reef, Kure

Atoll, Laysan, and Lisianski. Sightings on the main Hawaiian Islands have become more common in the past 15 years and a birth was recorded on Kauai and Oahu in 1988 and 1991 respectively (Kenyon 1981; Riedmann 1990). Midway was an important breeding rookery, but is no longer used (Reeves et al. 1992).

Abundance

The total number of Mediterranean monk seals may be less than 500 and is fragmented into a number of isolated populations.

There more than 1,500 Hawaiian monk seals and the population appears to be increasing slowly (Reeves et al. 1992).

Diet and Foraging Behavior

The Mediterranean monk seal feeds primarily on fish and octopus (Reeves et al. 1992). Hawaiian monk seals feed primarily on reef and benthic fishes and invertebrates, such as flatfish, eels, octopuses and lobsters (Reeves et al. 1992).

Diving Behavior

Mediterranean monk seals forage primarily in water less than 70m deep (Reeves et al. 1992). Hawaiian monk seals dive to at least 490m and stay submerged for 20min (Reeves et al. 1992).

Social Behavior

Monk seals are generally solitary at sea and on land are one of the least gregarious pinnipeds (Riedman 1990). However, small numbers aggregate at preferred haul out areas.

Reproduction and Population Parameters

Monk seals probably have the lowest reproductive rate of all pinnipeds. Mediterranean monk seals may become sexually mature at 5-6 years of age and live to 20 or 30 years (Reeves et al. 1992). However, many females probably do not produce pups every year.

Hawaiian monk seals mature at about 5 years and only 54% of females give birth every year (Johanos et al. 1994). The mean interval between births in successive years was 381 days, and females breed earlier in the season after they have skipped a year of reproduction (Johanos et al. 1994). Adults can live for up to 30 years.

Breeding Areas

Mediterranean monk seals breed in isolated caves throughout there range. Some breeding caves have underwater entrances (Reeves et al. 1992).

Hawaiian monk seals breed primarily on the Leeward Islands of French Frigate Shoals, Pearl and Hermes Reef, Kure Atoll, and Laysan and Lisianski Islands.

Speed of Travel and Movements

Most Mediterranean monk seals are thought to only move about 20-40km along the shoreline in the region of haul out areas. But movements of 600km have been recorded. At least one large male moved between five different sea caves some of which were 20km apart (Reeves et al. 1992).

Hawaiian monk seals are also generally resident to the waters near haul out areas. But some long distance movements between islands do occur. For example, a tagged pup moved at least 1,013km between, Laysan and Johnston Islands, in 5 months (Reeves et al. 1992).

Vocal Behavior

Studies on the vocal behavior of monk seals are limited. Job et al. (1995) found that female Hawaiian monk seals do not identify individual pups from by their vocalizations.

Hearing Range

There are no data on the hearing of Mediterranean monk seals. Hawaiian monk seals have underwater hearing from below 2- 40kHz, and their best underwater hearing is at 12-28kHz and 60-70kHz (reviewed in Richardson et al. 1995).

Known Impacts of Human Activity

Populations of all monk seals have been reduced to either extinction (Caribbean monk seal), or near extinction (Mediterranean and Hawaiian monk seals). The main threats have been commercial and subsistence hunting, intentional harassment, competition with commercial fisheries, entanglement in fishing gear, habitat destruction on breeding beaches, pollution, and unintentional human disturbance (Kenyon 1981; Riedman 1990; Reeves et al. 1992).

Mediterranean monk seals in the western Black Sea were driven to extinction by hunting and trapping in the late 1980’s (Kirac and Savas 1996). In Greece 62% of all known deaths were caused by deliberate killing by fishermen and 24% by entanglement in fishing gear (Panou et al. 1993). Toxic levels of Mediterranean monk seals on the Saharan coast were low and likely insignificant, but toxic levels from one male from the Mediterranean were higher than the threshold thought to cause immune suppression in mammals (Borrell et al. 1977).

Hawaiian monk seals are protected from most negative human impacts, but the population is only recovering slowly (Reeves et al. 1992).

There are no data on the potential impacts of loud low frequency sound on monk seals. However, because they are endangered and close to extinction, an LFA exclusion zones around known breeding areas is prudent.

SEALS (*PHOCA* SP.)

Summary

There are eight species in the genus *Phoca*. Two species are confined to lakes or inland seas (Caspian seal *P. caspica* and Bikal seal *P. sibrica*) and two are confined to Arctic waters (harp seal *P. groenlandica* and ringed seal *P. hispida*). The remaining three species (the ribbon seal *P. fasciata*, harbor seal *P. vitulina*, and spotted seal *P. largha*) have the potential to be impacted by LFA activities and are discussed in more detail. Ribbon and spotted seals are pack ice breeding species that rarely venture into the north Pacific. Harbor seals are widely distributed from the Arctic to the temperate waters off Baja California, Mexico. All three of these Phoca species are relatively abundant, have a broad diet, make no clear long distance migrations, and are seasonally monogamous or mildly polygynous breeders. They have all been hunted commercially or in an attempt to reduce population sizes. There is no indication that they are detrimentally impacted by loud low frequency sound.

Protected Status

The ribbon, harbor, and spotted seals are all protected by the U. S. Marine Mammal Protection Act.

Distribution

Ribbon seals: The ribbon seal is found primarily near ice in the Bering, Chukchi, and Okhotsk seas. However, individuals occasionally stray into the North Pacific both South of the Aleutian Islands, and West of the Kurile Islands and northern Hokkaido Island (Bonner 1990; Reeves et al. 1992). The vast majority of the population is in the Okhotsk and Bering Sea.

Harbor seals: The harbor seal is found in subarctic and temperate waters of the Northern Hemisphere. In the Eastern Atlantic harbor seals are found from France, Great Briton and Ireland, north across Norway to Iceland and southern Greenland; a few individuals stray South to Portugal (Reeves et al. 1992). There is an apparently isolated population at Svalbard Island, Norway.

Spotted seals: The spotted seal is found in the Bering and Chuckchi Seas, the Sea of Japan, and the Sea of Okhotsk (Bigg 1981; Reeves et al. 1992). They range into the Pacific around the eastern Aleutian Islands, the Kamchatka Peninsula, and Japan (Bigg 1981). There are at least two separate populaitons one in the Bering and Chukchi Seas and the other from the Sea of Okhotsk south.

Abundance

Ribbon seals: There are an estimated 240,000 ribbon seals world wide with perhaps 90,000 in the Bering Sea (Riedman 1990; Reeves et al. 1992).

Harbor seals: There are an estimated 500,000 thousand harbor seals with 300,000 in the North Pacific. An estimated 60% of the North Pacific population is in Alaskan water. There are 13,000 harbor seals in Eastern Canada to the South of Labrador, less than 25,000 in Great Britain, 13,000 in Main, and 4,000 in New Hampshire (Reeves et al. 1992).

Spotted seal: There are at least 200,000 spotted seals in the Bering and Chukchi Seas and an estimated 130,000 in the Sea of Okhotsk population (Reeves et al. 1992).

Diet and Foraging Behavior

Ribbon seals: Ribbon seals feed on crustaceans, fish, krill, and cephalopods (Riedman 1990).

Harbor seals: Harbor seal pups feed on benthic crustaceans. Adults eat a variety of prey across their large diverse range. This includes pelagic and benthic fishes, cephalopods, and crustaceans (Bigg 1981; Reeves et al. 1992). In some areas they feed on commercially valuable fishes such as salmon and cod (Brown and Pierce 1997).

Spotted seals: Spotted seal pups feed on small amphipods around ice flows (Bigg 1981). Adults feed on a wide variety of fish, cephalopods and crustaceans (Bigg 1981; Reeves et al. 1992).

Diving Behavior

Ribbon seals: No data.

Harbor seals: Adult harbor seals dive to more than 500m and for up to 30min (Eguchi and Harvey 1995). Average dives were 17-87m and 3-7min. More dives occurred at night than during the day.

Spotted seals: Adult spotted seals dive to at least 300m (Reeves et al. 1992)

Social Behavior

Ribbon seals: Ribbon seals breed on the pack ice, are slightly polygynous and are solitary or in small groups during breeding (Riedman 1990).

Harbor seals: Harbor seals are social at haul out locations. Mating occurs around weaning and most copulations take place in the water. Males fight in the water for access to female and the breeding season is likely serial polygamy; males mating with several females over the course of the breeding season (Bonner 1990).

Spotted seals: Spotted seals breed on the ice and are considered annually monogamous with receptive females being widely spaced and males attending females for perhaps 10 days (Reeves et al. 1992).

Reproduction and Population Parameters

Ribbon seals: Female ribbon seals are sexually mature at 2-5 years, males at 3-5 years (Reeves et al. 1992). About 95% of females give birth every year. Mortality before sexual maturity is estimated at 58%, but ringed seals may live for 20-30 years (Reeves et al. 1992).

Harbor seals: Females are sexually mature at 3-6 years, males at 3-7 years (Reeves et al. 1992). Mortality before sexual maturity is estimated at 80-55%. After sexual maturity mortality of adult males is about 9%/year (Reeves et al. 1992). Female mortality may be slightly lower.

Spotted seals: Female spotted seals become sexually mature at 3-4 years and males at 4-5 years (Reeves et al. 1992). Most give birth every year

Breeding Areas

Ribbon seals: Breeding in ribbon seals takes place on pack ice throughout the Bering, Chukchi, and Okhotsk seas (Riedman 1990).

Harbor seals: Breeding in harbor seals takes place on a variety of small colonies on pack ice, islands, offshore rocks, isolated mainland beaches, log booms, and other surfaces throughout their breeding range (Riedman 1990).

Spotted seals: Breeding takes place on pack ice throughout the range (Reeves et al. 1992).

Speed of Travel and Movements

Ribbon seals: Ribbon seals make seasonal movements with the pack ice (Riedman 1990).

Harbor seals: Maximum recorded swimming speed for harbor seals were ove 13km/hr (Bigg 1981). There are no set seasonal migrations and most individuals stay within 300km of their breeding areas (Reeves et al. 1992).

Spotted seals: Spotted seals make seasonal movements with the pack ice (Riedman 1990).

Vocal Behavior

Ribbon seals: Ribbon seal vocalizations are from 0.1 – 7.1kHz with a source level of 160dB (reviewed in Richardson et al. 1995).

Harbor seals: Harbor seals are probably the least vocal pinnipeds. They produce vocal sounds from 0.1 – 150 kHz, with most sounds in the range of 0.1-2 and 12-40 kHz. Source levels are up to 169dB (reviewed in Richardson et al. 1995).

Spotted seals: No data.

Hearing Range

Ribbon seals: No data.

Harbor seals: Harbor seals hear best sounds from 1-180kHz, with peak sensitivity at 32kHz (Møhl 1968; Terhune 1991). Temporary threshold shift has been reported after exposure to broad band construction noise (Kastak and Schusterman 1996).

Spotted seals: No data

Known Impacts of Human Activity

Ribbon seals: From 1961-1967 the USSR initiated intensive commercial hunting (Burns 1981). The take of about 13,000 seals reduced the population considerably and since 1968 the quota has been reduced. Current takes are small and subsistence related

Harbor seals: Traditional or subsistence hunting for harbor seals continues in Alaska, Greenland, the former Soviet Union, and northern Canada (Reeves et al. 1992). In Alaska subsistence hunters take an estimated 2,500 harbor seals/year (Reeves et al. 1992). Throughout most of their range harbor seals are protected from all but subsistence hunting. Where not subjected to intense competition with commercial fisheries harbor seal populations appear to be expanding.

Spotted seals: Intensive commercial hunting by Japanese and Russian sealers has apparently stopped. Subsistence takes in Alaska are thought to be about 2,400/year (Reeves et al. 1992). Intensive commercial fishing in the Bering Sea may threaten their food supply, and petrochemical exploration and extraction poses some threats to their habitat (Reeves et al. 1992).

GREY SEAL (*HALICHOERUS GRYPUS*)

Summary

Grey seals occur in three populations in the north Atlantic. They are relatively abundant and their population is increasing in many parts of their range, but decreasing in the Baltic Sea. They forage on a number of species including valuable commercial fish, such as cod and salmon, and dive to a maximum depth of 400m. Grey seals are not know to be impacted by loud low frequency sound.

Protected Status

The grey seal is protected by the U. S. Marine Mammal Protection Act.

Distribution

The grey seal (*Halichoerus grypus*) is found only in the North Atlantic where it is divided into three distinct populations in the Baltic Sea, Eastern North Atlantic (southern Iceland, Briton, Ireland, northwest France and Norway), and Western North Atlantic (Newfoundland, Nova Scotia, and Gulf of St. Lawrence) (Bonner 1981).

Abundance

There were an estimated 120,000 grey seals in the early 1980's (Bonner 1981), and that number increased to more than 200,000 in the early 1990's (Reeves et al. 1992). The Baltic population has declined considerably since the 1930's (Reeves et al. 1992).

Diet and Foraging Behavior

Grey seals feed primarily on a wide variety of fish. To a lesser extent they feed on crustaceans, squid, and octopus (Bonner 1981). Commercially valuable fish such as Atlantic salmon and cod make up a large part of their diets, but they also eat non-commercially harvested fishes such as sandlance and hake (Reeves et al. 1992). They are an important intermediate host for cod worm or seal worm; a parasite that decreases the commercial value of cod.

Diving Behavior

Average and maximum dive duration have been recorded at 2.5 and 27.5 min respectively (Boyd and Croxall 1996), and 1.8 and 9.1min respectively (Lydersen et al. 1994). Maximum dive depth was about 400m.

Social Behavior

Grey seals are polygynous. They are gregarious at haul outs during breeding and molting, but more solitary at sea.

Reproduction and Population Parameters

Females reach sexual maturity at 4-5 years. Males reach physical sexual maturity as early as 8, but breeding males are usually between 12 and 18 (Platt et al. 1975).

Breeding Areas

Grey seals breed on drifting ice and offshore islands throughout their range. As of the early 1990's there were no significant breeding colonies in the U. S. or France (Reeves et al. 1992).

Speed of Travel and Movements

Average speed of travel of a radio tagged individual was 4.5km/hr. Recaptures of marked animals suggest an average speed of 50-65 km/day during post weaning dispersal (Reeves et al. 1992). A radio tagged sub adult traveled 520km in eight days, but spent most of its time within 25km of a breeding rookery (Sjoberg et al. 1995).

Grey seals do not undertake long-distance migrations, but weaned pups are known to disperse widely.

Vocal Behavior

Grey seals vocalize at 0.1-16 kHz with most vocalizations at 0.1-4kHz and 10kHz (reviewed in Richardson et al. 1995).

Hearing Range

Grey seals have underwater hearing from 2.0 – 90 kHz, with best underwater hearing being at 20 and 50-60kHz (reviewed in Richardson et al. 1995).

Known Impacts of Human Activity

Historically, grey seals have been hunted for food or predator control throughout their range (Reeves et al. 1992). Today, most hunting is for predator or population control. Grey seals also suffer mortality from entanglement in fishing gear. Most grey seal breeding rookeries are protected or sufficiently remote that disturbance by humans is not severe.

NORTHERN AND SOUTHERN ELEPHANT SEALS (*MIROUNGA ANUSTIROSTRIS AND M. LEONINA*).

Summary

Elephant seals are large, highly polygynous seals that have recovered from severe over-exploitation. They are now quite abundant. They dive deep and dive frequently to feed on mesopelagic squid, and fish such as sharks and hake, and they make long migrations between foraging and breeding areas. They are probably the best studied of all marine mammals. Elephant seals produce and hear low frequency sound. Field experiments suggest that there is no short term behavioral impact of LFA and other low frequency sounds on foraging northern elephant seals.

Protected Status

Elephant seals (*Mirounga* sp.) are protected by the U. S. Marine Mammal Protection Act.

Distribution

Northern elephant seals are distributed throughout the northwest Pacific from the Gulf of California, Mexico north across the Gulf of Alaska to the Aleutian Islands (LeBoeuf and Laws 1994).

Southern elephant seals have a circumpolar distribution between about 40 degrees and 62 degrees South (King and Bryden 1981)

Abundance

Northern elephant seal population size is estimated at over 130,000 individuals (Stewart et al. 1994).

Southern elephant seals are estimated at under 400,000 individuals (Laws 1994).

Diet and Foraging Behavior

Northern elephant seals feed primarily on cephalopods, hake and other epi-, meso- and bathy-pelagic fishes and crustaceans such as Pacific whiting and pelagic red crabs (Antonelis et al. 1994). Male and female diets are relatively similar (Antonelis et al. 1994). All significant prey species make vertical migrations and are part of the deep scattering layer (Antonelis et al. 1994).

Southern elephant seals also appear to feed primarily on squid and deep scattering layer fish (Laws 1977).

Diving Behavior

Elephant seals dive deep, dive long, and dive continuously (LeBoeuf and Laws 1994). Maximum dives for northern elephant seals are 1,503m for a males and 1,273m for a female (LeBoeuf and Laws 1994). Maximum dive times are 66.7min for males and 67.9min for females. Average dive depth and duration are about 500m and 25min for females and 330m and 21min for males (LeBoeuf and Laws 1994). Females spent on average less than 10% of their time at the surface and males spent less than 14% of their time at the surface (LeBoeuf and Laws 1994).

Southern elephant seals show remarkably similar dive patterns (Slip et al. 1994). Maximum dives for a southern elephant seals was 1,403m and 120min (Slip et al. 1994).

Social Behavior

Both species of elephant seals are gregarious on the breeding colony, but appear to be relatively solitary at sea. They are harem polygynous; males defending a group of females from other males during the breeding season (LeBoeuf and Laws 1994). Both sexes fast for the entire period that they are on the breeding colony. Male mating success is highly skewed with as few as 5 males, out of 180, being responsible for more than 90% of copulations (LeBeouf and Laws 1994).

Reproduction and Population Parameters

Age at first breeding in northern elephant seal females was 3-6 with a mode of 4 years (Sydeman and Nur 1994). Males become sexually and socially mature at about 9-10 years (Clinton 1994). Maximum male life span is 14 years in the northern and 20 years in the southern elephant seal (LeBoeuf and Laws 1994). Maximum age for females is about 20 years. Most females give birth every year.

Breeding Areas

Northern elephant seals breed on at least 16 islands and mainland rookeries from central Baja California, Mexico to central California, USA (Stewart et al. 1994).

Southern elephant seals breed on at least 14 colonies around the Antarctic convergence between about 40 degrees and 62 degrees South latitude (Laws 1994).

Speed of Travel and Movements

Both elephant seals make long migrations from foraging areas to breeding areas. Northern elephant seals forage breeding on islands in California forage in the pelagic waters of the Gulf of Alaska (LeBoeuf and Laws 1994). Round trip migrations can be more than 7,000km (LeBoeuf 1994).

Vocal Behavior

Both species of elephant seals produce low frequency sounds on the breeding colony (reviewed in Richardson et al. 1995).

Hearing Range

Northern elephant seal hearing has been recorded from less than 0.075 – 6.4kHz with peak sensitivity at 70-80kHz (reviewed in Richardson et al. 1995). Hearing in southern elephant seals is likely similar.

Known Impacts of Human Activity

Northern elephant seals, and to a lesser extent, southern elephant seals were hunted to the brink of extinction in the late 1800's. With regulation of hunting or complete protection, both species have made a tremendous comeback. The southern elephant seal is now declining in some populations potentially due to natural factors that limit population growth (Laws 1994; Hindell et al. 1994). The northern elephant seal continues to increase in population size and range (Stewart et al. 1994).

Experimental releases of northern elephant seals, with attached dive recorders, into areas where loud low frequency sounds were being broadcast (ATOC and LFA) indicate that theses sounds did not cause short term changes elephant seal behavior (D. Costa pers. comm.). These experiments suggest that LFA operations will not cause short-term changes in elephant seal behavior. The large population sizes of both elephant seal species, and the ease with which populations can be monitored will make it possible to detect long-term populations changes although attributing them to a specific cause (e.g. masking of prey sounds caused by human produced low frequency sound) will be difficult.

CETACEANS

Summary

In the United States, all marine mammals (common, threatened, and endangered) are protected under the Marine Mammal Protection Act (MMPA). In addition all *Balaenoptera* whales are protected by the Endangered Species Act (ESA). Many animals are also internationally protected as CITES-designated species. Human activities that can influence marine mammal behavior or cause physiological damage are considered to constitute harassment, a violation of the MMPA and ESA.

A general description of the order Cetacea can be found in Leatherwood et al. (1983a) and Simmonds and Hutchinson (1996). The order includes two living suborders: Mysticeti (baleen whales) and Odontoceti (toothed whales). Cetaceans are highly modified marine mammals that have secondarily returned to the ocean. Unlike other groups, cetaceans have forsaken terrestrial phases in their life history. The order includes a diverse group with a wide range in body size. All species have lost their hind limbs and have developed flukes, flippers and blubber to cope with the high density and high heat conductance of seawater. Cetaceans have evolved to exploit virtually all productive marine, estuarine, and many river habitats. Some (e.g. blue, beaked, and pygmy and dwarf sperm) occur individually or in small groups while others (e.g. killer and sperm) are found in larger groups of related individuals. Some (e.g. many of the pelagic dolphins) form large, groups with functional sub-units. Most major cetacean groups feed upon fish, squid or crustaceans over pelagic waters within the LFA operating area. While most species feed in waters less than 200m, a few species (e.g. sperm whales, bottlenosed whales) are capable of diving to at least 2,000m. Their distributions are roughly correlated with that of their prey and they are often associated with continental shelves, fronts, upwelling areas, or convergence zones. Generally, cetaceans spend over 90% of their lives below the water surface.

All cetaceans bear a single, precocious young and have generally low reproductive rates. Many populations have been reduced due to prior exploitation. Social systems range from solitary (e.g. blue whales) to highly social (e.g. sperm whales). While some species have well-defined breeding areas (e.g. gray whales, right whales), most species breed at sea in dispersed regions at times which correspond to high productivity. Many species undergo seasonal north-south migrations that track seasonal peaks in prey availability.

The sense of smell in cetaceans appears to be absent, and they lack taste buds. However, the sense of hearing in most cetceans is highly developed. Many cetaceans find prey by passive listening, active echolocation, or other forms of acoustic imaging. Cetaceans can hear a wide range of frequencies, including LFS, and can accurately detect the directions of incoming sounds. Information on sounds produced and hearing thresholds in cetaceans are limited, but some generalizations can be made: 1) the dominant frequencies in the vocalizations of toothed whales range from several hundred Hz to150 kHz (Cummings and Fish 1971; Popper 1980). 2) Underwater audiograms of belugas, killer whales, and horbor porpoise demonstrate hearing at frequencies below 1,000 Hz with optimal sensitivity around 10-80 kHz (Andersen 1970a; Hall and Johnson 1972; White et al. 1978; Awbrey et al. 1988; Johnson et al. 1989). 3) Most vocalizations of baleen whales contain frequencies below 1,000 Hz and source frequencies above 170 dB (Norris et al. 1977; Thompson et al. 1979; Watkins and Wartzok 1985).

Shock waves, such as those caused by explosions can cause direct tissue damage to cetaceans. Organisms with air cavities such as fish with swim bladders, and air-breathing vertebrates are particularly vulnerable to underwater explosions (Gordon and Moscrop 1996). Because ears are adapted to be highly sensitive to sound, they are vulnerable to physical damage from high sound levels and rapid pressure changes (as occurs with explosions). In humans, sounds become uncomfortably loud at 100-120 dB above threshold at 1 kHz (126-146 dB). A sound 155 dB above threshold (176-196 dB) is high enough to cause immediate damage and permanent threshold shift (PTS) (Kryter 1985). Richardson et al. (1991) found that belugas have an auditory threshold of 40 dB. This suggests, by analogy, that belugas experience discomfort at sounds of 140-160 dB (Gordon and Moscrop 1996). If cetaceans such as baleen whales have similarly low auditory thresholds for LFS, then sound levels of 195-210 dB could result in immediate damage and PTS. Such levels could be experienced close to seismic arrays and other powerful sound sources such as supertankers and SURTASS LFA.

Following explosions for excavation off Newfoundland two humpback whales which were trapped in fishing nets were found to have badly damaged ear structures likely cause by explosive shock waves (Ketten et al. 1993). It is important to note that cetologists studying this population noted no changes in residency, resight patterns, or movements (Lien et al. 1993). Exposure to high sound levels may not result in acute damage but lead to an increasing in the hearing threshold (temporary threshold shift – TTS). The cumulative impacts of repeated incidents of TTS is not clear, but may lead to gradual hearing loss and eventual PTS. In humans, sound intensity of 80-100 dB above threshold at peak sensitivity can cause TTS. If we again assume that baleen whales have a threshold of around 40 dB re 1 μPa, then noise levels of 120-140 dB re 1 μPa could cause TTS. If the ability to detect faint sounds is important to the life history of the cetacean, loss of sensitivity could affect survival or reproductive success.

In acoustically oriented animals many biologically important sounds can be masked by increased levels of background noise. These include passive cues for foraging, sounds important in navigation, and social sounds important in coordinating movement and breeding. Au et al. (1985) found that belugas shifted the frequency and increased the intensity of their echolocation signals in response to elevated background noise levels. Such shifts may reduce the efficiency of vocal signaling in cetaceans (Gordon and Moscrop 1996).

Because all species of mysticete whale recorded to date produce loud, species-specific signals in the low-frequency band, they are particularly at risk from manmade LFS. It is unclear whether low-frequency signals produced by most mysticetes are used for communication, orientation, navigation, or detection of predators and prey. However, disruption of any of these functions could interfere with normal activities and behavior, and potentially impact the reproductive success of individuals and eventually the size of a population. Thus, it is difficult to accurately predict the potential impact of manmade LFS on important social and ecological functions.

The beaked whales (e.g. *Ziphius*, *Mesoplodon*) are believed to be pelagic, deep-diving cetaceans that feed primarily upon squid. The beaked whales are poorly understood– new species are regularly encountered and described– making it difficult to assess the potential impacts of human-produced LFS on their reproduction and ecology. It is clear, however, that sound plays an important role in their life history and thus is of particular concern.

Anthropogenic sounds in the ocean that mask sounds associated with foraging can decrease these animals' ability to find and capture food. This can decrease population growth rates if: 1) population growth is limited by food rather than predation or disease; and, 2) the species in question does not regulate the population size of its prey. In addition, many marine animals use sound to maintain contact between group members (e.g. females and their offspring), or for other forms of communication. Again, anthropogenic noise in the ocean that masks these communication sounds can decrease the ability of individuals to maintain contact with group members. For example, Payne and Webb (1971) estimated that for blue and fin whales, the increase in ambient noise levels generated by human activities may have reduced the area over which animals could communicate several orders of magnitude from ca. 6×10^5 nmi^2 under pre-shipping conditions to ca. 6×10^3 nmi^2 under present shipping conditions. Examples of the potential effects of such reductions could include: increased calf mortality or changes in group spacing to closer than optimal spacing. Consequently, the most serious potential impacts of LFA are likely its potential contribution to a long-term decrease in the foraging efficiency or communication efficiency of marine animals. Because some marine animals (e.g. large social odontocete cetaceans such as *Pyseter*, *Hyperoodon*, and *Berardius*) have extremely low potential population growth rates, are poorly known, and difficult to study, small decreases in their reproductive rate could have serious impacts on population size yet be undetected by any known monitoring system.

The most endangered cetaceans are the river dolphins (*Lipotes vexelifer, Platanista* sp.), the Gulf of California harbor porpoise (*Phocoena sinus).* They are not found in the area of LFA operations.

Recently, considerable progress has been made in understanding the potential mechanisms by which LFS could cause physical damage to a marine mammal's auditory system (Ketten 1992, 1994), and a predictive body of literature exists based upon human subjects. Some progress has also been made in understanding some of the potential short-term impacts of human-produced LFS on marine mammals (review by Richardson et al. 1995). Observed short-term responses include silencing, disruption of activity, and movement away from the source (e.g. Watkins and Schevill 1975; Watkins et al. 1985; Finley et al. 1990).

It is useful to note that studies on the effects of boat traffic on cetacean behavior have found: 1) belugas avoided ships at ranges of 45-60 km, were displaced by as much as 80 km, and took up to 48 hours to resume normal activity (Cosens and Dueck 1988; Finley et al. 1990). 2) narwhals exposed to approaching ships exhibited a “freeze” response and formed tight pods (Finley et al. 1990). 3) Belugas did not react to oil-industry-related noise up to 60 dB re 1 µPa above ambient (Finley et al. 1990). 4) Humpback whales avoid approaching vessels when noise was strong or rapidly changing (Watkins 1986; Beach and Weinrich 1989). 5) Many species (especially calves) of cetacean approach ships (e.g. Bryde’s whales, bottlenosed whales). 6) Gray whales, humpback whales, fin whales, and blue whales exhibit short-term flight when approached by boats (Reeves 1977; Swartz and Cummings 1978; Swartz and Jones 1978, 1981; Jurasz and Jurasz 1979; Edds and Macfarlane 1987; Baker et al. 1982, 1983). 7) Sperm whales appeared to habituate to the presence of whale-watching boats with powerful motors (Gordon et al. 1992).

Studies of the effects of industrial noise on cetaceans have found: 1) migrating gray whales exhibited an 80% avoidance reaction to oil exploration sounds played at 130 dB re 1 µPa (Malme et al. 1983). 2) Migrating gray whales exhibited a 10% avoidance response to airgun sounds played at 164 dB re 1 µPa (Malme et al. 1983). 3) Bowhead whales avoided full seismic arrays (broadband received level at 115 dB) at a range of 2 km (Richardson et al. 1986). 4) Mate et al. (1994a) found that sperm whales moved out of areas in response to seismic surveys. 5) Bowles et al. (1994) reported that sperm whales stopped vocalizing in response to weak seismic pulses from a distant ship (>200 km distant).

Reactions of cetaceans to sonar sounds include: 1) cessation of activities and scattering away from sonar signals between 3.25 and 8.4. 2) Increased strandings of dead beaked whales correlated with the times of naval operations (Simmonds and López-Jurado 1991) found. 3) Twelve Cuvier’s beaked whales stranded alive along the coast of Greece after tests of naval sonar systems (Frantzis 1998). 4) Cessation of sperm whale echolocation clicks in reaction to an acoustic thermography sound source (Bowles et al. 1994).

Longer-term studies have inferred that: 1) Increased human activities in gray whale calving lagoons led to abandonment of Laguna Guerrero Negro (Bryant et al. 1984). 2) Decreased abundance of breeding humpback whales resulted from increases in human activities (review by Norris and Reeves 1978). 3) Increased tour ship traffic led to a reduction in humpback whale numbers in Glacier Bay, Alaska (Baker et al. 1983), but it is not clear if this is food related (Dean et al. 1985). 4) Bowhead whales decreased their utilization of areas associated with intense offshore oil activity (Richardson et al. 1985a,b,c).

Recent experiments funded by the Office of Naval Research and SPAWAR have made progress in understanding the short-term behavioral impacts of the SURTASS LFA sound source on marine mammals over time scales of minutes to a few weeks and spatial scales of 1-100 nmi2 (Clark et al. 1998; Clark et al. 1998; Frankel and Clark 1998; Tyack and Clark 1998).

It is possible (perhaps likely) that brief interruptions of normal behavior or short-term physiological responses to LFS have few serious welfare implications and no serious effects on survival and reproductive success in cetacean populations. However, long-term impacts (e.g. displacement, masking of biologically important signals), while more difficult to identify and quantify, may be biologically significant through reductions in foraging efficiency, survival, or reproductive success. In many cases the basic information needed to understand the long-term consequences of human-produced sound is missing. As a result, completely different conclusions may be drawn from the same sparse data set (Gordon and Moscrop 1996).

MYSTICETES (BALEEN WHALES)

BALAENOPTERIDAE

BLUE WHALE (*BALAENOPTERA MUSCULUS*)

Summary

The blue whale is the largest living animal. They feed almost exclusively on euphausiids, and consumes up to 2 metric tons per day (Rice 1978), diving to at least 200m (Croll and Tershy pers. obs.). Important foraging areas include the edges of continental shelves, and ice edges in polar regions. While many stocks appear to seasonally migrate between polar and temperate regions, several stocks appear to remain within temperate/tropical regions year round. The species is currently divided into two forms: *B. musculus* (Southern Hemisphere, North Atlantic and North Pacific), and *B. m. brevicauda* (pygmy blue whale, subantarctic Indian Ocean and southeast Atlantic) (Clapham and Brownell 1996). Before stock reductions due to whaling, individuals of the Antarctic population were recorded up to 30.5m, weighing in excess of 160 tons. Northern Hemisphere populations are smaller, reaching 24 to 26m in length (Leatherwood et al. 1983a).

This species is known to produce and respond to LFS, but the function of these sounds is unknown. Some speculate that the species may use LFS to communicate over long distances, thus it is a species that may be impacted by LFA sounds.

Protected Status

With the advent of modern whaling methods, blue whale populations were severely depleted until 1966 when it was listed as a protected species by the International Whaling Commission. Since that time the various populations have been slow to recover (Clapham and Brownell 1996). Blue whales are federally listed as endangered species, protected under the Marine Mammal Protection Act, listed as CITES Appendix 1 species, and classified as Endangered by the IUCN. Although protected, nonmember nations have reportedly taken a small number, and Yablokov (1994) and Brownell (1995) provides evidence of extensive under-reporting of Soviet catches of blue whales.

Distribution

Blue whales occur in all oceans (Yochem and Leatherwood 1985). In temperate and tropical zones they are found primarily along the edge of continental shelves (North and South America (Reilly and Thayer 1990)) while in polar zones they may be found associated with ice fronts (Southern Hemisphere populations (Yochem and Leatherwood 1985). However, individuals may also be found in deep oceanic and shallow inshore regions. Traditionally, it has been speculated that blue whale distribution and movement patterns consist of a seasonal migration from high latitudes where foraging takes place to low latitudes where they mate and give birth (e.g. Mackintosh 1965; Lockyer 1981). However, data from the Pacific indicate that feeding also takes place at low latitude, "upwelling-modified" waters (Reilly and Thayer 1990), and data from both the Pacific and Indian Oceans indicate that some individuals remain at low latitudes year-round (Yochem and Leatherwood 1985).

Pacific

During the spring and summer months blue whales may be found in an arc including the Gulf of Alaska, along the Aleutian Islands (especially the south side), near the Kurile Islands, and the Kamchatka Peninsula (review by Yochem and Leatherwood 1985). In the Western Pacific, blue whales have been reported as far north as the northwest Bering and southwest Chuckchi seas (Tomilin 1957; Sleptsov 1961; Berzin and Rovnin 1966). Despite extensive surveys in the Chuckchi and Eastern Bering Seas (Leatherwood et al. 1983b), they are uncommon in the Bering Sea north of the Aleutians (Omura 1955; Murie 1959; Nishiwaki 1966a). However, Eskimo whalers near St. Lawrence Island reported the presence of blue whales prior to the 1950's (Yochem and Leatherwood 1985).

The fall and winter distribution in the North Pacific is not clear as the southern and pelagic limits of movements are not defined. Blue whales have been found during the fall and winter in the mid-Pacific from 20° to 35°N (Rovnin 1969; Thompson and Friedl 1982); in the east approximately 700nm off of Guatemala (Rice 1978), and in the west off Taiwan, Japan, and Korea (Tomilin 1957; Rice 1978).

The northward movement of whales in the spring in the Eastern North Pacific splits into two groups: one which moves north to the Queen Charlotte Islands and northern Gulf of Alaska and the other which moves northwest towards the Aleutian Islands (Berzin and Rovnin 1966). In the Western North Pacific blue whales reportedly migrate to Kamchatka or off the Kurile Islands then along the Kuriles to the northeast. The northward movement in spring occurs further off shore than the southern fall migration (Omura 1950; Nemoto 1959, 1970). Returns from discovery tags in the North Pacific indicate that there is movement between the western and eastern North Pacific (Yochem and Leatherwood 1985).

In the eastern North Pacific blue whales are found year-round off California and both costs of Baja California (Rice 1974; Sears 1987; Reilly and Thayer 1990). In the eastern tropical Pacific they are found year-round in the vicinity of the Costa Rican dome between 5° and 10°N and 70° and 90°W (review by Yochem and Leatherwood 1985), and off of Peru (Donovan 1984)

Atlantic

In the North Atlantic blue whales are found from San Cristobal in Panama and the Cape Verde Islands to the pack ice. They migrate to Arctic waters to feed during the spring and summer and are found in the east Atlantic from the British Isles and southern Norway as far north as 80°N (Scoresby 1820; Jonsgård 1955). On the west side from the Gulf of St. Lawrence and southern Greenland north to the edges of the pack ice (Kapel 1979a). The winter grounds and southern limits of the North Atlantic blue whales are not known, but reports exist as far south as San Cristobal, Panama and the Cape Verde

Islands, west Africa. Evans (1980) suggested that North Atlantic blue whales, similar to North Pacific whales, feed on euphausiids associated with the continental shelf.

Southern Hemisphere (including Indian Ocean)
The main austral summer feeding grounds of blue whales in the Southern Hemisphere are generally south of 40°S during the summer, between the Antarctic pack Ice and Antarctic convergence (Leatherwood et al. 1983a; Yochem and Leatherwood 1985). During the austral winter the population(s) move north to subtropical and tropical breeding grounds, the locations of which are unknown but presumed to range to Brazil, Ecuador, South Africa and (less commonly) Australia and New Zealand (Leatherwood et al. 1983a; Yochem and Leatherwood 1985). Year-round populations have been described in the Northern Hemisphere portions of the Indian Ocean (Yochem and Leatherwood 1985).

The pygmy blue whale (*B. m. brevicauda*) is found primarily in the waters around Marion Island, Crozet Island, and the Kerguelen Islands from 80° to 0°E and north of 54°S (Ichihara 1966). However, they have also been reported off South Africa, the west coast of Australia, Chile, Peru, and near the Galapagos Islands (review by Yochem and Leatherwood 1985).

The range of *B. m. brevicauda* overlaps with *B. m. intermedia* in the Indian Ocean, but genetic interchange is unknown.

Abundance

Global population estimates of the blue whale range from 11,200 to 13,000 individuals (Maser et al. 1981; U. S. Department of Commerce 1983); considerably below estimates of pre-whaling populations which exceed 200,000. Rough estimates of the North Pacific stock of blue whales ranges from 1400 to 1900, however rigorous line-transect data and mark recapture data independently estimate the California population alone at 2200 individuals (Barlow 1994; Barlow and Calambokidis 1995). The stock of Atlantic blue whales has been estimated at from a few hundred individuals (Allen 1970; Mitchell 1974) to 1,000 to 2,000 individuals (Sigurjonsson 1995). Sigurjonsson (1995) estimates the Iceland population is recovering at a rate of approximately 5% per annum. Estimates of the Southern Hemisphere population range from 5000 to 6000 (review by Yochem and Leatherwood 1985) with an average rate of increase of 4 to 5% per annum, but Butterworth et al. (1993) estimated the Antarctic population at 710 individuals. The pygmy blue whale population has been estimated at 6,000 individuals (Yochem and Leatherwood 1985)

Several authors have remarked that previously over-exploited blue whale populations are either not recovering, or only recovering slowly. However, given the wide range of population estimates it is impossible to assess whether blue whale populations are recovering (Gerrodette 1995). The hypothesis that the recovery of Southern Hemisphere blue whales has been inhibited by competition with minke whales lacks supporting data (IWC 1994, 1995; Clapham and Brownell 1996).

Diet and Foraging Behavior

Blue whales feed almost exclusively on a few species of euphausiid (Nemoto 1970; Kawamura 1980), using their unique feeding apparatus and baleen to "gulp" dense swarms of euphausiids. Fiedler et al. (1998a) suggested a preference for adult krill. Analyses of stomach contents suggest peaks in feeding activity during the evening and early morning hours, corresponding with the diel migration of their prey (Nishiwaki and Ohe 1951; Nemoto 1957; Maser et al. 1981). Fiedler et al. (1998a) reported blue whales foraging on euphausiid schools both near the surface and at depth. Croll et al. (1998) and Fiedler et al. (1998a) report that during the day California blue whales fed exclusively upon dense schools of euphausiids between 100 and 200 m. These concentrations formed downstream from upwelling centers in close proximity to regions of steep topographic relief off the continental shelf break. At dusk the dives of foraging whales tracked the upward migration of euphausiids, and nighttime dives were generally less than 50m in depth (Croll and Tershy pers. obs.). Sigurjonsson (1995) similarly found blue whales concentrated in foraging areas on the continental shelf break. Reilly and Thayer (1990) found that the distribution of blue whales in the eastern tropical Pacific (ETP) corresponded to relatively cool, upwelling-modified waters with relatively large standing stocks of euphausiids. Thus, the distribution of euphausiids appears to be a strong predictor of the distribution of blue whales during the foraging season.

Diving Behavior

Generally, blue whales make 5-20 shallow dives at 12-20 sec intervals followed by a deep dive of 3 to 30 min (Mackintosh 1965; Leatherwood et al. 1976; Maser et al. 1981; Yochem and Leatherwood 1985; Strong 1990; Croll and Tershy pers. obs.). Croll and Tershy (pers. obs.) found that the dive depths of blue whales foraging off of California during the day averaged 132 m (± 42m), maximum recorded dive depth was 204 meters, and mean dive duration was 7.2 min (±2.4 min). Strong (1990) reported mean dive durations for foraging blue whales as 8.0 min, 3.8 min, 9.7 min, and 4.0 min in the western Gulf of California, eastern Gulf of California, Monterey Bay, and Gulf of the Farallones, respectively. Croll and Tershy (pers. obs.) found average descent and ascent rates of 1.4 m/sec and 1.0 m/sec, respectively. They also found that dive depths and durations were significantly shorter at night than during the day, presumably in response to the rise of euphausiids in the evening.

Social Behavior

Blue whales are usually found swimming alone or in groups of two or three (Ruud 1956; Slijper 1962; Nemoto 1964; Mackintosh 1965; Pike and MacAskie 1969; Aguayo 1974). However, larger foraging aggregations and aggregations mixed with other rorquals such as fin whales are regularly reported (Schoenherr 1991; Fiedler et al. 1998a; Croll and Tershy pers. obs.). Little is known of the mating behavior of blue whales.

Reproduction and Population Parameters

In the Northern Hemisphere blue whales calve and mate in late fall and winter (Millais 1906; Tomilin 1957). Mating season in the Southern Hemisphere occurs during the austral winter, with a peak in mating in July (Mackintosh and Wheeler 1929; Nishiwaki 1952; Tomilin 1957). Because the breeding season of the two northern and southern hemisphere population are approximately 6 months out of phase, it is unlikely that interbreeding occurs. After gaining sexual maturity at approximately 5 years (21-24 m), females give birth to a single calf every 2-3 years (review by Yochem and Leatherwood). Gestation is estimated at 10-11 months (Mackintosh and Wheeler 1929; Tomilin 1957; Laws 1959; Slijper 1962), calves are 6-7m long at birth and weaned at 7 months (approximately 16 m). Males reach sexual maturity at approximately 5 years (20-21 m).

Data on the age of blue whales are limited, however estimates range from 30 years (Slijper 1962) to 80-90 years (Nishiwaki 1972; Klinowska 1980).

Breeding Areas

No specific breeding areas are known, although mating presumably occurs some time when blue whales are at lower latitudes during the fall and winter.

Speed of Travel and Movements

Swimming speeds range are 2 to 6.5 km/hr while feeding and 5 to 33 km/hr while migrating (Lockyer 1981). Maximum speeds range from 20 to 48 km/hr during chases or other harassment (Lockyer 1981).

Vocal Behavior

Known vocalizations of blue whales include a variety of sounds described as low frequency moans or long pulses (Cummings and Thompson 1971, 1977; Edds 1982, Thompson and Friedl 1982; Edds-Walton 1997). Blue whales produce a variety of low frequency sounds in the 10-100 Hz band (Cummings and Thompson 1971; Edds 1982; Thompson and Friedl 1982; McDonald et al. 1995; Clark and Fristrup 1997; Rivers 1997; Ljungblad et al. in press). The most typical signals are very long, patterned sequences of tonal infrasonic sounds in the 15-40 Hz range. Estimated source levels are as high as 180-190 dB (Cummings and Thompson 1971). Ketten (1997) reports the frequencies of maximum energy between 12 and 18 Hz. In temperate waters, intense bouts of long patterned sounds are very common from fall through spring, but these also occur to a lesser extent during the summer in high latitude feeding areas. Short sequences of rapid FM calls in the 30-90 Hz band are associated with animals in social groups (Clark pers. obs., McDonald pers. comm.). The seasonality and structure of long patterned sounds suggest that these sounds are male displays for attracting females and/or competing with other males. The context for the 30-90 Hz calls suggests that they are communicative but not related to a reproductive function.

Vocalizations attributed to blue whales have been recorded in presumed foraging areas, along migration routes, and during the presumed breeding season (Beamish and Mitchell 1971; Cummings and Thompson 1971, 1977, 1994; Cummings and Fish 1972; Thompson et al. 1996; Rivers 1997; Tyack and Clark 1997; Clark et al. 1998). Blue whales recorded off Oregon, central California, and the Gulf of California had similar two-part calls (likely the same population); blue whales recorded in the Gulf of Mexico had a three-part call, while blue whales recorded off Oahu, Hawaii, and the Atlantic Ocean had two-part calls but with different frequency characteristics. Blue whales recorded in the St. Lawrence River had a one-part call (reviewed by Rivers 1997).

The function of vocalizations produced by blue whales is unknown. Hypothesized functions include: 1) maintenance of inter-individual distance, 2) species and individual recognition, 3) contextual information transmission (e.g. feeding, alarm, courtship), 4) maintenance of social organization (e.g. contact calls between females and offspring), 5) location of topographic features, and 6) location of prey resources (review by Thompson et al. 1979). Responses to conspecific sounds have been demonstrated in a number of mysticetes, and there is no reason to believe that blue whales do not communicate similarly (Edds-Walton 1997). The low-frequency sounds produced by blue whales can, in theory, travel long distances, and it is possible that such long-distance communication occurs (Payne and Webb 1971; Edds-Walton 1997).

Hearing Range

No studies have directly measured the sound sensitivity of blue whales. In a study of the morphology of the blue whale auditory apparatus, Ketten (1997) hypothesized that blue whale have acute infrasonic hearing.

Known Impacts of Human Activity

Beyond direct effects due to whaling activities, few studies have assessed the impact of human activities on blue whales. In one of the few studies to date, Aburto et al. (1997) found no change in blue whale vocalization pattern and movements relative to estimated received levels of 70to 85 dB re 1 Pa of an LFA sound source.

FIN WHALE (*BALAENOPTERA PHYSALUS*)

Summary

The second largest whale, fin whales can grow up to 25 and 27m in males and females, respectively in the Southern Hemisphere and 22 and 24 m, respectively in the Northern Hemisphere (Gambell 1985a). The color of the head is asymetrical: the left side is totally dark while the right lower jaw is white. They are found in all of the oceans of the world, and most populations appear to migrate seasonally. They feed primarily upon planktonic crustaceans, but also take fish and squid. Studies of their foraging ecology indicate that the species dives repeatedly to concentrations of schooling prey down to at least 300m.

This species is known to produce and respond to LFS, but the function of these sounds is unknown. Some speculate that the species may use LFS to communicate over long distances, thus it is a species that may be impacted by LFA sounds.

Status

Most stocks were heavily fished since the advent of modern whaling, particularly upon the decline of blue whale stocks (Gambell 1985a); some stocks as much as 20% of their former levels (Meredith and Campbell 1988). Whaling ceased in Canada and the USA in 1972, followed by IWC control of harvests in 1976 with a subsequent moratorium on whaling. Some harvest of fin whales continues by Iceland, Spain, Korea, and perhaps the People's Republic of China. Fin whales are currently protected under the Endangered Species Act and theMarine Mammal Protection Act, listed as a CITES Appendix 1 species, and classified as Endangered by the IUCN.

Distribution

The fin whale has a global distribution concentrated in temperate and polar waters (Fig. 2 in Meredith and Campbell 1988). Most populations undergo a feeding migration to higher latitudes during the summer and lower latitudes during the summer. However, recent data indicate that some whales remain year-round at high latitudes (Clark and Charif 1998) and other areas such as the Gulf of California (see below), migrating only short distances (100-200 km) (Agler et al. 1993). Foraging areas tend to be characterized as coastally productive upwelling areas or thermal fronts (Gaskin 1972; Sergeant 1977; NCC 1979). They tend to avoid tropical and pack ice waters (Meredith and Campbell 1988). Forcada et al. (1995, 1996) found the highest densities of Mediterranean fin whales in cooler waters (mean=23.9°C)

Berube et al. (1998) examined genetic material from various populations in the northern hemisphere and suggested occasional gene flow between the North Pacific and North Atlantic populations. They hypothesized several recently diverged populations in the North Atlantic and Mediterranean Sea, with some limited gene flow between populations.

Pacific

It is generally considered that there are two stocks of fin whale in the North Pacific (Fujino 1960; Nishiwaki 1966a). The eastern population summers in the Chukchi Sea and Bering Strait down to the coast of southern California south to about 18 N and as far west as 138 -158 W (Meredith and Campbell 1988). The western population summers around the Sea of Okhotsk and are winter south in the Sea of Japan, East China Sea, Yellow Sea, and the Philippines Sea (Gambell 1985a). It has been hypothesized that there is a resident population in the Gulf of California (Gambell 1985a), but a test of this hypothesis was inconclusive (Tershy et al. 1991). Concentrations of fin whales may be found along the Aleutian Islands, Gulf of Alaska, British Columbia coast, Queen Charolette Islands, and Channel Islands during the summer (Nishiwaki 1966a; Pike and MacAskie 1969; Fiedler et al. 1998a).

Atlantic

Fin whales are widely distributed over areas of high productivity in the North Atlantic. The northern limits appear to be set by ice and the southern limits set by warm water of approximately 15 C (Sergeant 1977). Several potential stocks have been recognized in the eastern North Atlantic (Mitchell 1974; Sergeant 1977), although this subdivision has been questioned (Gambell 1985a). Populations appear to migrate seasonally from foraging areas in the north during the summer to southern wintering areas. A resident population of fin whales has been reported in the Mediterranean Sea (Duguy 1977; Duguy et al. 1990), however Jonsgård (1966) and Forcada et al. (1996) indicate that migrations into and out of the Mediterranean take place.

Southern Hemisphere (including Indian Ocean)

Fin whales are widely dispersed throughout the southern oceans south of 50°S in the summer. Unlike blue and minke whales they do not appear to associate with the ice edge. They migrate into the Atlantic, Indian, and Pacific Oceans during the winter as far north as Peru, Brazil, Africa north of South Africa, and the islands north of Australia and New Zealand (Gambell 1985a).

Abundance

Allen (1980) estimated the pre-exploitation and present abundance fin whales as 53,000 and 20,000, and 490,000 and 103,000 for the North Pacific and Southern Hemisphere populations, respectively. Sergeant (1977) estimated the pre-exploitation size of the North Atlantic population between 30,000 and 50,000 with current population size of approximately 13,000 individuals (Meredith and Campbell 1988). Forcada et al. (1996) estimated the abundance of Mediterranean fin whales as 3,583 individuals. Ratnaswamy and Winn (1993) estimated annual rates of calf production at 4-7% in the western Atlantic, and suggested that the population was potentially increasing.

Diet and Foraging Behavior

Feeding is accomplished by an engulfing technique where the whale takes in a mouthful of water containing the food, the mouth is closed, and the water is squeezed out between the baleen plates leaving the prey to be swallowed. There is considerable variation by area and season, but fin whales predominantly feed upon crustaceans, particularly euphausiids, fish and some cephalopods (Gambell 1985a). Several authors have suggested that fin whales feed opportunistically upon whatever is most available (reviewed by Gambell 1985a). However, Tershy et al. (1993) found that in the Gulf of California they fed exclusively on euphausiids. In the north Atlantic fin whales feed on schooling fish such as herring (*Clupea pallasii*), capelin (*Mallotus villosus*), and sandlance (*Ammodytes amercanus*) (Watkins and Schevill 1979). Stomach content data from the north Pacific suggest that whales in this region select euphausiids over fish (Nemoto and Kawamura 1979). Croll and Tershy (pers. obs.) have found that fin whales foraging in the Gulf of California and off southern California dive repeatedly to feed upon aggregations of euphausiids between 100 and 200m on the edge of the continental shelf. Piatt et al. (1989) and Piatt and Methven (1992) found that the seasonal appearance of fin whales correlated with capelin school abundance and fin whales fed upon capelin schools when mean daily capelin densities exceeded a threshold of 5 schools per linear km.

Diving Behavior

Generally, fin whales make 5-20 shallow dives of 13-20 sec duration followed by a deep dive of 1.5 to 15 min (Gambell 1985a; Strong 1990; Croll and Tershy pers. obs.). Croll and Tershy (pers. obs.) found that the dive depths of fin whales foraging off of California during were between 100 and 200m, and maximum recorded dive depth was 300 meters. Croll and Tershy (pers. obs.) found that dive depths and durations were significantly shorter at night than during the day, presumably in response to diel migrating behavior of of euphausiids. In a study of ventilation behavior of fin whales in the western Atlantic, Kopelman and Sadove (1995) measured mean blow interval (time at surface breathing) as 47.9 sec for surface-feeding and 57.9 sec for non-surface-feeding whales and mean dive duration as 159.5 sec for surface-feeding whales and 185.9 for non-surface-feeding whales.

Social Behavior

Fin whales are often found singly or in pairs, but also commonly form larger groupings greater than 3 individuals, particularly while feeding. Tershy et al. (1993) described group foraging behavior where 2-4 animals swam less than 50m apart in an echelon formation and lunged synchronously, right side down. They found that group composition was not stable: membership and group size changed frequently during feeding events, and associations beyond female calf were brief.

Reproduction and Population Parameters

Analysis of whales harvested in whaling activities indicate that in Southern Hemisphere fin whales conception occurs between April and August while in Northern Hemisphere whales conception occurs some time near December and January. Gestation lasts a little over 11 months, and calves are weaned after 6-7 months at approximately 12m. The female then undergoes a “resting phase” of 5-6 months before mating again next winter (Gambell 1985a).

Southern fin whales become sexually mature at 19.9 and 19.2m in females and males, respectively. Northern fin whales become sexually mature at 18.3 and 17.7m, respectively. Due to an increase in growth rates since the reduction of fin whale populations, they are reaching sexual maturity at younger ages and having higher pregnancy rates than during pre-whaling. Presently fin whales appear to mature at 6 to 7 years.

Breeding Areas

No specific breeding areas are known, although mating presumably occurs some time when fin whales are at lower latitudes during the fall and winter.

Speed of Travel and Movements

Fin whales are known as one of the fastest whale species. Ray et al. (1978) tracked a radio-tagged whale at an average speed of 9 km/hr, and Watkins (1981) tracked a radio-tagged fin whale between Iceland and Greenland at 12.1 km/hr. Whalers have reported bursts of over 30 km/hr.

Agler et al. (1993) reported that female fin whales in the Gulf of Maine exhibited strong site fidelity.

Vocal Behavior

Underwater sounds of the fin whale are one of the most studied *Balaenoptera* sounds. Fin whales produce a variety of low-frequency sounds in the 10-200 Hz band (Watkins 1981; Watkins et al. 1987a; Edds 1988; Thompson et al. 1992). The most typical signals are long, patterned sequences of short duration (0.5-2s) infrasonic pulses in the 18-35 Hz range (Patterson and Hamilton 1964). Estimated source levels are as high as 180-190 dB (Patterson and Hamilton 1964; Watkins et al. 1987a; Thompson et al. 1992; McDonald et al. 1995). In temperate waters intense bouts of long patterned sounds are very common from fall through spring, but also occur to a lesser extent during the summer in high latitude feeding areas (Clark and Charif 1998). Short sequences of rapid FM calls in the 20-70 Hz band are associated with animals in social groups (McDonald et al. 1995; Clark pers. comm.; McDonald pers. comm.). The seasonality and stereotypy of the bouts of patterned sounds suggest that these sounds are male reproductive displays (Watkins et al. 1987a), while the individual counter-calling data of McDonald et al. (1995) suggest that the more variable calls are contact calls. Some authors feel there is geographic differences in the frequency, duration and repetition of the pulses (Thompson et al. 1992).

As with other mysticete sounds, the function of vocalizations produced by fin whales is unknown. Hypothesized functions include: 1) maintenance of inter-individual distance, 2) species and individual recognition, 3) contextual information transmission (e.g. feeding, alarm, courtship), 4) maintenance of social organization (e.g. contact calls between females and offspring), 5) location of topographic features, and 6) location of prey resources (review by Thompson et al. 1992). Responses to conspecific sounds have been demonstrated in a number of mysticetes, and there is no reason to believe that fin whales do not communicate similarly (Edds-Walton 1997). The low-frequency sounds produced by fin whales have the potential to travel over long distances, an it is possible that such long-distance communication is occurs in fin whales (Payne and Webb 1971; Edds-Walton 1997).

Hearing Range

No studies have directly measured the sound sensitivity of fin whales. Presumably fin whales are able to receive sound signals of the same frequency they are producing. In a study of the morphology of the mysticete auditory apparatus, Ketten (1997) hypothesized that large mysticetes have acute infrasonic hearing.

Known Impacts of Human Activity

Beyond direct effects due to whaling activities, few studies have assessed the impact of human activities on fin whales. In a review of anecdotal records, Watkins (1986) found that the reaction of fin whales to the presence of vessels modified over time from predominantly negative reactions to predominantly uninterested reactions. He speculated that whales reacted negatively to sounds that were: 1) too loud, 2) unexpected, 3) suddenly louder, or 4) associated with potentially threatening source. In addition he reports negative reactions to brightly reflective objects in the water. He commented that “whales appeared to habituate rapidly”. In early years Watkins (1986) found that fin whales appear to react strongly to low-frequency ship sounds and moved rapidly away when approached by ship. In addition, Watkins (1982) reports that fin whales were consistently silent for long periods after being disturbed. In later years Watkins found that fin whales were more likely to ignore vessels, seldom diverting from activities unless the vessel passed within 30m.

Several studies have reported low levels of organochlorides (Aguilar and Borrell 1994; Marsili and Focardi 1996), and heavy metals (Sanpera et al. 1996) in fin whales.

BRYDE’S WHALE (*BALAENOPTERA EDENI*)

Summary

Bryde’s whales are found throughout the tropical and subtropical waters of the world (Omura 1959), but little is known if seasonal movement patterns.

Status

Bryde’s whales (*Balaenoptera edeni*) are currently protected under the Marine Mammal Protection Act, and classified as a data deficient species by the IUCN.

Distribution

Bryde’s whales are found globally at low densities in tropical and subtropical waters, they are most commonly encountered in waters warmer than 15-20°C, for the most part restricted between 40°N and 40°S latitudes. There is some indication that there is a shift to higher latitudes during the winter (Kishiro 1996).

Pacific

In the western Pacific Bryde’s whales occur from Japan to New Zealand; in the eastern Pacific from Baja California to Chile (Cummings 1985a). Bryde’s whales have been regularly taken off the Bonin Islands, and Kishiro reports some evidence for winter movements from this area to higher latitudes (around 25° N). He also reported that catches at higher latitudes where dominated by females. Tershy (1992) found that Bryde’s were seasonally abundant in the central Gulf of California, indicating annual shifts in distribution.

Atlantic

In the Atlantic Bryde’s whales are seen from Virginia, the Gulf of Mexico, and Caribbean south to Brazil and Morocco as far south as the Cape of Good Hope. Best (1974) has described an inshore, year-round resident population, and offshore migratory population off South Africa. The two populations are morphologically distinct based upon baleen characteristics.

Southern Hemisphere (including Indian Ocean)

In the Indian Ocean Bryde’s whales range from the Persian Gulf to the Cape of Good Hope, and from Indonesia to Western Australia (Cummings 1985a).

Abundance

Population estimates for most regions are not available. In the western North Pacific, estimates range from 10,000 (Best 1975) to 49,000 (Ohsumi 1978). Nishiwaki (1972) speculated that due to this species’ limited migration and confined distribution, the total world population is likely relatively small.

Diet and Foraging Behavior

Feeding is accomplished by the typical rorqual engulfing technique where the whale takes in a mouthful of water containing the food, the mouth is closed, and the water is squeezed out between the baleen plates leaving the prey to be swallowed (Gambell 1985a,b). Bryde's whales feed primarily on schooling fish (e.g. sardines, herring, pilchard, mackerel) and euphausiids (Best 1960; Nemoto and Kawamura 1977; Cummings 1985a; Tershy 1992; Tershy et al. 1993).

Tershy (1992) reports that Bryde's whales increased feeding around dawn and dusk.

Diving Behavior

Cummings (1985a) reports that Bryde's whales come to the surface as often as once every 1 min, and dive as long as 20 min.

Social Behavior

Bryde's whales are usually found alone or occasionally in pairs (Tershy 1992).

Reproduction and Population Parameters

Data from the coast of Japan indicate that females reach sexual maturity at 10 years, and males between 9-13 years (Cummings 1985a). Best (1960) reports that Bryde's whales breed throughout the year off South Africa, and Tershy et al. (1990) reported Bryde's whale calves were present throughout the year in the Gulf of California. However, Best (1975) also reported that the offshore population off South Africa bred only in the fall. Gestation is believed to be about 1 year.

Breeding Areas

No specific breeding areas are known.

Speed of Travel and Movements

Tershy (1992) reports that Bryde's whales are resident in the northern Gulf of California, and Best (1960) found that the inshore population of Bryde's whales is resident off of South Africa. Data on the speed of travel are not available, but are generally similar to those of fin and blue whales (Croll and Tershy, pers. obs.).

Vocal Behavior

Cummings (1985a) reports underwater sounds of Bryde's whale from the Gulf of California as 0.4 sec (0.2 to 1.5 sec) low-frequency moans concentrated at 124 Hz (70-245 Hz) with little energy above 250 Hz with as much as 15 Hz of frequency modulation (upwards or downwards). Source levels were estimated at 156 dB re 1 uPa at 1m. Edds et al. (1993) reports pulsed sounds and as well as the moans reported by Cummings.

The function of Bryde's whale vocalizations is not known. Edds-Walton (1997) suggested that different call types may occur in different contexts. In addition, she noted that Bryde's whales sound frequencies overlap with those of sympatric fin and minke whales, and speculated that differences in call structure may be important for species recognition.

Hearing Range

No studies have directly measured the sound sensitivity of Bryde's whales. In a study of the morphology of the blue whale auditory apparatus, Ketten (1997) hypothesized that mysticete whales have acute infrasonic hearing.

Known Impacts of Human Activity

Besides the direct affects of whaling, no studies have been published on the impacts of human activity on Bryde's whales.

SEI WHALE (*BALAENOPTERA BOREALIS*)

Summary

Sei whales are broadly distributed in all oceans. They are found primarily in temperate zones, and do not venture as far into polar waters as blue, fin, and minke whales.

Status

Although some sei whales (*Balaenoptera borealis*) were taken in Japanese net fisheries from the early 17th century, most stocks were not heavily fished until the advent of modern whaling, particularly upon the decline of blue whale stocks (Gambell 1985a). Sei whales are currently protected under the Endangered Species Act and the Marine Mammal Protection Act, listed as a CITES Appendix 1 species, and classified as Endangered by the IUCN.

Distribution

The sei whale has a global distribution concentrated in more temperate waters (Gambell 1985b). As with other rorquals, populations appear to undergo a feeding migration to higher latitudes during the summer and lower latitudes during the summer, although much less is known about their movements. They tend to avoid pack ice waters (Gambell 1985b). Due to the juxtaposition of seasons, the northern and southern hemisphere populations likely do not mix.

Pacific

In the North Pacific, sei whales can be found during the summer from California to the Gulf of Alaska in the east, across the Bering Sea and down to the coasts of Japan and Korea in the west. During the winter, centers of abundance move south to around 20 N (Gambell 1985b). In the eastern North Pacific sei whales have been reported during the summer from at least 35° 30 N south to 35° 30 N. Little is known of population separation, but 3 populations are recognized (Leatherwood et al. 1983a).

Atlantic

Less is known of the distribution of sei whales in the North Atlantic. Two stocks are believed to occupy the waters off Nova Scotia and Labrador during the summer. Individuals are known to move west to Greenland in the western north Atlantic. Individuals from these stocks are believed to winter as far south as Florida (Leatherwood et al. 1983a). In the eastern north Atlantic winter stocks are found off Spain, Portugal, and northwest Africa. These stocks likely move towards Norway and more nothern waters during the summer (Gambell 1985b). Sei whales are taken in the Denmark Strait during the summer, but the winter area of these whales is not known.

Southern Hemisphere (including Indian Ocean)

Generally the movements of sei whales in the southern hemisphere are similar to those of fin and blue whales (Gambell 1985b), except they do not migrate as far south. Their main summer concentrations are between 40 and 50 S. In the winter, sei whales are present off Brazil, the east and west coasts of South Africa, and Australia. Open ocean wintering grounds are not known (Gambell 1985b).

Abundance

Allen (1980) estimated the pre-exploitation and present abundance sei whales as 63,000 and 14,000, and 191,000 and 37,000 for the North Pacific and Southern Hemisphere populations, respectively. Sigurjonsson (1995) reports estimates for the pre-exploitation size of the North Atlantic population between 10,000 and 15,000 with a current population size of approximately 13,500 individuals.

Diet and Foraging Behavior

Feeding is accomplished by either skimming plankton as the swims forward or by an engulfing technique where the whale takes in a mouthful of water containing the food, the mouth is closed, and the water is squeezed out between the baleen plates leaving the prey to be swallowed (Gambell 1985b). In the higher latitude portions of their range sei whales feed primarily upon crustaceans, predominantly calanoid copepods and euphausiids (Jonsgård and Darling 1977; Nemoto and Kawamura 1977; Kawamura 1994; Sigurjonsson 1995). Their diet is more varied at lower latitudes and includes a variety of schooling fish (Nemoto and Kawamura 1977; Rice 1977a). Copepods are the smallest prey item taken by any of the rorquals and is made possible by a finer baleen fringe (Gambell 1985b).

Diving Behavior

Generally, sei whales make 5-20 shallow dives of 20-30 sec duration followed by a deep dive of up to 15 min (Gambell 1985b). The depths of sei whale dives have not been studied, however the composition of their diet suggests that they do not perform dives in excess of 300 m.

Social Behavior

Sei whales are usually found in small groups of upt to 6 individuals, but also commonly form larger groupings on the feeding grounds (Gambell 1985b)

Reproduction and Population Parameters

There appears to be some differences in reproductive patterns between northern and southern populations of sei whales, but generally females give birth approximately once every 2-3 years (Rice 1977a; Gambell 1985b). Analysis of whales harvested in whaling activities indicate that in Southern Hemisphere sei whales conception occurs between April and August (Gambell 1985b). Gestation lasts between 11 and 13 months (Masaki 1976; Rice 1977a; Gambell 1985b), and calves are weaned after 6-9 months (Rice 1977a; Gambell 1985b). The female then undergoes a “resting phase” of 6-14 months before mating again next winter (Rice 1977a; Gambell 1985b).

Sei whales become sexually mature at a mean age of 11 years (Rice 1977a) and length of 12-13 m or 13-14 m in males and females, respectively. Due to an increase in growth rates since the reduction of rorqual whale populations, they are reaching sexual maturity at younger ages and having higher pregnancy rates than during pre-whaling. In some areas sei whales become sexually mature at 6 to 8 years.

Breeding Areas

No specific breeding areas are known, although mating presumably occurs some time when sei whales are at lower latitudes during the fall and winter.

Speed of Travel and Movements

Whalers considered the sei whale to be one of the fastest whale species. However, records of the movement speeds of sei whales are not available.

Vocal Behavior

No studies have been published on the vocal behavior of sei whales.

Hearing Range

No studies have directly measured the sound sensitivity of sei whales.

Known Impacts of Human Activity

No studies have been published on the impacts of human activity, other than whaling, on sei whales.

HUMPBACK WHALE (*MEGAPTERA NOVAEANGLIAE*)

Summary

Humpback whales are primarily near-shore feeders and breeders that travel over deep pelagic waters during migration between mid and high latitude feeding areas and breeding areas near isolated tropical shallows. Compared to other myticetes they eat a wide variety of small schooling prey which they capture using a variety of prey concentrating techniques. Humpback whales were severely over-hunted in the early 1900's and protected from all commercial hunting in 1966. Since then most populations have shown significant recovery. The foraging distribution and breeding areas of humpback whales are well known in some areas. Experimental field studies showed only slight statistical responses of breeding humpback whales to low frequency sound at received levels of 190 dB.

Protected Status

Humpback whales (*Megaptera novaeangliae*) are federally protected by the U. S. Endangered Species Act, the U. S. Marine Mammal Protection Act, and CITES. Commercial humpback whaling was banned in all waters by 1966.

Distribution

Humpbacks can be found throughout the world between the Arctic and Antarctic pack ice (Leatherwood et al. 1983a; Winn and Reichley 1985). In the northern Hemisphere they tend to migrate between coastal feeding grounds that are generally on or near the continental shelf, and isolated shallow breeding grounds in tropical waters (Winn and Reichley 1985). Existing data indicate that movements between breeding and feeding grounds are essentially straight line and frequently cross pelagic waters (Winn and Reichley 1985; Mate pers. comm.). Humback whales in the Arabian sea are an isolated population that remains in tropical waters throughout the year (Mikhalev 1997). Their prey is likely generally found above 300 m so it is unlikely that they make deep prolonged dives.

Abundance

Recent population estimates for humpbacks total about10,000 animals, with about 3,000 in the Southern Hemisphere, 1,000 in the North Pacific, and 5,000 in the North Atlantic (Winn and Reichley 1985).

Diet and Foraging Behavior

Humpback whales feed on small schooling prey (primarily euphausiids and small fish) which they capture by gulping a large volume of prey filled water, then forcing the water out though their baleen and retaining the prey (Clapham 1996). Compared to blue and fin whales their diet is much more variable (Gaskin 1982). However, there is a tendency for humpback whales in the northern Hemisphere feed primarily on small schooling fish, while humpbacks in the southern hemisphere feed primarily on euphausiids (Nemoto 1957; Slijper 1962; Piatt et al. 1989; Piatt and Methven 1992; Sigurjonsson 1995;

Clapham 1996; Weinrich et al. 1997). Humpbacks use a variety of individual and group techniques to concentrate prey or limit the escape response of prey (Hain et al. 1982; Baker and Herman 1984; D'Vincent et al. 1985).

Diving Behavior

The deepest recorded humpback dive was 240m (Hamilton et al. 1997). Croll and Tershy (pers. obs.) recorded a dive of 150m off central California. Dives on feeding grounds ranged from 2.1 – 5.1 min in the north Atlantic (Goodyear unpubl. manus.). In southeast Alaska average dive times were 2.8 min for feeding whales, 3.0min for non feeding whales, and 4.3min for resting whales (Dolphin 1987). In the Gulf of California humpback whale dive times averaged 3.5min (Strong 1989). Because most humpback prey is likely found above 300m most humpback dives are probably relatively shallow.

Social Behavior

Humpback social behavior is reviewed by Clapham (1996). They form small unstable groups during the breeding season. During the feeding season they form small groups that occasionally aggregate on concentrations of food. Feeding groups are sometimes stable for long-periods of times. There is good evidence of some territoriality on feeding grounds (Clapham 1994, 1996), and on wintering ground (Tyack 1981).

On the breeding grounds males sing long complex songs directed towards females, other males or both. The breeding season can best be described as a floating lek or male dominance polygygy (Clapham 1996). Intermale competition for proximity to females can be intense as expected by the sex ratio on the breeding grounds may be as high as 2.4:1.

Reproduction and Population Parameters

Males and females reach sexual maturity at about 5 years (Chittleborough 1965; Clapham 1992).

Females calve regularly every 2 – 3 years, but several cases of annual births have been reported (Baker et al. 1987; Clapham and Mayo 1990). The population growth rate in the western north Atlantic is estimated at 1.065%/year (Barlow and Clapham 1997). Some populations appear to be recovering from severe over hunting that ended in 1967 (Bannister 1994; Findlay and Best 1996; Barlow and Clapham 1997).

Breeding Areas

Humpback whales have well defined breeding areas in tropical waters on isolated islands or sea mounts. In the north Pacific there are breeding grounds around Mariana, Bonin, Ogasawara, Okinawa, and Ryukyu Island and Taiwan; around the main Hawaiian Islands; off the tip of Baja California, and off the Revillagigedo Islands. In the north Atlantic there are breeding areas near Bermuda, the West Indies, and Trinidad in the West; and Cape Verde Islands and off northwest Africa in the East.

Speed of Travel and Movements.

Maximum recorded swimming speeds are 27 km/hr (Tomilin 1957). Estimated speed during migration is about 8 km/hr (Chittleborough 1953). A tagged whale in the western north Atlantic traveled 260km between two foraging areas with an average minimum speed of 5.6km/hr (Goodyear et al. unpubl. manus.). Tagged humpbacks have moved more than 100 km/day (Watkins et al. 1978; 1981).

Humpback whales make annual migrations between temperate and sub-arctic feeding grounds and tropical breeding areas. These migrations can be from 4,000 – 8,000 km (Clapham 1996). Recently the migratory path and speed of travel have been recorded by Mate (pers. comm.). Male biased sex ratios of 2.4:1 on the migration route indicate that many females do not participate in this annual migration (Brown et al. 1995).

Vocal Behavior

Humpbacks produce a great variety of sounds. During the breeding season males sing long complex songs, with frequencies in the 25-5000 Hz range and intensities as high as 181 dB (Payne 1970; Winn et al. 1970a; Thompson et al. 1986). The songs appear to have an effective range of approximately six to 12 mi (10 to 20 km). Animals in mating groups produce a variety of sounds (Tyack 1981; Tyack and Whitehead 1983, Silber 1986). Feeding groups produce distinctive sounds ranging from 20 Hz to 2 kHz (Thompson et al. 1986). These sounds are attractive and appear to rally animals to the feeding activity (D'Vincent et al. 1985; Sharpe and Dill 1997). In summary, humpback whales produce at least three kinds of sounds: 1) complex songs with components ranging from at least 20Hz – 4 kHz with estimated source levels from 144 – 174 dB; these are mostly sung by males on the breeding grounds (Payne 1970; Winn et al. 1970a; Richardson et al. 1995). 2) Social sounds in the breeding areas that extend from 50Hz – more than 10 kHz with most energy below 3kHz (Tyack and Whitehead 1983, Richardson et al. 1995). 3) Feeding area vocalizations that are less frequent, but tend to be 20Hz – 2 kHz with estimated sources levels in excess of 175 dB re 1 uPa-m (Thompson et al. 1986; Richardson et al. 1995).

Hearing Range

No direct data. However, humpback whales reacted to low frequency industrial noises at estimated received levels of 115 – 124 dB (Malme et al. 1985), and to conspecific calls at received levels as low as 102dB (Frankel et al. 1995).

Known Impacts of Human Activity

Humpback whales are occasionally killed or injured in fishing nets and traps, especially in western north Atlantic (Winn and Reichley 1985). The impacts of pollutants and coastal habitat destruction are not known. Human over-fishing can directly or indirectly affect the availability of humpback prey and consequently their distribution (Piatt et al. 1989; Weinrich et al. 1997).

Humpbacks make frequent aerial, surface, and subsurface displays so their responses to disturbance are often more obvious than those of other rorquals which generally change course and dive sooner and for longer periods, (Tershy pers. obs.). Consequently, there are numerous accounts of humpback whale reaction to aircraft and boat disturbance (e.g. Payne 1978; Shallenberger 1978). There is abundant evidence of disturbance to humpack whales from boat traffic on the breeding grounds (Herman 1979; Kaufman and Wood 1981; Green 1990; Bauer et al. 1993; Norris 1994; Corkeron 1995). However, these effects are short-term and it is not known to what extent whales will habituate to boat traffic.

On the feeding grounds there is evidence that whales move away from large cruise ships (Jurasz and Jurasz 1979; Baker et al. 1982, 1983; Dean et al. 1985). There was concern that increased vessel activity caused humpbacks to leave Glacier Bay, Alaska in 1978, however evidence was inconclusive (Marine Mammal Commission, unpub. rep.). As on the wintering grounds, it is clear that humpbacks alter their behavior in response to some boat activity, however the long-term effects are less clear and there is evidence of habituation to boat traffic (Beach and Weinrich 1989; Clapham et al. 1993).

Humpback whales produce and respond to LFS. Humpback whales apparently reacted to 3.1 – 3.6 kHz sonar by changing behavior (Maybaum 1990, 1993). Malme et al. (1985) found no clear response to playbacks of drill ship and oil production platform noises at received levels up to 116dB re 1 u Pa. Studies of reactions to airgun noises were inconclusive (Malme et a. 1985). Humback whales on the breeding grounds did not stop singing in response to underwater explosions (Payne and McVay 1971). Humpback whales on feeding grounds did not alter short-term behavior or distribution in response to explosions with received levels of about 150dB re 1 uPa/Hz at 350Hz (Lien et al. 1993; Todd et al. 1996). However, at least two individuals were likely killed by the blasts and extensive had mechanical injuries in their ears (Ketten et al. 1993; Todd et al. 1996). The explosions may also have increased the number of humpback whales entangled in fishing nets (Todd et al. 1996). Frankel and Clark (1998) showed that breeding humpbacks showed only a slight statistical reaction to playback of 60 – 90 hZ sounds with a received level of up to 190dB. While these studies have shown short-term behavioral reactions to boat traffic and playbacks of industrial noise, the potential for habituation, and thus the long-term effects of this disturbances are not known.

MINKE WHALE (*BALAENOPTERA ACUTOROSTRATA*)

Summary

Minke whales are the smallest rorqual, seldom exceeding 10.1 m. They are widespread and seasonally abundant, undergoing seasonal migrations between higher latitudes in the spring and summer and lower latitudes in the winter. They feed on a diverse array of prey, primarily schooling fish and crustaceans. The taxonomy of minke whales is under debate: North Atlantic (*B. a. acutorostrata*), North Pacific (*B. a. davidsoni*), and Southern Hemisphere (*B. a. bonarensis*) subspecies have been proposed (Omura 1975, Rice 1977b). They have been exploited in whaling operations since at least 1923 (Kellogg 1931), but global populations appear to be healthy. A wide variety of sounds have been recorded from minke whales.

Status

Minke whales (*Balaenoptera acutorostrata*) are federally protected under the U. S. Marine Mammal Protection Act, and are listed as IUCN lower risk/near threatened species.

Distribution

Generally, most minke whale populations undergo seasonal migrations from high latitudes in the spring and summer to lower latitudes in the winter. Their distribution appears to reflect that of their prey, and Tynan (1997) reported that southern ocean minke whales were concentrated along fronts in the Antarctic Circumpolar Current, particularly where they meet shoal waters. Northern and Southern Hemisphere minke whales constitute genetically distinct populations (Kasamatsu et al. 1995; Van Pijlen et al. 1995).

North Atlantic

Minke whales are widespread and seasonally abundant in the North Atlantic (Stewart and Leatherwood 1985). The International Whaling Commission recognizes four North Atlantic stocks: Canadian east coast, west Greenland, central North Atlantic, and northeast Atlantic.

In the northwest Atlantic, distribution ranges from Davis Strait and Baffin Bay during the summer south to the Florida Keys and Gulf of Mexico (mostly immature animals), and West Indies during the winter (Stewart and Leatherwood 1985). In the spring and summer animals migrate north both inshore and in pelagic waters, reaching Nova Scotia by May and the northern Labrador coast by August (Katona et al. 1977). They are common in the Gulf of St. Lawrence, Newfoundland and southwest Greenland throughout the summer (Stewart and Leatherwood 1985), and are reported to migrate to offshore temperate waters in the winter (Stewart and Leatherwood 1985).

In the northeast, minkes migrate into Norwegian and adjacent Arctic waters as far north as Spitsbergen in the spring. They are rare in the Baltic Sea, but common in the inshore northern and western coastal waters of British Seas in the summer and early fall. In the fall they are believed to migrate south to temperate waters, where little is known of their distribution. It has been reported that the species separate by sex and age in the summer, with males migrating north in open seas and females remaining in more southern and coastal areas, and immature minke whales further south (Stewart and Leatherwood 1985).

North Pacific
Whales in both the eastern and western Pacific appear to migrate north along the coast in the spring and summer and south, offshore, during the fall and winter. In the northeast Pacific, minkes range from the Chuckchi Sea and Pt. Barrow, Alaska south to Islas Revillagigedos, Mexico (Stewart and Leatherwood 1985). They are common in the Bering Sea, Gulf of Alaska, Puget Sound, San Juan Islands, and Strait of Juan de Fuca during the spring and summer (Stewart and Leatherwood 1985). While some animals may be resident in the Puget Sound/San Juan Island (Dorsey 1983), they are also known to occur sparsely off central and northern California (Dohl et al. 1980). In the western Pacific minkes range from the Okhotsk to the Bering Seas and as far south as the Sea of Japan and the Yellow Sea (Stewart and Leatherwood 1985). A few records exist from the tropical Pacific.

Southern Hemisphere
Minkes are circumpolar between Antarctica and New Zealand, Argentina, central Chile, Brazil, Surinam, Angola, and Madagascar (Stewart and Leatherwood 1985). They are commonly associated with pack-ice and ice-free waters off Antarctica during the summer. Sightings and tag return data suggest that minkes migrate from temperate waters south to Antarctic waters in spring and summer, returning north towards South America, South Africa, and New Zealand in fall and winter (review by Stewart and Leatherwood 1985). Similar to migrations in the northern hemisphere, males appear to migrate further south than females, and immatures do not appear to travel as far south as either males or females. In addition, whaling records suggest that adult females migrate into southern waters later than males.

Abundance

North Atlantic
The population of minke whales in Norwegian waters has been estimated at 80,000 individuals (Schweder et al. 1993). The entire northeast Atlantic population has been estimated at 70,000 to 186,000 (best estimate = 113,000) individuals (Christensen and Rørvik 1981); and 60,500 – 117,500 (best estimate 86,736) individuals (Schweder et al. 1993). Estimates for the entire North Atlantic population are not available.

North Pacific
While Wada (1976) estimated the entire north Pacific stock at 9,000 whales, Ohsumi (1981) estimated the west Pacific minke whale stock alone to number between 17,000 and 28,000.

Southern Hemisphere
Estimates for the southern hemisphere stock range from 200,000 (Laws 1977) to 416,700 (Ohsumi 1979a).

Diet and Foraging Behavior

Similar to other *Balaenoptera* whales, minke whales in the Northern Hemisphere primarily feed on small schooling fish (Kawamura 1980; Gaskin 1982; Piatt et al. 1989; Haug et al. 1995; Haug et al. 1996; Tamura et al. 1998). However, in some regions (e.g. Okhotsk Sea, North Pacific, North Atlantic) schooling crustaceans are also taken (Omura and Sakiura 1956; Nemoto and Kawamura 1977; Haug et al. 1996). Dominant species taken in the North Atlantic include Gadoids, herring, mackerel, salmon, whiting, sprat, wolffish, pollack, haddock, capelin, *Thysanoessa* sp. (Stewart and Leatherwood 1985; Haug et al. 1995, 1996); dominant species taken in the North Pacific include Pacific saury, Japanese anchovy, euphausiids, copepods, and sand lance (Stewart and Leatherwood 1985; Tamura et al. 1998).

Lynas and Sylvestre (1988) studied minke whales foraging in the St. Lawrence River and described feeding maneuvers reflecting the type of prey (e.g. sub-surface circles and ellipses, surface lunges) and behaviors used to entrap prey (use of rock faces, currents, and the air/water interface).

Diving Behavior

When traveling minke whales surface once or twice before sounding (Horwood 1981), and are thus easily missed. Because they often feed on small schooling fish near the surface, dive depths are likely to be relatively shallow (less than 300 m). While feeding, they have been observed to drive schooling fish close to the surface. Folkow and Blix (1993) radio-tagged four minke whales and reported that surfacing rates were significantly higher during the day than at night. In addition, they speculated that the whales appeared to sleep for approximately 3 hours during the night. In a separate study, Folkow and Blix (1992) reported the respiratory frequency of minke whales as 0.76 breaths/min, with a low of 0.48 breaths/min in sleeping whales. Lynas and Sylvestre (1998) characterized 3 swimming patterns and related them to traveling, searching, and feeding.

Markussen et al. (1992) modeled the activity budget of minke whales and assumed that 6 h/day is spent in resting/sleeping, 14 h/day is spent swimming at 1.7 m/sec, and 4 h/day is spent swimming at 7.2 m/sec.

Social Behavior

Minke whales occur singly or in groups of two or three, although larger groups are regularly reported (Stewart and Leatherwood 1985). They have been known to approach boats (review by Stewart and Leatherwood 1985), confounding population estimates. As pointed out earlier, it appears that there are age- and sex-related differences in the seasonal distribution of minke whales.

Reproduction and Population Parameters

Conception occurs in the fall or winter, and calves are born approximately 10 months after conception (Stewart and Leatherwood 1985), and weaned 3-6 months later. Both males and females reach sexual maturity some time between 5-7 years. Ohsumi (1970) reported that males and females reach physical maturity at 18-22 years.

Breeding Areas

Breeding appears to take place during the winter in warmer waters, but little is known of breeding areas (Kasamatsu et al. 1995). However, for the Southern Hemisphere populations, Kasamatsu et al. (1995) suggested 4 breeding areas: 2 in the eastern and western south Pacific, and 2 in the eastern and western Indian Ocean. They also suggested that breeding populations are relatively dispersed in open waters.

Speed of Travel and Movements

Dorsey (1983) found that in the waters off Washington state some minke whales had exclusive home ranges. Normal swimming speed has been reported as 1.7 m/sec (Lockyer 1981). During migration, speeds up to 7.2 m/sec have been observed (Lockyer 1981).

Vocal Behavior

Minkes produce a variety of sounds in the 80-5000 Hz range. Most sounds during the winter consist of 10-60 s sequences of short 100-300 ms pulses (Schevill and Watkins 1972; Winn and Perkins 1976; Thompson et al. 1979; Edds 1980; Leatherwood et al. 1981; Mellinger and Clark 1998; Gademke pers. comm.). In the Northern Hemisphere, sounds recorded include low-frequency “grunts” (80-140 Hz, 165-320 msec duration), “thumps” (100-200 Hz, 50-70 msec duration), “ratchets” (850 Hz 1-6 msec duration), and “pings and clicks” at various frequencies (3.3 kHz-over 20kHz, 0.5-20 msec duration) (Winn and Perkins 1976). Thompson et al. (1979) speculated that “thump trains” contain individual signature information, although this is under debate (Clark pers. comm.). Beamish and Mitchell (1973) reported 4-7.5 kHz “clicks” repeated in 50, 200-click series at a rate of 6.75 clicks/sec. Schevill and Watkins (1972) recorded low-frequency FM downsweeps (130-115 to 60 Hz) lasting 200-300 msec. Edds (pers. comm. in Stewart and Leatherwood 1985) reported that nearly 80% of over 400 Minke calls recorded in the St. Lawrence River consisted of FM downsweeps (80-200 Hz to 10-70 Hz, 0.4 sec duration. However Edds also reported that sound production was infrequent. Sounds recorded in the Southern Hemisphere include “whistle series, clanging bell series, clicks, screeches, low-frequency grunts, and FM modulated sweeps” (Leatherwood et al. 1981).

The function of minke whale vocalizations is unknown, but they are assumed to be used for communication.

Hearing Range

No studies have directly measured the sound sensitivity of minke whales. Presumably minke whales are able to receive sound signals of the same frequency they are producing. In a study of the morphology of the mysticete auditory apparatus, Ketten (1997) hypothesized that mysticetes have acute infrasonic hearing.

Known Impacts of Human Activity

In addition to the direct effects of whaling harvest, indirect impacts of human activities include trophic impacts due to the collapse of human fisheries, such as herring and capelin in the North Atlantic (Haug et al. 1995).

Low levels of contaminants including heavy metals (Watanabe et al. 1998), and organochlorides (Aono et al. 1998) have been reported in minke whales.

ESCHRICHTIIDAE (GRAY WHALE)

GRAY WHALE (*ESCHRICHTIUS ROBUSTUS*)

Summary

Gray whales are the most coastal of all mysticetes. They are confined to shallow waters of the continental from the Bering and Chukchi Seas south to southern Japan in the west and the tip of Baja California in the east. They generally dive to the bottom in shallow water to feed on benthic amphipods. Every year most of the population makes a large north south migration from high latitude feeding grounds to low latitude breeding grounds. The north Atlantic population is extinct and the western Pacific population is endangered. The eastern Pacific population was severely reduced by commercial whaling, but has recovered to near pre-whaling numbers.

Gray whales produce and likely hear LFS. Observational and experimental data demonstrate that feeding and migrating individuals alter their short-term behavior in response to LFS. There are no data on the long-term effects of LFS on gray whales. Negative impacts of LFA on gray whales can likely be avoided by confining operations to deep waters. However, great care should be taken to avoid potential impact to the western Pacific population. Gray whale feeding and migration behavior is stereotypical and predictable making them ideal subjects with which to measure the impacts of LFS. Experimental play back studies have shown that gray whales avoid novel low frequency sound sources, including LFA sounds, when received levels are about 160 dB, or source levels are about 170 – 178 dB.

Protected Status

The north Atlantic population is extinct (Mitchell 1974). There are two extant populations of gray whales (*Eschrichtius robustus*) one in the western and one in the eastern Pacific. The western Pacific population is critically endangered and may be extinct (Jefferson et al. 1993). The eastern Pacific stock is a conservation success story. After being severely overexploited around the turn of the century they received protection from hunting in 1946 and their population has grown to the point where they were recently taken off the U. S. endangered species list. However, they are still protected by the U. S. Marine Mammal Protection Act. There is currently no commercial whaling for gray whales, and no subsistence hunting in the western Pacific population (Reeves and Mitchell 1988). The eastern Pacific population has had annual take of ~150 – 250 individuals per year for the benefit of indigenous people in the Russian and USA Arctic. The 1999 harvest by indigenous people in the Russian and USA Arctic is 120 and four respectively. This will be reduced to 60 and four respectively by 2004 (U. S. National Marine Fisheries Service Press Release).

Distribution

Gray whales are found only in the North Pacific and are the most coastal of all mysticetes (Jefferson et al.1993). They are essentially confined to shallow waters on the continental shelf (Reeves and Mitchell 1988).

In the western North Pacific they are found from the Straits of Korea and Seto Sea in the South, to the Sea of Okhotsk and Kamchatka Peninsula in the North (Reeves and Mitchell 1988). There appear to be two migratory routes for this population. One migrates along the east coast of Japan and possible calves off Seto Sea, while the other migrates along the coasts of Korea, Honshu, and Kyushu (Reeves and Mitchell 1988).

In the eastern North Pacific gray whales are found from the upper Gulf of California (Tershy et al. 1991), down to the mouth of the Gulf of California and up the Pacific coast from the tip of Baja California north, and up into the Chukchi Sea and eastern Siberian Sea (Jefferson et al. 1993). There is a pronounced seasonal north south migration (see movements and speed of travel below), but as the population continues to grow, there are likely to be a few individuals in most parts of the species range at any time of year.

Abundance.

The North Atlantic population was driven to extinction by Yankee whalers.

The western Pacific is severely depleted due to over hunting. It may have numbered several thousand whales at one time, and now numbers in the tens to low hundreds (Rice and Wolman 1971; Reeves and Mitchell 1988). Recent sightings of gray whales in the western Pacific may, however, be strays from the eastern Pacific population. Thus, it is possible that the Western Pacific population is extinct (Jefferson et al. 1993).

The eastern Pacific population has been well studied. Its decimation and subsequent recovery is a conservation success story. The population prior to commercial whaling was estimated at 10,000 – 30,000 (Scammon 1874; Henderson 1984). After the discovery of the breeding lagoons by whalers the population was rapidly decimated to fewer than 4,000 – 5,000 (Ohsumi 1976). After it was granted full protection in 1946 the populations started to recover. Since 1967 the population has been increasing at about 2.5% per year and in 1980 was estimated at 15,000 – 17,000 whales (Reilly 1984; Rugh 1984). Today it is estimated as over 20,000 and has been removed from the endangered species list.

Diet and Foraging Behavior

All data are from the eastern Pacific population. Gray whales feed primarily on benthic amphipods (Rice and Wolman 1971). They capture them by sucking amphipod filled sediment off the sea floor and then expelling the sediment and water through their baleen while retaining the amphipods (Oliver et al. 1984; Nerini 1984; Guerrero 1985). Most feeding takes place in the broad shelf of the Bering Sea, however there is considerable evidence of bottom feeding along the migratory routes (Nerini 1984). In addition to benthic amphipods, gray whales feed on a variety of other invertebrates including mysiids, euphausiids, and pelagic red crabs (Nerini 1984; Reeves and Mitchell 1988).

Gray whale foraging has a profound impact on the soft bottom benthic communities of the Bering Sea (Oliver and Slattery 1985). By sucking up amphipod filled sediment they alter the structure and species composition of the sea floor.

Diving Behavior

Gray whales are not deep divers. While foraging they typically dive to the bottom in shallow waters less than 80 m. Average dive times of foraging whales were 4 – 5 min. Gray whale diving behavior while traveling and feeding is stereotyped and predictable making them ideal subjects for experiments on the effects of LFA.

Social Behavior

Gray whales are often seen alone on the northern feeding grounds, although large aggregations are sometimes recorded. During migration lone individuals are also common, as are groups of they form groups of over 10 individuals. The mating system is thought to be promiscuous with males competing for temporary access to fertile females. There is no evidence of long-term associations between individuals other than females and their young.

Reproduction and Population Parameters

Age at sexual maturity is 6-8 years (Rice and Wolman 1971; Blokhin and Tiupeleyev 1987). Females give birth every second year. The peak of mating is in late November and early December. Estimated population growth rates are 2.5% per year.

Breeding Areas

Most gray give birth and mate in or near the shallow water hypersaline lagoons along the west coast of Baja California (Scammon 1874). Although some gray whales mate and give birth near lagoons in the eastern Gulf of California, or along the migration route, the Baja California lagoons are critical habitat for the gray whale.

Speed of Travel and movements.

Migrating gray whale adults travel about 6 – 8 km/hr. Females with calves travel about 4–5 km/hr. Radio tagged adults traveled about 85km/day during the northern migration. Daily distance traveled was greater further north than it was in Baja California and southern California (Mate and Harvey 1984). Gray whales make the longest annual migration of any mammal. Most of the population migrates from summer feeding grounds in the Bering Sea to winter breeding lagoons on the Pacific Coast of Baja California, Mexico- a round trip of 18,000km. The timing and main migratory paths are well known over much of the migratory range (see chapters in Jones et al. 1984). On the northern migration females with young return latter in the season and migrate closer to shore than do adults without young (Poole 1984).

Vocal Behavior

Gray whales produce a variety of sounds between 15Hz and 20kHz (Dahlheim et al. 1984; Moore and Ljungblad 1984). The most common sounds are knocks and pulses with frequencies from <100 Hz–2 kHz, with most energy between 327 and 825 Hz

(Richardson et al. 1995). The source level for some of these sounds was –142 dB re 1 uPa-m (Cummings et al. 1968).

Hearing Range

No data.

Known Impacts of Human Activity

As discussed above, past hunting has decimated two populations of gray whales and caused the extinction of a third. Gray whales are now protected from non-sustainable hunting. Entanglement in fishing gear, particularly nets is a source of mortality that has likely increased steadily since the 1950's (Norris and Prescott 1961; Talbot 1985; IWC 1986; Reeves and Mitchell 1988). There is mixed evidence on the impacts of whale watching boats, but this is now relatively well regulated (Sánchez pers. comm.). Past and proposed industrial development in and adjacent to the breeding lagoons may have a negative impact on gray whales (Sánchez pers. comm).

Gray whales have been observed to change course or slow down in response to playbacks of the higher frequency components of a large helicopter (Malme et al. 1983). Observations from aircraft suggest that animals, especially females with young, reacted to small planes flying at 335 m (Clarke et al. 1989).

In the breeding lagoons gray whales rarely respond negatively to slow moving boats and there is some evidence that whales habituate to the close proximity of boats during the breeding season (Swartz 1986). However, gray whales stopped using one of the breeding lagoons when dredging and ship traffic started and returned to the breeding lagoon several years latter when these noise sources had stopped (Bryant 1984). Furthermore, Dahlheim (1984) noticed a decrease in numbers in one of the breeding lagoons after a long period of play back experiments, with number returning to normal in the following year when play back experiments were not resumed.

Migrating gray whales slowed or turned away from airgun pulses when received levels were more than 160 dB re 1 µPa (Malme et al. 1984). Gray whales on the summer feeding grounds avoided air guns when received levels were 163dB (Malme et al. 1986; 1988). Migrating gray whales showed very similar responses to LFA playbacks with source levels of 170 and 178 dB (Tyack and Clark 1998).

BALAENIDAE (RIGHT WHALES)

BOWHEAD WHALE (*BALAENA MYSTICETUS*)

Summary

Bowhead whales (*Balaena mysticetus*) are large mysticetes with populations that have not recovered from heavy exploitation, but populations are slowly recovering. Although they appear to dive deeper than other members of their family, they are not deep divers. Rather, they are slow moving, migratory whales that feed primarily on plankton. They are found only in arctic and subarctic regions. Distribution and movement patterns have been relatively well studied. All recorded sounds known from this species are less than 3,500 Hz in frequency. The function of their sounds remains unknown.

Its endangered status, low population growth rate, and apparent reliance on low-frequency sounds make this species susceptible to negative impacts of LFA. On the other hand, its restricted distribution makes the species less vulnerable to LFA than other cetacean species. Since distribution and movements of bowhead whales are relatively well-known, it may be possible to quantify any negative impacts of LFA activity.

Protected Status

The bowhead whale is federally listed as endangered under the U. S. Endangered Species/Marine Mammal Protection acts (kingfish.ssp.nmfs.gov/tmcintyr/spec_idx.html). It is listed as a lower risk/conservation dependent species by the Cetacean Specialist Group of the International Union for the Conservation of Nature (www.wcmc.org.uk/data/database). It has been commercially exploited for centuries. It had a circumpolar distribution into four or five stocks (Rice 1977b; Mitchell and Reeves 1982). The Bering-Chukchi-Beaufort Seas stock, also known as the western Arctic stock, is the largest extant stock (IWC 1984) and is estimated to be between 25% and 77% of its historic carrying capacity (Angliss et al. 1998). Recent data indicate that this stock is increasing at a healthy rate (Zeh et al. 1995; Raftery and Zeh 1998). Average length of harvested adult females and males have also increased, a result consistent with a model of an increasing population with density dependent reproduction and juvenile survival (Angliss et al. 1998). The stock has rebounded from close to 1,000 animals present when commercial whaling ended in the western Arctic around 1917 (Eberhardt and Breiwick 1980). At least 18,000 individuals were harvested from this stock during the whaling years 1848-1915 (Bockstoce and Botkin 1983). In 1993, subsistence hunters landed 41 whales from this stock (George et al. 1995). Commercial whaling on the Baffin Bay/Davis Strait stock ended in about 1915, but occasional killing continued until as recently as the 1970s (Reeves and Heide-Jørgensen 1996). Prehistoric Thule Eskimo hunters selected yearlings and two- to three-year-old subadults, to the almost complete exclusion of calves and adults (McCartney and Savelle1993). The current world population is threatened by small-scale hunting by Alaskan, Canadian and Russian natives, and by various forms of habitat degradation, including disturbance from oil and gas exploration (review by Jefferson et al. 1993).

Distribution

Bowhead whales are found only in arctic and subarctic regions, from 54° to 85°N (review by Moore and Reeves 1993). These whales live much of their lives among the pack ice, migrating to the high arctic in the summer, but retreating southward in winter with the advancing ice edge (review by Jefferson et al. 1993).

Bowheads have been assigned into five stocks: the Bering-Chukchi-Beaufort seas, the Okhotsk Sea, the Davis Strait, the Hudson bay, and the Spitsbergen (review by Moore and Reeves 1993). The Bering-Chukchi-Beaufort Seas stock moves west and south from the Beaufort and Chukchi Seas to winter in the Bering Sea, probably mainly off Siberia but also around the St. Lawrence and St. Matthew Islands, and perhaps in the Sea of Okhotsk (review by Evans 1987). During their westward migration each autumn, whale distribution overlaps oil and gas lease area boundaries around Point Barrow, Alaska, particularly in nearshore sub-blocks east, north, and southwest of Point Barrow (Moore and Clarke 1993). Also during autumn, two important feeding areas appear to be the Chukotka coast, Russia, and areas near and east of Point Barrow (Landino et al. 1994; Moore et al. 1995). Migration occurs in three or four pulses, and follows ice leads close to the coast through the Bering Strait into the Chukchi Sea and then past Point Barrow, Alaska, into the Beaufort Sea (review by Evans 1987). Whales reach Cape Bathurst and he Amundsen Gulf as early as May, but elsewhere the late break up of the ice prevents them from using the Mackenzie Delta and the coast of Yukon until late July (review by Evans 1987). In Russia, part of the bowhead whale population of the Bering-Chukchi-Beaufort Seas stays for the summer in the Chukchi Sea, as suggested by the long period of spring migration along the coast of the Chukotski Peninsula, their regular occurrence in the western part of the Chukchi Sea in early summer, and the autumn migration to the coast of Chukotka from the northwest (Mel'nikov et al. 1998). An acoustic study off Point Barrow, Alaska, on the Bering-Chukchi-Beaufort Sea bowhead whale population shows that throughout the 1993 migration period 86% of the vocalizing animals were within 4km of the nearshore ice edge (Clark et al. 1996). There is variability in selection of habitat by bowheads in Northern Alaska (Moore 1998). In summer they occur in continental slope waters and moderate ice conditions, in autumn they occur in inner shelf waters and light ice conditions (Moore 1998).

The Davis Strait stock inhabits Davis Strait, Baffin Bay, and their adjoining sounds and inlets (review by Moore and Reeves 1993). These whales have historically wintered in Baffin Bay and Davis Strait, including waters along the west coast of Greenland in and near the entrance of Disko Bay (Reeves and Heide-Jørgensen 1996; Richard et al. 1998). During the spring migration, there are potentially three migration routes used by bowhead whales to enter Foxe Basin, Canada; once in northern Foxe Basin, bowheads aggregate in a well-defined area north of Igloolik Island (Cosens et al. 1997).

The Hudson Bay stock lives in northwestern Hudson Bay and northern Foxe Basin, having a disjunct summer distribution with the Davis Strait stock (review by Moore and Reeves 1993). The Spitsbergen stock inhabits the Greenland and Barents seas, it remains severely depleted (review by Moore and Reeves 1993).

Abundance

Population size is estimated as 8,000-8,200 bowhead whales (95% CL= 6,900-9,200) for the Bering-Chukchi-Beaufort Seas stock (Zeh et al. 1995; Raftery and Zeh 1998). The annual rate of population increase is estimated at 3.2% (95% CL= 1.4-5.1%) from 1978 to 1993 (Raftery and Zeh 1998). However, recent evidence suggests that bowhead whale counts at Cape Barrow are underestimated and do not reflect the abundance of the entire population (Mel'nikov et al. 1998).

The current Davis Strait/Baffin Bay stock stock size is a small fraction of what it was prior to commercial whaling (Reeves and Heide-Jørgensen 1996). Based on two aerial surveys, the number of bowheads present at the surface in northern Foxe Basin in August of 1994 was 256 ± 31.3 and 284 ± 48.6 whales (Cosens et al. 1997). Bowhead whales have apparently become rarer off Coast Island, Canada, with only two sightings since 1981, compared to several annually in the 1920s (Gaston and Ouellet 1997). Aerial surveys of the Disko Bay region during late winter (1981, 1982, 1990, 1991, 1993 and 1994) showed that it was still visited regularly by a few tens of whales (Reeves and Heide-Jørgensen 1996). The low numbers of bowheads observed off West Greenland in recent years are consistent with the results of surveys of the summering grounds in the eastern Canadian Arctic, indicating that any recovery has been exceedingly slow (Reeves and Heide-Jørgensen 1996).

Diet and Foraging Behavior

Bowhead whales eat mostly copepods, but they also feed on euphasiids, mysids, amphipods, isopods, and pteropods (Gaskin 1976, 1982; Lowry and Frost 1984).

They feed primarily by skimming with their mouths open through surface concentrations of plankton (Lowry and Frost 1984). They have been observed feeding alongside one another in a V formation, feeding on or near close to the bottom, feeding in the water column, and stirring the mud with their tails in shallow water (Fraker and Würsig 1981; Würsig et al. 1984a,b, 1986; Landino et al. 1994). During surface skim feeding, coordinated group patterns have been observed, including whales feeding in V-shape formation (Würsig et al. 1984b, 1986).

Bowhead whale distribution has coincided with physical oceanographic fronts in feeding areas (Moore et al. 1995). In the Great South Channel area in the southern Gulf of Maine, northern right whales tend to concentrate near the leading edge of low-salinity plumes where copepods are more abundant (Kann and Wishner 1995). In addition, whales apparently prefer regions in which a particular type of copepod is more abundant (Kann and Wishner 1995).

Diving Behavior

Bowhead whales can dive as deep as 455 m (Krutzikowsky and Mate 1993). Diving characteristics of whales from the Davis Strait stock include time at surface, 1.5 min per surfacing; number of blows per surfacing, 6.0; mean blow intervals, 17.1; and mean dive time, 9.3 min (Würsig and Clark 1993). Diving characteristics of whales from the Bering-Chukchi-Beaufort Seas stock include time at surface, 1.7 min per surfacing;

number of blows per surfacing, 6.5; mean blow intervals, 17.2; and mean dive time, 18.2 min (Würsig and Clark 1993).

Social Behavior

Bowhead whales are usually seen in groups of three or fewer, but larger aggregations for during the autumn migration and on the feeding grounds (review by Jefferson et al. 1993). Based on aerial photogrammetric techniques, the length structure of the Bering-Chukchi-Beaufort Seas stock of the bowhead whale population is 41.1% adults, 53.7% juveniles, and 5.2 % calves (Angliss et al. 1995).

Females are slightly larger than males, the mean length at sexual maturity of males is 0.95 times that of females (Lockyer 1984). The breeding system of this species is thought to be similar to that of other members of the family, with males using a form of sperm competition (review by Jefferson et al. 1993).

Reproduction and Population Parameters

Females are sexually mature between 12.2 and 14.2 m (Lockyer 1984; George et al. 1998). Males appear to reach sexual mature between 12.6 and 13.6 m (George et al. 1998). Gestation period is estimated at about 13-14 months, and lactation may occur for at least one year (Nerini et al. 1984). Based on photogrammetry, Koski et al. (1993) suggested a lactation period of nine to 12 months. Pregnancy rate is estimated at 0.15 and calving interval is about once every three to six years (Nerini et al. 1984). More recently, pregnancy rate for the period 1973 to 1993 as determined by the recovery of fetuses from landed whales was estimated at 22.2-35% (George et al. 1995). Gross annual reproductive rate has been estimated at 3.6 % (Nerini et al. 1984).

Breeding Areas

For the Bering-Chukchi-Beaufort Seas stock, mating and calving occurs in spring and early summer during the early stages of the migration northeast (Evans 1987). Conception probably occurs in late winter while the whales aggregate in the Bering Sea, but may extend into May (Nerini et al. 1984). Calving season may extend from March to August but probably peaks in May (Nerini et al. 1984).

Speed of Travel and Movements

Migratory travel appears to be at a mean speed of 4.7 ± sd 0.60 km/h and as low as 3.1 ± sd 2.7 km/h (Braham et al. 1980b; Rugh and Cubbage 1980).

Vocal Behavior

Bowhead whales produce sounds between 20 and 3,500 Hz, with dominant frequencies from 100-400 Hz (Ljunblad et al. 1982a; Clark and Johnson 1984; Würsig et al. 1985; Cummings and Holliday 1987; Würsig and Clark 1993). Most calls are tonal frequency-modulated (FM) sounds at 50-400 Hz (Clark and Johnson 1984; Würsig and Clark 1993). Single notes may be as short as 0.4 s and as long as 3.7 s, most last about 1 s (Ljungblad et al. 1982a; Würsig et al. 1985). They also produce various nonvocal and slap sounds (Würsig et al. 1989; Würsig and Clark 1993).

Peak to peak source levels as high as 189 dB (re: 1uPa @ 1 m) have been measured (Ljungblad et al. 1982a). However, source levels of simple moans range from about 128 to 178 dB re: 1 μPa @ 1 m (Clark et al. 1986; Cummings and Holliday 1987). A few calling bowheads are detectable up to 20 km away, most are less than 10 km away (Cummings and Holliday 1985; Davis et al. 1985; Clark et al. 1986).

Bowhead whales sing during spring migration (Ljungblad et al. 1982a; Cummings and Holliday 1987; Würsig and Clark 1993). Song notes are longer, have a broader frequency range, and show more FM and amplitude-modulated variation than calls (Würsig and Clark 1993). In general, there is little conclusive evidence of associations between specific sounds and behaviors for bowhead whales (Würsig and Clark 1993). Thus, functions of bowhead calls remain unknown.

Hearing Range

Based on behavioral responses to airgun pulses and underwater playbacks of man-made sounds, bowhead whales can listen to sounds with dominant components in the 50- to 500-Hz (review by Richardson et al. 1995). However, data are limited by background noise, actual hearing thresholds may be lower (Richardson et al. 1995).

Known Impacts of Human Activities

Reactions of bowheads to aircraft are variable, apparently depending on behavioral state an habitat (review by Richardson et al. 1995). Bowheads begin to avoid approaching diesel-powered vessels 4 km or more away (Richardson et al. 1985b,c; Koski and Johnson 1987). In one case, the received level near fleeing whales (range 4 km) was only about 84 dB (re: 1 μPa @ 1 m) in the dominat 1/3-octave band, or about 6 dB above ambient in that band (Koski and Johnson 1987). Bowhead whales are more tolerant of vessels moving slowly or in directions other than toward the whales (Richardson and Finley 1989; Wartzok et al. 1989). Some whales tolerated received levels up to 110-115 dB re: 1 μPa @ 1 m (Wartzok et al. 1989). As with aircraft, the reaction to boats might depend on their behavioral state (Wartzok et al. 1989). About 1% of bowhead whales of the Bering-Chukchi-Beaufort Seas stock harvested by Alaskan Eskimos exhibits scars from ship collisions; however, occurrence of ship strikes has not prevented the stock from increasing in size (George et al. 1994).

It is unclear whether rate of bowhead calls declines in the presence of drilling noise (Richardson et al. 1995). However, there is data suggestive that migrating bowheads divert from drillsites when they are more than 20 km away; noise at 10 km, where most if not all whales react, averaged 114 dB broadband and 104 dB (re: 1 μPa @ 1 m) in the two 1/3-octave bands with strongest noise (review by Richardson et al. 1995). In general, bowheads in spring, summer, and autumn often tolerate drilling sounds whose received levels are well above the ambient level; however, when the received level becomes high enough, avoidance reactions occur (review by Richardson et al. 1995). Most bowheads show strong avoidance when an operating seismic vessel is within six to eight km; however, effects at distances as 24 km have been recorded (review by Richardson et al. 1995).

Whales seem to tolerate pulse seismic sounds more than continuous ones, such as those from vessels, dredging, drilling, or oil production (review by Richardson et al. 1995). Bowheads flee when received noise levels are 150-180 dB (re: 1 μPa @ 1 m), much higher than the levels of continuous sounds at which whales react, and sometimes show no overt reactions to noise pulses from ships six to 25 km away (review by Richardson et al. 1995).

NORTHERN RIGHT WHALE (*EUBALAENA GLACIALIS*)

Summary

Northern right whales (*Eubalaena glacialis*) are large mysticetes that have not recovered from heavy exploitation, being the most endangered large whale in the world. They do not appear to be deep divers, rather they are slow moving, migratory whales that feed on plankton. They are distributed primarily in temperate and subpolar waters of the Northern Hemisphere, mostly in the northwestern Atlantic. The distribution and fine-scale and large-scale movements of the northwestern Atlantic population have been relatively well studied. The species has very low reproductive and population growth rates. The few sounds known from this species are less than 400 Hz in frequency. Sounds are apparently used to maintain acoustical contact.

Although this species does not appear to be a deep diver, its low abundance, low population growth rate, and apparent reliance on low-frequency sounds make it a very susceptible species to any negative impacts of LFA. Since their distribution and movements are relatively well known, it may be possible to quantify any negative impacts of LFA activity, at least in the northwestern Atlantic population.

Protected Status

The northern right whale is federally listed as endangered under the U. S. Endangered Species/Marine Mammal Protection acts (kingfish.ssp.nmfs.gov/tmcintyr/spec_idx.html). It is also listed as endangered by the Cetacean Specialist Group of the International Union for the Conservation of Nature (www.wcmc.org.uk/data/database). Northern right whales are the most endangered large whale in the world and show few signs of recovery despite over 60 years of protection; in contrast, the South Atlantic right whale (*E. australis*) appears to be recovering successfully (Schaeff et al. 1997). The population growth rate reported for the North Atlantic population is only 33% of that reported for South Atlantic right whales (Brown et al. 1994). Several factors appear to influence the recovery of the North Atlantic right whale; they exhibit significantly less genetic variation, fewer actively reproducing females and lower reproductive rates of some females than South Atlantic right whales (Brown et al. 1994; Schaeff et al. 1997). Apparently, exploitation reduced genetic variation in northern right whales (Rosenbaum et al. 1998). Taken together, data indicate that North Atlantic right whales may be suffering from reduced fertility, fecundity, and juvenile survivorship, and support the hypothesis that inbreeding depression is influencing the recovery of this species (Schaeff et al. 1997). The hypothesis that interspecific competition has affected the recovery of northern right whales appears to be unsupported by most recent data (Clapham and Brownell 1996). Northern right whales were the first targets of commercial whaling, starting in the 11th century (Jefferson et al. 1993). They were common across the North Pacific and North Atlantic oceans; however, they were almost exterminated in the Pacific as a result of intense commercial whaling in the 1800s, and in the Atlantic by a millenium of whaling before the end of the 19th century (Harmer 1928; Brown 1986; Brueggeman et al. 1986; Reeves and Mitchell 1986; Scarff 1986, 1991). The species received international protection since 1935 (Brownell et al. 1986); however, whaling continued until the 1960s (Klumov 1962 in Goddard and Rugh 1998; Omura et al. 1969; Yablokov 1994).

Distribution

Northern right whales are distributed primarily in temperate and subpolar waters of the Northern Hemisphere (review by Jefferson et al. 1993). They are found in general between 70°and 23°N, along the shores of Europe, America, and Asia (review by Jefferson et al. 1993). There are, however, extralimital records from Hawaii, the Gulf of Mexico, and the Canarias (Herman et al. 1980; review by Jefferson 1993).

Right whales are very rare in the North Pacific and the northeastern Atlantic (Scarff 1986; Leatherwood et al. 1988a; Martin and Walker 1997). In the North Pacific, the southeastern portion of the Bering Sea has apparently been one of the habitats preferred by the species, specially in the area centered around 170°W between Atka, St. Matthew, and Nunivak islands (Omura 1958; Omura et al. 1969; Berzin and Doroshenko 1982; Scarff 1991). Recently one calf was possibly sighted among a group of whales in the northeastern Pacific (Goddard and Rugh 1998). The latest confirmed sighting of a calf in the northeastern Pacific was made 150 years ago (Goddard and Rugh 1998). In the northwestern Pacific, four groups of right whales were recently sighted around the Ogasawara Islands, Japan, a winter whaling ground in the early 1900's (Mori et al. 1998).

The two North Atlantic populations are presumably isolated from each other, and the eastern stock is thought to be extinct (Jefferson et al. 1993). However, there are records of right whales from the Cantabrian and Galician coasts, Spain, during the period 1981-1990 (Cendrero 1993). More recently, an adult and a calf were sighted off Cape St. Vincent, Portugal, being perhaps the first record off mainland Europe in this century (Martin and Walker 1997). It is unknown whether the pair belongs to the northeastern Atlantic population or to the northwestern Atlantic population (Martin and Walker 1997). Northwestern Atlantic right whales probably represent a single breeding population (Schaeff et al. 1993).

Right whales in the northwestern Atlantic are distributed primarily between Florida and Nova Scotia aggregating seasonally in five known geographical areas: southeast USA, Bay of Fundy, Great South Channel, Massachussetts Bay, and Brown-Baccaro Banks, the latter four are feeding areas during spring, summer and fall (Brown et al. 1998). The first area, between Savannah, Georgia, and West Palm Beach, Florida, is used in the winter for calving, with an area of high-density occurring between Brunswick, Georgia, and St. Augustine, Florida (Slay and Kraus 1998). There is data to support the hypothesis that calving right whales reside in areas of heavy shipping traffic for longer than they do in other areas of their winter range (Slay and Kraus 1998). The four feeding areas are used during spring, summer, and fall for feeding and nursing (Kraus and Slay 1998). However, this migration pattern is restricted to pregnant and calving females, a few juveniles and rarely adult males; and it is thought that the remainder adult males stay in northern waters, possibly offshore (Kraus and Slay 1998). Migrating whales move constantly and their routes come very close to shore (Slay and Kraus 1998). Whales are not randomly distributed among their five aggregation areas, cow-calf pairs predominate off the southeast USA, Bay of Fundy, and Massachussets Bay; adults predominate in the Great South Channel; and males are more abundant than females in the Brown-Baccaro Banks (Brown et al. 1998). Northern right whales typically strand during the winter and spring months in North Carolina, as they migrate along the coast (Webster et al. 1995). During the summer, the Bay of Fundy is the only known nursery area and one of the essential feeding areas of northwestern Atlantic right whales (NMFS 1991 in Woodley and Gaskin 1996; Schaeff et al. 1993). In the Bay of Fundy, six individuals tracked by satellite for more than 12 days left the bay at least once (Mate et al. 1997). Three of these whales traveled more than 2,000 km each before returning to the general tagging area, and one adult female with a calf went to New Jersey and back to the bay (3,761 km) in 42 days (Mate et al. 1997).

A study of satellite-tagged whales in and around the Bay of Fundy showed that whales were typically located along bank edges, in basins or along the continental shelf; mostly in water 182 m deep (Mate et al. 1997). They were located in or near shipping lanes, and their distribution coincided with areas intensively used by humans for fishing, shipping, and recreation (Mate et al. 1997). One whale appeared to spend time at the edge of a warm core ring and others spent extended periods in upwellings (Mate et al. 1997).

During the summer of 1997 in the southeast Bering Sea, North Pacific right whales shifted their distribution from their historical pattern on the shelf edge to an extensive coccolithophore bloom developed over the middle shelf in response to warm waters (Tynan 1998).

Abundance

The North Pacific and northeastern Atlantic populations appear to be nearly extinct (Brown 1986; Scarff 1986). There is no accurate abundance estimate for the North Pacific population; however, there may be only a few hundred whales (Braham 1986). It is estimated that 16 right whales (95% Bootstrap CL= 0-59) were present in California during winter/spring of 1991/1992 (Forney et al. 1995). Estimated density was 0.0001 whales/km^2 (Barlow 1995).

Although the northwestern Atlantic population has fared better than the other two populations, there is no evidence that the population is increasing at a large rate (CETAP 1982; Kraus 1985 in Kraus 1990). It is estimated that 295-300 right whales, at most less than 350 individuals, comprise this population (Knowlton et al. 1994; Kenney et al. 1995; Slay and Kraus 1998). The reproductively active female pool remained static at approximately 51 animals from 1987 to 1992 (Knowlton et al. 1994). Gross annual reproductive rate, population growth rate, and mortality rate have been estimated to be 4.5%, 2.5%, and 2.0%, respectively (Knowlton et al. 1994).

Diet and Foraging Behavior

Northern right whales feed on a variety of copepods as well as euphasiids (Omura 1958; Omura et al. 1969). They generally feed by slowly skimming through patches of concentrated prey at or near the surface (Jefferson et al. 1993).

Diving Behavior

Northern right whales dive as deep as 306 m (Mate et al 1992). In the Great South Channel, average diving time is close to two min; average dive depth is 7.3 m with a maximum of 85.3 m (Winn et al. 1994). In the U.S. Outer Continental Shelf the average diving time is about 7 min (CETAP 1982).

Social Behavior

Northern right whales are mostly seen in groups of less than 12, most often singles or pairs (review by Jefferson et al. 1993). Larger groups may form on feeding or breeding grounds (review by Jefferson et al. 1993). In the North Pacific, most recent sightings have been of singles or pairs; however, two groups numbering six to ten and more than three whales were sighted in the northeastern Pacific (Goddard and Rugh 1998).

Based on photoidentification techniques, the population structure of northwestern Atlantic right whales is estimated as 61% adults, 28% juveniles and 11 % unknown (Hamilton et al. 1998). This population can be divided into two subgroups based on their use of the Bay of Fundy nursery (Schaeff et al. 1993). Approximately two-thirds of reproductive females use the Bay of Fundy nursery, while one-third does not; in contrast, males are less philopatric than females (Schaeff et al. 1993). Animals from the two subgroups have been seen on the southern Scotian shelf, where most right whale courtship behavior was observed in the study (Schaeff et al. 1993).

Females are larger than males, the modal length of mature males is 0.92 times that of females (Omura 1958). Male right whales have huge testes and long penises, two characteristics predicted in species in which males compete for females primarily through sperm competition, rather than by direct aggression (review by Jefferson et al. 1993).

Reproduction and Population Parameters

Gestation period is ten months and the calving interval is usually three years, but it can be two or four years (review by Evans 1987). Like other mysticetes, right whales are weaned sometime near the end of their first year, varying from eight to 17 months (Hamilton et al. 1995). Based on photoidentification techniques, mean age at first parturition of northwestern Atlantic right whales has been estimated at 7.57 years (Knowlton et al. 1994). The mean calving interval of 3.67 years is significantly longer than the South African southern right whale population, but not different from the Argentine population (Knowlton et al. 1994). Five individual northern right whales have documented reproductive spans ranging from three to 27 years (Hamilton et al. 1998). Apparently, the longest sighting history of any wild mammal is a female northern right whale sighted over a 60-year period between 1935 and 1995 (Hamilton et al. 1998).

The most unbiased estimate of sex ratio in northwestern Atlantic right whales is 1.06:1 in favor of males (Brown et al. 1994). Only 38% of the females in this population have been reproductively successful compared with 54% in the population of southern right whales in the southwestern Atlantic (Brown et al. 1994). In addition, 13 adult North Atlantic females have been identified that have not been known to calve during the past 11 years (Brown et al. 1994).

Breeding Areas

Bowhead whales calve off the northeast coast of Florida and off southeastern Georgia from November to March (review by Evans 1987).

Speed of Travel and Movements

Six whales tracked by satellite outside the Bay of Fundy had higher average speeds (high vinculum x= 3.5 km/hr) than those that stayed within the bay (high vinculum x= 1.1 km/hr) (Mate et al. 1997).

Vocal Behavior

Limited data indicate that northern right whales produce moans of less than 400 Hz in frequency (Watkins and Schevill 1972; Thompson et al. 1979; Spero 1981). Apparently, whales use low frequency sounds as contact calls while summering in the Bay of Fundy (Spero 1981).

Hearing Range

No data available.

Known Impacts of Human Activities

Slowly moving boats are typically able to approach right whales; however, a fast moving boat will cause the whales to move away (Watkins 1986; Goodyear 1989, 1993; Brown et al. 1991). Close passage of small whales does not disturb whales if feeding and mating, as long as the there is no abrupt change in course or engine speed (Goodyear 1989; Mayo and Marx 1990). Due to their slow-moving trait, these whales are not very successful in avoiding collisions, thus ships strike many right whales and kill some (Brownell et al. 1986; Kraus 1990; Kenney and Kraus 1993). It has been suggested that approximately one third of right whale mortality in the northwestern North Atlantic is caused by human activities, namely ship collisions and entanglements (Kraus 1990). Preliminary results indicate that 58.1% of the northwestern Atlantic population have scarring caused by entanglement (45.5% males, 40.7% females, 13.9% undetermined sex) and 4.8% carry propeller wounds (33% males, 67% females; Marx et al. 1998). Slay et al. (1993) indicated that a vessel speed limit of less than 9 km/h may reduce collisions.

A light single-engine aircraft appears to be tolerated by right whales, as suggested by feeding observations made by Watkins and Schevill (1976, 1979). However, some disturbance may occur when the aircraft is below 150 m (Watkins and Moore 1983). Northern right whales did not react to sonic tags at 50 kHz (Goodyear 1993). There is no data on the reaction of right whales to dredges, including impact on number of whales present.

SOUTHERN RIGHT WHALE (*EUBALAENA AUSTRALIS*)

Summary

Southern right whales (*Eubalaena australis*) are large mysticetes that are slowly recovering from heavy exploitation. They are not regarded as deep divers, rather they are slow moving, migratory whales that feed only on small plankton, particularly copepods. Southern right whales are found throughout the Southern Hemisphere. Like most large mysticetes, they appear to have a low reproductive rate. All sounds known from this species are less than 2,200 Hz in frequency. Sounds are used to bring groups together and apparently to maintain acoustical contact.

Although this species is not a deep diver, its endangered status and reliance on low-frequency sounds make it a very susceptible species to any negative impacts of LFA. Since their distribution and large-scale movements are relatively well known, it may be possible to quantify any negative impacts of LFA activity.

Protected Status

The southern right whale is federally listed as endangered under the U. S. Endangered Species/Marine Mammal Protection acts (kingfish.ssp.nmfs.gov/tmcintyr/spec_idx.html). It is listed as a lower risk/conservation dependent species by the Cetacean Specialist Group of the International Union for the Conservation of Nature (www.wcmc.org.uk/data/database). The total population may have exceeded 100,000 before commercial exploitation on a major scale began in the late 18th century (Mackintosh 1965; reviews by Leatherwood et al. 1983a; Evans 1987). The species was hunted extensively along the coasts of New Zealand from the beginning of the 19th century onward, with peak whaling from shore stations in the late 1840s (Dawbin 1986). Prior to exploitation the New Zealand population is estimated to have included more than 10,000 individuals (Richards 1994 in Patenaude et al. 1998). In South Africa, 67 whales were taken between 1908 and 1930 (Best 1994a). Due to severe depletion the species became fully protected internationally in 1935 (review by Evans 1987). However, at least 3,349 right whales in the southern Hemisphere were hunted illegally from 1950 to 1971 (Yablokov 1994; Zemsky et al. 1995). This may explain why breeding populations showed no measurable signs of recovery until the last 30 years (Whitehead et al. 1986; Bannister 1990; Best 1990).

Distribution

Southern right whales are distributed throughout the Southern Hemisphere, from approximately 17° to 55°S, although they have been observed as far south as 63°S (review by Jefferson et al. 1993; Lodi et al. 1996).

Southern right whales migrate from high latitude feeding areas to lower latitude breeding grounds during the winter, where the distribution centers along coastlines, except Tristan da Cunha, Brazil. However, their migrations seem much less extensive, regular and coherent than those of other baleen whales (reviews by Leatherwood et al. 1983a; Evans

1987). They are most likely to be encountered at latitudes lower than 50° during winter, and at latitudes higher than 40° during spring, summer, and fall, but in the middle parts of their range, 40°-50°, they can be encountered in any season (review by Leatherwood et al. 1983a). The migration streams of the southern right whale are quite widely separated from one another, with most of the main zones of winter concentration adjacent to land masses (Townsend 1935). It has been suggested that the distribution of southern right whales has shifted approximately 10° southwards since the 19th century (Best et al. 1998). Summer feeding grounds are not well known, although historically they were found in the Southern Ocean around subantarctic islands such as South Georgia, and around the Crozet and Kerguelen islands (review by Evans 1987). Southern right whales are the commonest large whales around South Georgia, a highly productive former whaling ground in the sub-Antarctic (Moore et al. 1998). At least two individuals from Argentina have been resighted in the feeding area of South Georgia (Moore et al. 1998).

Resightings of individuals from different areas suggest that the potential for intermingling between populations on either side of the South Atlantic seems greater than previously considered (Best et al. 1993). However, genetic analyses indicate that whales from Peninsula Valdes and whales from South Africa should be considered distinct stocks (Marshall-Tilas et al. 1998; Portway et al. 1998).

Abundance

Worldwide estimates range from 1,500-3,000 whales (Doi et al. 1971; Best 1974; Masaki 1979) to around 3,000 whales (review by Evans 1987).

Populations wintering along the coasts of Australia, South Africa and South America are reported to be increasing (Bannister 1990; Best 1990; Payne et al. 1990). Although total counts in South Africa have increased by a best estimate of 6.8% per year (95% CL: 4.6-9.0%) from 1971 to 1987, some concentration areas have failed to show an increase, apparently due to a shift to the main nursery areas to the west, off De Hoop (Best 1990). Sightings are infrequent along the coasts of New Zealand (Cawthorh 1995 in Patenaude et al. 1998). However, at least 96 whales have been observed in the Auckland Islands in August (Stewart in Patenaude et al. 1998).

Diet and Foraging Behavior

Right whales feed on small plankton (review by Gaskin 1982). They prey preferably on copepods (*Calanus* sp.), but also on euphasiids, including the large (55-65 mm) *Euphausia superba* (Mackintosh 1974; Gaskin 1976, 1982). They apparently shun fish and the larger invertebrates altogether (review by Leatherwood et al. 1983a). Surface and subsurface skim feeding is the rule in this species; however, sometimes they feed near the bottom (reviews by Gaskin 1982; Jefferson et al. 1993).

Carbon isotope ratios from whales off South Africa indicated feeding north of or at the Subtropical Convergence (STC), alternating with feeding south of the STC (Best and Schell 1996). Carbon and nitrogen isotope ratios also indicated that feeding ceased when the northern migration began and did not resume until the southern migration was under way (Best and Schell 1996). In Peninsula Valdes, carbon and nitrogen isotope ratios of stranded calves indicate that their mothers fed in waters south of the STC and may have continued to feed as they moved northward during the last few months of gestation (Marshall-Tilas et al. 1998).

Diving Behavior

They are not regarded as deep divers, since they find their prey not far below the surface, and maximum submergence times are about 20 minutes (review by Leatherwood et al. 1983a).

Social Behavior

Females are larger than males (review by Leatherwood et al. 1983a). Male right whales have huge testes and long penises, two characteristics predicted in species in which males compete for females primarily through sperm competition, rather than by direct aggression (review by Jefferson et al. 1993). Females may be surrounded by two to six (sometimes up to 14) competing males and in this situation pushing and head butting frequently occurs, leading to scars and gouges on the skin (Payne and Dorsey 1983; Cummings 1985b). Females apparently copulate with more than one male (review by Evans 1987).

In Argentina, Australia, and South Africa, the lack of sightings of females in the year prior to calving has been interpreted as: 1) they visit the coast only briefly in the year prior to calving, 2) gestation is greater than 12 months, 3) delayed fertilization or implantation is taking place, or 4) conceptions occur well outside coastal waters (Best 1994b; Burnell and Bryden 1997). Data from the same three areas indicate that mature females spent the least amount possible in coastal waters (breeding areas) during their non-calving years or possibly do not migrate to them at all (Best 1994b; Burnell and Bryden 1997). As stated by Burnell and Bryden (1997) this result suggests a sex-segreggated migration similar to the one proposed for humpback whales (*Megaptera novaeangliae*) (Brown et al. 1994).

In the breeding grounds in Argentina, mothers and their young occupy the areas closest to shore while other groups of up to ten adults and subadults engage in active social and sexual behavior at the entrance to the bays (review by Evans 1987). However, it is thought that mating at this time do not lead to conception and instead occur primarily in deeper waters on the feeding grounds just prior to or during migration (review by Evans 1987). Female right whales may be surrounded by up to six males and triads commonly occur where one male may support the female from below while the others mate with her (review by Evans 1987). The right whale calf spends its early life close to its mother circling and moving back and forth but always within her vicinity (Taber and Thomas 1982). During this period it also performs various play behaviors which allow it to master actions that will be a vital part of adult life (Thomas 1986).

Reproduction and Population Parameters

Observations off Argentina suggest that the calving interval is usually three years, but it can be two or four years (review by Leatherwood et al. 1983). Calving interval is close to 3.67 years in the Argentine population, shorter in the South African population (review by Knowlton et al. 1994). Gestation period is ten months and lactation apparently lasts 12-14 months (Taber and Thomas 1982; Evans 1987).

Carbon and nitrogen isotope ratios from whales off South Africa suggested that growth in body length slows markedly between weaning and the first year, and may be almost negligible from one to four years of age (Best and Schell 1996).

A total of 54% of females in the population of right whales in the western South Atlantic have reproduced successfully (review by Brown et al. 1994).

Breeding Areas

Major breeding areas are: 1)nearshore off southern Australia, particularly the Head of the Great Australian Bight; 2)southern South America along the Argentine coast, particularly Peninsula Valdes, Uruguay, and southern Brazil; 3)around Tristan da Cunha; and 4)along the southern coast of South Africa, particularly in the vicinity of Muizenberg and De Hoop (review by Evans 1987; Bannister 1990; Best 1990; Payne et al. 1990; Burnell and Bryden 1997). Recent evidence suggests that the historically used Auckland Islands and Campbell Island, off New Zealand, are also important breeding areas (Patenaude et al. 1998). Breeding areas are apparently also found along the Chilean coast (Canto et al. 1994)

Off South Africa, calving season lasts 118 days from late June to late October, with a peak in late August (Best 1994b). In South America the peak months of conception are August to October, while the peak months of birth are May to August (Taber and Thomas 1982). In Australia, the effective calving season lasts around three months (peak between mid-June to mid-August), however whales are sighted in the breeding area for more than five months, from mid-May to late October (Burnell and Bryden 1997). In Brazil, from Ilha do Cardoso to Nova Vicosa, most southern right whale sightings are made between July and October, with 78.1% of those winter sightings consisting of mother-calf pairs (Lodi et al. 1996). During the southern winter (between July and November), southern right whales gather to calve in shallow sheltered bays such as Peninsula Valdes, Argentina (Clark 1983). In Argentina, most females return to the breeding area every third year, while males usually return annually (Leatherwood et al. 1983a). It has been suggested that increasingly intense harassment by gulls may compromise calf development and might even induce right whales to abandon Peninsula Valdes for other calving grounds (Rowntree et al. 1998).

Speed of Travel and Movements

They are slow swimmers and can exceed 12 km/h only in short bursts (Leatherwood et al. 1983a).

Vocal Behavior

Southern right whales make various sounds, ranging from 30-2,200 Hz, with most energy between 50-1,000 Hz (Cummings et al. 1972; Clark 1982, 1983). Sounds used include tones, high-frequency tonal frequency-modulated (FM) sweeps, complex amplitude-modulated pulsatile sounds, mixtures of amplitude and frequency modulation, noisy broadband blows, and impulsive slaps (Clark 1982, 1983). Source levels of right whale calls have been estimated as 172-187 dB re: 1 μPa @ 1 m (review by Richardson et al. 1995).

Southern right whales use a simple tonal FM upsweep at 50-200 Hz and lasting 0.5-1.5 s, for long-distance contact and to help bring groups together (Clark 1983). A low-frequency tonal FM downsweep of 0.5-1.5 s duration at 100-200 Hz may be used to maintain acoustic but not physical contact (Clark 1983). Type of sounds produced is related to the activity, size, and sexual composition of the right whale group (Clark 1983).

Hearing Range

They show little reaction to playbacks of killer whale calls from distant locations (Cummings et al. 1972, 1974).

Known Impacts of Human Activities

In Argentina, reactions to small outboard-powered boats are variable: some whales allowed the boat to approach to touching distance only when the boat moved slowly, some approached stationary boats, others avoided boats altogether (Cummings et al. 1972; Payne et al. 1983). Similar observations have been reported for whales wintering off South Africa (Donnelly 1969; Saayman and Tayler 1973a). However, recent data from Argentina suggest that females with calves avoid whale-watching boats more frequently than adults and juveniles (Rivarola and Carribero 1998).

Most reactions of southern right whales to a light aircraft circling 65-150 m were brief, only about 2% swam rapidly or dove as the aircraft came overhead (Payne et al. 1983). Southern right whales usually react more strongly to the sudden appearance of a swimmer or kayaker than to the approach of a noisy outboard vessel (Würsig pers. comm. in Richardson et al. 1995).

There is no data on reaction to dredges; however, on one occasion, the propeller of a dredge killed a right whale calf (Best 1984).

PYGMY RIGHT WHALE (*CAPEREA MARGINATA*)

Summary

The pygmy right whale (*Caperea marginata*) is the most poorly known extant baleen whale. It is confined to waters between 30° and 60°S, where it feeds on copepods. There are no detailed data on abundance, fine scale distribution, or movements. Vocalizations from one temporarily captive individual were from 60 to 300 Hz in frequency.

Protected Status

The pygmy right whale is the least known of all baleen whales (review by Jefferson et al. 1993). It is not federally listed under the U. S. Endangered Species/Marine Mammal Protection acts (kingfish.ssp.nmfs.gov/tmcintyr/spec_idx.html). However, it is listed as a lower risk/least concern species by the Cetacean Specialist Group of the International Union for the Conservation of Nature (www.wcmc.org.uk/data/database). It is the only baleen whale that has not been the target of large-scale commercial whaling (reviews by Leatherwood et al. 1983a; Jefferson et al. 1993). However, some animals are incidentally captured in coastal nets off South Africa (review by Leatherwood et al. 1983a; Jefferson et al. 1993).

Distribution

Sightings at sea are extremely rare partly because the species is inconspicuous, partly because it is difficult to distinguish from the minke whale (*Balaenoptera acutorostrata*) (reviews by Leatherwood et al. 1983a; Evans 1987). The pygmy right whale is known only from temperate waters of the Southern Hemisphere, between the Antarctic Convergence and the 20° isotherm (about 60° to 30° S) in both coastal and oceanic waters (reviews by Leatherwood et al. 1983a; Jefferson et al. 1993).

It has been observed in Tasmania all seasons (review by Leatherwood et al. 1983a). It occurs during the southern winter in South Africa, particularly between False Bay and Algoa Bay (review by Evans 1987). It is also known to be present at least seasonally along the coasts of southern Australia and New Zealand (review by Leatherwood et al. 1983a). There are pelagic records from the South Atlantic and the southern Indian oceans (review by Leatherwood et al. 1983a).

There is some evidence for an inshore movement in spring and summer, but no long-distance migration has been documented (review by Leatherwood et al. 1983a). While inshore, the pygmy right whale seems to have a strong preference for sheltered, shallow bays (review by Leatherwood et al. 1983a). It has been found in water temperatures ranging from 5° to 20°C (review by Leatherwood et al. 1983a).

Abundance

No data available.

Diet and Foraging Behavior

Pygmy right whales feed on copepods of the genus *Calanus* (Ivashin et al. 1972 in Gaskin 1982; Ross et al. 1975).

Diving Behavior

It does not seem to be a deep or prolonged diver; however, it apparently spends little time at the surface (review by Leatherwood et al. 1983a).

Social Behavior

Groups of up to eight individuals have been seen, but singles or pairs are most common (Ross et al. 1975; Baker 1985). This species is sometimes seen with other species of whales and dolphins (reviews by Leatherwood et al. 1983a; Jefferson et al. 1993).

Based on descriptions by Ross et al. (1975), Baker (1985) and Brownell and Ralls (1986), it has been proposed that pygmy right whales have a promiscuous mating system where adult males compete for complete mating access to females (Evans 1987).

Based on less than 10 individuals per sex, the maximum length of pygmy right whale males is 0.94 times that of females (Ross et al. 1975; Lockyer 1984).

Reproduction and Population Parameters

The gestation period is thought to be about 12 months long, with a lactation period of perhaps five to six months (Ross et al. 1975).

Breeding Areas

There are no apparent breeding areas. Mating and calving seasons are unknown; however, they are believed to be protracted (Ross et al. 1975; Lockyer 1984; Baker 1985).

Speed of Travel and Movements

Swimming speed seems to range between five and eight km/h, though the observed individual seemed capable of extremely rapid acceleration (review by Leatherwood et al. 1983a).

Vocal Behavior

A juvenile produced short thumplike pulses in pairs 0.5 s apart and lasting 140-225 ms (Dawbin and Cato 1992). Each pulse consisted of a frequency downsweep, with most energy between 60 and 120 Hz (Dawbin and Cato 1992). Pulses went higher than 300 Hz, and source levels varied between 165 and 179 dB (re: 1 μPa @ 1 m) peak to peak (Dawbin and Cato 1992).

Hearing Range

No data available.

Known Impacts of Human Activities

No data available.

ODONTOCETES (TOOTHED WHALES)

FAMILY PHYSETERIDAE (SPERM WHALE)

SPERM WHALE (*PHYSETER MACROCEPHALUS*)

Summary

The sperm whale (*Physeter macrocephalus*) is the largest of the toothed whales and has the largest range of all cetaceans except the killer whale (*Orcinus orca*) (Rice 1989). It has one of the slowest reproductive rates of any mammal (IWC 1982a), a tightly nit matrilineal social systems with overlapping generations (Richard et al. 1996), and extreme sexual selection and geographic separation of the sexes (Best 1979; Rice 1989). Sperm whales make long deep dives to feed on mesopelagic prey, especially squid (Reeves and Whitehead 1997). Because of their large size and abundance sperm whales are thought to be ecologically important marine predators, potentially consuming more prey than all the world's fisheries combined (Clarke 1977). Sperm whales use low frequency sound for echolocation while hunting for food, and for communication while socializing at the surface (Weilgart and Whitehead 1993).

Because they spend large amounts of time at depth and use low frequency sound they are likely to be vulnerable to any negative effects of low frequency sound in the ocean. Even though sperm whales are abundant (Reeves and Whitehead 1997), because their potential rate of reproduction is so low, even small negative impacts of low frequency sound could cause population declines. Furthermore, because of their apparent role as important predators of mesopelagic squid and fish, changes in their abundance could affect the distribution and abundance of other marine species.

Sperm whales are better studied than any other large pelagic deep diving odontocete (e.g. Baird's beaked whale *Berardius bairdii* and the bottlenosed whales *Hyperoodon sp.*) all of which are much less abundant. The scant data on the biology of these other species suggest that they are vulnerable to any negative impacts of low frequency sound (see below). Consequently, research on the impacts of low frequency sound on sperm whales

Protected Status

Sperm whales are federally listed as an endangered species under the U. S. Endangered Species/Marine Mammal Protection acts (kingfish.ssp.nmfs.gov/tmcintyr/spec_idx.html) and are listed as CITES Appendix 1 species which outlaws trade in sperm whale parts or products. There is currently no commercial whaling for sperm whales and only one small indigenous catch- in Indonesia (Barnes 1991). Sperm whales are not in immediate danger of extinction because their population is relatively large and they are widely distributed with only a few separate populations (Reeves and Whitehead 1997). However their low reproductive rate makes them vulnerable to environmental perturbations.

Distribution

Sperm whales are found throughout the world's oceans between the Arctic and Antarctic ice caps (Reeves and Whitehead 1997). There is pronounced sexual segregation with females and young males found in tropical and temperate waters with surface temperatures above 15°C, and mature males spending much of their time in more polar waters (Rice 1989). They are most abundant at the continental shelf break, the edges of oceanic islands, and other areas of steep topographic relief and deep water (Townsend 1935; Berzin 1971; Jaquet 1996). At large spatial scales their abundance, as determined by Yankee whaling catches, is correlated with primary productivity (Jaquet et al. 1996). However, primary productivity is unlikely to predict the abundance of sperm whales on smaller spatial scales relevant to LFA operations.

In the North Pacific Sperm whales are found in all suitable habitats. This includes deeper waters in the Bering Sea, East China Sea, South China Sea, Sea of Japan, Sea of Okhotsk, Gulf of Alaska, and Gulf of California (Rice 1989). Females and young males are usually found south of 42N (just north of the subarctic Boundary) (Rice 1989), except in El Niño years when they can be found further north (Pike and MacAskie 1969; Reeves and Whitehead 1997).

Sperm whales are deep-water pelagic animals. They are generally found in water over 1,000m deep, but males also use habitats with depths between 1,000 and 200m (Caldwell et al. 1966a; Reeves and Whitehead 1997). However, in some areas, such as the northern Gulf of California male sperm whales can be found in water less than 100m deep.

Data from discovery tags, genetic studies, and photo-identification studies indicate that there is only one Pacific population (Reeves and Whitehead 1997). For example, tagged sperm whales have crossed the Pacific from East to West and moved from the north to the south Pacific (Kasuya and Miyashita 1988), photo-identified individuals have moved from the Galapagos Islands to the coast of Ecuador, 1,000 km away, and an analysis of mitochondiral DNA variation showed no geographic structure at any scale suggesting the population has no clear geographic range (Dufault and Whitehead 1993; Dillon 1996; Reeves and Whitehead 1997).

Abundance

Reliable estimates of sperm whale population size are not available. Visual censuses provide minimum population sizes or densities only, because they have been unable to correct for whales not counted during long dives (e.g. Barlow 1995). Photo-identification mark recapture studies provide better estimates, but only for small area (e.g. Whitehead and Gordon 1986). Current estimates for discrete parts of the world's oceans in aggregate suggest a world population of several hundred thousand (Reeves and Whitehead 1997) to almost 2 million (Rice 1989).

Current estimates for areas of the North Pacific range from 250,000 for temperate waters (Gosho et al. 1984) to 23,000 for the tropical waters of the eastern Pacific (Wade and Gerrodette 1993), and less than 1,000 for the waters off California (Barlow 1995).

Both traditional open boat whalers and modern factory whalers hunted sperm whales, especially males. Current world populations are thought to be well below (10-30%) pre-whaling population sizes, especially for males (Whitehead 1995).

Diet and Foraging Behavior

Sperm whales feed primarily on mesopelagic and bathypelagic squid, with more than 55 species recorded (Kawakami 1980; Clarke et al. 1993). They also feed on demersal and mesopelagic fishes, however these are much less frequently taken than squid and seem to be most important in the diets of males at high latitudes (Reeves and Whitehead 1997). Squid eaten by sperm whales range in size from giant squid as long as sperm whales to small species only 400-500 g. These smaller species are more common and there is some evidence that larger species of squid are preyed on primarily by males (Reeves and Whitehead 1997).

Data from the Azores (Clarke et al. 1993) suggest that most of the squid consumed by sperm whales are small slow moving species with bioluminescent organs. These are likely easily captured, but may be of relatively low caloric value. A smaller proportion of the squid captured are larger, fast swimming species.

Individual sperm whales cover large expanses of ocean in search of prey, moving as much as 1,000 km (Whitehead 1996a; review by Reeves and Whitehead 1997). They apparently feed both day and night (Rice 1989), and individuals almost certainly use echolocation to locate prey (Weilgart and Whitehead 1993; Goold and Jones 1995).

Because of their size and abundance sperm whales are thought to consume tremendous quantities of prey, more than all human fisheries combined (Clarke 1977). If these estimates are anywhere close to reality, then sperm whales likely play an important ecological role in structuring the distribution and abundance of mesopelagic squid.

Diving Behavior

Sperm whales are likely the deepest and longest diving mammal. Typical foraging dives last 40 min and descend to about 400m followed by approximately 8 min of resting at the surface (Gordon 1987; Papastavrou et al. 1989). However, dives of over 2 hr and as deep as 3,000 m have been recorded (Clarke 1976; Watkins et al. 1985). Descent rates recorded from echo-sounders were approximately 1.7m/sec and nearly vertical (Goold and Jones 1995). There are no data on diurnal differences in dive depths in sperm whales. However, like most diving vertebrates for which there is data (e.g. rorqual whales, fur seals, chinstrap penguins), sperm whales probably make relatively shallow dives at night when deep scattering layer organism move towards the surface.

Social Behavior

Female sperm whales are highly social, displaying traits such as stable social groups with overlapping generations, alloparental care, and high intragroup genetic relatedness that are common in other highly social animals such as humans, wolves, mongooses, and mole rats. Females and young males live in groups of about 12 closely related females and their offspring (Richard et al. 1996). Males leave these groups when they are about 6 years old and move to higher latitude feeding areas where they form small groups or aggregations (Best 1979). As males grow they move to even higher latitudes and form smaller groups so that by 20 years they are thought to be essentially solitary unless at a feeding aggregation. Males appear to become socially mature when over 20 years old at which time they start to rove between groups of females and their young- apparently in search of estrus females (Whitehead 1993; review by Reeves and Whitehead 1997).

Sperm whales have extreme sexual size dimorphism with males twice as large as females (Rice 1989). This size dimorphism, the late age of social maturity for males, the low reproductive rate of females, the apparent absence of male parental investment, and the presence of scars from interspecific fights on many males (Whitehead 1993) suggests extreme competition for access to fertile females which tends to cause male biased mortality rates and female biased sex ratios (Trivers 1972).

The groups of closely related females and their offspring have group specific dialects (Weilgart and Whitehead 1997), alloparental guarding of young at the surface (Whitehead 1996b), and alloparental nursing (Reeves and Whitehead 1997). Extrapolation from better-studied species with similar social systems suggest that females can survive well beyond the end of their reproductive lives.

Reproduction and Population Parameters

Females reach sexual maturity at seven to 13 years (Rice 1989) and then give birth about every four to six years (Best et al. 1984). They can live to 60 or 70 years (Rice 1989). The potential rate of population increase in these extreme k selected animals is less than 1% (IWC 1982a).

Breeding Areas

There are no specific mating areas. Instead, mating occurs in low latitude waters throughout the worlds oceans where female groups are found (Rice 1989).

Speed of Travel and movements.

When foraging sperm whales travel at about 4 km/hr (Reeves and Whitehead 1997). Over a twelve hr period female sperm whale groups in the Galapagos moved less than 5km straight line distance to more than 50 km (reviewed in Reeves and Whitehead 1997). Males move more on average than females since they rove between female groups and feed at higher latitudes (Reviewed by Reeves and Whitehead 1997).

Vocal Behavior

Sperm whales produce loud broad-band clicks from about 0.1 to 20 kHz (Weilgart and Whitehead 1993, 1997; Goold and Jones 1995). These have source levels estimated at 171 dB re 1uPa (Levenson 1974). Current evidence suggests that the disproportionately large head of the sperm whale is an adaptation to produce these vocalizations (Norris and Harvey 1972; Cranford 1992; but see Clarke 1979). This suggests that the production of these loud low frequency clicks is extremely important to the survival of individual sperm whales.

The function of these vocalizations is relatively well-studied (Weilgart and Whitehead 1993, 1997; Goold and Jones 1995). Long series of monotonous regularly spaced clicks are associated with feeding and are thought to be produced for echolocation. Distinctive, short, patterned series of clicks, called codas, are associated with social behavior and intragroup interactions. They are though to be for intra pecific communication, perhaps to maintain social cohesion with the group (Weilgart and Whitehead 1993).

Hearing Range

The only data on the hearing range of sperm whales are evoked potentials from a stranded neonate (Carder and Ridgway 1990). These data suggest that neonatal sperm whales respond to sounds from 2.5-60 kHz.

Known Impacts of Human Activities

Sperm whales frequently stop echolocating in the presence of underwater pulses made by echosounders and submarine sonar (Watkins and Schevill 1975; Watkins et al. 1985). They also stop vocalizing for brief periods when codas are being produced by other individuals, perhaps because they can hear better when not vocalizing themselves (Goold and Jones 1995). Sperm whales have moved out of areas after the start of air gun seismic testing (Davis et al. 1995).

KOGIIDAE

PYGMY AND DWARF SPERM WHALES (KOGIIDAE)

Summary

There are two species in the family Kogiidae, the pygmy sperm whale (*Kogia breviceps*) and the dwarf sperm whale (*K. simus*). These are small, relatively solitary, apparently deep diving, toothed whales that live in temperate and tropical deep waters. Very little is known about any aspect of their biology. They are found in deep waters of all temperate, sub-tropical, and tropical seas where they apparently feed on a wide variety of deep-water squid and fish as well as some crabs. They are though to be relatively abundant and little impacted by direct human impacts. Consequently, they are not listed as endangered or threatened species by the U. S. Endangered Species Act, or the Marine Mammal Protection Act. Little is known about their vocal behavior or hearing. However, studies on injured captive animals indicate that vocalizations and peak auditory sensitivity are above 50 kHz.

Protected Status

The pygmy sperm whale and the dwarf sperm whale are not federally listed under the U. S. Endangered Species/Marine Mammal Protection acts (kingfish.ssp.nmfs.gov/tmcintyr/spec_idx.html). They are both listed as lower risk/least concern species by the Cetacean Specialist Group of the International Union for the Conservation of Nature (www.wcmc.org.uk/data/database). Neither species has been hunted commercially, nor are they frequently captured by commercial fisheries (Jefferson et al. 1993). There are small traditional takes of *Kogia* in the Philippines (Dolar et al. 1994) and the Lesser Antilles (Caldwell DK et al. 1973; Caldwell and Caldwell 1975a; Reeves 1988). Small whaling operations off Japan and Indonesia appear to have stopped (Barnes 1991; Baird et al. 1996). *Kogia* are incidentally taken by gillnets in the Philippines, central North Pacific and off Sri Lanka (Omura et al. 1984; Leatherwood and Reeves 1989; Dolar et al. 1994). Incidental takes have been documented in the eastern tropical Pacific (Scott and Cordaro 1987) and in Hawaii (Edmonson 1948). Dwarf sperm whales are also captured as bycatch in the pelagic driftnetting fishery off southern Brazil (Sousa et al. 1998).

Distribution

Pygmy and dwarf sperm whales are rarely observed at sea, thus their distribution is known mostly from stranded animals. They are apparently distributed in deep waters of all temperate, subtropical and tropical seas between 60°N and 40°S (reviews by Evans 1987; Jefferson et al. 1993). However, dwarf sperm whales apparently prefer slightly warmer waters than pygmy sperm whales (Caldwell and Caldwell 1989).

In the northeastern Pacific, pygmy sperm whales occur between the state of Washington and the Gulf of California (Scheffer and Slipp 1948; Brownell 1969); in the northwestern Pacific they have been recorded from the coasts of Japan, Taiwan and the Philippines (Omura and Takahashi 1981; Evans 1987). In the southwestern Pacific, pygmy sperm whales have stranded in New Zealand (Brabyn 1991 in Baird et al. 1996); in the southeastern Pacific they have been recorded as far south as Chile (review by Baird et al. 1996). In the northwestern Atlantic, pygmy sperm whales have stranded as far north as the French Isle de Miquelon and Saint John, New Brunswick (Nelson et al. 1991; McAlpine et al. 1997); in the northeastern Atlantic they have been recorded as far north as Ireland (Fraser 1974 in Baird et al. 1996). In the southeastern Atlantic pygmy sperm whales have been recorded as far south as Buenos Aires, Argentina (review by Evans 1987); in the southwestern Atlantic they have been recorded as far south as South Africa (Ross 1984). In the northwestern Pacific, dwarf sperm whales have been recorded from the coast of Japan, Taiwan, and the Philippines (Yamada 1954; Nagorsen 1985; Sylvestre 1988); in the northeastern Pacific, they occur from Vancouver Island to Central America, including the Gulf of California (Roest 1970; Nagorsen and Stewart 1983; Scott and Cordaro 1987; Breese and Tershy 1993). In the northwestern Atlantic, dwarf sperm whales have stranded as far north as Sable Island, off Nova Scotia (Lucas and Hooker 1997); in the northeastern Atlantic they have been recorded as far north as Senegal (Maigret and Robineau 1981). In the southwestern Atlantic dwarf sperm whales have stranded as far south as Rio Grande do Sul, Brazil (Pinedo 1987); in the southeastern Atlantic they have been recorded as far south as South Africa (Ross 1979). In the South Pacific, dwarf sperm whales have stranded in New Zealand and Chile (Crovetto and Toro 1983; Brabyn 1991 in Willis and Baird 1998). In the Southern Ocean dwarf sperm whales have stranded in South Australia (Hale 1963 in Willis and Baird 1998). The two species occur in the Indian Ocean, Gulf of Mexico and the Caribbean Sea (HandleDy 1966; Caldwell DK et al. 1973; de Silva 1987; Leatherwood and Reeves 1989; Debrot and Barros 1992; Mullin et al. 1994a; Ballance and Pitman 1998; Davis et al. 1998).

Pygmy sperm whales are not known from the Mediterranean Sea (Baird et al. 1996); however, a dwarf sperm whale stranded in Italy (Baccetti et al. 1991).

The two species appear to be especially common along the continental shelf break (reviews by Evans 1987; Jefferson et al. 1993). In the western tropical Indian Ocean, 58% of the variance in the distribution of pygmy sperm whales is explained by their association with deep, clear (low sea surface chlorophyll) water characterized by a deep thermocline (Ballance et al. 1998). In the northern Gulf of Mexico pygmy and dwarf sperm whales occur mostly in waters 400-600 m deep, between the upper continental slope and the deepest waters of the northern Gulf of Mexico (Mullin et al. 1994a; Davis et al. 1998). Although typically an offshore species, there are sightings of dwarf sperm whales in nearshore waters (Aurioles-G et al. 1993; Willis and Baird 1998). In the eastern tropical Pacific dwarf sperm whales are found throughout the area but most frequently near the shore (Wade and Gerrodette 1993).

There is no conclusive evidence regarding seasonal movements for either species. Pygmy and dwarf sperm whales apparently occur year-round in the Gulf of Mexico, South Africa, southwest Gulf of California and eastern North America (Ross 1979; Leatherwood et al. 1983; Aurioles-G et al. 1993; Jefferson 1995). Seasonal movements for pygmy sperm whales are inferred from stranding records off South Australia, eastern North Pacific, Europe and New Caledonia (review by Baird et al. 1996). Likewise, based on stranding and fisheries records, seasonal movements of dwarf sperm whales have been suggested in the Gulf of Mexico and Japan (Yamada 1954; Odell et al. 1985).

No information on stock identity is available. In South Africa, Ross (1984) suggested a segregation by age with young dwarf sperm whales utilizing the outer section of the shelf and the upper portion of the slope, while adults utilize deeper waters.

Abundance

The worldwide population of both pygmy and dwarf sperm whales is unknown. However, frequent stranding in Florida, New Zealand, South Africa and Hawaii, and the difficulty in detecting either species in nature are interpreted as evidence that the two species are fairly common (Caldwell and Caldwell 1989; Baird et al. 1996).

It is estimated that 11,200 dwarf sperm whales (95% bootstrap CL= 7,700-16,200) inhabit the eastern tropical Pacific; however, it is likely an underestimate by as much as one half (Wade and Gerrodette 1993). Overall density values in the eastern tropical Pacific were estimated from Wade and Gerrodette (1993) as mean population size divided by study area, results are 0.0006 whales/km^2; however, density values vary within the study area. It is estimated that 870 pygmy sperm whales (95% bootstrap CL= 0-2741) were found during the summer and fall of 1991 in California (Barlow 1995). Estimated density was 0.013 whales/km^2 (Barlow 1995).

Diet and Foraging Behavior

Pygmy and dwarf sperm whales have similar food habits, feeding primarily on deep-water cephalopods, and less frequently on fish and crabs. The diet comprises at least 15 squid families, which relative importance varies with location, at least seven families of fish, octopus, and decapod crustaceans (Fitch and Brownell 1968; Ross 1979; Jones 1981; Nagorsen and Stewart 1983; Candela 1987; Pinedo 1987; Klages et al. 1989; Nelson et al. 1991).

Based on the habits of squid, pygmy and dwarf sperm whales appear to occur primarily along the edge of the continental shelf in epi- and meso-pelagic waters (Fitch and Brownell 1968; Ross 1979; Klages et al. 1989; Nelson et al. 1991). However, in South Africa dwarf sperm whales appear to feed farther inshore, in shallower waters, whereas pygmy sperm whales appear to feed on the edge of the continental shelf (Ross 1979; Klages et al. 1989). In the Gulf of Mexico, differences in hemoglobin between the two species suggest a potential on-shore/off-shore difference in ecotype (Barros et al. 1998). Stable isotopic ratios of nitrogen and carbon indicate that dwarf sperm whales have dietary habits more similar to those of pelagic odontocetes (Barros et al. 1998). Habits of prey items indicate that pygmy and dwarf sperm whales feed at a variety of depths: 1) within 100 m from the surface, 2) between 250-1500 m deep, and 3) the ocean bottom (Fitch and Brownell 1968; Ross 1979; Jones 1981; Maigret and Robineau 1981)

The anatomy of the hyoid apparatus of pygmy and dwarf sperm whales indicates powerful suction feeding (Reidenberg and Laitman 1994). The small mouth and anteroventrally flattened snout are interpreted as evidence that the two species feed on or near the ocean floor (Gaskin 1982).

Diving Behavior

Based on their geographic distribution and the habitat of their preferred prey, it is likely that both pygmy and dwarf sperm whales are deep divers. However, information on diving behavior is scarce. A released pygmy sperm whale in Florida dove for more than 12 min (Hohn et al. 1995). In the Gulf of California, dwarf sperm whales dive as long as 43 minutes (Breese and Tershy 1993). Surface behavior of *Kogia* sp. in the Gulf of California consisted of resting at the surface for approximately one min, followed by a brief dive of less than three min (Barlow pers. comm. in Willis and Baird 1998). In the same area, 59 dive intervals of *Kogia* sp. indicated a median dive time of 8.6 minutes and a median resting time at the surface of 1.2 minutes; dives up to 25 minutes and resting periods at the surface of up to 3 min were common (Barlow pers. comm. in Willis and Baird 1998).

Social Behavior

Information is scarce on the social behavior of both pygmy and dwarf sperm whales. Based on their group sizes, the two species are apparently not gregarious. Group sizes for both species range from one to ten individuals (Yamada 1954; Handley 1966; Ross 1984; Au and Pitman 1988). In the eastern tropical Pacific, dwarf sperm whale groups averaged 1.7 individuals (CV= 0.07) (Wade and Gerrodette 1993). In the same region, group sizes of unidentified *Kogia* averaged 2 ± sd 1 whales (Au and Pitman 1988).

Three different compositions of groups have been recorded for dwarf sperm whales: females with calves, adults of both sexes without calves, and immature individuals (Ross

1984). Males and females of both species are similar in size and appearance (Odell et al. 1984; Caldwell and Caldwell 1989). In Florida, the mean length of pygmy sperm whale males is 1.01 times that of females (Odell et al. 1984). In Florida, based on less than 10 individuals per sex, the maximum length of dwarf sperm whale males is equal to that of females (Caldwell and Caldwell 1989). The length of testes of sexually mature dwarf sperm whale males varies between 9.8 to 22.2 % of total body length (Willis and Baird 1998).

Reproduction and Population Parameters

Female pygmy sperm whales reach sexual maturity at lengths of 2.6 to 2.8 m, males at 2.7 to 3.0 m; both male and female dwarf sperm whales apparently reach sexual maturity at lengths of 2.1 to 2.2 m (Ross 1979, 1984; Odell et al. 1984; Caldwell and Caldwell 1989). Age at sexual maturity and longevity are unknown for both species. The gestation period is considered to be between 7 and 11 months in the pygmy sperm whale, and 9.5 months in the dwarf sperm whale (Ross 1979, 1984; Pinedo 1987). Records of females that are pregnant and lactating, or accompanied by a calf, suggest that both species are capable of reproducing every year and might explain the high frequency of cow/calf strandings in South Africa (Ross 1979; Eliason and Houck 1986; Plön et al. 1998).

Breeding Areas

The inshore waters of Florida appear to be a calving area for both species (Evans 1987). It has been suggested that the Mahia Peninsula area of the north island of New Zealand is a calving area for pygmy sperm whales (Brabyn 1991 in Baird et al. 1996), and that mating and calving occur from autumn through spring in pygmy sperm whales off South Africa (Ross 1979). Southern Hemisphere records suggest that mating in dwarf sperm whales occurs in summer and calving in early summer (Pinedo 1987). Calving season for this species may last up to five months (Ross 1979; Nagorsen 1985).

Speed of Travel and Movements

The two species appear to move slowly, rarely engaging in rapid activity (Handley 1966). They typically float at the surface with the back of head and the anterodorsal surface exposed (Yamada 1954; Leatherwood et al. 1983a; Caldwell and Caldwell 1989; Breese and Tershy 1993; Willis and Baird 1998).

Vocal Behavior

There are no data on vocalizations in the wild for either pygmy or dwarf sperm whales. However, based on captive individuals, neither species appears to be particularly vocal (Caldwell et al. 1966b; Caldwell and Caldwell 1989). Pygmy sperm whales recovered from strandings showed low-amplitude, echolocation-like clicks with a directional beam and peak frequencies below 13 kHz (Caldwell et al. 1966b; Caldwell and Caldwell 1987). However, recent recordings from captive individuals indicate that they produce sounds between 60 and 200 kHz, with peak frequencies at 120-130 kHz (Santoro et al. 1989; Carder et al. 1995). Thomas et al. (1990a) recorded a low frequency sweep ascending sound, heard singly or in pairs, between 1.3 and 1.5 kHz from a captive pygmy sperm whale. There is no information on the source levels for these sounds.

Hearing Range

An auditory brainstem response study indicates that pygmy sperm whales have their best underwater hearing range at 90-150 kHz (Carder et al. 1995). Nothing is known about the hearing range of the dwarf sperm whale.

Known Impacts of Human Activities

Information is scarce regarding the impact of human activities on pygmy and dwarf sperm whales. In the northern Gulf of Mexico, the two species usually dove when a Twin Otter flew over at 150-230 m altitude in the Gulf of Mexico (Mullin et al. 1991). In the same area, both species showed the most avoidance reactions to survey ships and aircraft (Würsig et al. 1998). They oriented away from survey vessels in 11 of 15 sightings and changed their behavior in response to the airplane in 12 of 30 sightings (Würsig et al. 1998). Caldwell and Caldwell (1989) suggest that some *Kogia* sp are likely injured or killed from boat collisions; however, such events are probably rare (Willis and Baird 1998).

ZIPHIIDAE (BEAKED WHALES)

BAIRD'S AND ARNOUX'S BEAKED WHALES (*BERARDIUS* SP.)

Summary

Baird's beaked whales (*Berardius bairdii*) and Arnoux's beaked whales (*B. arnuxii*) are large, pelagic, deep diving toothed whales. They feed primarily on squid and are highly social. Little is known about their movements, fine scale distribution, or abundance. Although recorded vocalizations of Baird's beaked whales are above 12 kHz, their large size suggests they can produce and receive low frequency sounds. Like most other large odontocetes, they likely have a relatively low reproductive rate. For these reasons they are probably at greater risk from LFA activities than are most other marine mammals. Unfortunately, like the other large, deep diving odontocetes, with the possible exception of the sperm whale, they are poorly known and difficult to study.

Protected Status

Baird's beaked whales and Arnoux's beaked whales are not federally listed under the U. S. Endangered Species/Marine Mammal Protection acts (kingfish.ssp.nmfs.gov/tmcintyr/spec_idx.html). They are both listed as lower risk/least concern species by the Cetacean Specialist Group of the International Union for the Conservation of Nature (www.wcmc.org.uk/data/database). Some Baird's beaked whales were taken by coastal whalers from the USA and Canada between California and Alaska; 60 whales reportedly taken between 1912-1966 (review by Reeves and Mitchell 1993). Commercial whalers from the former Soviet Union captured 100 whales between 1933-1954 and 76 whales between 1955-1974 (Tomilin 1957; review by Reeves and Mitchell 1993). In Japan, whales have been taken since at least the early 17th century with 600 whales taken between 1907 and 1947; 3,900 (with a peak of 322 in 1952) between 1948 and 1986; and 40 whales per year between 1972 and 1990 (Omura et al. 1955; Ohsumi 1983; IWC 1992). Whaling stations in Japan continue to take up between 54 and 60 Baird's beaked whales per year, mainly off the coastal waters of the Boso Peninsula (review by Reeves and Mitchell 1993). Some Baird's beaked whales have also been caught in Japanese salmon driftnets (review by Jefferson et al. 1993). There has not been any substantial commercial hunting for Arnoux's beaked whales, but some have been taken for scientific study (review by Jefferson et al. 1993).

Distribution

Both the Baird's and Arnoux's beaked whales are deep-water temperate and sub-tropical species that are likely distributed throughout most of the world's oceans. Like many deep-water species they appear to be most abundant at areas of steep topographic relief such as shelf breaks and seamounts. Little is known about the distribution and movements of Baird's and Arnoux's beaked whales at spatial and temporal scales relevant to LFA vessel activity.

Baird’s beaked whales are found in deep oceanic waters of the North Pacific Ocean and the Japan, Okhstok, and Bering seas; between 23°N and 62°N (Tomilin 1957; Rice 1974; review by Balcomb 1989). Arnoux’s beaked whales probably have a circumpolar distribution in deep cold temperate and subpolar waters of the Southern Hemisphere, as far north as 30°S and as far south as 77°S (Ponganis et al. 1995; reviews by Leatherwood et al. 1983a; Jefferson et al. 1993).

Baird’s beaked whales have been observed from Mattew Island in the Bering Sea to the southern Gulf of California, México (Hanna 1920; review by Vidal et al. 1993). In the northwest Pacific, they are found east of the Kamchatka Peninsula, Russia, down to the southern region of the island of Honshu, Japan (Kasuya 1971, 1986; review by Reeves and Mitchell 1993). The normal northern limit of the species is considered to be Cape Navarin (62-62°30’N) in the western Bering Sea (Tomilin 1957). The species is thought to be distributed continuously across the Pacific Ocean north of 35°N (Kasuya and Ohsumi 1984; review by Balcomb 1989). Most records of Arnoux’s Beaked whales are of stranded animals, but apparently they are distributed from the spring ice edge of McMurdo Sound, Ross Sea, to New Zealand (from where a large number of stranding records come) and central Chile in the Pacific, to Argentina and South Africa in the Atlantic, and probably to the southern Indian Ocean since there have been records off South Africa and Western Australia (review by Evans 1987; Ponganis et al. 1995).

Baird’s beaked whales primary habitats appear to be over or near the continental slope and oceanic seamounts (review by Balcomb 1989). They are known to be associated with subsurface seamounts in California (review by Evans 1987). They are usually found far offshore, in waters deeper than 1000 m (Dohl et al. 1983; Kasuya 1986a; Leatherwood et al. 1988a). They have been observed in waters less than 500 m deep in the northern Sea of Okhostk (Fedoseev in Kasuya 1986a). In the eastern tropical Pacific they appear to be found only along the coast of Baja California, México (Wade and Gerrodette 1993). Arnoux’s beaked whales in the Antarctic are well adapted to life in ice-covered waters; being able to find breathing sites in what appears to be unbroken ice. This allows them to exploit food resources inaccessible to other predators (Hobson and Martin 1996).

There is some evidence of at least three separate populations of Baird’s beaked whales in the northwestern Pacific, apparently separated by shallow straits (Omura et al. 1955; Kasuya 1986a; Kasuya and Miyashita 1989): 1) in the deep channels east of the Kamchatka Peninsula, in the Sea of Okhostk (off Abashiri but also in more shallow waters north of Sakhalin) and off the Kurile Islands. 2) In the Sea of Japan (Toyama Bay and west coast of southern Hokkaido). 3) In the coastal waters of the Pacific coast of Japan (mainly between 140° and 144° E). Seasonal north-south movements have been postulated for the latter population, moving northwards in summer in response to the seasonal expansion of the Kuroshio Current (Kasuya 1986a). The species is absent from Japanese coastal waters from January to April, with only small numbers present in December and May (Kasuya 1971). Aerial surveys and catch statistics suggest peaks of abundance of Baird’s beaked whales off central and northern California in July and September-October, apparently due to inshore-offshore movements rather than to a north-south migration (Rice 1974; Dohl et al. 1983). Baird's beaked whales were observed off the west coast of Vancouver Island by whalers from May through September, especially in July and August (Pike 1953; Reeves et al. 1985). Survey data suggest that Baird's beaked whales are present throughout much of the year off central and northern California (Dohl et al. 1983; Leatherwood et al. 1987). The continental slope (at depths of 1,000-3,000 m) north of 34°N appears to be favored by the species, and the movement is probably associated with the subsurface Oyashio Current off Japan (Kasuya 1986a; review by Evans 1987). Seasonal shifts in distribution have not been confirmed for Arnoux's beaked whales (review by Leatherwood et al. 1983a).

Abundance

No worldwide population estimates are known for either species.

The population of Baird's beaked whales in the northwestern Pacific has been estimated at 5,870 whales: 3,950 (CV= 0.27) off the Pacific coast; 1,260 (CV= 0.45) in the Sea of Japan; and 660 (CV= 0.27) in the Okhotsk Sea (IWC 1991; Miyashita 1991). The catch of 54-60 whales by Japan represents a removal rate of about 0.01 per year of the Pacific coast population; however, since some of the catches occur in the other two areas, the removal rate may be actually lower (review by Reeves and Mitchell 1993). The number of Baird's beaked whales during summer and fall of 1991 was estimated at 38 whales (95% bootstrap CL: 0-127) in California (Barlow 1995). Estimated density was 0.001 whales/km^2 (Barlow 1995).

Diet and Foraging Behavior

The Ziphiidae is a family of predominantly cephalopod-eating species, the most important of the families of cephalopods represented in the diet are the oceanic Ommastrephidae, Histioteuthidae, and Cranchiidae (Clarke 1996). Baird's beaked whales feed mainly on squid and deep-sea fish (Nishiwaki and Oguro 1971). Other prey items include various species of fish, cephalopods, crustaceans, and sea cucumbers (Tomilin 1957; Nishiwaki and Oguro 1971; Kasuya 1986a). Baird's beaked whales off Japan feed during early summer and fall on benthic or epibenthic prey in waters 1000 to 3000 m deep that are affected by a cold subsurface current (Kasuya 1986a). It is assumed that the diet of Arnoux's beaked whales is similar to that of Baird's beaked whales (review by Jefferson et al. 1993).

Anatomical data support the hypothesis that beaked whales (Ziphiidae) use suction to acquire prey (Heyning and Mead 1996).

Diving Behavior

Baird's beaked whales are known as deep divers. Thirty dives of undisturbed whales off Japan averaged 20 min, with a maximum of 67 min (Kasuya 1986a). Most periods at the surface lasted less than five min; however, one group remained at the surface for 14 minutes (Kasuya 1986a). Pike (1953) reported a story of a whaler telling of a Baird's beaked whale that took about 914 m of line straight down at a fast speed. Arnoux's beaked whales at narrow cracks or leads in sea ice near the Antarctic Peninsula dove with a mode of 35-65 min and a maximum of at least 70 min (Hobson and Martin 1996). Eight periods of respiration varied between 1.2 and 6.8 min, with an average of 9.6

blows/min (Hobson and Martin 1996). Also in Antarctica, Arnoux's beaked whales dove for 10-45 min (Ponganis et al. 1995). The species is one of the most accomplished mammalian divers, capable of swimming up to an estimated 7 km between breathing sites in sea ice (Hobson and Martin 1996).

Social Behavior

Baird's beaked whales live in pods up to 30 whales, although groups of up to 50 are occasionally seen (review by Jefferson et al. 1993). Off the Pacific coast of Japan, 42 groups observed from ships averaged 7.4 individuals with a mode of four whales and a maximum of 30 whales (Kasuya 1986a). Arnoux's beaked whales are found in groups between six and ten individuals, but some as large as 80 whales have been seen (review by Jefferson et al. 1993).

There is evidence of segregation by age and sex in Baird's beaked whales. Three group types have been observed: females with calves, adults of both sexes with or without calves, and adult males (Kasuya 1986a). Baird's beaked whale groups are close-knit and remain together when pursued (Pike 1953; Tomilin 1957).

Female Baird's beaked whales appear to be slightly larger than males. In Japan, the modal length of mature Baird's beaked whale males is 0.97 times that of females (Omura et al. 1955). The maximum weight of male Baird's beaked whales appears to be 0.9 times that of females (review by Evans 1987). Male Arnoux's beaked whales appear to be slightly longer than females. Based on less than 10 individuals per sex, the maximum length of Arnoux's beaked whale males is 1.02 times that of females (Mead 1984). Males and, to a lesser extent, females in both species have many linear white scars on the body, apparently because of intraspecific fighting (review by Leatherwood et al. 1983a). Unlike most other beaked whales, females of both species have functional teeth (review by Leatherwood et al. 1983a).

The lack of sexual dimorphism in Baird's beaked whales, the higher female mortality and excess of mature males over females suggest that males provide significant parental care (Kasuya 1995; Kasuya et al. 1997). This appears to be a novel social solution to aquatic living (Connor et al. 1998a).

Reproduction and Population Parameters

Mean length of sexual maturity in Baird's beaked whales is 9.8-10.6 m for males and 10.0-10.4 m for females (Omura et al. 1955; Kasuya et al. 1989). These lengths correspond to ages of 6-10 years and 11-15 years, respectively (Kasuya 1977; Kasuya et al. 1989; Kasuya et al. 1997). The gestation period has been estimated at around 17 months (Kasuya 1977; Ohsumi 1983). The calving interval is assumed to be about three years (Omura et al. 1955; Kasuya 1977; Mead 1984). Pregnancy and ovulation rates are estimated as 0.30 and 0.47, respectively (Kasuya et al. 1989). There is no evidence that pregnancy rates decline with increasing age (Kasuya et al. 1989). It appears that males live longer than females (age 84 versus 54) and that females have no post-reproductive stage (Kasuya et al. 1989; Kasuya et al. 1997). The difference is reflected in a male-biased sex ratio among adults (Kasuya et al. 1997). Natural mortality rate is estimated at 0.083 (Ohsumi 1979b).

Breeding Areas

There are no apparent special breeding areas. Mating in Baird's beaked whales generally occurs in October and November, and most births have been recorded from November to July, with a peak in March and April (Kasuya 1977).

Speed of Travel and Movements

No data available.

Vocal Behavior

Baird's beaked whales have been recorded producing sounds between 12.1 and 134 kHz, with dominant frequencies between 23-24.6 and 35-45 kHz (Dawson et al. 1998a).

Hearing Range

No data available.

Known Impacts of Human Activities

It has been suggested that reduced catches of Baird's beaked whales off parts of Japan were caused by greatly increased ship traffic (Nishiwaki and Sasao 1977). However, changes in hunting effort and no systematic analysis of other potential disturbances make it difficult to evaluate the hypothesis that number of whales declined as a result of shipping (Payne 1978b in Richardson et al. 1995). The continued presence of beaked whales off the entrance of Tokyo Bay despite heavy ship traffic shows considerable tolerance of shipping (Richardson et al. 1995).

NORTHERN AND SOUTHERN BOTTLENOSE WHALES (*HYPEROODON* SP.)

Summary

Northern bottlenose whales (*Hyperoodon ampullatus*) are the largest of species in the poorly known family Ziphiidae, and the second largest of all the toothed whales. They are pelagic, deep divers that feed primarily on squid. They are only found in the North Atlantic. Like most large odontocetes, they are thought to have a low reproductive rate.

They produce low frequency sounds, spend large amounts of time at depth, and likely rely heavily on sound to find prey and maintain contact with group members. Thus, they are likely to be one of the species susceptible to negative impacts of LFA. Unfortunately, they are rarely sighted and difficult to study so quantifying any negative impacts of LFA activity will be extremely difficult.

Protected Status

The northern and southern (*Hyperoodon planifrons*) bottlenose whales are not federally listed under the U. S. Endangered Species/Marine Mammal Protection acts (kingfish.ssp.nmfs.gov/tmcintyr/spec_idx.html). They are both listed as lower risk/conservation dependent species by the Cetacean Specialist Group of the International Union for the Conservation of Nature (www.wcmc.org.uk/data/database). Northern bottlenose whales have traditionally been the most heavily hunted of the beaked whales (review by Jefferson et al. 1993). The major bottlenose whaling nation was Norway, and to a lesser degree Scotland and Canada (review by Leatherwood et al. 1983a). It is speculated that the species originally numbered 130,000 at a maximum and that whaling reduced it by at least 70% (Hooker and Baird in press). Norwegian sealers killed an average of 2,500 whales per year during the 1890s; although the fishery ceased in the 1920s, it resumed after the Second World War (review by Leatherwood et al. 1983a). As a result, the stocks in the northeastern Atlantic near the Faeroes, Iceland, Jan Mayen, Svalbard, and Norway are probably depleted (review by Leatherwood et al. 1983a). No hunting has been conducted by Norway since 1977 (Benjaminsen and Christensen 1979). The Faeroese bottlenose whaling industry, opportunistic drive fishery of pods sighted very close to shore, reported 811 whales taken between 1584-1993 (Bloch et al. 1996). Southern bottlenose whales have never been taking commercially, but some have been killed during whaling for research purposes (review by Jefferson et al. 1993). Recently, individuals of the southern bottlenose whale have been recorded as accidental victims of drifnet fishing in the Tasman Sea (review by Jefferson et al. 1993).

Distribution

Northern bottlenose whales are a cold temperate to subarctic species found only in the North Atlantic, between 80°N and 35°N (review by Jefferson et al. 1993). Southern bottlenose whales are thought to be distributed south of 20°S, with a circumpolar distribution in the Southern Hemisphere (reviews by Leatherwood et al. 1983a; Jefferson et al. 1993). Strong evidence suggests that southern bottlenose whales may range into equatorial waters of the Indian Ocean, the Gulf of Mexico, the Gulf of California, and as far north as the northwestern Pacific and Isla Guadalupe, México (Kasuya 1986a; Leatherwood et al. 1988a; Wade and Gerrodette 1993; Urbán-R. et al. 1994; Gallo-Reynoso and Figueroa-Carranza 1995). More recently, however, sightings of possible southern bottlenose whales in the equatorial Indian and Pacific oceans are considered to be sightings of the Longman's beaked whale (*Indopacetus pacificus*) (Pitman et al. 1998).

In the northwestern Atlantic, northern bottlenose whales are found from Rhode Island to Davis Strait and southern Greenland to the edge of pack ice (reviews by Leatherwood et al. 1983a; Jefferson et al. 1993). In the northeastern Atlantic, they are found from the Strait of Gibraltar to Svalbard and the Greenland and Barents seas (reviews by Leatherwood et al. 1983a; Jefferson et al. 1993). They enter the deep channels of the Gulf of Saint Lawrence (review by Evans 1987). They also possibly enter the Baltic and Mediterranean seas (review by Leatherwood et al. 1983a). There are confirmed records of southern bottlenose whales in the western Atlantic from southern Brazil to Tierra del Fuego; in the eastern Atlantic they have been recorded from South Africa to the subantarctic islands of the South Atlantic (reviews by Leatherwood et al. 1983a; Evans 1987). In the Pacific, there are confirmed records of southern bottlenose whales from Australia, New Zealand, and Chile to Antarctic waters (reviews by Leatherwood et al. 1983a; Evans 1987). There are also records of southern bottlenose whales from the Indian sectors of the Antarctic (review by Leatherwood et al. 1983a). Sightings of beaked whales that appear to be southern bottlenose whales have been recorded off Sri Lanka, the equatorial Pacific, the western North Pacific, the Gulf of California, and the Gulf of Mexico (Kasuya 1986a; Leatherwood et al. 1988a; Wade and Gerrodette 1993; Urbán-R. et al. 1994). However, at least in the equatorial Indian and Pacific oceans, these sightings are now considered to be Longman's beaked whales (Pitman et al. 1998).

Both northern and southern bottlenose whales are found in deep waters, mostly seaward of the continental slope (review by Jefferson et al. 1993). Northern bottlenose whales appear to prefer water deeper than 1,000 m and are seldom found in waters shallower than 180 m (review by Leatherwood et al. 1983a). They are often found along boundaries between cold polar currents and warmer Atlantic curents (review by Leatherwood et al. 1983a).

Northern bottlenose whales have a well-defined migratory pattern (review by Leatherwood et al. 1983a). They are found at low latitudes only during winter, but by early spring (March and April) they are already present in subarctic regions pattern (review by Leatherwood et al. 1983a). They summer in subarctic and arctic latitudes, and begin to move southward in late summer and early fall (review by Leatherwood et al. 1983a). However, some individuals almost certainly winter in high latitudes (Leatherwood et al. 1983a). Apparently northern bottlenose whales migrate along the British and Dutch coasts, although in declining numbers (review by Evans 1987). Northern bottlenose whales are probably year-round residents of the Gully southeast of Sable Island and the northern Labrador Sea near the entrance to Hudson Strait (reviews by Leatherwood et al. 1983a; Evans 1987).

In the Antarctic, southern bottlenose whales range over a wide area (Kasamatsu and Joyce 1995). This species apparently also migrates since they are found in Antarctic waters during the southern summer, particularly January, and sightings of bottlenose whales, apparently southern bottlenose whales, have been made in the equatorial Pacific in February and August (reviews by Leatherwood et al. 1983a; Jefferson et al. 1993). The species apparently has seasonal movements in South Africa, with peaks in February and October and high abundance in the Antarctic from December to February; suggesting a general movement northward out of the Antarctic in February and southward to the Antarctic in October (Findlay et al. 1992; Sekiguchi et al. 1993).

Abundance

The worldwide population size of northern bottlenose whales is unknown, but apparently declined in the last half century (review by Evans 1987). The worldwide population size of southern bottlenose whales is unknown.

The main summering areas of northern bottlenose whales appear to be between Iceland and Jan Mayen, and the Norwegian Channel west of Ålesund in Norway (review by Evans 1987). The Gully southeast of Sable Island and the northern Labrador Sea near the entrance to Hudson Strait are also areas of known concentration (reviews by Leatherwood et al. 1983a; Evans 1987). It is estimated that about 230 whales (95% CL= 160-360) reside in the Gully (Whitehead et al. 1997).

It is estimated that 599,300 beaked whales (CV= 0.15), mostly southern botttlenose whales, are present south of the Antarctic Convergence in January, with an estimated biomass of 2.70 million tonnes (Kasamatsu and Joyce 1995).

Diet and Foraging Behavior

Northern bottlenose whales feed mainly upon squid from at least 14 different families, cartilaginous fish, *Chimaera*, deepwater fish, sea cucumbers, starfish, and gammarid and decapod crustaceans (Tomilin 1957; Benjaminsen and Christensen 1979; Gaskin 1982; Clarke 1986). Southern bottlenose whales take mostly small oceanic squid (typically, <100 g, up to 4.1 kg) and fish (Goodall in Clarke 1986; Sekiguchi et al. 1993; Clarke and Goodall 1994; Slip et al. 1995).

Bottlenose whales appear to do much of their feeding on or near the bottom and they often feed in large groups (reviews by Evans 1987; Jefferson et al. 1993). Anatomical data support the hypothesis that beaked whales (Ziphiidae) use suction to acquire prey (Heyning and Mead 1996).

Southern bottlenose whales may play an important role in the Antarctic ecosystem. Consumption of food (mostly squid) in January for south of the Antarctic Convergence by beaked whales (mostly southern bottlenose whales) is estimated as 9.6 million tons (Kasamatsu and Joyce 1995). Indirect consumption of Antarctic krill through the predation of squid by beaked whales is estimated to be almost 24 million tons (Kasamatsu and Joyce 1995).

Diving Behavior

Dives of more than 60 min have been recorded for both species (review by Jefferson et al. 1993). Recently, northern bottlenose whales have been recorded diving for as long as 70 min and as deep as 1453 m (Hooker and Baird in press). After a long dive, northern bottlenose whales usually remain at the surface for 10 min or more, blowing at regular intervals before making another dive (review by Leatherwood et al. 1983a). Southern bottlenose whales have been observed diving from 11 to 46 min, with an average of 25.3 min (Sekiguchi et al. 1993).

Social Behavior

Most groups of northern bottlenose whales contain four to ten whales, and pairs and solitary individuals are also commonly seen; sometimes groups may be as large as 35 whales (Benjaminsen and Christensen 1979; reviews by Evans 1987; Jefferson et al. 1993). Most groups of southern bottlenose whales have numbered less than ten individuals, but groups with as many as 25 whales have been seen (review by Jefferson et al. 1993).

Limited evidence suggests segregation by age and sex during migration in northern bottlenose whales (Benjamin and Chirstensen 1979). Three group types have been observed: females with calves, adults of both sexes with or without calves, and adult males (Benjaminsen and Christensen 1979; Evans 1987). Northern bottlenose whales appear to have strong social ties, members of a group will not desert a wounded companion until it is dead (reviews by Leatherwood et al. 1983a; Jefferson et al. 1993). This species readily approaches vessels, and will stay near a drifting or idling craft for a long time (review by Leatherwood et al. 1983a). These two traits permitted whalers to kill large numbers of whales at the same time (reviews by Leatherwood et al. 1983a; Jefferson et al. 1993).

Male northern bottlenose whales are slightly larger than the females (review by Leatherwood et al. 1983a). In adult males the bulbous forehead is very steep, bulging, with an squarish profile, and nearly white (reviews by Leatherwood et al. 1983a; Jefferson et al. 1993). The pair of teeth that occurs in both species usually erupt only in old males, the teeth are also more stout in males than females (review by Leatherwood et al. 1983a). The social structure of northern bottlenose whales includes permanent coalitions between adult males and a network of looser associations between females (Gowans and Whitehead 1998). It has been proposed that northern bottlenose whales have a polygynous mating system with adult male associating with a group of females for protracted period (Evans 1987).

Reproduction and Population Parameters

Mean lengths at sexual maturity for northern bottlenose whales are 6.9 m for females and 7.5 m for males (Benjaminsen and Christensen 1979; Mead 1984). The minimum age of sexual maturity is seven years for both sexes; the mean age of sexual maturity is 11 years for females and seven to 11 years for males (Benjaminsen and Christensen 1979; Mead 1984). The gestation period is 12 months and the calving interval is two to three years

(Benjaminsen and Christensen 1979; Mead 1984). Northern bottlenose whales probably live at least 37 years (review by Evans 1987).

Breeding Areas

There are no apparent special breeding areas. The peak breeding and calving season of northern bottlenose whales is spring, specially April and May (Benjaminsen and Christensen 1979; Mead 1984). Speed of Travel and Movements
No data available.

Vocal Behavior

Northern bottlenose whales produce echolocation-type clicks between 8-12 kHz; whistles between 3-16 kHz and clicks between 0.5-26 kHz (Winn et al. 1970b). More recently sounds as high as 30 kHz have been recorded (Fauchner and Whitehead in Dawson et al. 1998a). Off Nova Scotia, predominant sounds of northern bottlenose whales were clicks of two types: regular click series, which have consistent inter-clik intervals (x=0.51 s, CV=24%), and click trains, which have short and variable inter-click intervals (x=0.07 s, CV=86%; Hooker and Whitehead 1998). Regular click series, which are produced at depth, had higher peak frequencies (6-8 kHz and 16-20 kHz) than click trains (2-4 Khz and 10-12 kHz), which are produced at the surface (Hooker and Whitehead 1998). Clicks of both types contained two pulses during 73% of the time (Hooker and Whitehead 1998). The click interval of regular series suggest a range of 380 m, comparable to that of sperm whales (*Physeter catodon*) (Hooker and Whitehead 1998). The 20 kHz frequency of clicks is optimal for an object of 7.5 cm, the approximate size of the primary prey species, the squid *Gonathus fabricii* (Hooker and Whitehead 1998).

Hearing Range

No data available.

Known Impacts of Human Activities

Unlike other beaked whales, northern bottlenose whales frequently approach stationary or slow-moving ships, circling a vessel for more than one hour (Reeves et al. 1993). The small size of the Gully population and its persistent use of a very small, bathymetrically unique ocean area make it vulnerable to human disturbance (Whitehead et al. 1997).

BEAKED WHALES (*MESOPLODON* SP.)

Summary

The 12 species in the genus *Mesoplodon* are poorly studied, deep-diving, pelagic toothed whales distributed throughout the world's oceans. New species have been described as recently as 1997 and undescribed species may still exist. They feed primarily on squid. They are less social than the larger deep-diving toothed whales (sperm whales, bottlenose whales, and Baird's beaked whales).

Their smaller size compared to other Ziphiids suggests that they may not produce low frequency sounds and thus less sensitive to low frequency sound. However, because they are very poorly known and difficult to study, it would be extremely difficult to detect any negative impacts of LFA.

Protected Status

The genus *Mesoplodon* consists of 12 poorly known species. The newest recognized species is the pygmy beaked whale (*M. peruvianus*), found between México and Perú (Reyes et al. 1991; Urbán-Ramírez and Aurioles-Gamboa 1992; Wade and Gerrodette 1993). Most recently, a new species (*M. bahamondi*) has been proposed based on one skull from Robinson Crusoe Island, Chile (Reyes et al. 1997). The authors suggest that this new species may be related to the unidentified *Mesoplodon* species (*Mesoplodon* "A") found in the eastern tropical Pacific (Wade and Gerrodette 1993).

None of the *Mesoplodon* species are federally listed under the U. S. Endangered Species/Marine Mammal Protection acts (kingfish.ssp.nmfs.gov/tmcintyr/spec_idx.html). They all are listed as data deficient species by the Cetacean Specialist Group of the International Union for the Conservation of Nature (www.wcmc.org.uk/data/database). Four species have not been exploited, and in three species only one individual each was taken but no further exploitation has been documented (review by Jefferson et al. 1993). American and other whalers (Mitchell 1975) possibly harvested some *Mesoplodon* populations in the 19th century and earlier. Blainville's beaked whales (*M. densirostris*) has been taken in the North Pacific, Philippines and, incidentally, in the Indian Ocean (Dolar et al. 1994; review by Mead 1989; Jefferson et al. 1993). A few Ginkgo-toothed beaked whales (*M. ginkgodens*) and Hubb's beaked whales (*M. carlhubbsi*) have been taken by coastal fishermen off Japan (review by Jefferson et al. 1993). Pygmy beaked whales *(M. peruvianus*) are taken by driftnet fishery for sharks off the coast of Perú (review by Jefferson et al. 1993). Sowerby's beaked whales (*M. bidens*) have been taken at a small scale off Newfoundland (review by Jefferson et al. 1993). Stejneger's beaked whales (*M. stejnegeri*) have been taken in salmon driftnets off Japan (Nishimura and Nishiwaki 1964).

Distribution

The distribution of the majority of species is poorly documented and is mostly known from stranding records (review by Jefferson et al. 1993). In general, the genus is distributed in all oceans between 72°N and 60°S, including the Gulf of Mexico and the Mediterranean, North and Caribbean seas (review by Leatherwood et al. 1983a; review by Jefferson et al. 1993; Carlström et al. 1997). The most widely distributed species is the Blainville's beaked whale, roughly from 60°N to 50°S (reviews by Houston 1990a; Jefferson et al. 1993). Gray's beaked whales (*M. grayi*) are found from 10° (extralimital records to 10°N) to 60°S, and strap-toothed whales (*M. layardii*) from 10° to 60°S (review by Jefferson et al. 1993). These three species have been recorded in all oceans in their range. A fourth species, the Hector's beaked whale (*M. hectori*) is a Southern Hemisphere cool temperate water species, from 20° to 60°S, that has been occasionally recorded as far north as southern California, about 35°N (review by Jefferson et al. 1993). Most *Mesoplodon* species appear to be distributed in temperate and tropical waters (review by Mead 1989). However, a few species, such as Sowerby's beaked whales, found only in the North Atlantic, and Stejneger's beaked whales, found only in the North Pacific, are from cold temperate to subpolar areas (review by Jefferson et al. 1993; Carlström et al. 1997).

Although Blainville's beaked whales might be one of the most common species, they are apparently not abundant and appear to be relatively uncommon of the West Coast of North America (Mitchell 1975; Leatherwood et al. 1988a). Sowerby's beaked whales appear to be more common in the northeastern Atlantic than in the northwestern Atlantic (review by Evans 1987). Ginkgo-toothed beaked whales appear to be more common in the northwestern Pacific than in the rest of their range (review by Evans 1987). Stejneger's beaked whales appear to be more common in the vicinity of the Aleutian Islands (review by Evans 1987).

Mesoplodon species are found mostly offshore in deep waters (Moore 1966; Leatherwood et al. 1988a; Wade and Gerrodette 1993). In the western tropical Indian Ocean, 41% of the variance in the distribution of *Mesoplodon* sp. is explained by its association with deep, clear (low sea surface chlorophyll) water characterized by a deep thermocline (Ballance et al. 1998). In the northern Gulf of Mexico they occur in the deepest waters (Davis et al. 1998). Blainville's beaked whales appear to prefer tropical and subtropical waters (review by Houston 1990a). The distribution of Hubb's beaked whales coincides with the confluence of the Kuroshio and Oyashio currents in Japan, and of the Subarctic and California currents in North America; and apparently is related to the distribution of its prey (Mead et al. 1982). Similarly, the distribution of the Stejneger's beaked whale appears to coincide with the Subarctic current systems, in waters ranging in depth from 730 to 1,560 m on the steep slope of the continental shelf (Loughlin et al. 1982; review by Houston 1990b). The distribution of the Sowerby's beaked whale appears also to be restricted to cool offshore waters where squid are abundant (Sergeant and Fisher 1957).

Abundance

Worldwide population size is unknown for all species of the genus.

A total of 25,300 (95% bootstrap CL= 17,400-34,400) and 250 (95% bootstrap CL= 0-746) *Mesoplodon* whales have been estimated for the eastern tropical Pacific and

California, respectively (Wade and Gerrodette 1993; Barlow 1995). Overall density values in the eastern tropical Pacific were estimated from Wade and Gerrodette (1993) as mean population size divided by study area, results are 0.001 whales/km^2; however, density values vary within the study area. Estimated density in California was 0.004 whales/km^2 (Barlow 1995).

Diet and Foraging Behavior

The Ziphiidae is considered a family of predominantly cephalopod-eating species, the most important of the families of cephalopods represented in the diet are the oceanic Ommastrephidae, Histioteuthidae, and Cranchiidae (Clarke 1996). Stomach contents available from some species included mostly squid, but also mesopelagic fish, deepwater fish, and shrimp (Nishiwaki and Kamiya 1958; Sullivan and Houck 1979; Mead 1981; Mead et al. 1982; Leatherwood et al. 1988a; review by Jefferson et al. 1993). Oceanic squids, some of which occur at a great depth, accounted for 94.8% of counted prey items of strap-toothed whales from South African and New Zealand coasts (Sekiguchi et al. 1996). In the northwestern Atlantic, isotopic comparisons indicate that the diet of Sowerby’s beaked whales has a large contribution from small offshore squid (Ostrom et al. 1993); however, stomach contents of individuals captured in pelagic drifnet fisheries were dominated by benthopelagic fishes, with very few squid consumed (Gannon et al. 1998a).

In general, cephalopods eaten by strap-toothed whales are not significantly different from those eaten by smaller odontocetes, such as spotted dolphins (*Stenella attenuata*) and dwarf sperm whales (*Kogia simus*) (Sekiguchi et al. 1996). However, the size of cephalopods taken is significantly smaller than those eaten by larger odontocetes, such as false killer whales (*Pseudorca crassidens*), long-finned pilot whales (*Globicephala melas*), Cuvier's beaked whales (*Ziphius cavirostris*), and southern bottlenose whales (*Hyperoodon planifrons*) (Sekiguchi et al. 1996). Isotope data suggest that Sowerby’s beaked whales in the western North Atlantic feed at similar trophic positions to pygmy sperm whales (*Kogia breviceps*) and sperm whales (*Physeter catodon*) (Ostrom et al 1993). In addition, all fish species consumed by Sowerby’s beaked whales are primarily bottom-dwelling species living in waters deeper than 400 m (Gannon et al. 1998a).

Anatomical data support the hypothesis that beaked whales (Ziphiidae) use suction to acquire prey (Heyning and Mead 1996). In strap-toothed whales the presence of fully-erupted teeth in adult males did not seem to influence the size of prey ingested, even though an adult male could only open its jaws about half as wide as a female (Sekiguchi et al. 1996).

Diving Behavior

Dives over 45 min have been recorded for some species (review by Jefferson et al. 1993). Blainville’s beaked whales dive for 20 min or longer (Leatherwood et al. 1988a).

Social Behavior

Mesoplodon species are most commonly seen as single individuals or pairs, sometimes trios (review by Jefferson et al. 1993). However, Blainville's beaked whales have been seen in larger groups, up to ten whales (Leatherwood et al. 1988a). Stejneger's beaked whales, a species distributed in the North Pacific, is usuall found in groups of five to 15 individuals (Loughlin et al. 1982). In addition, a mass stranding of 28 Gray's beaked whales has also been recorded (review by Leatherwood et al. 1983a). In the eastern tropical Pacific, groups of *Mesoplodon* whales averaged 3.0 individuals (CV= 0.11); however, it is likely an underestimate by as much as one half (Wade and Gerrodette 1993).

Groups of Stejneger's beaked whales often contain animals of various sizes, suggesting intermingling of ages and sexes (Loughlin et al. 1982).

In most cases, male and female individuals of the genus *Mesoplodon* appear to be similarly sized. As with most ziphiids, males are generally more heavily scarred than females, maybe the result of intraspecific fighting (Leatherwood et al. 1988a; Heyning 1984; MacLeod 1998). It has been proposed that unpigmented intraspecific scars act as an indicator of male 'quality' during aggressive interactions to avoid costly and dangerous fights (MacLeod 1998). As with most ziphiids, functional teeth regularly protrude above the gumline in adult males, but not in females, and selected, as weapons for male-male competition. (Leatherwood et al. 1983a; MacLeod 1998). In Blainville's beaked whales, males appear to engage frequently in aggressive interactions with other males but not so with females or calves, suggesting that their mating system might be one where mature males rove between receptive females (MacLeod and Claridge 1998).

Reproduction and Population Parameters

Age at sexual maturity has been estimated as nine years for Blainville's beaked whales (Leatherwood et al. 1983a). Minimum longevity for Gervai's beaked whales has been estimated as 27 years (Leatherwood et al. 1983a).

Breeding Areas

There are no apparent special breeding areas. The breeding season of Sowerby's beaked whales, a species distributed in the North Atlantic, appears to be late winter or spring (review by Jefferson et al. 1993). The breeding season of strap-toothed whales appears to be spring or summer (review by Jefferson et al. 1993). The breeding season of Hubb's beaked whales appears to occur in the summer and the gestation period is about 12 months (Mead et al. 1982).

Speed of Travel and Movements

Stejneger's beaked whales probably swim at speeds of five to seven km/h with a maximum of almost 11 km/h (Bruyns 1971 in Loughlin and Perez 1985).

Vocal Behavior

Hubb's beaked whales have been recorded producing whistles between 2.6 and 10.7 kHz, and pulse sounds between 0.3 and 80+ kHz, with dominant frequencies from 0.3 to 2 kHz

(Buerki et al. 1989; Lynn And Reiss 1992). A young beaked whale, apparently a Blainville’s beaked whale, produced chirps and whistles below 1kHz up to 6 kHz (Caldwell and Caldwell 1971a).

Hearing Range

No data available.

Known Impacts of Human Activities

Beaked whales (Ziphiidae) seem especially sensitive to aircraft overflights, usually diving immediately and sometimes remaining submerged for long periods thereafter (CETAP 1982; Dohl 1983 et al.; Mullin et al. 1991). In the northern Gulf of Mexico, beaked whales showed the most avoidance reactions to survey ships and aircraft (Würsig et al. 1998). They oriented away from survey vessels in 11 of 15 sightings and changed their behavior in response to the airplane in eight of nine sightings (Würsig et al. 1998). Sorensen et al. (1984) found evidence that densities of “squid-eating cetaceans” may be reduced within several kilometers of vessels off the U. S. east coast. During the Heard Island Feasibility Test in the southern Indian Ocean, sighting rates for beaked whales were lower during than before transmissions (Bowles et al. 1994). In this test, sound at ~57 Hz was projected intermittently from ~175 m deep for 7.3 days, usually for periods of 0.5-1 h every 3 h; overall, source levels were initially 218-221 dB re: 1uPa @ 1 m, later diminishing to ~205 dB (Birdsall et al. 1994). The transmitted sounds may have elicited avoidance by some whales; however, evidence was inconclusive because sample sizes were low, differences were not statistically significant, and whales probably reacted to the ships in addition to any reactions to the transmitted sounds (Bowles et al. 1994).

CUVIER’S BEAKED WHALE (*ZIPHIUS CAVIROSTRIS*)

Summary

Cuvier’s beaked whales (*Ziphius cavirostris*) are one of the most abundant and widespread species in the family Ziphiidae. Like other species of this family they are pelagic, deep diving, and feed primarily on squid. They occur in all oceans between 60°N and 60°S. They appear to be more social than species in the genus *Mesoplodon*. There are no data on reproductive rate, but it is likely low.

There are no data on vocalizations or hearing. However, the size, distribution and deep diving behavior of these whales suggest that they would be more sensitive to negative impacts of LFA.

Protected Status

The Cuvier’s beaked whale is not federally listed under the U. S. Endangered Species/Marine Mammal Protection acts (kingfish.ssp.nmfs.gov/tmcintyr/spec_idx.html). It is listed as a data deficient species by the Cetacean Specialist Group of the International Union for the Conservation of Nature (www.wcmc.org.uk/data/database). There have been no major fisheries for Cuvier’s beaked whales. However, 13 to 60 whales per year have been taken in Japan, two specimens in the Lesser Antilles, and three whales between 1971 and 1976 in France (Caldwell and Cadwell 1975; Duguy 1977; Klinowska 1980).

Distribution

Cuvier’s beaked whales are the most widely distributed beaked whale and one of the most widely distributed cetaceans. They are found in offshore waters of all oceans, from the tropics to the polar regions, between 60°N and 60°S (review by Jefferson et al. 1993). The species appears to be more common in subtropical and temperate waters than in tropical and subpolar waters of their range (review by Evans 1987). These whales apparently avoid high latitude waters (review by Leatherwood et al. 1983a).

Stranded specimens have been noted in the northwestern Atlantic as far north as Cape Cod, and in the northeastern Atlantic as far north as the North Sea, including the Netherlands (Van Waerebeek et al. 1997a; review by Leatherwood et al. 1983a). In the southwestern Atlantic they have been recorded in Tierra del Fuego; in the southeastern Atlantic they have been recorded in the Cape of Good Hope (review by Leatherwood et al. 1983).

In the North Pacific, Cuvier’s beaked whales have been recorded in the southern Bering Sea; in the south Pacific they have been recorded in Australia and New Zealand (review by Leatherwood et al. 1983a). Records in the eastern tropical Pacific demonstrate that the species ranges far from continental land masses and into warm waters (Wade and Gerrodette 1993). The species is also found in the Gulf of Mexico, and the Caribbean and Mediterranean seas (review by Evans 1987).

Cuvier's beaked whales appear to prefer deep waters, usually offshore of the 1,000 m contour (review by Houston 1991). They are relatively abundant and found throughout the eastern tropical Pacific (Wade and Gerrodette 1993). They are also fairly common in the Mediterranean and Caribbean seas, and the Sea of Japan (reviews by Leatherwood et al. 1983a; Evans 1987; Jefferson et al. 1993). They appear to be less common in the higher latitudes of their range (review by Evans 1987).

Data on seasonal distribution are inconclusive, though summer and winter movements are thought to occur inside the Mediterranean Sea (review by Evans 1987). The species is apparently a year-round inhabitant of at least some parts of its range, off New Zealand, the British Isles, western North America, and Japan (Omura et al. 1955; review by Leatherwood et al. 1993).

Abundance

Worldwide population is unknown. Stranding records suggest that Cuvier's beaked whales are more common than the lack of sightings suggests (review by Leatherwood et al. 1983a).

Ship surveys give an estimate of 1,621 Cuvier's beaked whales (95% bootstrap CL= 186-5,555) in California (Barlow 1995). Estimated density was 0.023 whales/km^2 (Barlow 1995). A total of 20,000 Cuvier's beaked whales (95% bootstrap CL= 13,800-34,500) have been estimated for the eastern tropical Pacific, making it a relatively abundant species (Wade and Gerrodette 1993). Overall density values in the eastern tropical Pacific were estimated from Wade and Gerrodette (1993) as mean population size divided by study area, results are 0.001 whales/km^2; however, density values vary within the study area.

Diet and Foraging Behavior

The Ziphiidae is considered a family of predominantly cephalopod-eating species, the most important of the families of cephalopods represented in the diet are the oceanic Ommastrephidae, Histioteuthidae, and Cranchiidae (Clarke 1996). Cuvier's beaked whales feed mainly on deep-sea squid, but also take fish and some crustaceans (review by Jefferson et al. 1993). At least six families of squid are prey items of this species (Nishiwaki and Oguro 1972; Ross 1984; Clarke 1986, 1996).

Anatomical data support the hypothesis that beaked whales (Ziphiidae) use suction to acquire prey (Heyning and Mead 1996).

Diving Behavior

Dives of more than 30 min, up to 40 min have been recorded (reviews by Heyning 1989; Jefferson et al. 1993).

Social Behavior

Cuvier's beaked whales are found in small groups of two to seven whales, although single individuals and groups of as many as 25 whales have been observed (reviews by Leatherwood et al. 1983a; Jefferson et al. 1993). In general, group size averages 2.3 individuals with a maximum of seven whales (review by Heyning 1989). In the eastern tropical Pacific, group size averaged 2.2 individuals (CV= 0.06); however, it is likely an underestimate by as much as one half (Wade and Gerrodette 1993).

Except for occasional individuals, which seem to be solitary bulls, no generalizations can be made about group composition (review by Leatherwood et al. 1983a).

Female Cuvier's beaked whales appear to be sligthly larger than males. In Japan, the modal length of mature Cuvier's beaked whale males is 0.95 times that of females (Omura et al. 1955). Based on less than 10 individuals per sex, the maximum weight of males is 0.73 times that of females (review by Heyning 1989). The back and sides of the body are usually covered with linear scars, attributed to intraspecific fighting (review by Leatherwood et al. 1983a). The head and much of the back of adult males can be completely white (review by Jefferson et al. 1993). The single pair of teeth is slender and pointed in females, and does not normally erupt; the teeth of males are massive and erupt early in life (review by Leatherwood et al. 1983a).

Reproduction and Population Parameters

In Japan, the average length at sexual maturity is 5.8 m in females and 5.5 m in males (Omura et al. 1955). Seasonality of calving is unknown (review by Jefferson et al. 1993). This species is believed to live at least 35 years (review by Mead 1984).

Breeding Areas

No data available.

Speed of Travel and Movements

Cuvier's beaked whales are strong swimmers, but usually travel at a leisurely pace of five to six km/h (review by Houston 1991).

Vocal Behavior

No data available.

Hearing Range

No data available.

Known Impacts of Human Activities

Mass strandings of Cuvier's beaked whales are rare, with less than a dozen cases reported (Rosario-Delestre and Mignucci-Giannoni 1998). Frantzis (1998) reported that between 11 and 12 of May of 1998, twelve Cuvier's beaked whales stranded alive along the coast of Greece. The stranding was atypical because whales were separated by a mean distance of 3.5 ± 2.8 km, unlike other simultaneous strandings that involve more than one whale. Necropsies of eight animals were unable to pinpoint abnormalities or wounds. The timing of the strandings and its atypical characteristics suggest that they were caused by tests conducted on May 11 on the Low Frequency Sonar system by the NATO R/V Alliance (editor’s note: NATO has since revealed that the R/V Alliance was testing a high frequency sonar system around the time of the strandings). This episode is reminiscent of previous mass strandings of beaked whales (Ziphiidae) that occurred when there were naval maneuvers offshore (Simmonds and López-Jurado 1991).

SHEPHERD’S BEAKED WHALE (*TASMACETUS SHEPHERDI*)

Summary

The Shepherd’s beaked whale (*Tasmacetus shepherdi*) is one of the most poorly known cetaceans. All available information is from partially decomposed animals found on the shore of circumpolar waters in the Southern Hemisphere.

Protected Status

The Shepherd’s beaked whale is not federally listed under the U. S. Endangered Species/Marine Mammal Protection acts (kingfish.ssp.nmfs.gov/tmcintyr/spec_idx.html). It is listed as a data deficient species by the Cetacean Specialist Group of the International Union for the Conservation of Nature (www.wcmc.org.uk/data/database). No records of human exploitation exist (reviews by Leatherwood et al. 1983a; Jefferson et al. 1993).

Distribution

All of the confirmed records of this species are from partially decomposed strandings, with only two possible sighting records (review by Jefferson et al. 1993). The species is thought to have a circumpolar distribution in cold temperate waters of the Southern Hemisphere, south of 30°S (review by Jefferson et al. 1993). However, the species has apparently stranded in the Galápagos Islands (review by Evans 1987).

In the southwestern Atlantic, there are records of this species from Brazil to Tierra del Fuego (review by Evans 1987). There are also records from some islands in the South Atlantic, although no records exist from South Africa or Antarctica (reviews by Evans 1987; Jefferson et al. 1993). In the South Pacific, there are records from New Zealand and Chile to the Galápagos Islands (reviews by Evans 1987; Jefferson et al. 1993).

Shepherd’s beaked whales are probably oceanic, deep water animals (review by Jefferson et al. 1993).

Abundance

No data available.

Diet and Foraging Behavior

Shepherd’s beaked whales feed on small squid, euphasiids, decapod crustaceans and fish (Mead and Payne 1975; review by Evans 1987). They apparently feed near the bottom in deep waters (reviews by Leatherwood et al. 1983a; Jefferson et al. 1993).

Diving Behavior

No data available.

Social Behavior

It is unknown whether this species is sexually dimorphic. Based on less than ten individuals per sex from different regions, the maximum length of males is 1.06 times that of females (Mead and Payne 1975). The mandible is lined with sharp, functional teeth; at the end of the mandible there is a pair of much larger teeth, which apparently erupt only in males (review by Leatherwood et al. 1983a).

Reproduction and Population Parameters

A female 6.6 m long was sexually mature (review by Leatherwood et al. 1983a).

Breeding Areas

No data available.

Speed of Travel and Movements

No data available.

Vocal Behavior

No data available.

Hearing Range

No data available.

Known Impacts of Human Activities

No data available.

LONGMAN'S BEAKED WHALE (*INDOPACETUS PACIFICUS*)

Summary

Almost nothing is known about Longman's beaked whales (*Indopacetus pacificus*).

Protected Status

The Longman's beaked whale is perhaps the most poorly known of all marine mammals (review by Jefferson et al. 1993). It is not federally listed under the U. S. Endangered Species/Marine Mammal Protection acts (kingfish.ssp.nmfs.gov/tmcintyr/spec_idx.html). This beaked whale is also listed as a data deficient species by the Cetacean Specialist Group of the International Union for the Conservation of Nature (www.wcmc.org.uk/data/database). There is no known exploitation of this species (review by Jefferson et al. 1993).

Distribution

It is believed that the Longman's beaked whale is limited to the Indo-Pacific region (reviews by Leatherwood et al. 1983a; Jefferson et al. 1993). The species is only known from two recovered skulls from Queensland, northern Australia, and Danane, Somalia (reviews by Evans 1987; Jefferson et al. 1993). Recent sightings in the equatorial Indian and Pacific oceans have been tentatively assigned to this species (Ballance and Pitman 1998; Pitman et al. 1998).

Abundance

No data available.

Diet and Foraging Behavior

No data available.

Diving Behavior

No data available.

Social Behavior

Groups of presumed Longman's beaked whales had a mean size of 18.5±21.7 whales (n=39), which is a large average for a beaked whale (Pitman et al. 1998).

Reproduction and Population Parameters

No data available.

Breeding Areas

No data available.

Speed of Travel and Movements

No data available.

Vocal Behavior

No data available.

Hearing Range

No data available.

Known Impacts of Human Activities

No data available.

MONODONTIDAE

BELUGA (DELPHINAPTERUS LEUCAS)

Summary

Beluga (*Delphinapterus leucas*) are the best-studied non-delphinid odontocete. They are abundant and wide spread in arctic and subarctic waters. However several populations are declining or recovering slowly due to subsistence hunting. The most threatened population in the Saint Lawrence Estuary also suffers from high levels of contaminants and habitat destruction. They are a coastal species but dive to depths of at least 800 m to feed primarily on fish found on or near the bottom. They aggregate in shallow estuaries and at the mouths of rivers in the summer.

Beluga vocalizations are as low as 200 Hz, but most vocalizations are above 2kHz. Most studies suggest that their hearing below 1kHz is poor, however, there is some contradictory evidence that they can detect sounds as low as 100Hz that are only 1dB above ambient levels

Protected Status

Beluga are not federally listed under the U. S. Endangered Species/Marine Mammal Protection Acts (kingfish.ssp.nmfs.gov/tmcintyr/spec_idx.html). However, they are listed as vulnerable by the Cetacean Specialist Group of the International Union for the Conservation of Nature (www.wcmc.org.uk/data/database). There is a long history of direct hunting, both subsistence and commercial, of beluga by native peoples, Russians, and western Europeans (Jefferson et al. 1993). There is evidence that beluga were hunted as early as 500-600 years ago (McGhee 1974; Mitchell and Reeves 1981). Although commercial hunting has ceased, belugas are still taken by indigenous Arctic people for food (Kemper 1980; Seaman and Burns 1981; Stewart and Stewart 1989). Catches apparently total several thousand per year (Jefferson et al. 1993), but major depletion probably a resulted from past exploitation (Klinowska 1991). In the decades following 1923, large commercial catches for beluga are thought to have caused a decline in numbers until commercial hunting stopped in 1960 (Mitchell and Reeves 1981). Belugas in Canada and Alaska are only taken by indigenous subsistence hunters (Stewart and Stewart 1989; Richard 1991).

In parts of the beluga range, oil and gas exploitation activities have been a source of concern (review by Jefferson et al. 1993). Some populations are far below historic levels (Braham 1984). The populations inhabiting the Gulf of St. Lawrence, Cumberland Sound in western Davis Strait, Ungava Bay in Hudson Strait, and eastern Hudson Bay have been severaly depleted by historical over-exploitation and other forms of disturbance (Leatherwood et al. 1983a). Three stocks have received endangered listing by the COSEWIC: the St. Lawrence River (Pippard 1985), the Ungava Bay (Smith and Hammill 1986), and the Southeast Baffin Island populations (Richard 1991). The Baffin

Bay stock of beluga is considered vulnerable until better information on population trends is available (Doidge and Finley 1993).

The most threatened beluga population is in the St. Lawrence estuary. The population was initially reduced to an estimated 300-350 beluga by extensive commercial hunting which lasted until 1979 (Kingsley 1998). Although it is now legally protected from all forms of direct exploitation (Reeves and Mitchell 1984), there are continued threats from chemical pollution and loss of suitable habitat (Reeves and Mitchell 1984). Most recently ecotourism boats may be causing some disturbance (Blane and Jaakson 1994).

Lesage and Kingsley (1998) updated the information on the St. Lawrence estuary stock, which is at the southern limit of the distribution of this species. The large distances separating this population from northern beluga, its low genetic variability, and the rarity of beluga sightings outside their normal range in the Gulf, suggest that it is isolated from its northern conspecifics. Over-exploitation and attempted extermination reduced this population to the low hundreds; it is now conservatively indexed at between 600 and 700 and is slowly increasing. Factors potentially limiting the size of this population include limits on food stocks and extent of critical habitat; its growth rate may be affected by low genetic variability, boat traffic, and environmental contamination. Pollution reductions upstream and improved controls on toxic compounds, are helping to reduce ambient levels of contaminants, but efforts to accelerate and maintain this progress are important.

Distribution

Belugas are found in arctic and subantarctic waters, from 82° to 47°N (Stewart and Stewart 1989; Jefferson et al. 1993). However, the furthest south extralimital record is from 39°N in New Jersey, USA (review by Stewart and Stewart 1989). Although they are usually found in shallow waters, they move at times into deep, offshore waters (Jefferson et al. 1993). Beluga also enter estuaries and rivers (review by Jefferson et al. 1993). Like several other arctic marine species, beluga have discontinuous distributions in the Canadian Arctic, apparently resulting from a major geographical barrier or gap in the central Canadian Arctic separating western and eastern populations of the species (Stewart and Burt 1995).

In the northwestern Atlantic, beluga spend the summer in Baffin Bay, from Lancaster Sound to Hudson Bay (Evans 1987). On the West Coast of Greenland, beluga summer in Melville Bay and Thule district, and winter in Disko Bay or further south (Evans 1987). Beluga also occur further south off the coast of eastern Canada, as far down as the Gulf of St. Lawrence (Evans 1987). In the northeastern Atlantic, beluga are found between east Greenland and Franz Josef Land and Novya Zemlya (Evans 1987). Occasionally, they wander near the North Sea coasts, at times as far south as the Dutch coasts (Evans 1987). In the Pacific, beluga summer in the Okhotsk, Chukchi, Bering and Beaufort seas, the Anadyr Gulf, and off Alaska. They commonly occur in Cook Inlet during the summer and fall, with smaller numbers being observed in the winter (Hansen and Hubbard 1998; Rugh et al. 1998). Beluga winter in the Bering Sea, Alaska, and perhaps Russia (Evans 1987).

A total of 16 beluga stocks have been recognized based on morphological, genetic and distribution differences (review by Reeves and Leatherwood 1994). There is a high degree of philopatry to specific summering areas by the species (Gladden et al. 1997). There appears to be significant genetic differentiation between geographically distinct summering groups, attributed to maternal fidelity to summer migration areas even if individuals winter in the same place (Hoelzel 1994). Overall, the patterns of mtDNA variation in beluga whales indicated that the summering concentrations are demographically, if not phyletically, distinct. Population structure appears to be maintained primarily by natal homing behavior, dispersal, although limited, appears to be biased toward older adult males and may be associated with the type of mating system (O'Corry-Crowe et al. 1997). Haplotype sudies indicate two lineages, one occurring primarily in whales from the St. Lawrence estuary and eastern Hudson Bay and the other primarily in beluga sampled in the waters of western Hudson Bay, southern Baffin Island, western Greenland, the Canadian High Arctic, and the eastern Beaufort Sea. These lineages may represent the original Pacific and Atlantic "refugial" stocks that colonized the Arctic after deglaciation. Further, the present segregation is consistent with the hypothesis that the mitochondria of the beluga summering in western Hudson Bay are descended from those of a Pacific refugial stock and those of beluga summering in eastern Hudson Bay are descended from those of an Atlantic refugial stock. The clear differentiation of beluga from different summering locations provides evidence for strong maternally directed philopatry to the summering locations (Brennin et al. 1997).

Some beluga populations are strongly migratory, others basically resident in a well-defined area, such as the St. Lawrence estuary (reviews by Leatherwood et al. 1983a; Evans 1987). The primary determinant of beluga movements is ice cover since they cannot maintain breathing holes in heavy pack ice and landfast ice (reviews by Leatherwood et al. 1983a; Stewart and Stewart 1989). In winter, beluga are restricted to polynyas or loose pack ice, such as those found in Lancaster Sound and the North Water of Baffin Bay (Jonkel 1969; Gurevich 1980; Stirling et al. 1981; Richard et al. 1998). In spring and autumn, beluga may be observed following ice edges closely and penetrating areas with ice cracks (Stirling 1980). In summer, when coastal areas are largely ice-free, many beluga move into more shallow waters (Brodie 1971; Seaman and Burns 1981). Especially relatively warm estuaries and fresh waters far up rivers where they can form large aggregations (Smith et al. 1985). It has been hypothesized that these habitats are less energetically demanding so that fat reserves can be mobilized for growth (Sergeant and Brodie 1969; St-Aubin and Geraci 1989). However, they may also be related to the distribution of prey. The large summer aggregations may be related to calving and neonate survival, feeding, or molting (Sergeant 1962a, 1973; Stirling et al. 1981).

Daily movements in the open-water season are influenced by tide in some locations: ascending rivers or estuaries on flood tides and descending on ebb tides (Pippard 1985). However, beluga in the Mackenzie estuary do not show such movements (Stewart and Stewart 1989). Long-range movements up river systems, such as the Amur and Rhine, are common (review by Stewart and Stewart 1989).

Although there is some variability in habitat used beluga in Northern Alaska, they prefer continental slope waters regardless of the ice cover (Moore 1998). In summer they occur in continental slope and basin waters in moderate to heavy ice conditions, in autumn they occur in outer shelf and continental slope waters and moderate to heavy ice conditions (Moore 1998).

Abundance

It is estimated that there is a worldwide population of 100,000 beluga (IWC 1992).

Population estimates and exploitation rates (annual catch adjusted to include percent loss) are: 5,000+, 3 to 4%, Alaska (IWC 1981); less than 500, 18-24% Cumberland Sound (Richard and Orr 1986; Richard 1991); 750 to 2,000, ca. 20%, eastern Hudson Bay (Smith and Hammill 1986); 12,000 to 14,000, 9 to 10%, western Greenland (IWC 1980); 680, 0%, St. Lawrence River (Kingsley 1998). Other estimates include 10,000 beluga in Lancaster Sound and adjacent areas and more than 11,000 in western Hudson Bay and Hudson Strait (Leatherwood et al. 1983a).

About 300 beluga have been removed from Cumberland Sound between 1987 and 1989, while net recruitment during those years was probably fewer than 15 animals (Richard 1991). At the present rate of exploitation the Cumberland Sound population must be declining and could be extirpated in less than a decade (Richard 1991).

An annual average increase for 1979-1995 of 2.6% ± 1.0 has been estimated for the St. Lawrence estuary population; however the population is still at risk (Kingsley 1998). Recent surveys suggest that this endangered population is not recovering significantly despite 20 years of protection. Dead individuals that have been autopsied show high levels of tumors and infections. This situation could be a result of pollution, loss of genetic variation, inbreeding depression, or a combination of these factors. Analyses of DNA fingerprints from St. Lawrence beluga indicate a reduced level of genetic variation compared to Beaufort Sea animals, suggesting that this population is composed of individuals which are related. Inbreeding depression could therefore be a factor in the lack of recovery of the St. Lawrence beluga population (Patenaude et al. 1994).

The population off West Greenland apparently has declined considerably during the past 13 years, perhaps by as much as 62% (Heide-Jørgensen and Reeves 1996). The Baffin Bay population of approximately 12,000 is subject to an annual harvest of 50 beluga in the Canadian high arctic and 700 in Greenlandic. This take may exceed production (Doidge and Finley 1993).

Diet and Foraging Behavior

Belugas apparently feed primarily on shallow-water fish (review by Gaskin 1982), but also take squid, euphausiid and decapod crustaceans, mollusks and annelids (Tomilin 1957; Gaskin 1976, 1982; Gurevich 1980). Diets vary with season, location, age, and body size (Sergeant 1962a; Gaskin 1982). In the Saint Lawrence estuary beluga feed mainly on capelin and sandeel, but also on squid and crustaceans; in the Barents, White and Kara seas their diet includes haddock, cod, arctic cod, herring, Atlantic salmon, arctic char, and smelt (review by Evans 1987). Based on stomach contents, beluga are thought to feed mostly on or near the bottom (review by Jefferson et al. 1993).

Having few functional teeth, beluga use alternative means of food capture (review by Evans 1987). These involve suction and the emission of a jet of water to dislodge prey such as bottom-living fish and mollusks (review by Evans 1987). The highly flexible neck aids the scanning of a broader area of sea bottom and the capture of mobile prey (review by Evans 1987). Prey are held by the beluga's hard lips and teeth, while the mobile tongue aids in orientation and swallowing (review by Stewart and Stewart 1989). Captive beluga have been observed to employ the perimeter netting of their enclosure to corral and then engulf large numbers of fish (Ridgway and Carder 1998).

Body measurements, weight changes, and food consumption of nine captive beluga show a significant negative correlation between average monthly water temperature and average daily food intake per month. This relationship and water temperature within the distribution of beluga were used to calculate that a wild adult female of 600-700 kg may eat around 4900 kg of fish per year or 8.144.000 kcal/year (Kastelein et al. 1994).

Diving Behavior

Trained belugas are capable of diving as deep as 647 m and as long as 15 min and 15 s (Ridgway et al. 1984). In the Canadian high Arctic, beluga diving behavior was categorized as: 1) dives of short-duration, 1 min or less; 2) spike dives of 4 min or less to 20-150 m depth; and, 3) prolonged, flat-bottom dives to depths of 20-350 m with duration ranging between 9.3-13.7 min (Martin and Smith 1992). The speed of descent varied between 1.43 and 2.20 m/s, while the speed of ascent varied between 1.23 and 1.84 m/s; however, within periods of 20 s duration, maximum descent ad ascent rates were 2.55 and 2.35 m/s, respectively (Martin and Smith 1992). Up to 42% of an animal's time could be spent at depths of 8 m or more (Martin and Smith 1982). Beluga may remain submerged for 15 to 20 minutes and may travel up to two to three km on one dive (Seaman and Burns 1981; Ridgway et al. 1984). Data from six belugas near eastern Devon Island, Canada, show that the mean of the daily maximum depths of dives was 483-665 m (Heide-Jørgensen et al. 1998). The deepest dive recorded was 872 m (Heide-Jorgensen et al. 1998). Few dives lasted more than 18 min, and most lasted either less than 1 min or for 9-18 min (Heide- Jørgensen et al. 1998). Vertical speeds ranged from 0.5 ms-1 to 1.9 ms-1 for depths of 52-800 m. (Heide- Jørgensen et al. 1998). Two trained adult white whales dove to a test platform suspended at depths of 5-300 m (Shaffer et al. 1997). Behavior was monitored for 457 dives with durations of 2.2-13.3 min (Shaffer et al. 1997). Descent rates were generally less than 2 m/s and ascent rates averaged 2.2-3 m/s (Shaffer et al. 1997). Maximum breath-hold duration was 17 min (Shaffer et al. 1997). Results of the study are consistent with the calculated aerobic dive limit of nine to ten min (Shaffer et al. 1997).

Social Behavior

Although beluga are highly gregarious, sometimes seen in aggregations of thousands, group sizes are usually smaller than 15 individuals (Jefferson et al. 1993). The largest beluga concentrations are found in estuaries during the summer (Leatherwood et al.

1983a). In Lancaster Sound, Canada, groups average 3.8 individuals with a maximum of 200 belugas (Cosens and Dueck 1991). In the Gulf of Alaska, groups average 9 individuals with a maximum of 100 belugas (Fiscus et al. 1976). Beluga groups in the Soviet Arctic average 32.9 with a maximum of 500 beluga (Ognetev 1981).

Groups are closely aggregated on the breeding grounds but spread out during feeding (Evans 1987). Within the group there is obvious segregation by age and sex (Evans 1987). Two main types of groups have been reported: nursery groups of females and their calves with immature animals, and groups of adult males (Brodie 1971; Sergeant 1973). A 1:1 sex ratio is thought to be realistic (Doan and Douglas 1953; Sergeant 1973; Seaman and Burns 1981). Calves remain with their mother for two years (Leatherwood et al. 1983a). During mating season, there is temporary movement of males into the female groups, forming aggregations that may number hundreds to several thousand individuals (Evans 1987).

In the Bering, Chuckchi and Beaufort Seas, grouping patterns are highly dynamic and consistent with fission-fusion societies, with beluga groups containing closely related and unrelated individuals (O-Crowe et al. 1998). Although both females and males disperse from groups, the latter show greater movement than the former (O-Crowe et al. 1998). More than one male fathers calves within a group although not all mature males appear to breed within the group in which they are found (O-Crowe et al. 1998).

Although adult body size varies geographically, male beluga are larger than females (Sergeant and Brodie 1969; Stewart and Stewar 1989). The maximum length of males is 1.18 times that of females (Braham 1984). The maximum weigth of males, based on less than 10 individuals per sex, is 1.41 times larger than that of females (Brodie 1989). The distal edge of the flippers curls upwards in adult males, with the degree of curling increasing with age (review by Stewart and Stewart 1989). The teeth of males are longer, erupt farther, have thicker cementum and wear more at the tip than those of females (Sergeant 1973). It has been proposed that belugas are polygynous (Sergeant 1962a; Fraker 1980) or have a promiscuous mating system where adult males compete for complete mating access to females (Evans 1987).

Reproduction and Population Parameters

Females reach sexual maturity at four to seven years of age, males at seven to nine (Brodie 1971; Sergeant 1973; Mitchell 1975; Seaman and Burns 1981). The gestation period is 14 to 15 months, with a lactation period of 20 to 24 months and a calving interval of three years (Sergeant 1962a, 1973; Brodie 1971; Braham 1984). However, a small proportion of belugas may have biennial breeding cycles (Mitchell 1975). A typical female may have a maximum of 10 pregnancies in a full reproductive lifetime (Sergeant 1973). Belugas are believed to live at least 25 to 30 years (Brodie 1969, 1971; Sergeant and Brodie 1975).

Gross reproductive rate in various estuaries range from 0.056 to 0.121 (Braham 1984). Sergeant (1973) suggested a mortality rate of 0.095 between 2 and 6 months of age. It has been suggested that beluga, like other cetaceans, have a net annual recruitment rate as low as 2 to 3% of total population size, a conclusion supported by attempts to model population growth (Richard and Orr 1986). However, Brodie et al. (1981) estimated annual recruitment at 7.5% of population size for the Cumberland Sound population.

Breeding Areas

Mating occurs in the spring with geographical variations in peak of mating. In most areas peak months of conception are April and May; however, mating can occur from as early as February to as late as September (Doan and Douglas 1953; Kleinesberg et al. 1969; Brodie 1971; Sergeant 1973; Seaman and Burns 1981). Calving occurs mostly in the summer and there are appears to be more variation in calving times, with peaks of calving starting as early as late March and as late as early August (Sergeant 1962a, 1986).

Speed of Travel and Movements

Maximum swimming speeds are 16 to 22 km/h (review by Stewart and Stewart 1989). Swimming performance of two whales trained to follow a boat at speeds of 1.4-4.2 m/s showed respiratory rates ranged from 1.6 breaths/ min at rest to 5.5 breaths/min during exercise and decreased with increasing swim speed. Compared to other small cetaceans, belugas are not well adapted for high-speed swimming (Shaffer et al. 1997).

Vocal Behavior

Beluga have are famous for being very vocal (Parry 1821). They possess a large vocal repertoire (Fish and Mowbray 1962; Morgan 1979; Sjare and Smith 1986a). They produce pulsed calls, associated with echolocation, and tonal calls (Fish and Mowbray 1962; Gurevich and Evans 1976; Au et al. 1985; Sjare and Smith 1986a,b). The tonal calls (whistles) have been classified into 16 contour types, while pulsed calls have been classified into click series, pulsed tones, and noisy vocalizations (Sjare and Smith 1986a). Whistles are produced as low as 0.26 kHz and as high as 20 kHz, with dominant frequencies at 2-5.9 kHz (Schevill and Lawrrence 1949; Sjare and Smith 1986 a,b). Pulsed tones are produced as low as 0.4 kHz and as high as 12 kHz, with dominant frequencies at one to eight kHz (Schevill and Larwrence 1949; Sjare and Smith 1986 a,b). Noisy vocalizations are produced as low as 0.5 kHz and as high as 16 kHz, with dominant frequencies at 4.2-8.3 kHz (Schevill and Larwrence 1949; Sjare and Smith 1986 a,b). There are several dominant frequencies of beluga sounds: one to eight kHz, 40-80 kHz, 100-120 kHz (Gurevich and Evans 1976; Schevill and Larwrence 1949; Au et al. 1985, 1987; Sjare and Smith 1986 a,b). In Cunnigham Inlet, Northwest Territories, approximately 50% of the click series were broadband pulses with energy distributed throughout the frequency of the recording system (0.2-25 kHz). The other 50% of the click series had all or most energy distibuted within a mean frequency bandwith of 2.9 kHz (sd= 2.3), it has been suggested that this type of click series may have a communicative function (Watkins and Schevill 1971). The recorded source level (dB re: 1µPa @ 1m) of beluga vocalizations ranges from 206 to 225 dB (Au et al. 1985, 1987). However, pulses are extremely brief, apply only to a narrow range of directions in front of the animals, and source levels are higher than the rms pressure averaged over the short duration of a typical pulse (Au 1993). Thus, the overall energy content and acoustic power of beluga pulses are not very high when compared to some man-made sources (Richardson et al. 1995). Echolocation signals are very short in duration, varying from

40 to 70 s, with relatively large bandwidths on the order of 30 to 40 kHz. The spectrum of echolocation signals can be bimodal, with a low-frequency (40-60 kHZ) and a high-frequency (100-120 kHz) peaks (Au et al. 1985, 1987). Beluga have been demonstrated to echolocate (Au et al. 1985, 1987; Au 1993). They have better echolocation abilities than bottlenose dolphins because their shorter interclick intervals allow them to process more information per unit time (Turl et al. 1987), and because they have better ability to detect echo pulses amidst ambient noise (Richardson et al. 1995). With a 7.62-cm sphere as target, a trained beluga had good echolocation abilities at distances up to at least 80 m (Au et al. 1987). Echolocation signals are emitted in a forward directional beam in the horizontal plane, upwards at an angle of 5 to 10° in the vertical plane; the 3-dB beamwidth is approximately 6.5° (Au et al. 1987). The increase in intensity due to directionality is 32 dB in the beluga (Au et al. 1987). Such extreme directionality helps provide a good target localization ability and strong echo returns from targets (Richardson et l. 1995). A trained beluga produced higher frequency clicks in an area where ambient noise was higher by 15 to 20 dB than in a less noisy area (Au et a. 1985). It has been postulated that such high-frequency clicks were a by-product of the animals producing high intensity clicks to overcome snapping shrimp noise (Au et al. 1985). Apparently beluga can produce low and high intensity clicks at high frequencies, but cannot emit loud clicks at low frequencies (Turl et al. 1991; Au et al 1985; Au and Nachtigall 1997). Three different patterns of click intervals have been recorded in belugas (Au et a. 1987; Turl and Penner 1989). It is speculated that these different patterns of sonar emissions allow beluga to echolocate in the highly reverberant under-ice acoustic environment (Au and Nachtigall 1997).

The number of beluga whistles do not appear to vary with behavioral state; however, there were fewer pulsed tones emitted by alarmed whales than beluga in other behavioral states (Sjare and Smith 1986b). Individual signals have been recorded in beluga in association with foraging (Bel'kovich and Shchekotov 1992). Presumably these signals could function to acoustically identify individuals. Beluga may remain in acoustic contact over ranges of 300-500 m (Bel'kovich and Shchekotov 1992).

Hearing Range

Belugas hear underwater to sounds equal or less than 120 dB (re: 1μPa @ 1m) in the range of 0.125 kHz to 125 kHz (Awbrey et al. 1988; Johnson et al. 1989). At a frequency of 1 kHz, beluga can hear pure tones that have an intensity of at least 90-100 dB re: 1μPa @ 1m (Thomas et al. 1988a). The best underwater hearing of the species occurs at 11 kHz, where the threshold level is 40-50 dB re: 1μPa @ 1m (Sauerland and Dehnhardt 1998). Although the data indicate that their sensitivity at low frequencies is poor, they may be more sensitive to some combination of low-frequency particle motion and pressure fluctuations when in the near-field of the acoustic source (Turl 1993). It is important to note that estimated auditory thresholds for many cetacean species may be inaccurate, and possibly too high, for frequencies below 1-10 kHz because the small tanks in which the experiments are frequently conducted create echoes, standing waves, elevated noise levels, and pressure release boundaries (Cummings et al. 1975 in Richardson et al. 1995). Below ~10 kHz, beluga sensitivity deteriorates with decreasing frequency; below 1 kHz, sensitivity seems poor (Richardson et al. 1995).

Recent evidence indicate that beluga, and presumably other cetaceans, are able to hear as well at depth, at least to 300 m, as near the surface (Ridgway et al. 1997). In general, beluga auditory thresholds are lower as single pulse duration decreases until 0.1 s, and then thresholds increase with decreasing single pulse duration (Johnson 1991). Critical ratios of beluga below 2 kHz, measured between 40 Hz to 115 kHz, were unrelated to frequency and above 2 kHz they increased with frequency; critical ratios of beluga are about 3 dB smaller than those of bottlenose dolphins (Johnson et al. 1989). Data suggest that beluga can detect sounds to as low as 100 Hz at intensities just above the ambient ocean noises at those frequencies (Awbrey et al. 1988). Beluga have good hearing abilities for high-frequency echolocation sounds in the presence of noise (Richardson et al. 1995). They detect sounds with received levels several dB less than the background noise level in the corresponding critical band (Turl et al. 1987). Thus, they probably hear quite faint signals from man-made sonar operating at high frequencies (Richardson et al. 1995). However, their hearing sensitivity is much poorer at the low frequencies where many other man-made noises are concentrated (Awbrey et al. 1988; Johnson et al. 1989). However, low frequency noise pulses from marine seismic exploration are so strong that beluga as much as 100 km away should be able to detect them (Richardson and Würsig 1997).

At frequencies below 800 Hz, the masking band of beluga apparently widens from less than 1/6 octave to 1/3-2/3 octaves (Johnson et al. 1989). However, these values depend on the equal-power assumption to calculate the masking bandwidth (Richardson et al. 1995). If correct, they imply that the maximum radius of audibility in beluga is lower for sounds below 800 Hz than for sounds above 800 Hz. Audibility is also higher for sounds above ~300 Hz than the radius calculated from the usual assumption of 1/3 octave wide masking band, and lower for sounds below ~300 Hz than the radius calculated from the usual assumption of 1/3 octave wide masking band (Richardson et al. 1995). Belugas apparently are specialized for high-frequency hearing and yet maintain narrow critical bands at frequencies as low as a few hundred hertz (Richardson et al. 1995). Data indicate that beluga hearing at low frequencies is apparently limited by hearing thresholds, while it may be limited by ambient noise (sea state level) from a few kilohertz up to ~100 kHz (Richardson et al. 1995).

Known Impacts of Human Activities

Concern has been expressed recently over disturbance by whale watchers to regular concentrations of beluga in Glacier Bay, Alaska, and the St. Lawrence estuary (review by Evans 1987). The Saint Lawrence estuary population is likely threatened by human activities including elevated noise levels due to a wide range of anthropogenic sources including merchant shipping and whale watching activities (Scheifele 1997). Ambient noise levels at 200 Hz, 500 Hz, 1 kHz, and 40 kHz were high enough that there was a substantial probability of hearing damage in several parts of this populations range (Scheifele 1997).

Human activities such as oil and gas development, mining, hydroelectric plant construction and increased commercial fishing may be leading to changes in white whale distribution, because white whales migrate to relatively few estuaries and river mouths for calving (Ridgway 1997). Beluga show short-term localized displacement when harassed, but persist in using traditional summering grounds even when hunted intensively (Finley et al. 1982 in Richardson et al. 1995).

Playback experiments underwater at 163 dB (re: 1μPa @ 1m) suggest that belugas respond more negatively to sudden changes in sound level sounds by swimming away from the source than to sustained sound levels (Awbrey and Stewart 1983).

Richardson et al. (1995) reviewed the reaction of beluga to aircraft and vessel traffic. In general, beluga dive abruptly or swim away suddenly as the aircraft gets closer to the surface (150-460 m). This reaction distance is variable and sometimes no overt response is observed even if the aircraft flies within 100-200 m. Beluga reactions to vessels range from great tolerance to extreme sensitivity, apparently depending on whale activities and experience, habitat, boat type, and boat behavior. Continued harassment of beluga by hunters in estuarine concentration areas will cause them to temporarily vacate the area but they return usually within a few hours. Certainly they return in the following year, even if seriously over hunted. They are rather tolerant of the frequent passages by large vessels traveling in consistent directions; however, they flee from fast and erratic moving small boats. Some also disperse when small ships approach. There is evidence of some long-term and seasonal habituation of St. Lawrence beluga to boats: 1) avoidance responses to “unobtrusive” approaches have become less frequent, 2) cases of beluga approaching boats have become more common, 3) approaching by beluga is more common late than early in the summer field season. Evidence suggest that beluga habituate to fishing boats and are more responsive to outboard motorboats. In contrast, they react strongly and at extraordinarily long ranges to noise from ships and icebreakers in deep channels of the Canadian high arctic during spring. They swim rapidly away when a ship approaches within 35-50 km. Presumed alarm calls from beluga indicated that they detected a 105 Hz tone from an ore carrier at 85 km. Thus, it appears that vessel traffic may have stronger influences when beluga movements are partly confined by ice.

After beluga were initially displaced in response to relatively low levels of noise from approaching ice breakers (94-105 dB re: 1μPa @ 1m in the 20- to 1000-Hz band), the whales sometimes returned 1-2 days later when icebreaker noise levels were still as high as 120 dB in that band (Finley et al. 1990). Beluga near ice in spring sometimes react to noise from approaching ships at distances of 50 km or more (Richardson et al. 1995). At some other times, belugas tolerate very high levels of human activity (Richardson et al. 1995).

When communication at one frequency is masked by strong man-made noise, calls or call components at other frequencies may still be audible (Richarsdon et al. 1995). Beluga may sometimes take advantage of this phenomenon by emitting communication calls dominated by frequencies subject to little noise interference, thus they shift frequency of communication calls (Lesage et al. 1993). Thus, they can adjust the frequencies of their echolocation signals to avoid a frequency range where the background noise level is hign (Au et al. 1985). Beluga also take advantage of their directional sound emission and hearing capabilities while echolocating (Penner et al. 1986). They have been observed to direct its echolocation beam such that echolocation signals were bounced off the water's surface, providing angular separation between returning echoes and a point of source background noise; allowing the beluga to detect the target when the noise level was too high to allow detection by conventional straight-line echolocation (Penner et al. 1986). Frequency-shifting and sound-bouncing indicate that the characteristics of the echolocation sounds of beluga are modified in response to prevailing background noise to maximize the efectiveness of echolocation (Richardson et al. 1995).

Construction equipment operated on small artificial islands seemed to have little effect on beluga. They were seen within a few feet on an artificial island during quiet periods, and moved farther away but did not leave the area when construction equipment was in use (Fraker 1977a in Richardson et al. 1995). Perhaps because sounds produced on islands are attenuated greatly at the air-water and bottom-water interfaces (Richardson et al. 1995). Beluga in the Mackenzie estuary showed less reaction to stationary dredges than to moving barges despite similarities in their sounds (Ford 1977 in Richardson et al. 1995; Fraker 1977a in Richardson et al. 1995). Reactions to drilling are summarized by Richardson et al. (1995). Beluga swimming along an ice lead in spring changed course when they came within one km of a stationary drillship, and exhibited more active avoidance when support vessels were moving near the drillship. In other areas, migrating belugas did not show an overt reaction until they were 200-400 m from playbacks of a steady low-frequency (<350 Hz) drilling noise. The noise was detectable five km away. Within 200-400 m some beluga diverted or hesitated for a few minutes, but then continued within 50-200 m of the operating projector. Beluga might not have heard the sounds until they came within ~200-400 m, given their poor hearing sensitivity below one kHz. During playback sounds from a semisubmersible drillship beluga within 1.5 km moved faster in the same direction, respiration rates increased. Beluga swimming towards the noise did not react overtly until they were within 50-75 m and 300-500 m. However, most beluga passed close to the projector where received sound levels must have been high. Captive beluga did not show short-term behavioral or physiological effects (no elevated levels of catecholamines) to playback of actual or simulated submersible drillship sounds, which excluded the lowest-frequency components, despite the high level of noise that the beluga were exposed to (153 dB re: 1μPa @ 1m). Authors recommended caution in extrapolating these results to wild beluga because noise exposure was of short duration. These results on drilling may be another example of the degree to which beluga can adapt to ongoing man-made noise when it is not associated with negative consequences. In other situations, strong avoidance can occur in response to weak sounds (e.g. response to ice-breakers).

Success was limited when using small explosive charges to scare beluga away from salmon in Alaska during 1950s; however, they strongly avoided the rivers during underwater playbacks of killer whale calls at source level 170 dB re: 1μPa @ 1m (Fish and Vania 1971).

PHOCOENIDAE (PORPOISES)

SPECTACLED PORPOISE (AUSTRALOPHOCAENA DIOPTRICA)

Summary

The spectacled porpoise (*Australophocaena dioptrica*) was assigned to a new genus in the mid 1980s (Barnes 1985). However, recent genetic analysis supports retaining the spectacled porpoise within the genus *Phocoena* (Rosel et al. 1995). Spectacled porpoises are circumpolar, found in cool temperate, sub- and low-Antarctic waters. They appear to feed on small fish and crustaceans. Based on their distribution and feeding habits, they may be shallow divers. There are no data on vocalizations and hearing from this species; however, the communication system of other members of the family appears adapted to high-frequency sounds.

Their small size, distribution, probable diving habits, and presumed vocalizations and hearing abilities make it unlikely that spectacled porpoises will be vulnerable to LFA activity. However, because spectacled porpoises are not well known, it would be difficult to detect any negative impacts of LFA.

Protected Status

The spectacled porpoise is not federally listed under the U. S. Endangered Species/Marine Mammal Protection acts (kingfish.ssp.nmfs.gov/tmcintyr/spec_idx.html). This porpoise is listed as a data deficient species by the Cetacean Specialist Group of the International Union for the Conservation of Nature (www.wcmc.org.uk/data/database). The species is incidentally taken in gillents in Argentina and, occasionally, in the Chilean Strait of Magellan (Crespo et al. 1994; Goodall et al. 1994). It appears that at least 34 individuals were incidentally taken off Tierrra del Fuego between 1975 and 1990 (Goodall et al. 1994). However, the impact of incidental takes in the population is unknown (Jefferson and Curry 1994).

Distribution

The spectacled porpoise is a circumpolar species found in cool temperate, sub- and low-Antarctic waters, from about 32° to 59° S (reviews by IWC 1991; Goodall and Schiavini 1995). The species appears to have both coastal and pelagic distributions. It is found along the coast of Argentina, in offshore waters, and around offshore islands: Tierra del Fuego, the Falklands (Malvinas), and South Georgia in the southwestern Atlantic; Auckland and Macquarie in the southwestern Pacific; and Heard and Kergulen in the southern Indian Ocean (reviews by Brownell 1975; IWC 1991; Goodall and Schiavini 1995). Sightings of the species have occurred in water temperatures as low as 5°C (Kasamatsu et al. 1990).

Abundance

Although there are no world-wide population estimates, the species is considered rare (Goodall and Schiavini 1995).

Diet and Foraging Behavior

The few stomach contents analyzed contained anchovy (*Engraulis* sp.), small crustaceans, and one nematode each (review by Goodall and Schiavini 1995).

Diving Behavior

No data available.

Social Behavior

Spectacled porpoises do not appear to form large groups; all sightings have been of only one to three individuals (review by Goodall and Schiavini 1995).

It is unknown whether there is sexual dimorphism in size. Based on a sample of less than ten individuals per sex, the maximum length of males is 1.09 times that of females (Goodall and Schiavini 1995). The dorsal fin, however, is highly sexually dimorphic (Bruch 1916; Goodall and Schiavini 1995).

Reproduction and Population Parameters

Females as small as 1.86 m have been recorded pregnant (Bruch 1916). They appear to reach sexual maturity at about 1.85 m (Goodall and Schiavini 1995). Males may reach sexual maturity at about 1.90 to 2.10 m (Goodall and Schiavini 1995). Limited data suggest that individuals of this species may reach sexual maturity at three years or younger (Goodall and Schiavini 1995).

Breeding Areas

No data available.

Speed of Travel and Movements

No data available.

Vocal Behavior

No data available.

Hearing Range

No data available.

Known Impacts of Human Activities

No data available.

PORPOISES (*PHOCOENA* SP.)

Summary

The genus *Phocoena* comprises three species: the harbor porpoise (*P. phocoena*), the Burmeister's porpoise (*P. spinipinnis*), and the vaquita (*P. sinus*). This last species is considered as the most endangered marine cetacean in the world (Bjørge and Donovan 1995). Like other members of the family, these are coastal species: harbour porpoises have an almost circumpolar distribution in the temperate regions of the northern hemisphere, Burmeister's porpoises are found around the coast of South America, and vaquitas are restricted to a small area in the northwestern Gulf of California. They eat mostly fish and invertebrates, and appear to dive to shallow or moderate depths. Harbour porpoises are not known to produce sounds lower than 2 kHz in frequency. Although they can hear sounds as low as 0.1 kHz, their best hearing occurs at mid-frequencies.

Their small size, distribution, and vocalizations make it unlikely that porpoises of the genus *Phocoena* will be vulnerable to LFA activity. However, their diving and hearing abilities suggest that harbour porpoises may be vulnerable to LFA activity. Since distribution and movements of this species are relatively well-known in some areas, it may be possible to quantify any negative impacts of LFA activity.

Protected Status

The vaquita is federally listed as endangered under the U. S. Endangered Species Act (kingfish.ssp.nmfs.gov/tmcintyr/spec_idx.html). The harbor porpoise is federally proposed as threatened under the U. S. Endangered Species Act (kingfish.ssp.nmfs.gov/tmcintyr/spec_idx.html). The Burmeister's porpoise is not federally listed under the U. S. Endangered Species/Marine Mammal Protection acts (kingfish.ssp.nmfs.gov/tmcintyr/spec_idx.html).

The vaquita is one of world's two most endangered cetaceans, and one of the few marine mammals listed as critically endangered by the Cetacean Specialist Group of the International Union for the Conservation of Nature (www.wcmc.org.uk/data/database). The harbor porpoise is listed as vulnerable by the Cetacean Specialist Group of the International Union for the Conservation of Nature (www.wcmc.org.uk/data/database). The Burmeister's porpoise is listed as data deficient species by the Cetacean Specialist Group of the International Union for the Conservation of Nature (www.wcmc.org.uk/data/database). Directed hunts for harbor porpoises have occurred in Turkey, Rusia, Denmark, USA, Canada, Iceland, Polland, and Greenland; however, they appear to be now limited to west Greenland and the Black Sea (reviews by Gaskin 1992a; Jefferson et al. 1993; Reeves and Leatherwood 1994; Donovan and Bjørge 1995). Incidental catches in gillnets or salmon drift nets occur throughout the range of this species (Kock and Benke 1996; Sequeira 1996; de Lens 1997; Chivers et al. 1997; reviews by Gaskin 1992a; Jefferson and Curry 1994; Reeves and Leatherwood 1994; Donovan and Bjørge 1995). Harbor porpoises have virtually disappeared from much of the Baltic Sea and the Black Sea, and are rapidly declining in the southern North Sea and

English Channel (review by Gaskin 1992a). The bycatch of the population in the Gulf of Maine and Bay of Fundy is probably unsustainable (Read et al. 1993). The decline of the species in many parts of its range is most likely a consequence of incidental catches in fishing gear (review by Gaskin 1992a).

Burmeister's porpoises are incidentally caught in nets in Perú, Chile, Uruguay, and Argentina (Pilleri and Gihr 1972a; Goodall 1978, 1989; Brownell and Praderi 1982, 1984; Bastida et al. 1992; Oporto and Brieva 1994; Reyes and Oporto 1994; Corcuera et al. 1995; Goodall et al. 1995a; Van Waerebeek et al. 1997b). There are reports of the species being deliberately taken in Perú and Chile (Brownell and Praderi 1984; Cárdenas et al. 1987; Van Waerebeek et al. 1997b). Vaquitas are caught incidentally in gillnets throughout their range in the northern Gulf of California, México (review by Jefferson and Curry 1994). The population is declining at about 18% per year (Barlow et al. 1997).

Distribution

Harbour porpoises have an almost circumpolar distribution in the temperate regions of the northern hemisphere, from about 15° to 70°N (reviews by Gaskin 1992a; Jefferson et al. 1993). Burmeister's porpoises are found around the coast of South America from northern Perú to southern Brazil, from about 5° to 55°S (reviews by Goodall et al. 1995a,b). Because porpoises from Argentina and Uruguay are larger than individuals from Perú and Chile, it has been suggested that at least two stocks of this species exist (Brownell and Praderi 1984; Corcuera et al. 1995). Vaquitas are endemic to México and limited to a small area in the northwestern Gulf of California (Gerrodette et al. 1995).

Harbour porpoises are most frequently encountered in coastal waters, however they also occur over adjacent offshore shallows and, at times, over deep water (review by Gaskin 1992a). In California, they are generally not found in waters deeper than about 125 m (Barlow 1988). In northwestern Europe, they are widely distributed over the continental shelf; however, they show seasonal variations in distribution, with onshore movements implied for particular regions at certain times of the year (Heimlich-Boran et al. 1998). Harbour porpoises are typically found within waters of about 5 to 16°C, only a small percentage of animals appears to penetrate Arctic waters of 0 to 4°C (review by Gaskin 1992a). However, the distribution of harbour porpoises appears related to oceanographic phenomena, such as upwellings or water masses of certain temperature, with which their main prey items are associated (review by Gaskin 1992a). This species is usually scarce in areas without significant coastal fronts or topographically generated upwellings (Gaskin 1992a). Migration patterns have been inferred for most populations of harbour porpoises (review by Gaskin 1992a). However, data suggest that seasonal movement patterns of individual porpoises are discrete and not temporally coordinated migrations (Read and Westgate 1997). In addition, harbour porpoises appear to be resident in certain areas (Berrow et al. 1998).

Three major isolated populations of the harbour porpoise exist: 1) the North Pacific, 2) the North Atlantic, and 3) the Black Sea-Sea of Azov (Yurick and Gaskin 1987). However, morphological and genetic data suggest the existence of different populations within these three geographic regions. In the northeastern Pacific harbour porpoises are distributed almost continuously, however DNA analysis identified three populations: 1) outer coastal areas of California, Oregon, Washington, and British Columbia; 2) inland waters of Washington and British Columbia; and 3) Alaska (Chivers et al. 1998). In the northwestern Atlantic, three populations have been suggested: 1) eastern Newfoundland, 2) Gulf of St. Lawrence, and 3) Gulf of Maine/Bay of Fundy (Gaskin 1984, 1992a; Read and Westgate 1997). In addition, gene flow is restricted to some degree even among closely adjacent geographical units (Gao and Gaskin 1996). In the North Atlantic, morphological and genetic analyses support the recognition of various (sub)populations: 1) Baltic Sea, 2) Kattegat-Skagerrak seas, 3) off the west coast of Norway, 4) West Greenland, 5) inner Danish waters, 6) North Sea, and 7) the southern (Dutch) North Sea (Andersen 1993; Andersen et al. 1997; Borjesson and Berggren 1997; Wang and Berggren 1997; Addink et al. 1998).

Catch statistics from 1900 to 1993 indicate an annual average take of 668 harbour porpoises in Greenland, ranging from 27 to 1,531 animals (Teilmann and Dietz 1998). A decline in the reported catch has been recorded since 1980 (Teilmann and Dietz 1998). In the Celtic Sea, the estimated total annual by-catch of 2,200 porpoises (95% CL= 900-3,500) is 6.2% of the estimated number of porpoises and there is serious cause for concern about the ability of the population to which they belong to sustain this level of by-catch (Tregenza et al. 1997a). In the Swedish Skagerrack Sea, it has been estimated a removal rate of harbour porpoises in bottom set gilnets for cod and pollock of 2.4% (Carlström and Berggren 1998). Since bycatches of porpoises have also been documented in several other fisheries, it is likely that the total removal rate exceeds 4%; the estimated maximum growth rate of a harbour porpoise population (Carlström and Berggren 1998). Data indicate that harbour porpoises in European waters, particularly in the Baltic Sea, are depleted (Wang and Berggren 1997). High diversity estimates suggest that the northwestern Atlantic subpopulations are not seriously depleted of genetic variation (Wang et al. 1996). The combined by-catch for the Bay of Fundy/Gulf of Maine population in 1993 was approximately 1,800 porpoises and ranged from 2.7 to 4.3% of total population size (Trippel et al. 1996).

Although the Burmeister’s porpoise appears to be a shallow-water, coastal species, incidental catches have occurred as far as 55 km from shore and in water at least as 60 m deep (review by Goodall et al. 1995b). Sightings of this species have occurred in bays, in fjords, in nearshore waters, in river mouths, and even up rivers (review by Goodall et al. 1995b). The distribution of this species in the northern portions of its range appears to be related to the cool northward flowing Peru (Humboldt) and Falkland (Malvinas) currents (Goodall et al. 1995a). Burmeister’s porpoises have been sighted in waters as cold as 3° C and as warm as 19.5° C; however, they appear to prefer warm waters, at least in certain areas (review by Goodall et al. 1995b). Seasonal movements of Burmeister’s porpoises have been proposed for certain regions of Chile and Argentina (Würsig et al. 1977; Oporto and Brieva 1994). However, the species appears to be present year-round in the Canal del Beagle (Goodall et al. 1995b). The preferred habitat of vaquita in the Upper Gulf of California is comprised of soft bottoms composed of clay-silt, water depth between 20 and 50 m, and turbid waters ranging from 0.5 to 1.9 m in transparency (Gallo-Reynoso and Torre-Cosío 1998).

Abundance

There are no worldwide population estimates of harbour or Burmeister’s porpoises. The worlwide population of vaquita is approximately 224 individuals (CV= 0.39) (Barlow et al. 1997).

The population of harbour porpoises in the North Atlantic is estimated at 456,717 individuals (IWC 1996). It is estimated that 4,785 harbour porpoises live in the Swedish Skagerrack Sea (Carlström and Berggren 1998). Approximately 27,000 porpoises are found around Iceland (Northridge 1995). Total abundance of this species in Danish waters is estimated as approximately 100,000 porpoises, with population density varying considerably by area (review by Teilmann and Lowry 1996). A total of 37,500 porpoises (95% CL= 26,600-86,400) have been estimated for the Gulf of Maine/Bay of Fundy population (Palka 1995). Ship surveys give an estimate of 52,743 harbour porpoises (95% bootstrap CL= 0-147,905) in California (Barlow 1995). Overall density is estimated at 0.758 porpoises/km^2 (Barlow 1995). A total of 10,300 ± 3,400 harbour porpoises have been estimated for theBlack Sea (Sokolov et al. 1997).

Diet and Foraging Behavior

In the Bay of Fundy/Gulf of Maine population, harbor porpoises feed on pelagic schooling fish, but also on hake, squid, and octopus (Read and Gaskin 1988; Recchia and Read 1989; Gannon et al. 1998b). In West Greenland, their predominant prey item is capellin (*Mallotus villosus*), similar to individuals off north Norway but different to the predominantly benthic species off Denmark and the Black Sea (Tomilin 1957; Heide-Jørgensen and Lockyer 1998). Harbor porpoises have been observed feeding in association with trawls (review by Fertl and Leatherwood 1997).

Burmeister’s porpoises feed mostly on fish, but also consume snails, shrimps, and molluscs (review by Goodall et al. 1995a). In Perú and Chile, anchovy (*Engraulis ringens*) and hake or merluza (*Merluccius gayi*) appear to be favorite prey items (Escare and Oporto 1992; Reyes and Van Waerebeek 1995). It is considered that this species may feed at varying distances from the coast (Reyes and Van Waerebeek 1995).

Diving Behavior

Harbor porpoises can dive for as deep as 226 m and as long as 5.35 min (Westgate et al. 1995). In Japan, harbor porpoises dived continuously, most dives were V-shaped and shallower than 20 m deep (Otani et al. 1998). Descent rate was not constant during a dive, the deeper the dive depths, the faster the mean descent and initial descent rates (Otani et al. 1998). In Denmark, a subadult harbour porpoise male dived to a maximum 166 m and 7 min; a calving female dove to a maximum 44 m and 9 min (Teilmann et al. 1998). In the Bay of Fundy, mean dive depth ranges from 14 to 41 m, mean dive duration ranges from 0.73 to 1.71 min (Westgate et al. 1995). Rates of ascent and descent were similar, ranging from 1.1 ± 0.6 to 2.3 ± 1.4 m/s, and from 0.9 ± 0.6 to 2.1 ± 1.4 m/s, respectively (Westgate et al. 1995). Between 22 and 70% of the dives are made to depths ranging from 20 to 130 m (Westgate et al. 1995).

Burmeister's porpoises dive as long as 3.3 minutes (Würsig et al. 1977). Their typical diving pattern consists of seven to eight surfaces followed by a dive lasting one to three minutes (Würsig et al. 1977).

Social Behavior

Porpoises of this genus are found in small groups, although aggregations up to a hundred individuals have been recorded. In harbor porpoises, mean group size is 1.2 individuals in the Bay of Fundy, Canada (Watts and Gaskin 1985). In the Gulf of Farallones, USA, groups average 2.0 porpoises, with a maximum of 15 individuals (Huber et al. 1982). In Monterey Bay, USA., mean group size is 3.1 individuals, and the largest group size is 25 porpoises (Sekiguchi 1995). In the western North Atlantic, groups average 3.8 individuals (CETAP 1979). In the Gulf of Alaska, mean group size is 5.7 individuals, and the largest group size is 100 porpoises (Fiscus et al. 1976). In vaquita, mean group size is 1.9 individuals, with a maximum of 7 vaquitas in the northern Gulf of California (Silber et al. 1994). Burmesteir's porpoises are typically found in groups of one to six individuals, although groups as large as 70 porpoises have been reported (review by Goodall et al. 1995b).

Female harbor porpoises grow faster and are larger than males (Read and Tolley 1997). In the North Atlantic, the asymptotic length of harbor porpoise males is 0.92 times that of females, while their asymptotic weight is 0.91 times that of females (Heide-Jørgensen and Lockyer 1998). In the Celtic/Irish Sea and in the North Sea, a sex-related difference in population genetic structure suggests that males disperse more than females (Walton 1997). It has been proposed that the mating system of this species involves sperm competition (Gaskin 1992a).

Based on a sample of less than ten individuals per sex, the maximum length of vaquita males is 0.97 times that of females, while their asymptotic weight is 0.81 times that of females (Hohn et al. 1996). Unlike the other species of this genus, Burmeister's porpoise females are smaller than males (Reyes and Van Waerebeek 1995). In Perú, the mean length of Burmeister's porpoise males is 1.03 times that of females, while their maximum weight is 0.91 times that of females (Reyes and Van Waerebeek 1995).

Reproduction and Population Parameters

West Greenland harbor porpoises are significantly heavier and fatter for length than Canadian and North Sea porpoises (Heide-Jørgensen and Lockyer 1998). In West Greenland, females are sexually mature when they are three to four years old at a length of about 1.35 m and males when they are two years old upwards at a length more than 1.25 m (Heide-Jørgensen and Lockyer 1998). In the Bay of Fundy and Gulf of Maine, mean age at sexual maturation of females is 3.4 years (Read and Hohn 1995). In the North Sea, males are sexually mature when five years old, females at six years of age (van Utrecht 1978). In the Bay of Fundy, gestation and lactation periods last 10.6 and eight to twelve months, respectively (Read 1990). Harbor porpoises from West Greenland have a longevity of 12 years in females and 17 years in males, which is similar to the 13 years life span reported for eastern Canada where there is also a history of bycatches, but lower than the 24 years reported for British Isles (Gaskin and Blair 1977; Heide-Jørgensen and Lockyer 1998). Unlike many odontocetes, this species appears to have a strong seasonal male sexual cycle (Gaskin et al. 1984). It is unlikely that harbour porpoises can sustain an annual incidental mortality of 5% or more (Woodley and Read 1991).

In Burmeister’s porpoises from Perú, 50% of males and 50% of females attained sexual maturity at body lengths of 1.60 and 1.55 m, respectively (Reyes and Van Waerebeek 1995). The gestation period is estimated to be 11 to 12 months (Reyes and Van Waerebeek 1995). In vaquita, a small sample size suggest that lifespan, patterns of growth, age at sexual maturation, and seasonal reproduction are similar to those of the highly exploited harbor porpoise population from the Bay of Fundy (Hohn et al. 1996). However, unlike that harbor porpoise population, the calving interval of vaquita is greater than one year (Hohn et al. 1996).

The cold habitat (6-19°C) of the harbor porpoise has produced wide bodied females with low surface area to volume ratios and small bodied males with higher surface area to volume ratios, but thicker blubber than that of females (Tolley et al. 1998). The temperate environment (15-22°C) of the Burmeister’s porpoise has produced longer, thinner bodied individuals with thin blubber and low surface area to volume ratios (Tolley et al. 1998).

Breeding Areas

Mating season varies in harbor porpoises from region to region (Gaskin et al. 1984). Harbor porpoises from the southern (Dutch) North Sea have a parturition period of about four months, with neonates found from May to the end of August and into September (Addink et al. 1998). The mating season appears to be extended as well, from March until late September (Addink et al. 1998). In West Greenland mating season appears to occur in late summer (Heide-Jørgensen and Lockyer 1998). In the Fundy region, the peak of parturation occur in May, the peak of conception is in June (Read 1990). Parturition likely occurs in May-June in northern Japanese waters (Gaskin et al. 1993). In the North Sea, the coastal waters of Schleswig-Holstein, Germany, are considered an important breeding and nursing area for the harbor porpoise (Sonntag et al. 1998).

It is considered that the peak of the mating season in Burmeister’s porpoises from Perú occurs between February and March (Reyes and Van Waerebeek 1995). In vaquita, births apparently occur from late February to early April (Hohn et al. 1996).

Speed of Travel and Movements

Harbour porpoises can swim as fast as 16.6 to 22.2 km/h (Kanwisher and Sundnes 1965; Gaskin et al. 1974). Individual harbour porpoises exhibit a large degree of variability in habitat utilization and movement patters (Palka et al. 1996; Read and Westgate 1997). In Denmark, a subadult harbor porpoise male moved more than 800 km within 26 days, while a calving female remained within a well-defined coastal route that included some of the highest densities of gillnets (Teilmann et al. 1998). Burmeister's porpoises were recorded on one occasion swimming at speeds that varied between 3.5 and 4.5 km/h (Würsig et al. 1977).

Vocal Behavior

Harbor porpoises produce vocalizations as low as 2 kHz and as high as 160 kHz, with dominant frequencies at 2 kHz and at 110-150 kHz (reviews by Popper 1980; Richardson et al. 1995). The maximum peak to peak source level (re: 1uPa@1m) of harbour porpoise sounds is 177 dB (review by Richardson et al. 1995). Although the pulse sounds produced by this species have comparatively low peak levels, their pulses are longer than those of some larger odontocetes (Au 1993). Thus, these pulses contain more energy than would similar-level pulses from larger animals (Au 1993). Vocalizations of vaquita have been recorded at 128-139 kHz (review by Richardson et al. 1995).

Harbor porpoises produce narrow band directional clicks, with energy concentrated around 120-130 kHz, no energy below 100 kHz and a 3-dB bandwidth of only 10-22 kHz (Møhl and Andersen 1973; review by Au 1993). However, sounds other than clicks appear to be omnidirectional (Møhl and Andersen 1973). Preliminary data suggest that harbour porpoises search for prey using a narrowbeam, narrowband, high-frequency sonar with a detection range, for single fish of an ingestible size, up to 30 m (Goodson and Sturtivant 1996). Echolocation rates in captive porpoises changed frequently, ranging from 0 to 25 per minute, and were affected by feeding, individual difference, and enclosure type such as the net enclosure and the pool (Akamatsu et al. 1994).

Hearing Range

Harbor porpoises listen underwater to sounds equal or softer than 120 dB (re: 1 μPa @ 1 m) in the range of 0.1 kHz to 140 kHz (Andersen 1970a). At a frequency of 1 kHz, harbour porpoises listen to pure tones that have an intensity of at least 80-90 dB re: 1 μPa @ 1 m (Andersen 1970a). Based on the audiogram curve, the best underwater hearing of the species occurs approximately at 8-30 kHz, where the threshold level is 40-50 dB re: 1 μPa @ 1 m (Andersen 1970a). However, the best threshold determined by auditory evoked potential methods is much higher, 125-130 kHz (Voronov and Stosman 1983; Popov et al. 1986; Bibikov 1992). This species appears to have excellent frequency and intensity discrimination abilities, at least at high frequencies (Popov et al. 1986). However, the ability of harbor porpoises to recognize a sound as being off the midline is apparently poorer than that of bottlenose dolphins (*Tursiops truncatus*), at least at frequencies between 2 and 6 kHz (Dudok van Heel 1959, 1962; Andersen 1970b).

Known Impacts of Human Activities

Harbour porpoises tend to change behavior and move away from boats (Flaherty 1981; Taylor and Dawson 1984). They appear to avoid nets with acoustic pingers (review by Richardson et al. 1995). In Northern Washington state, USA, pingers were effective in reducing the incidental catch of harbor porpoise in the Spike Rock Fishery during 1995 and 1996, without reducing the catch of target species (Gearin et al. 1998). However, a study that demonstrated a 92% reduction in bycatch of harbor porpoises in sink gillnets equipped with acoustic pingers has not yet been fully replicated (Dawson et al. 1998b). Burmeister's porpoises appear to avoid motorized vessels but tolerate kayaks (review by Goodall et al. 1995b).

DALL’S PORPOISE (*PHOCOENOIDES DALLI*)

Summary

The Dall’s porpoise (*Phocoenoides dalli*). The species has two color patterns: *truei*-type, which is the normal color pattern for the population off the Pacific coast of Japan; and *dalli*-type, which is the normal pattern for all other populations (Kasuya 1978; 1982). In addition, other uncommonly-occurring types have been described (review by Jefferson 1988). Dall’s porpoises are exclusively found in the North Pacific Ocean, primarily in continental shelf and slope waters, although they also inhabit deep waters more than 1,000 km from shore. They eat various species of epi- and meso-pelagic squid and mesopelagic schooling fishes, and are regarded as relatively deep divers. Dall’s porpoises are not known to produce sounds as low as 0.04 kHz in frequency.

Their distribution, diving, and vocalizations make Dall’s porpoises the most vulnerable member of the family to LFA activity. Since distribution and movements of this species are relatively well known in some geographical regions, it may be possible to quantify any negative impacts of LFA activity.

Protected Status

The Dall’s porpoise is not federally listed under the U. S. Endangered Species/Marine Mammal Protection acts (kingfish.ssp.nmfs.gov/tmcintyr/spec_idx.html). This porpoise is listed as a lower risk/conservation dependent species by the Cetacean Specialist Group of the International Union for the Conservation of Nature (www.wcmc.org.uk/data/database). The hand harpoon fishery off the Pacific coast of northern Japan (Sanriku) in winter takes mainly *truei*-type animals and a small number of *dalli*-types, the latter are members of the Sea of Japan-Okhotsk population and the offshore Pacific populations (Kasuya 1982; Miyazaki 1983; Amano et al. 1998). It is estimated that total fishing mortality (including struck-and-lost animals) is 1.10-1.14 times higher than the number of porpoises landed (Fujise et al. 1993). Dalls’s porpoises are incidentally captured by salmon fisheries from Japan, by squid driftnet fisheries from Japan, Taiwan, and Korea, and by gillnets and trawl nets in USA and Canada (Ohsumi 1975; Everitt et al. 1979; Loughlin et al. 1983; Jefferson 1987; Chivers et al. 1997; review by Jefferson 1988). Live captures of individuals of this species have occurred in USA and Japan (Norris and Prescott 1961; Ridgway 1966; Walker 1975; Kasuya et al. 1984). The hunt of the species in the Okhotsk Sea represents 4.2-6.3% of the exploited stocks (IWC 1992). In the northwestern Pacific, the density of Dall’s porpoises decreased significantly between 1984 and 1986 (Turnock and Buckland 1995). Another potential threat to this species may be environmental pollution by human activities (Jefferson 1990a).

Distribution

Dall's porpoises are exclusively found in the North Pacific Ocean, from the southern Chuckchi Sea to northern Baja California, México, on the eastern side and to southern Japan on the western side, including off the west coast of Japan, from about 28° to 63° N (reviews by Morejohn 1979; Jefferson 1988, 1990a; Jefferson et al. 1993). However, the species is only common between 32° and 62°N in the eastern North Pacific (Nishiwaki 1967; Morejohn 1979). This species is considered the most abundance porpoise north of Vancouver Island along the eastern Pacific coast, being frequently encountered in deep inshore waters (Leatherwood et al. 1988a).

The primary habitat of the species is cool (<17° C), deep (>180 m), continental shelf and slope waters (Jefferson 1988). However, they also inhabit deep waters more than 1,000 km from shore (Kasuya and Jones 1984). In inshore areas, this species appears to prefer open-ended channels with strong currents, wide straits, or deep canyons (Cowan 1944; Scheffer 1949; Loeb 1972). Off Canada, Dall's porpoises are found mostly over the Continental Shelf and slope, but also more than 2,400 km from shore (Pike and MacAskie 1969).

Dall's porpoises are seen year-round in California and throughout their range in the eastern North Pacific (Forney and Barlow 1998; reviews by Jefferson 1988, 1990a). However, they tend to have inshore and southern shifts in abundance for the winter, and offshore and northern shifts for the summer (Leatherwood et al. 1988a; Forney and Barlow 1998). In the western Pacific, movements appear to have a stronger north/south component and a weaker inshore/offshore component, with summers spent in the more northern portions of the range (Okada and Hayashi 1951; Nishiwaki 1967; Ohsumi 1975; Kasuya 1978, 1982)

Abundance

The entire North Pacific Ocean and Bering Sea population is estimated to be 1.4 to 2.8 million porpoises (Jones et al. 1987).

Ship surveys give an estimate of 78,422 Dall's porpoises (95% bootstrap CL= 33,462-150,487) in California (Barlow 1995). Estimated density was 1.127 porpoises/km^2 (Barlow 1995). The abundance of the three stocks in waters adjacent to Japan were estimated to be 111,000 (CV= 0.29) *dalli*-type in the northern Okhotsk Sea stock, 226,000 (CV= 0.15) *dalli*-type in the southern Okhotsk Sea stock, and 217,000 (CV= 0.23) *truei*-type in the central Okhotsk Sea stock (IWC 1992). It is conservately estimated that 141,800 Dall's porpoises (95% log-normal CL= 83,100-241,700) inhabit the northwestern Pacific; however, this estimate is possibly biased (Turnock et al. 1995). The overall density of this species in the northwestern Pacific during 1988 was estimated at 0.192 porpoises/km^2 (Turnock and Buckland 1995).

Diet and Foraging Behavior

Dall's porpoises feed on various species of epi- and meso-pelagic squid and mesopelagic schooling fishes; on occasion they also feed on crustaceans (Mizue and Yoshida 1965; Mizue et al. 1966; Loeb 1972; Morejohn 1979; Crawford 1981; Walker 1996). It has been considered that this species is a nocturnal feeder (Morejohn 1979; Stroud et al. 1981).

Diving Behavior

Dall's porpoises are considered deep divers (Ridgway 1966, 1972; Ridgway and Johnston 1966). They dive as deep as 275 m and as long as 8 min (Ridgway 1986; Hanson et al. 1998).

Social Behavior

Dall's porpoises are usually found in small groups, although aggregations of several thousand are seen at times (Scheffer 1950; Sullivan and Houck 1979; reviews by Jefferson 1988, 1990a). In British Columbia, Canada, mean group size is 2.6 individuals, and the largest group size is five porpoises (Jefferson 1987). In Prince William Sound, Alaska, groups average 4.7 porpoises, with a maximum of 35 individuals (Hall 1981). In Monterey Bay, USA, mean group size is 5.7 individuals, and the largest group size is 20 porpoises (Jefferson 1991). In the Gulf of Alaska, groups average 6.2 porpoises, with a maximum of 500 individuals (Fiscus et al. 1976). In Japan, mean group size is 7.4 individuals, and the largest group size is 70 porpoises (Miyashita and Kasuya 1988). In the northwestern Pacific, there appears to be some segregation by age, sex, and reproductive status (Wilke et al. 1953; Kasuya and Jones 1984). Dall's porpoises have been observed associated with other cetacean species (Morejohn 1979; Leatherwood et al. 1988a; Jefferson 1991). Recently, a hybrid foetus fathered by a male harbor porpoise (*Phocoena phocoena*) was found in a dead female Dall's porpoise (Baird et al. 1998a).

Males are longer and heavier than females (Kasuya 1978; Morejohn 1979; Newby 1982). The modal length of males is 1.05 times that of females (Jefferson 1990b). Based on a sample of less than ten individuals per sex, the maximum weight of males is 1.70 times that of females (Morejohn 1979). In addition, several morphological features are exaggerated in adult males, suggesting that Dall's porpoises are polygynous and that secondary sexual characters are used in male-male competition or female choice (Jefferson 1990b). However, sexual dimorphism is less developed in mature males from the northeastern Pacific than from other areas (Amano and Miyazaki 1996).

Reproduction and Population Parameters

Dalli-type males become sexually mature at an age of four to six years and a length of 1.80 to 1.86 m, and females at 3.5 to 4.5 years and 1.74 to 1.77 m (Kasuya and Shiraga 1985; Jones et al. 1987; Miyazaki 1987). *Truei*-type become mature at body lengths about 12 to 17 cm greater than these (Kasuya 1978; Kasuya and Shiraga 1985). Gestation lasts about 10 to 11.4 months (Kasuya 1978; Jones et al. 1983). It is believed that the lactation period is very short, perhaps two to four months long (Loeb 1972; Newby 1982). Mean calving interval for the Japanese-coastal population is three years (Kasuya 1978). Maximum age attained by animals in the northwestern North Pacific is 22 years (Newby 1982).

Breeding Areas

Inshore calving areas have been proposed for Puget Sound, USA, and British Columbia (review by Jefferson 1990a). A very strong calving peak is found mainly in the warmer months of the year, from June through August, and a smaller peak in March (Jefferson 1989).

Speed of Travel and Movements

This species is thought to be one of the fastest swimming small cetaceans (Brownell 1964; Norris and Prescott 1961; Ridgway 1966; Morejohn 1979). It is considered to be specialized for high speed underwater swimming (reviews by Jefferson 1988; Law and Blake 1994). The swimming behavior of Dall's porpoises at the surface has been classified as slow rolling, fast rolling, and rooster-tailing (Jefferson 1987; Law and Blake 1994). Slow rolling porpoises move at an average speed of five to 6.5 km/h, with values as low as 2.4 to 5.8 km/h and as high as 7.6 to 8.3 km/h (Jefferson 1987; Law and Bake 1994). When fast rolling, the mean speed of individuals is 9.4 km/h, with values ranging from 6.5 to 12.2 km/h (Law and Blake 1994). Individuals swim with an average speed of 15.5 km/h when rooster tailing and a range of values from 12.2 to 21.6 km/h (Law and Blake 1994). However, it has been suggested that Dall's porpoises may reach speeds of nearly 55 km/h for quick bursts (Leatherwood and Reeves 1986).

Individuals in certain areas appear to have restricted movements, at least for short periods of time. Tagged porpoises remained within a 25 km stretch of Haro Strait and Boundary Pass, USA, although localized movements of several kilometers occurred within a few hours (Hanson et al. 1998).

Vocal Behavior

Dall's porpoises produce vocalizations as low as 0.04 kHz and as high as 160 kHz (Ridgway 1966; Evans 1973; Awbrey et al. 1979; Evans and Awbrey 1984; Hatakeyama and Soeda 1990; Hatakeyama et al. 1994). The maximum peak to peak source level (re: 1uPa@1m) of Dall's porpoise sounds is 175 dB (review by Richardson et al. 1995). Dall's porpoises can emit low-frequency clicks (0.04-12 kHz) and apparently do not whistle often (Evans 1973; Awbrey et al. 1979). They also produce narrow band clicks, with energy concentrated around 120-130 kHz, no energy below 100 kHz, and a 3-dB bandwidth of only 10-22 kHz (review by Au 1993). Although the pulse sounds produced by this species have comparatively low peak levels, their pulses are longer than those of some larger odontocetes (Au 1993). Thus, these pulses contain more energy than would similar-level pulses from larger animals (Au 1993).

Hearing Range

No data available.

Known Impacts of Human Activities

It has been estimated that the reaction threshold of Dall's porpoises for pulses at 20-100 kHz is about 116-130 dB re: 1 µPa @ 1 m, but higher for pulses shorter than 1 ms or for pulses higher than 100 kHz (Hatakeyama et al. 1994).

Swimming velocity and rates of descent and ascent of Dall's porpoises were relatively high only for the first six to eight minutes after attachment of suction-cup tags, suggesting a reaction to tagging that lasted approximately eight minutes (Hanson and Baird 1998).

This species does not seem to be negatively affected by ships or vessels (Watkins et al. 1981; Withrow et al. 1985). However, some Dall's porpoises appear to be affected by flying aircraft. They reacted negatively to a Bell 205 helicopter flying over at 215-365 (Withrow et al. 1985). About 8 to 9% of them showed a negative reaction to a Twin Otter aircraft at 60 m altitude (Green et al. 1992).

DELPHINIDAE (DOLPHINS)

TUCUXI (*SOTALIA FLUVIATILIS*)

Summary

The tucuxi (*Sotalia fluviatilis*) has separate marine and freshwater populations, most of this account will refer to the marine form. Tucuxi are found along the coast of the western tropical Atlantic and part of the Caribbean. They feed mostly on shallow-water fish and squid. Based on their distribution and feeding habits, they may be shallow divers. This species is not known to produce sounds below 3 kHz and its best underwater hearing occurs at mid-frequencies.

Their small size, distribution, diving habits, and underwater hearing make it unlikely that this species will be vulnerable to LFA activity. However, because marine tucuxi are not well-known, it would be difficult to detect any negative impacts of LFA.

Protected Status

The tucuxi is not federally listed under the U. S. Endangered Species/Marine Mammal Protection acts (kingfish.ssp.nmfs.gov/tmcintyr/spec_idx.html). This dolphin is listed as a data deficient species by the Cetacean Specialist Group of the International Union for the Conservation of Nature (www.wcmc.org.uk/data/database). Tucuxi have been captured live in Brazil and Colombia for display in the United States and Europe (Herald 1967; Waterman 1967; Caldwell and Caldwell 1970; Harrison and Brownell 1971; Bossenecker 1978; Collet 1984; IWC 1984). They may be occasionally killed along the coast of Brazil as bait for sharks or shrimps traps or for human consumption (Geise and Borobia 1987; Perrin 1989; Van Waerebeek 1990). The greatest threat to this species is incidental capture by fisheries (da Silva and Best 1994). Tucuxi are captured in monofilament gill nets, shrimp and fish traps, and seine nets (Willliams 1928; Carvalho 1963; Herald 1967; Bossenecker 1978; Husson 1978; da Silva and Best 1985, 1986; Obregon et al. 1988; Perrin 1989; Van Waerebeek 1990). Damning of rivers and exposure to polluted waters appear also to be potential problems (review by da Silva and Best 1994).

Distribution

The marine form lives along the coast of the western tropical Atlantic and part of the Caribbean, from Santa Catarina, Brazil, to Honduras, approximately from 28°S to 15°N (Lailson-Brito et al. 1998; Pizzorno et al. 1998; review by da Silva and Best 1994). There are also records from off the Panama coast and for the Caribbean island of Trinidad (van Bree 1975; Bossenecker 1978). There is also a questionable record from Argentina (review by da Silva and Best 1994). They are distributed along the whole Colombian Caribbean coast (Avila and Dussn 1998), and are present year-round in Guanabara, Sepetiba, and North bays, Brazil (Flores 1998; Lailson-Brito et al. 1998; Pizzorno et al. 1998). Tucuxi are considered rather common in the mouths of large rivers in Suriname and frequent in the mouth of the Essequibo river, Guyana (Williams 1928;

Husson 1978). They are also common in Baía de Guanabara, Brazil, and in São Paulo State, Brazil (Lins de Almeida 1933, Carvalho 1963; Bittencourt 1984; Geise 1991)

It has been suggested that low sea-surface temperature may limit the distribution of marine tucuxi to the south (Simões-Lopes 1987, 1988; Borobia et al. 1991). This form prefers shallow protected estuarine waters or bays (da Silva and Best 1994). In the Baía de Guanabara, Brazil, they prefer the deep channels (~25 m depth) and avoid areas with less than six m of water (Geise 1984 in da Silva and Best 1994). In the Golfo de Morrosquillo, Colombia, tucuxi are most frequently found in waters five to 15 m deep and 500 to more than 1000 m from shore (Avila and Dussn 1998). The marine form may penetrate up to 130 km or more up large rivers (Hershkovitz 1963; Bossenecker 1978; Husson 1978; Meade and Koehnken 1991).

Abundance

Worldwide population is unknown.

The number of tucuxi in the area around Cananéia Island has been estimated at 2,829 ± sd 565 dolphins (Geise 1989). Approximately 144 tucuxis, with a density of 1.621 ind/km^2 inhabit Cispata Bay, Colombia (Avila 1995). There are seasonal variations in density, ranging from 1.022 ind/km^2 during the rainy season to 1.737 ind/km^2 during the dry season (Avila 1995). Estimates of tucuxi in Baía de Guanabara, Brazil, range from 65 dolphins (binomial 95% CL= 54-86) to 418 dolphins (Geise 1991; Pizzorno et al. 1998).

Diet and Foraging Behavior

Marine tucuxi feed on epipelagic schooling fishes, demersal fishes, and neritic cephalopods (Williams 1928; Carvalho 1963; Simões-Lopes 1988; Borobia and Barros 1989).

Tucuxi engage in various feeding behaviors, including individual feeding and group feeding (da Silva 1983; Borobia 1984; Geise 1989; Rossi-Santos and Flores 1998; da Silva and Best 1994). Behavior interpreted as feeding is more frequent in the early morning and in mid-afternoon in Baía de Guanabara and in Cananéia, respectively (Borobia 1984; Geise 1989). They have also been observed feeding in association with trawl nets (Barros and Teixeira 1994).

Diving Behavior

No data available.

Social Behavior

Marine tucuxi live in small groups, with a mode of 2 dolphins (Borobia 1984; Geise 1989). However groups of as many as 30 individuals have been recorded (Williams 1928; Carvalho 1963; Bossenecker 1978; Geise 1989, 1991; Simões-Lopes 1988). Group size varies according to time of day and activity (Geise 1989). Calves are usually in small groups of three, two adults and one calf, or four dolphins, two calves and two adults (Borobia 1984; Geise 1989).

Limited data suggest that there is sexual difference in body length of marine tucuxi (Carvalho 1963; Gewalt 1979; Terry 1983; Bittencourt 1984; Barros 1984; Simões-Lopes 1987). Based on a small sample of less than ten individuals per sex, the modal length of male riverine tucuxi is 1.01 times that of females, while their weight is 0.93 times that of females (reviews by Best and da Silva 1984; Perrin and Reilly 1984). Based on the relative large size of testes, up to 5% of body weight, it has been suggested that riverine tucuxi have a polyandrous mating system (Best and da Silva 1984).

Reproduction and Population Parameters

Most information comes from the riverine form. Marine tucuxi reach sexual maturity at 1.6-1.7 m long (da Silva and Best 1994). Male riverine tucuxi attain sexual maturity at more than 1.39 m in body length (Best and da Silva 1984). Female riverine tucuxi are sexually mature when their body length is 1.32-1.37 m (Best and da Silva 1984). Gestation period is estimated at 10.2 months (Best and da Silva 1984).

Breeding Areas

In the marine form, the southwest region of the Golfo de Morrosquillo, Colombia, is utilized as a mating and calving area (Avila and Dussn 1998). However, tucuxi mate and calve throughout their range. In the riverine form, reproduction is synchronized with the annual flooding cycle of the Amazon river (Best and da Silva 1984). Calving occurs in October and November, during the low water season (Best and da Silva 1984). Mating probably occurs during January and February (Best and da Silva 1984).

Speed of Travel and Movements

Marine tucuxi travel at variable speed (Borobia 1984; Geise 1989, 1991) and engage in various types of aerial behavior (da Silva 1983; Borobia 1984; Geise 1989).

Marine tucuxi appear to have a diurnal rhythm in their movements (review by da Silva and Best 1994). In Baía de Guanabara and in the Cananéia region,Brazil, they usually enter into the bay in the morning and leave in the afternoon of a different day (Borobia 1984; Geise 1989, 1991). In North Bay, Brazil, tucuxi individuals have predictable routes with estimated ranges up to 80km^2 (Flores 1998).

It is believed that individuals of the marine form have a defined home range (da Silva and Best 1994). Some studies have indicated that individuals may remain in one area for at least a year (Andrade et al. 1987; Geise 1989; Flores 1998; Lailson-Brito et al. 1998; Pizzorno et al. 1998).

Vocal Behavior

Tucuxi produce vocalizations as low as 3.6 kHz and as high as 100 kHz, with dominant frequencies at 7.1-18.5 kHz and 80-100 kHz (Caldwell and Caldwell 1970; Norris et al. 1972; Kamminga et al. 1993; Wang Ding et al. 1995a). They produce brief directional echolocation clicks in a single pulse or in two pulses, with dominant frequencies of 8-15, 30 and 95 kHz (Norris et al. 1972). The high repetition rates of their clicks, up to 1920 pulses/sec, would allow them to descriminate objects at distances of less than 15 cm (Norris et al. 1972). Whistles consist of signals less than 0.5 s long and with most energy at 10-15 kHz (Norris et al. 1972; Nakasai and Takemura 1975). Tucuxi can produce simultaneous high frequency and low-frequency clicks, about 94.7 kHz and 29.2 kHz, respectively (Wiermsa 1982). Whistles are very diverse, produced frequently, up to 38.5 whistles/min, and may play an important social role (Pereira et al. 1998; Simão et al. 1998). Tucuxi also produce whistles that could be signature whistles (Wang Ding et al. 1995a).

Hearing Range

Tucuxi hear underwater sounds equal or less than 120 dB (re: 1 μPa @ 1 m) in the range of <4 kHz to 135 kHz (Sauerland and Dehnhardt 1998). The best underwater hearing of the species occurs at 85 kHz, where the threshold level is 50 dB re: 1 μPa @ 1 m (Sauerland and Dehnhardt 1998).

Known Impacts of Human Activities

In North Bay, Brazil, 93.6% of encounters with tourism boats (n= 296) resulted in negative reactions by dolphins (Flores 1998). Riverine tucuxi move away from boats, but resume pre-disturbance activities within a few minutes (Leatherwood et al. 1991).

HUMP-BACKED DOLPHINS (*SOUSA* SP.)

Summary

The genus *Sousa* currently comprises five nominal species (Ross et al. 1994). Currently, three species appear to be recognized: the Indo-Pacific hump-backed dolphin (*S. chinensis*), the Atlantic hump-backed dolphin (*S. teuszii*), and the plumbeous dolphin (*S. plumbea*). Hump-backed dolphins inhabit tropical coastal waters, including estuaries, of West Africa and of the Indian and western Pacific oceans. They feed mostly on shallow-water fish. Based on their distribution and feeding habits, they are likely shallow divers. Hump-backed dolphins are not known to produce sounds below 1 kHz, although data are limited.

Their small size, distribution, diving habits, and known sound production make it unlikely that hump-backed dolphins will be vulnerable to LFA activity. Since the distribution of hump-backed dolphins is relatively well-known in South Africa and northeastern Australia, it may be possible to quantify any negative impacts of LFA activity in those areas.

Protected Status

Hump-backed dolphins are not federally listed under the U. S. Endangered Species/Marine Mammal Protection acts (kingfish.ssp.nmfs.gov/tmcintyr/spec_idx.html). The Indo-Pacific hump-backed dolphin and the Atlantic hump-backed dolphin are listed as data deficient species by the Cetacean Specialist Group of the International Union for the Conservation of Nature (www.wcmc.org.uk/data/database). The plumbeous dolphin was described since 1829 by G. Cuvier; however, until recently it was considered a subspecies of the Indo-Pacific hump-backed dolphin (Zhou Kaiya et al. 1980; Ross 1984). Direct catches of Indo-Pacific hump-backed dolphins for human consumption and oil occur in the northwest Indian Ocean (Jefferson et al. 1993). Dolphins of this genus are incidentally caught in fishing nets in West Africa, Djibouti, the Arabian Gulf, the Indus delta, the southwest coast of India and Sri Lanka, and in antishark gillnets off southeastern Africa and off eastern Australia (Al-Robaae 1970; Pilleri and Pilleri 1979; Maigret 1981; Leatherwood and Reeves 1989; Ross et al. 1994). In the Natal coast, South Africa, seven plumbeous dolphins were incidentally taken per year between 1980 and 1986 (Ross et al. 1994). Threats to the three dolphin species also include mangrove habitat degradation (Pilleri and Pilleri 1979).

Distribution

Hump-backed dolphins inhabit tropical coastal waters, including estuaries, of West Africa and of the Indian and western Pacific oceans (Ross et al. 1994). Indo-Pacific hump-backed dolphins are found from southeastern Australia and southern China in the east to Sumatra in the west, from 40°S to 30°N (review by Ross et al. 1994). Plumbeous dolphins are found along the coast of Africa on the Indian Ocean side, down to False Bay, and along the coast of Asia, up to eastern India, from 40°S to 30°N (review by Ross et al. 1994). Atlantic hump-backed dolphins occur in tropical to subtropical waters off

West Africa, from 0° to 20° N (review by Ross et al. 1994). They are found from Mauritania and Senegal to Cameroon (review by Ross et al. 1994). However, this species possibly occurs further south, in north Angola (review by Jefferson et al. 1993).

Hump-backed dolphins have been observed regularly in areas where water temperature ranges from 15° to 36° C (Saayman and Tayler 1979; Ridgway 1990 in Ross et al. 1994). They occur in shallow water less than 20 m deep throughout their range (Ross et al. 1994). Important populations are found in tropical deltas, with turbid channels, mangroves and sandbars (Gibson-Hill 1949; Pilleri and Pilleri 1979; Maigret 1981). They are also known to move into rivers (Wang Peilie 1985; Sudara and Mahakunlayanakul 1998). In South Africa, humpback dolphins occur less than 1 km offshore (Ross et al. 1994). In Australia, they occur up to 6 km offshore in association with bottlenose dolphins (*Tursiops truncatus*) while feeding on discards from trawlers (Corkeron 1990).

Although Maigret (1981) suggested that Atlantic hump-backed dolphins off Senegal may migrate northward in the summer, no seasonal migrations have been demonstrated thus far for any dolphin population of the genus (Ross et al. 1994). Plumbeous dolphins appear to be resident in Plettenbeg Bay, South Africa (Saayman and Tayler 1979). Indo-Pacific hump-backed dolphins are present throughout the year off southern China and northern Queensland, Australia (Heinsohn et al. 1980; Wang Peilie 1985). In Hong Kong, it appears that at least some individuals have restricted home ranges (Jefferson 1998).

Plumbeous dolphins utilize different habitats for various activities, they feed more on unsheltered rocky coastline, and rest or socialize in a sandy-bottomed sheltered bay (Saayman and Tayler 1979).

Abundance

Worldwide population is unknown.

It is estimated that 246 Indo-Pacific hump-backed dolphins use Hong Kong waters (Jefferson 1998). Rough populations estimates for the Indus delta were 500 Indo-Pacific hump-backed dolphins (Pilleri and Pilleri 1979). A total of 25 plumbeous dolphins were estimated to use the Plettenberg Bay area, South Africa (Saayman and Tayler 1979). There may be 200 dolphins along the Natal coasts (Ross et al. 1994). Rough populations estimates for the Saloum delta, Senegal, were 100 Atlantic hump-backed dolphins (Maigret 1981).

Diet and Foraging Behavior

Dolphins of this genus feed primarily on fish (Cadenat and Paraiso 1957; Mitchell 1975; Heinsohn et al. 1980; Cockcroft and Ross 1983; Robineau and Rose 1984). Stomach contents of plumbeous dolphins indicate a diet of mostly littoral or estuarine fishes, a few demersal reef fishes, and very rarely crustaceans (Cockcroft and Ross 1983). In Australia, Indo-Pacific hump-backed dolphins feed with bottlenose dolphins on trawl discards (Corkeron 1990; Leatherwood in Fertl and Leatherwood 1997; Jefferson in Fertl and

Leatherwood 1997). Atlantic hump-backed dolphins feed on demersal and on schooling fishes (Cadenat and Paraiso 1957; Mitchell 1975). Off the coast of Mauritania, fishermen using beach seines cooperate with bottlenose dolphins and with Atlantic hump-backed dolphins to capture mullet (Busnel 1973).

Diving Behavior

Plumbeous dolphins surface briefly and at 40-60 s intervals (Zbinden et al. 1977; Saayman and Tayler 1979). Indo-Pacific hump-backed dolphins in Pakistan dove for longer, averaging 5 min, apparently in response to the researcher's vessel (Pilleri and Gihr 1972b).

Social Behavior

Hump-backed dolphins live in small groups, ranging from one to about 25 individuals (Pilleri and Gihr 1973-74; Pilleri and Pilleri 1979; Saayman and Tayler 1979; Maigret 1981). Most commonly, groups number less than ten dolphins (Saayman and Tayler 1979; Wang Peilie 1985; Corkeron 1990). In Hong Kong, size of 80 Indo-Pacific hump-backed dolphin groups averaged 3.6±3.55 dolphins (Jefferson 1998). In South Africa, plumbeous dolphin groups average 6.6 individuals, with a maximum of 25 animals (Saayman and Tayler 1973b).

In Hong Kong, there appears to be great fluidity in group composition (Jefferson 1998). In South Africa, calves formed 2% of the small dolphin population in the Plettenberg Bay area, where dolphins appear to have a highly flexible social organization (Saayman and Tayler 1979).

There appears to be sexual dimorphism in length in southern African humpback dolphins (Ross et al. 1994). The maximum length of plumbeous dolphin males is 1.12 times that of females, while their weight, estimated from minimum weight-length curves, is 1.43 times that of females (Ross et al. 1994). Based on a sample of less than ten individuals per sex, the maximum length of Atlantic hump-backed dolphin males is 1.06 times that of females (review by Perrin and Reilly 1984). Dolphins off southern Africa and in the northern Indian Ocean may grow larger than those elsewhere (Ross et al. 1994).

Reproduction and Population Parameters

In South Africa, a pregnant female measured 2.44 m; a mature male measured 2.79 m (Ross 1984).

Breeding Areas

There are no apparent breeding areas. Plumbeous dolphins have calves year-round in South Africa, with a peak of almost 63% in summer (Saayman and Tayler 1979). Calving in Indo-Pacific hump-backed dolphins appears to occur also in the summer (Ross et al. 1994). Calving in Atlantic hump-backed dolphins apparently occurs in a protracted season from April to September (Maigret 1981; Ross et al. 1994).

Speed of Travel and Movements

Plumbeous dolphins usually swim slowly, almost 4.8 km/h (Saayman and Tayler 1979).

Vocal Behavior

Hump-backed dolphins produce vocalizations as low as 1.2 kHz and as high as 30 kHz (Zbinden et al. 1977; Schultz and Corkeron 1994). Zbinden et al. (1977) grouped sounds of hump-backed dolphins as clicks, whistles, and screams. Clicks are highly directional and are composed of series of single pulses repeated at rates between 10 and 500 Hz; they are apparently used for echolocation (Zbinden et al. 1977). Whistles are frequency modulated (FM) sounds, with durations of ms to s; screams were typically FM sounds with a harmonic structure produced in series (Zbinden et al. 1977). The high frequency component of these sounds were above the frequency range of ambient noise and sounds in the Indus delta (Pilleri et al. 1982).

Hearing Range

No data available.

Known Impacts of Human Activities

Dolphins of this genus react negatively to boats, rarely permitting to be approached and changing course underwater (Pilleri and Gihr 1973-74; Maigret 1981; Ross et al. 1994).

DOLPHINS (*CEPHALORHYNCHUS* SP.)

Summary

The genus *Cephalorhynchus* comprises four species: the Commerson's dolphin (*C. commersonii*), the Chilean dolphin (*C. eutropia*), the Heaviside's dolphin (*C. heavisidii*), and the Hector's dolphin (*C. hectori*). These dolphins are the smallest members of the family Delphinidae. These dolphins live in coastal temperate waters of the southern Hemisphere. They feed on nearshore and epipelagic fish, squid and other items, and appear to be brief divers. Dolphins of the genus *Cephalorhynchus* produce sounds as low as 0.32 kHz in frequency.

Their small size, distribution and apparent diving habits make it unlikely that *Cephalorhynchus* dolphins will be vulnerable to LFA. However, their vocalizations make at least some species vulnerable to LFA activity. Since few populations are relatively well-known, it would be difficult to detect any negative impacts of LFA.

Protected Status

None of the four species of this genus are federally listed under the U. S. Endangered Species/Marine Mammal Protection acts (kingfish.ssp.nmfs.gov/tmcintyr/spec_idx.html). The Commerson's dolphin, the black dolphin, and the Heaviside's dolphin are listed as data deficient species by the Cetacean Specialist Group of the International Union for the Conservation of Nature (www.wcmc.org.uk/data/database). The Hector's dolphin are listed as vulnerable by the Cetacean Specialist Group of the International Union for the Conservation of Nature (www.wcmc.org.uk/data/database). Commerson's dolphins are the small cetacean most frequently taken in fishing nets off South America, including offshore trawlers in northtern Patagonia (Goodall and Cameron 1980; Goodall et al. 1988a). Direct capture of Commerson's dolphins for bait may occur in the Beagle Channel, although it seems unlikely (Goodall 1994a). Commerson's dolphins have been deliberately taken for scientific purposes in Kerguelen (Robineau 1984). Several Commerson's dolphins have been captured for display in Japan, USA, and Gemany (review by Goodall 1994a). Chilean dolphins are illegally taken for bait and, possibly, for human consumption (review by Goodall 1994b). It has been calculated that as many as 1,300 to 1,500 dolphins are harpooned per year in the area near the western Strait of Magellan (Leatherwood et al. 1988b). Chilean dolphins are also incidentally captured in fisheries, particularly in the northern part of their range (Goodall and Cameron 1990). Heaviside's dolphins are taken by fishermen for human consumption (Rice and Saayman 1984). They are also incidentally captured in gillnets, beach-seine nets, and, less frequently, in trawlers (review by Best and Abernethy 1994). The greatest threat to Hector's dolphins appears to be incidental capture in gillnets (Dawson 1991a; Slooten and Dawson 1988; Slooten and Dawson 1995). Data suggest a decline in population in at least one area (Dawson 1991a; Slooten and Lad 1991; Slooten et al. 1992).

Distribution

Members of this genus are only found in the Southern Hemisphere and have a limited range. Commerson's dolphins live in two populations separated by about 8,500 km (review by Goodall 1994a). One population inhabits the coastal waters of the southwestern Atlantic off South America, including the Falkland (Malvinas) Islands, from about 40° to 62°S (review by Goodall 1994a). However, they are more common from Peninsula Valdés to northern Tierra del Fuego, from about 42° to 54°S (Goodall 1994a). The second population is limited to the vicinity of the Kerguelen Islands, in the southern Indian Ocean, around 49°S (Frost and Best 1976; Robineau 1989). The Chilean dolphin is restricted to the coast of Chile, from Valparaíso to Cape Horn, from about 33° to 55°S (review by Goodall 1994b). The ranges of Commerson's and Chilean dolphins might overlap sligthly in the Strait of Magellan and Beagle Channel; however, the former rarely occurs west of the strait and the latter is rarely sighted east of the strait (Goodall 1994b). Heaviside's dolphins are only found along the west coast of southern Africa, from about 17° and °34°S (review by Best and Abernethy 1994). Hector's dolphins are restricted to the South Island and to the west coast of the North Island of New Zealand, from about 36° to 47° S (Cawthorn 1988; Dawson and Slooten 1988).

Commerson's dolphins are coastal animals that are rarely seen far from shore (Goodall et al. 1988b; Goodall 1994a). They are more frequently found near the mouths of bays and estuaries, entering rivers at times, near kelp beds, or over the continental shelf (Goodall et al. 1988b; Robineau 1989; Goodall 1994a). The Chilean dolphin is considered a coastal species (Goodall 1994b). It is found in the channels along the southern coast of Chile and in open coasts, bays, and river mouths along the northern coast (Goodall 1994b). This species also enters estuaries and rivers (Goodall et al. 1988c). The distribution of Chilean dolphins is associated with waters warmer than those with which Commerson's dolphins are associated (Goodall et al. 1998b). Heaviside's dolphins have been sighted as far as 80 km from shore and in waters as deep as 180 m; however, they typically occur in waters less than 100 m deep (Best and Abernethy 1994). Hector's dolphins have a clumped distribution and a preference for shallow waters (Slooten and Dawson 1994). Genetic data indicate a marked segregation of maternal lineages between the North Island, the west coast of the South Island, and the east coast of the South Island, suggesting a low rate of female dispersal (Pichler et al. 1998).

Different pieces of evidence suggest seasonal movements of Commerson's dolphins in certain parts of their range (review by Goodall 1994a). Conversely, circumstantial data suggest the presence of resident groups of Chilean dolphins throughout their range (review by Goodall 1994b). There is no evidence of seasonal alongshore migrations in Hector's dolphins, but distribution offshore changes seasonally (Dawson and Slooten 1988).

Abundance

The total population of Hector's dolphins is estimated at 3,408 individuals (Dawson and Slooten 1988). Little is known about the abundance of the other species of the genus. It was estimated that 3,211 ± 1,168 Commerson's dolphins inhabit the northeastern Strait of

Magellan (Leatherwood et al. 1988c). However, the estimated number of dolphins in this area was 718 ± 196 individuals in a posterior year (Venegas 1996).

Diet and Foraging Behavior

In general, dolphins of this genus are considered generalized feeders. All four species appear to have similar feeding habits, preying mainly on demersal and pelagic fishes, squid, and invertebrates (Baker 1978; Goodall and Galeazzi 1985; Bastida et al. 1988; Slooten and Dawson 1988; Oporto et al. 1990; Clarke and Goddall 1994; Sekiguchi 1994; Sekiguchi et al. 1998). Cooperative feeding has been recorded in Commerson's dolphins (Goodall 1994a). Hector's dolphins feed at times in association with trawlers (Slooten and Dawson 1994).

Adult Commerson's dolphins of both sexes eat between nine and 12% of their body weight per day in captivity (Kastelein et al. 1993). The annual food intake of an average adult in the Strait of Magellan, South America, is thus estimated at around 1,850 kg of herring or 37×10^5 kcal (Kastelein et al. 1993).

Diving Behavior

All four species appear to be brief divers. A Heaviside's dolphin female and male made relatively shallow and short dives (Sekiguchi et al. 1998). Close to 81% of dives were less than 20 m, approximately 86% of dives lasted 0-2 min (Sekiguchi et al. 1998). The maximum depth recorded by the male was 104 m and by the female was 92 m (Sekiguchi et al. 1998). The male tended to dive deeper between 1500-2100 h and the female between 2100-0300 h (Sekiguchi et al. 1998). The average long dive of Hector's dolphins lasts 89.95 s and is followed by an interval of 54.36 s in which the dolphin breathes 6.03 times (Slooten and Dawson 1994).

Social Behavior

Members of this genus are generally found in small groups. In Tierra del Fuego, group sizes of Commerson's dolphins average 6.9 individuals, with a maximum of 110 dolphins (Goodall et al. 1988b). Chilean dolphins are typically found in groups of two to three individuals, although groups as large as 50 dolphins have been observed (Goodall 1994b). The largest aggregation of Chilean dolphins ever reported numbered perhaps 4,000 individuals (Oporto in Goodall 1994b). Mean group size of Heaviside's dolphins is 3.2 individuals, with a maximum number of 30 dolphins (Findlay et al. 1992 in Best and Abernethy 1994). Commerson's dolphins and Chilean dolphins associate at times with other small odontocetes (Würsig et al. 1977; Mermoz 1980; Goodall et al. 1988c). Hector's dolphins are usually found in goups of two to eight individuals (review by Slooten and Dawson 1994).

Females of this genus appear to be slightly larger than males, although sample size is small as to confirm sexual dimorphism in size. The modal length of males is 0.97 times that of females in Commerson's dolphins, while, based on less than ten individuals per sex, their maximum weight is 0.80 that of females (Lockyer et al. 1988). Dolphins from Kerguelen are larger and heavier than dolphins from South America (Goodall 1994a). Based on less than ten individuals per sex, the modal length of Heaviside's dolphin males is 0.97 times that of females (Best and Abernethy 1994). In Hector's dolphins, the maximum length of males is 0.95 that of females, while their maximum weight is 0.92 that of females (Slooten and Dawson 1994).

Hector's dolphins appear to reside in well-defined geographical areas, forming relatively closed populations (Slooten 1990 in Slooten and Dawson 1994). Within a population, individual Hector's dolphins associate both randomly and non-randomly, supporting the hypothesis that they live in fission-fussion societies (Slooten et al. 1993; Bedjer et al. 1998). Behavioral and group-composition data suggest that mate monopolization is not a prominent feature of the mating system of Hector's dolphins (Slooten et al. 1993; Slooten 1994). Rather, it is suggested that they live in a promiscuous system in which males search rather than monopolize sexually active females (Slooten 1991; Slooten et al. 1993).

Reproduction and Population Parameters

In Commerson's dolphins from South America, females are sexually mature at about five to eight years of age and 1.27 to 1.30 m in length. Males become sexually active around five to six years of age and 1.27 to 1.31 m in length (Goodall et al. 1988b; Lockyer et al. 1988). In Kerguelen, sexual maturity is attained at five years of age in females and eight years in males, at about 1.65 m (Collet and Robineau 1988). In Chilean dolphins, males as small as 1.50 m are sexually mature, females as small as 1.58 m have active mammary glands (Oporto et al. 1990). Limited data suggest that Chilean dolphins of both sexes reach sexual maturity between 1.56 and 1.59 m in length (Best and Abernethy 1994). In Hector's dolphins, males and females reach sexual maturity at six to nine and seven to nine years of age (Slooten 1991). Gestation in Commerson's dolphins appears to last 12 months (Leatherwood and Cornell 1985; Cornell et al. 1988). Data from photographically identified Hector's dolphins suggest a calving interval between two and four years (Slooten and Dawson 1994). Hector's dolphins can live to at least 20 years of age (Slooten 1990 in Slooten and Dawson 1994). Maximum population growth rates for Hector's dolphins fall between 1.8 and 4.9%, with the minimum estimate representing a moe plausible best case scenario (Slooten and Lad 1991).

Breeding Areas

There are no apparent breeding areas. Calving season in Commerson's dolphins apparently occurs from October to March (Goodall et al. 1988b; Goodall 1994a). Based on sightings of calves, a similar calving season might occur in the Chilean dolphin (Goodall et al. 1998c). Based on sightings of neonates, Heaviside's dolphins appear to calve in the austral summer (Goodall et al. 1998c). Calving season in Hector's dolphins lasts from early November to mid-Febraury (Slooten 1991).

Speed of Travel and Movements

Radio-tagged Heaviside's dolphin female and male stayed near the coast in waters less than 100 m deep (Sekiguchi et al. 1998). The range of the female covered approximately 43 km of coastline, that of the male was twice as large (Sekiguchi et al. 1998).

Vocal Behavior

Dolphins of this genus produce vocalizations as low as 0.32 kHz and higher than 150 kHz, with dominant frequencies at 0.8-1 kHz, 1-2 kHz, 4-4.5 kHz, 116-134 kHz (Watkins et al. 1977; Watkins and Schevill 1980; Kamminga and Wiersma 1981; Sho-Chi et al 1982; Evans and Awbrey 1984; Dawson 1988; Evans et al. 1988; Dziedzic and De Buffrenil 1989; Dawson and Thorpe 1990; Au 1993). The maximum peak to peak source level (re: 1 µPa @ 1 m) ranges from 160 dB for the Commerson's dolphin to 163.2 dB for the Hector's dolphin (review by Richardson et al. 1995).

Sounds of short duration (0.4-2.0s) termed cries are produced by all four species (Watkins et al. 1977; Dawson 1998; Dawson and Thorpe 1990). However, no whistles (pure tones) have yet been recorded for any member of the genus (Dawson and Thorpe 1990; Best and Abernethy 1994). Commerson's dolphins and Hector's dolphins produce narrow band clicks (3-dB bandwidth= 10-22 kHz), with energy concentrated around 120 to 130 kHz, and little or no energy below 100 kHz (review by Au 1993). The characteristics of their sounds have been likened to those of the Dall's porpoise *Phocoenoides dalli* (Evans and Awbrey 1984; Evans et al. 1988). It has been suggested that echolocation is not the sole function of Hector's dolphin clicks, and that communication and echolocation are likely to be closely linked (Dawson 1991b).

Hearing Range

No data available.

Known Impacts of Human Activities

Captive Commerson's dolphins leaped out of the water, fluke-slaped, generated bubbles, or exhibited aggression to one another in the presence of a gillnet with a pinger without obvious habituation (Anderson et al. 1998). Although aware of the net/pinger, individuals charged through or touched the net during agonistic encounters (Anderson et al. 1998).

Chilean dolphins are generally shy around boats, but sometimes approach them (Crovetto and Medina 1991). Hector's dolphins avoid fast-moving vessels by diving but do not appear to leave areas of high boat traffic (Slooten and Dawson 1994). They are significantly attracted to dolphin-watching boats during the 10th and 15th minute of an encounter; however, they approach the boat less frequently than expected as the duration of the encounter increases beyond 70 min (Bedjer 1997).

Changes in respiration patterns, behavior, and associations with companion individuals induced by suction-cup radio tags lasted from five to 40 min (average of 13.6 min) in Hector's dolphins (Stone et al. 1998).

RIGHT WHALE DOLPHINS (*LISSODELPHIS* SP.)

Summary

The genus *Lissodelphis* comprises two species of finless dolphins: the northern right whale dolphin (*L. borealis*) and the southern right whale dolphin (*L. peronii*). These dolphins inhabit deep, offshore waters in the North Pacific and between the Subtropical and Antarctic Convergences. They feed primarily on mesopelagic fishes and appear capable of deep dives. Northern right whale dolphins produce sounds as low as 1 kHz in frequency.

Their small size make it unlikely that right whale dolphins will be vulnerable to LFA activity. However, their distribution, diving potential, and vocalizations make them vulnerable to LFA activity. Since both species are poorly studied, so it would be difficult to detect any negative impacts of LFA.

Protected Status

Right whale dolphins are not federally listed under the U. S. Endangered Species/Marine Mammal Protection acts (kingfish.ssp.nmfs.gov/tmcintyr/spec_idx.html). The northern right whale dolphin is listed as a lower risk/least concern species by the Cetacean Specialist Group of the International Union for the Conservation of Nature (www.wcmc.org.uk/data/database). The southern right whale dolphin is listed as a data deficient species by the Cetacean Specialist Group of the International Union for the Conservation of Nature (www.wcmc.org.uk/data/database). The two species were directly taken on occasion by 19th century whalers (Mitchell 1975). Northern right whale dolphins are directly taken off Japan by the small cetacean fishery, although they are not the main target of the fishery (Miyazaki 1983). They have been incidentally caught in drifnets set for salmon, shark, swordfish and squid, and in purse-seines in Japan, Russia, USA, and throughout the range of the species (Chivers et al. 1997; Iwasaki and Kasuya 1997; review by Jefferson et al. 1994). The number of dolphins killed by the North Pacific squid driftnet fleets depleted the population to 24-73% of its pre-exploitation population size (Mangel 1993). Southern right whale dolphins are directly taken off Japan by the small cetacean fishery, although they are not the main target of the fishery (Miyazaki 1983). They have been incidentally captured by the swordfish gillnet fishery off northern Chile (review by Jefferson et al. 1994).

Distribution

Northern right whale dolphins are endemic to the North Pacific, from Baja California, México, to the Aleutian Islands, Alaska, from 29° to 59°N (review by Jefferson et al. 1994). However, they are more commonly found from 30° to 51° N (Sleptsov 1961 in Jefferson et al. 1994; Nishiwaki 1967; Leatherwood and Walker 1979). Southern right whale dolphins have a circumpolar distribution in the Southern Hemisphere (review by Jefferson et al. 1994). They are found from as far north as Brazil and near Pucusana, Perú, to as far south as the Antarctic Convergence, from about 13° to 64°S (Martuscelli et al. 1995; review by Jefferson et al. 1994). However, they generally occur between the Subtropical and Antarctic Convergences (Gaskin 1968). The northward extension of the range of southern right whale dolphins appears related to the cold-water, northward flowing Peru and Benguela currents (Brown 1973).

Right whale dolphins apparently prefer cool, deep, offshore waters. The northern species is most often observed in waters with temperatures of 8°-19° C (Leatherwood and Walker 1979). The southern species is most often observed in waters with temperatures of 1°-20° C (Cruickshank and Brown 1981; Kasamatsu et al. 1988).

Northern right whale dolphins move in both sides of the Pacific, south and inshore during the winter and north and offshore during the summer (Kasuya 1971; Leatherwood and Walker 1979). They appear to be the second most abundant ceteacean off California (Leatherwood and Walker 1979). A northern migration for southern right whale dolphins during the austral winter and spring has been suggested (Van Waerebeek et al. 1991). However, the species appears to be a year-round resident off Namibia, Africa (Rose and Payne 1991). Southern right whale dolphins may be one of the most common cetaceans in northern Chile (Van Waerebeek et al. 1991).

Abundance

Worldwide population is unknown.

Ship surveys give an estimate of 9,342 northern right whale dolphins (95% bootstrap CL= 2,125-21,488) in California (Barlow 1995). Estimated density was 0.134 dolphins/km^2 (Barlow 1995).

Diet and Foraging Behavior

Right whale dolphins feed primarily on mesopelagic fishes, particularly myctophids, and squid (review by Jefferson et al. 1994). The two species may dive to more than 200 m in depth while searching for prey (Fitch and Brownell 1968; Baker 1981).

Diving Behavior

Northern right whale dolphins dive as long as 6.25 min (Leatherwood and Walker 1979). Southern right whale dolphins dive as long as 6.5 min (Cruickshank and Brown 1981).

Social Behavior

Group sizes of right whale dolphins are variable (review by Jefferson et al. 1994). Along the U. S. Pacific coast, groups average 9.9 individuals, with a maximum of 60 dolphins (OCS 1992). In the northeastern Pacific, groups average 110.2 individuals, with a maximum of 2,000 dolphins (Leatherwood and Walker 1979). The mean group size of southern right whale dolphins off Chile is 210 individuals (Van Waerebeek et al. 1991).

The two species associate with various species of marine mammals (review by Jefferson et al. 1994). Mass strandings have only been reported for the southern species (Fraser 1955; Goodall 1978; Baker 1981; Cawthorn 1990).

Males are somewhat larger than females (Jefferson et al. 1994). The asymptotic length of northern right whale dolphin males is 1.26 times that of females (Ferrero and Walker 1993). Based on less than ten individuals per sex, the maximum weight of northern right whale dolphin males is 1.39 times that of females (Leatherwood and Walker 1979).

Reproduction and Population Parameters

In the northeastern Pacific, northern right whale dolphin males reach sexual maturity at 2.12-2.20 m in length, while females become mature when they attain two m in length (review by Jefferson et al. 1994). In the northwestern Pacific, northern right whale dolphin females are sexually mature when they reach 2.06-2.12 m in length (Miyazaki 1986 in Jefferson et al. 1994). In the central North Pacific, northern right whale dolphin males reach sexual maturity at 2.15 m in length and 9.9-10.1 years of age, while females become mature when they attain 2.00-2.01 m in length and 9.7-10.4 years of age (Ferrero and Walker 1993). For southern right whale dolphins, females of 2.18 and 2.29 m and a male of 2.51 m were all sexually mature (Baker 1981; Van Waerebeek and Oporto 1990). Gestation period in northern right whale dolphins is estimated at 12.1-12.3 months, with a minimum calving interval of two years (Ferrero and Walker 1993). The northern species can live to at least 27 years (Ferrero and Walker 1993).

Breeding Areas

There are no apparent breeding areas. In the central North Pacific, calving appears to peak in July and August (Ferrero and Walker 1993). However, most sightings of calves are made between winter and early spring (Leatherwood and Walker 1979; Dohl et al. 1983; Leatherwood et al. 1988a).

Speed of Travel and Movements

Right whale dolphins appear to be fast swimmers. Northern right whale dolphins can swim as fast as 34 km/hr (Leatherwood and Walker 1979). Southern right whale dolphins can swim as fast as 22 km/hr (Cruickshank and Brown 1981).

Vocal Behavior

Northern right whale dolphins produce vocalizations as low as 1 kHz and as high as 40 kHz or more, with dominant frequencies at 1.8 and 3 kHz (Fish and Turl 1976; Leatherwood and Walker 1979). The maximum peak to peak source level (re: 1 µPa @ 1 m) of northern right whale dolphin sounds is 170 rms (Fish and Turl 1976). The echolocation signals of northern right whale dolphins are directional and can be detected at distances of 730 m (Leatherwood and Walker 1979).

Hearing Range

No data available.

Known Impacts of Human Activities

No data available.

FRASER'S DOLPHIN (*LAGENODELPHIS HOSEI*)

Summary

Fraser's dolphins (*Lagenodelphis hosei*) are relatively poorly studied, small odontocetes. They are found in oceanic tropical and subtropical waters around the world and appear to be relatively abundant in certain areas. They appear to be mid-water divers that feed mostly on mesopelagic fish. They are very gregarious and vocalizations may play an important role in their communication. This species is not known to produce low-frequency sounds; all recorded sounds are higher than 4 kHz; however data are limited.

Their distribution and diving habits suggest that this species may be vulnerable to LFA activity. However, their apparent use of medium frequency sounds suggests that they may be less sensitive to low frequency sound than other cetacean species. However, because they are relatively poorly known and difficult to study, it would be difficult to detect any negative impacts of LFA.

Protected Status

The Fraser's dolphin is not federally listed under the U. S. Endangered Species/Marine Mammal Protection acts (kingfish.ssp.nmfs.gov/tmcintyr/spec_idx.html). This species is listed as a data deficient species by the Cetacean Specialist Group of the International Union for the Conservation of Nature (www.wcmc.org.uk/data/database). Fraser's dolphins are taken by drive fisheries in Japan and Taiwan (Hammond and Leatherwood 1984; IWC 1994). They are taken by harpoon fisheries in Sri Lanka, the Lesser Antilles, Fiji, and the Philippines (Caldwell et al. 1976; Leatherwood and Reeves 1989; Baker 1990; Aragones 1994). Direct fishing also occurs in Indonesia (Barnes 1991; Perrin et al. 1994a). A few individuals have been captured for scientific research in the western Pacific and off South Africa (Miyazaki and Wada 1978a; Ross 1984). Incidental catches occur in tuna purse seines in the eastern tropical Pacific and Philippines (Perrin et al. 1973; Dolar et al. 1994). In the eastern tropical Pacific, 773 dolphins were killed between 1971 and 1977, and 125 between 1986 and 1989 (Horwood 1981; Hall and Boyer 1989, 1990, 1991; Whalen et al. 1988). Some dolphins are also taken in trap nets in Japan (IWC 1994). Catches in gillnets have been reported in South Africa, Sr Lanka, Japan, and the Philippines (Uchida 1985; Leatherwood and Reeves 1989; Cockroft 1990; Dolar et al. 1994). Live capture for display has been conducted in the Philippines (Hammond and Leatherwood 1984).

Distribution

Fraser's dolphins are found in oceanic tropical and subtropical waters around the world, from about 40°S to 50°N (review by Jefferson and Leatherwood 1994). However, most records are from 30°S to 30°N (review by Jefferson and Leatherwood 1994). Strandings occurring in temperate areas represent extralimital occurrences (van Bree et al. 1986; Perrin et al. 1994a).

The range of this species is well documented only in the eastern and central tropical Pacific and around the central Visayas, Philippines (Leatherwood et al. 1992; Perrin et al. 1994a). In the offshore eastern tropical Pacific, they are distributed mainly in upwelling-modified water (Au and Perryman 1985). They also are found in equatorial waters far from shore (Wade and Gerrodette 1993). However, in the central Visayas, this species is seen near shore, along the outer continental shelf, an in deep oceanic waters (Leatherwood et al. 1992). In South Africa, most records are from the summer months when dolphin sightings correlate with the Agulhas current (Ross 1984; Findlay et al. 1992).

This species is not particularly common in the eastern tropical Pacific, although it is the fifth most abundant species (Wade and Gerrodette 1993). However, they are considered common around the central Visayas, Philippines (Hammond and Leatherwood 1984; Leatherwood et al. 1992). They appear to be moderately common off South Africa (Gambell et al. 1975; Findlay et al. 1992).

Abundance

Worldwide population is unknown.

A total of 289,300 (95% bootstrap CL= 138,000-508,100) Fraser’s dolphins have been estimated for the eastern tropical Pacific (Wade and Gerrodette 1993). Overall density values in the eastern tropical Pacific were estimated from Wade and Gerrodette (1993) as mean population size divided by study area, results are 0.015 whales/km2; however, density values vary within the study area.

Diet and Foraging Behavior

Fraser’s dolphins appear to feed principally on mesopelagic fish and squid; however, they also consume shrimp, cuttlefish, isopods, and benthic fish (Tobayama et al. 1973; Caldwell et al. 1976; Robison and Craddock 1983; van Bree et al. 1986; Sekiguchi et al. 1992; Perrin et al. 1994a).

Although they do not appear to feed near the surface, they have been observed feeding near the surface in South Africa and the Caribbean Sea (Ross 1984; Watkins et al. 1994). In the eastern tropical Pacific, Fraser’s dolphins appear to feed at depths of 250-500 m, based on habitat of prey items, and to show some selectivity (Robison and Craddock 1983). They may feed at night on vertically migrating organisms (Tobayama et al. 1973). This species has been observed herding rainbow runners (*Elegatis bipinnulata*) at the surface (Watkins et al. 1994).

Diving Behavior

No data available.

Social Behavior

Fraser’s dolphins move in large groups, typically between 100 and 1,000 individuals (Perrin et al. 1994a). In the eastern tropical Pacific, groups average 11.8 dolphins, with a maximum of 1,500 individuals (Wade and Gerrodette 1993). Social bonds among individuals of this species appear tighter than those of dolphins of the genus *Stenella* (Perrin et al. 1994a). Fraser's dolphins associate with other odontocetes species (Hammond and Leatherwood 1984; Au and Perryman 1985; Leatherwood et al. 1992, 1993; Perrin et al. 1994a). They also strand individually or in mass (Tobayama et al. 1973).

Most groups contain mixed age classes, and several mass strandings included both mature and immature individuals of each sex (van Bree et al. 1986; Praderi et al. 1992). Sexual dimorphism in total length and mass has not been demonstrated (Jefferson and Leatherwood 1994). However, mature males from Japan were larger in body length than mature females and showed apparent secondary sexual features: deepening of the tail stock and widening and darkening of the lateral dark snipe (Amano et al. 1996). Based on a sample of less than ten individuals per sex, the asymptotic length of males is 0.97 times that of females (review by Perrin and Reilly 1984). Adult males appear to have larger, more erect, dorsal fins than do other age and gender classes (Perrin et al. 1994a).

Reproduction and Population Parameters

In the eastern North Atlantic, sexual maturity in both genders occurs at about 2.30 m in length and 7 years of age (van Bree et al. 1986). From a school captured by the driving fishing method in Japan, age and body length at sexual maturity were estimated at seven to ten years and 220-230 cm in males and five to eight years and 210-220 cm in females, respectively (Amano et al. 1996). Limited data from other regions indicate similar results (Miyazaki and Wada 1978a; Robison and Craddock 1983; Ross 1984; Perrin and Reilly 1984; Praderi et al. 1992). However, a female as small as 2.06 m has been reported as sexually mature (Perrin et al. 1994a). The gestation period is assumed to be 10-12.5 months (Perrin and Reilly 1984; Amano et al. 1996). The annual ovulation rate of the school captured by the driven-fishery in Japan was 0.49 (Amano et al. 1996). The calving calving interval is estimated to be about two years (Amano et al. 1996). The oldest animals from a school captured by the driving fishing method in Japan were two males and a female of 17.5 years (Amano et al. 1996).

Breeding Areas

There are no apparent breeding areas. No conclusive evidence has been presented to suggest that there is seasonality in calving (Jefferson and Leatherwood 1994). However, it has been suggested that calving peaks in spring and probably also in fall in Japan (Amano et al. 1996).

Speed of Travel and Movements

This species is often seen in fast-moving herds that can move, when escaping, at speeds of more than 28 km/h (Jefferson and Leatherwood 1994). In other occasions, they may move as slow as four to seven km/h (Alling 1986).

Vocal Behavior

Free-ranging Fraser's dolphins produce clicks and whistles that are similar to those of other small oceanic dolphins (Watkins et al. 1994). Vocalizations range from 4.3 kHz to more than 40 kHz (Leatherwood et al. 1993; Watkins et al. 1994). Clicks are short, broadband sounds, without obvious emphasis at particular frequencies less than 40 kHz (Watkins et al. 1994). Clicks are directional and have echolocation-like characteristics (Watkins et al. 1994). Whistles are frequency modulated, narrowband tones with fundamental frequencies between 4.3 and 24 kHz, and duration between <0.1 to 2.15 s (Watkins et al. 1994). Repeated sounds with similar frequency/contours are suggestive of signature whistles (Watkins et al. 1994). Fraser's dolphins have relatively high rates of underwater acoustic activity during periods of apparent resting (Watkins et al. 1994).

Hearing Range

No data available.

Known Impacts of Human Activities

Fraser's dolphins always avoid ships in the eastern tropical Pacific, apparently a reaction of most dolphins to harassment by tuna seiners (Perrin et al. 1994a). They also often evade ships in the Philippines (Leatherwood et al. 1992). As in the eastern tropical Pacific, this might be a reaction to harpooning and purse seining (Jefferson and Leatherwood 1994).

DOLPHINS (*LAGENORHYNCHUS* SP.)

Summary

The genus *Lagenorhynchus* comprises six species: the Atlantic white-sided dolphin (*L. acutus*), the white-beaked dolphin (*L. albirostris*), the Peale's dolphin (*L. australis*), the Hourglass dolphin (*L. cruciger*), the Pacific white-sided dolphin (*L. obliquidens*), and the dusky dolphin (*L. obscurus*). However, the taxonomy of this genus is currently under review (IWC 1997). These dolphins primarily inhabit coastal temperate and cold areas; however, they also occur in deep, offshore waters. They feed on nearshore, epipelagic, and mesopelagic fish and squid. They are not regarded as deep divers. Dolphins of the genus *Lagenorhynchus* produce and hear sounds as low as 0.06 and 0.5 kHz in frequency, respectively.

Their small size and apparent diving habits make it unlikely that *Lagenorhynchus* dolphins will be vulnerable to LFA. However, their distribution, vocalizations, and hearing abilities make some of the species vulnerable to LFA activity. Since distribution and movements of some populations are relatively well-known, it may be possible to quantify negative impacts of LFA activity.

Protected Status

None of the six species in this genus are federally listed under the U. S. Endangered Species/Marine Mammal Protection acts (kingfish.ssp.nmfs.gov/tmcintyr/spec_idx.html). The Peale's dolphin and the dusky dolphins are listed as data deficient species by the Cetacean Specialist Group of the International Union for the Conservation of Nature (www.wcmc.org.uk/data/database). The Atlantic white-sided dolphin, the white-beaked dolphin, the Hourglass dolphin, and the Pacific white-sided dolphin are listed as lower risk/least concern species by the Cetacean Specialist Group of the International Union for the Conservation of Nature (www.wcmc.org.uk/data/database). Pacific white-sided dolphins have been targeted by Japanese drive and harpoon fisheries (Miyazaki 1983; Kishiro and Kasuya 1993). They are also incidentally caught in moderate numbers by gillnets throughout their range, and in large numbers by Japanese, Korean, and Taiwanese high-seas drift gillnets (Miyazaki 1983; IWC 1992; Perkins et al. 1993; Chivers et al. 1997; Iwasaki and Kasuya 1997). In the eastern Pacific, small numbers are taken in a fishery for live animals (IWC 1997). From 1978 to 1990, 49,000 to 89,000 Pacific white-sided dolphins were killed in Japanese, Korean, and Taiwanese squid driftnet fisheries as well as the Taiwanese large-mesh driftnet fishery (Tanaka 1993). White-beaked dolphins are directly taken and incidentally captured in various parts of their range (Jefferson et al. 1993; Reeves and Leatherwood 1994; IWC 1997; Kinze et al. 1997). Mortality rate from hunting for local consumption in Newfoundland and Labrador appears to represent more than 10% (Alling and Whitehead 1987). Atlantic white-sided dolphins are taken directly in southwest Greenland and the Faeroe Islands (Bloch and Hoydal 1990; Heide-Jørgensen 1990). Incidental catches in fishing gear also occur throughout their range (Reeves and Leatherwood 1994; Palka et al. 1997). Dusky dolphins are incidentally captured in gillnets in New Zealand (Slooten and Dawson

1995). They are also incidentally and deliberately taken for food consumption in Perú, with an annual take of about 3,000 dolphins, and for crab bait in Argentina and Chile (Cárdenas et al. 1987; Read et al. 1988; Van Waerebeek and Reyes 1990; Lescrauwaet and Gibbons 1994). They are also killed by trawls in Argentina (Dans et al. 1997). Peale's dolphins are incidentally caught in nets throughout their range (Goodall et al. 1994; Lescrauwaet and Gibbons 1994; Reeves and Leatherwood 1994). Direct takes for crab bait in the Beagle Channel, Strait of Magellan, and southernTierra del Fuego appear to pose a threat to populations of this species (Goodall and Cameron 1980; Leatherwood et al. 1988b; IWC 1997). There has never been any systematic exploitation of Hourglass dolphins, except for a few specimens taken for scientific study (Reeves and Leatherwood 1994; Goodall et al. 1997a). A few individuals have been incidentally caught in New Zealand and the South Pacific (Goodall et al. 1997a).

Distribution

Dolphins of this genus inhabit temperate to subpolar oceanic waters; three species live in the northern Hemisphere, three species live in the southern Hemisphere. Pacific white-sided dolphins live in temperate waters of the Pacific Ocean, from about 20° to 60° N (Walker et al. 1986; Aurioles et al. 1988; Leatherwood et al. 1988a; reviews by Stacey and Baird 1991a; Jefferson et al. 1993; Brownell et al. 1999). Both white-beaked dolphins and Atlantic white-sided dolphins are found in cold temperate to subpolar waters of the North Atlantic, from 35° to 80° N. However, the white beacked dolphin has a more northerly distribution than the latter (reviews by Evans 1987; Jefferson et al. 1993; Reeves and Leatherwood 1994; Northridge et al. 1997). White-beaked dolphins have also been recorded in the western Mediterranean Sea (Jefferson et al. 1993). Dusky dolphins live apparently in disjunct populations in coastal waters off New Zealand, South America, southwestern Africa, and around several islands in the South Atlantic and southern Indian Ocean, from about 60° to 9°S (reviews by Jefferson et al. 1993; Van Waerebeek et al. 1995; Brownell and Cipriano 1999). Peale's dolphins have the most restricted range of the genus (Reeves and Leatherwood 1994). They live in coastal and shelf waters of South America and around the Falkland Islands, from about 60° to 35° S, with a possible exceptional sighing from Palmerston Atoll, approximately 18°N 165°W, in the south Pacific (Leatherwood et al. 1991b; reviews by Jefferson et al. 1993; Reeves and Leatherwood 1994; Goodall et al. 1997b). They also occur around the Falkland (Malvinas) Islands (Reeves and Leatherwodd 1994). Hourglass dolphins are circumpolar in the higher latitudes of the southern Hemisphere, from approximately 68° to 33° S (Jefferson et al. 1993; Goodall et al. 1997a; Brownell and Donahue 1999). They are more commonly found south of 45°S (reviews by Goodall 1997; Goodall et al. 1997a). Sightings of *Lagenorhynchus*-like dolphins in tropical and sub-tropical waters of the Indian and Pacific oceans suggest the presence of an unrecognized species (Van Waerebeek et al. 1997c).

Pacific white-sided dolphins are widely distributed in deep offshore waters; however, they also extend onto the continental shelf and very near shore in some areas, including bays (Leatherwood et al. 1984a). The distribution of white-beaked and Atlantic white-sided dolphins overlaps throughout much of their range (review by Northridge et al.

1997). However, white-beaked dolphins appear more numerous than Atlantic white-sided dolphins in the northeastern Atlantic, while the converse is true in the northwestern Atlantic (Northridge et al. 1997). In the northwestern Atlantic, Atlantic white-sided dolphins are more numerous than white-beaked dolphins over continental shelf waters (Northridge et al. 1997; Palka et al. 1997). In the northeastern Atlantic, white-beaked dolphins are primarily distributed upon northern Britain and the North Sea and are generally associated with shelf waters, while Atlantic white-sided dolphins are primarily distributed upon the continental slope north of 54°N in more oceanic waters (Northridge et al. 1997; Heimlich-Boran et al. 1998). The dusky dolphin is recognized as a coastal and mesopelagic species, rarely found far from shore or shallow shelves and slopes (Würsig et al. 1997). It does not tend to occur in waters deeper than 2,000 m, except in areas with abrupt continental or island drop-offs (Jefferson et al. 1993). Peale's dolphins are found in two habitats: bays, inlets and protected channels, and over the continental shelf on waters at least 300 m deep (reviews by Goodall et al. 1997b, 1997c). Kelp beds appear to be an important habitat for this species in certain areas (Hamilton 1952; Moreno and Jara 1984; Lescrauwaet 1997). Hourglass dolphins appear to be pelagic; however, sightings have been made in waters of 200 m or less and close to shore (Goodall 1997). They occur mainly in the northern regions of Antarctic waters, seldom near the ice-edge (Kasamatsu and Joyce 1995).

Seasonal north-south movements of Pacific white-sided dolphins have been detected in California and the northeastern Pacific (Leatherwood et al. 1984a; Forney and Barlow 1998). Migrations along the Japanese coast have also been reported (Wilke et al. 1953). However, the species is a year-round resident in some areas (Leatherwood et al. 1988a). Atlantic white-sided dolphins apparently undergo seasonal movements in both sides of the Atlantic (Northridge et al. 1997). Seasonal movements of Peale's dolphins are inferred from sighting data in southwestern South America (Goodall et al. 1997b; Lescrauwaet 1997). There is evidence in hourglass dolphins of possible summer migration southward toward Antarctic waters (Kasamatsu and Joyce 1995).

Comparison of cranial characters suggests that the Pacific white-sided dolphins off Iki Island, Japan, belong to a different population from that in the oceanic waters of the northwestern Pacific (Miyazaki and Shikano 1997). Two to three populations of Pacific white-sided dolphins have also been tentatively identified along the northeastern Pacific coast (Walker et al. 1986; Lux et al. 1997). Based on skull characters, two populations each of white-beaked dolphins and Atlantic white-sided dolphins appear to occur in the North Atlantic (Mikkelsen and Lund 1994). In addition, breaks in distribution suggests the existence of three population units of Atlantic white-sided dolphins in the northwestern Atlantic: Gulf of Maine, Gulf of St. Lawrence, and the Labrador Sea (Gaskin 1992b). Variations in skull and body measurements indicate that dusky dolphins from the southeastern Pacific, New Zealand, and southwestern Africa may comprise different populations (Van Waerebbek 1993).

Abundance

There are no worldwide estimates for members of this genus.

The North Pacific populations of white-sided dolphins probably number 931,000 (95%CL= 206,000-4,216,000) individuals (Buckland et al. 1993). However, this might be an overestimate by as much as four times (Heise 1997a). Ship surveys give an estimate of 12,310 Pacific white-sided dolphins (95% bootstrap CL= 1,888-27,965) in California (Barlow 1995). Estimated density was 0.177 dolphins/km^2 (Barlow 1995). It has been estimated that between 30,000 and 50,000 Pacific white-sided dolphins live in waters around Japan (Nishiwaki 1972). The exact same estimate has been reported for the eastern Pacific, not including Alaskan waters, by the U. S. Department of Commerce (1988). Estimates of Atlantic white-sided dolphins in the northwestern Atlantic are: 1) 28,600 (CV= 0.21) dolphins between Cape Hatteras, North Carolina, and Nova Scotia; 2) 20,400 (CV= 0.63) dolphins in the northern Gulf Of Maine, lower Bay of Fundy, and western Scotia slope region; 3) 730 (CV= 0.47) dolphins from the southern edge of Georges Bank, accross the Northeast Channel to the southwestern edge of the Scotian shelf ; and 4) 27,200 (CV= 0.43) dolphins from Norfolk to the mouth of the Gulf of St. Lawrence (CETAP 1982; Blaylock et al. 1995; Waring et al. in press in Palka et al. 1997). A total of 3,486 white-beaked dolphins (95% CL= 2,001-4,971) have been estimated in shelf waters along the coast of Labrador (Alling and Whitehead 1987). The summer abundance of white-beaked dolphins is 11,760 individuals (CV= 0.30) in the North Sea (Hammond et al. 1995 in Kinze et al. 1997). Also in the North Sea, the summer abundance of either white-beaked or Atlantic white-sided dolphins was 11,760 (CV= 0.26) individuals (Hammond et al. 1995 in Kinze et al. 1997). It is estimated that 144,300 hourglass dolphins (CV= 0.17) are present south of the Antarctic Convergence in January, with an estimated biomass of 0.01 million tones (Kasamatsu and Joyce 1995).

Diet and Foraging Behavior

Pacific white-sided dolphins appear to be opportunistic feeders, preying on small epipelagic and mesopelagic schooling fish and squid, and occasionally on crustaceans and jellyfish (Scheffer 1953; Stroud et al. 1981; Heise 1997b). Feeding occurs both during the day and at night (Stroud et al. 1981; Walker et al. 1986; Heise 1997b). Apparently Atlantic white-sided dolphins feed primarily on small, pelagic schooling fish and squid (reviw by Palka et al. 1997). However, around Ireland they consume principally mesopelagic fish and squid (Couperus 1998). White-beaked dolphins feed primarily on fish, although they also consume squid (Ostrom et al. 1993; review by Kinze et al. 1997). Dusky dolphins feed on schooling fish in South America, mesopelagic fish in New Zealand, and both schooling and mesopelagic fish in South Africa (Würsig and Würsig 1980; Cipriano 1989, 1992; Würsig et al. 1991; McKinnon 1994; Sekiguchi 1994; Alonso et al. 1998). Difference in dental characters between skulls from these regions appear to be related to these dietary differences (Van Waerebeek 1993). Differences in diurnal movement patterns, diving cycle, and feeding behavior between dolphins in New Zealand and Argentina appear also to be related to these dietary differences (review by Würsig et al. 1997). Peale’s dolphins feed on demersal, bottom, and continental-shelf fish, shrimp, and squid (Iñíguez and de Haro 1994; Schiavini et al. 1997). The few stomach contents of Hourglass dolphins that have been examined contained small fish, squid, and some crustaceans (review by Goodall et al. 1997a).

Cooperative feeding is practiced by dusky dolphins in Argentina (Würsig and Würsig 1980). Pacific white-sided dolphins and Peale's dolphins also appear to use cooperative foraging techniques (Heise 1997b; Lescrauwaet 1997; Schiavini et al. 1997). The minimum caloric requirement of captive Pacific white-sided dolphins is 13,760-17,160 kcal/day/dolphin (Pérez 1990 in Heise 1997b).

Diving Behavior

Members of this genus do not appear to be deep divers. Based on feeding habits, it is inferred that Pacific white-sided dolphins dive to at least 120 m (Fitch and Brownell 1968). In addition, 70% of foraging dives last less than 15 or 20 s (Black 1994; Heise 1997b). A satellite-tagged Atlantic white-sided dolphin dove an average of 38.8 s, with 76% of dives lasting less than 1 min (Mate et al. 1994b). The average time that the dolphin was submerged was 89% ± sd 2.47 (Mate et al. 1994b). It appears that dives longer than 10 min are not common in this species (Mate et al. 1994b). In Argentina, mean dive time of dusky dolphins is 21 s, with shorter dives during the day and longer dives at night (Würsig 1982). Peale's dolphins dive for as long as 157 s; however, close to 90% of dives last less than 60 s and the average dive lasts 27.6 s (de Haro and Iñíguez 1997; Lescrauwaet 1997).

Social Behavior

There is variation in size of groups for all members of this genus. Pacific white-sided dolphins average 10.8 individuals in the U. S. Pacific coast (OCS 1992). A mean value of 13.9 dolphins, with a maximum of 50 individuals is reported for Monterey Bay, California (Barham 1982). However, in the eastern north Pacific groups average 88.0 dolphins, with a maximum of 6,000 individuals (Leatherwood et al. 1984a). Atlantic white-sided dolphins average 53.2 individuals per group in the western North Atlantic (CETAP 1979). Groups of dusky dolphins average 9.5 individuals, with a maximum of 24 in the Marlborough Sounds, New Zealand (Duffy and Brown 1994). In Argentina, groups average 36.0 dolphins, with a maximum of 300 individuals (Würsig 1978a). However, in Kaikoura, New Zealand, groups average 86.0 dolphins, with a maximum of 1,000 individuals (Cipriano 1992). In Argentina, Peale's dolphin groups average 2.1 individuals with a maximum of 13 dolphins (de Haro and Iñíguez 1997). A mean value of 4.29 dolphins, with a maximum of 20 individuals is reported for the Strait of Magellan, Chile (Lescrauwaet 1997). However, groups of Peale's dolphins as large as 100 individuals have been reported (Goodall et al. 1997b). In South America, groups of hourglass dolphins average 5.7 individuals, with a maximum group size of 16 dolphins (Goodall 1997). However, groups as large as 155 dolphins have been observed (Mikhalev 1978).

Pacific white-sided dolphins and dusky dolphins are commonly seen with other cetacean species (Würsig and Würsig 1980; Würsig et al. 1997; review by Stacey and Baird 1991a). Hourglass and Peale's dolphins have also been observed in association with other cetaceans (reviews by Goodall 1997; Goodall et al. 1997b). Mass strandings of dolphins of this genus are not uncommon (Sergeant 1982).

There is some age and sex segregation of groups in Atlantic white-sided dolphins, older immature individuals are not generally found in reproductive groups of mature females and young (Jefferson et al. 1993). There appears to be segregation by sex in white-beaked dolphins in the southern North Sea (Northridge et al. 1995).

Although males of this genus appear to be slightly larger than females, sexual dimorphism has only been demonstrated in a few cranial or body measurements (Cipriano 1991, 1992; Van Waerebeek 1993; Miyazaki and Shikano 1997). The asymptotic length of Pacific white-sided males is 1.04 that of females in the northcentral Pacific (Ferrero and Walker 1996). In Atlantic white-sided dolphins, maximum length and weight of males is 1.09 and 1.36 that of females, respectively (Addink et al. 1997). In white-beaked dolphins, mean value at physical maturity in males is 1.08 times that of females (Hai et al. 1996). Based on less than ten individuals per sex, the maximum length of dusky dolphin males is 1.09 that of females (review in Perrin and Reilly 1984). Based on less than ten individuals per sex, the maximum length of Peale’s dolphin males is 1.04 that of females (Goodall et al. 1997c).

Reproduction and Population Parameters

In Pacific white-sided dolphins, the average length at sexual maturation varies from 1.74 to 1.90 m for males and 1.78 to 1.92 m for females (Perrin and Reilly 1984; Cowan et al. 1986; Ferrero and Walker 1996). Males can be mature at ages as young as nine years, while females appear to reach maturity between 7.5 and 11 years (Ferrero and Walker 1996; Iwasaki and Kasuya 1997; Heise 1997a). In Atlantic white-sided dolphins, males appear to be sexually mature between 2.20 and 2.40 m in length (Sergeant et al. 1980). The smallest and the youngest sexually mature females were 2.01 cm long and 6 years in age (Sergeant et al. 1980). In white-beaked dolphins, the smallest sexually mature female and male were 2.40 and 2.51 m long, respectively (Kinze et al. 1997). A 1.85 m long female Peale’s dolphins was immature; a second, 1.93 m long, was at the onset of puberty; and a third, 2.10 m long, was mature (Claver et al. 1992). In hourglass dolphins, a 1.83 m female was nearing sexual maturity, while a 1.74 m male was sexually mature (Brownell and Donahue 1999; Goodall et al. 1997a). The estimated gestation period in Pacific white-sided dolphins is ten to 12 months (Harrison 1969; Perrin and Reilly 1984; Ferrero and Walker 1996; Heise 1997a). Lactation in this species appears to last eight to ten months (Heise 1997a). Gestation lasts approximately 11.4 months in dusky dolphins (Cipriano 1992). Calving interval in Pacific white-sided dolphins averages 4.67 years (Heise 1997a). Calving interval in Atlantic white-sided dolphins apparently lasts two year (Sergeant et al. 1980). Assuming that one growth layer group in teeth represents one year, Pacific white-sided dolphins may live at least 35 to 46 years (Walker et al. 1986; Ferrero and Walker 1996; Iwasaki and Kasuya 1997). Atlantic white-sided dolphins live to more than 27 years of age (Sergeant et al. 1980). Dusky dolphins may live at least between 35 and 36 years (Webber 1987). Annual pregnancy rate of Pacific white-sided dolphins has been estimated at 21.4% (Heise 1997a). The finite population growth rate of Pacific white-sided dolphins has been estimated between 0.94 and 1.02 per year, suggesting that the population is at best stationary (Heise 1997a). Possible hybrids between dusky dolphins and common dolphins (*Delphinus delphis*) have been reported in the wild (Reyes 1996; Würsig et al. 1997).

Breeding Areas

There are no apparent breeding areas. Based on back-calculations, calving in Pacific white-sided dolphins apparently occurs during late winter and spring (Ferrero and Walker 1996). However, limited sightings and foetal records suggest that mating and calving occur from late spring through autumn (Brown and Norris 1956; Tomilin 1957; Norris and Prescott 1961). In Atlantic white-sided dolphins calving occurs in the summer, with a peak in June and July (Sergeant et al. 1980). In white-beaked dolphins calving apparently occurs during the summer (review by Kinze et al. 1997). In Kaikoura, New Zealand, dusky dolphins calve apparently from November to February in a limited period of time (Cipriano 1992; Würsig et al. 1997; Yin and Würsig 1998). The calving season of the Peale’s dolphin appears to extend from the austral spring to autumn (Goodall et al. 1997c).

Speed of Travel and Movements

Dolphins of this genus, particularly dusky dolphins and Pacific white-sided dolphins, are some of the most active and highly acrobatic cetaceans (Jefferson et al. 1993). Captive Pacific white-sided dolphins swim up to 27.7 km/h during 2 s periods (Lang and Daybell 1963 in Fish and Hui 1991). A satellite-tagged Atlantic white sided dolphin swam at an average speed of 5.7 ± sd 3.66 km/h (Mate et al. 1994b). Dusky dolphins in Argentina move at an average speed of 7.7 km/h, moving faster as water depth increases (Würsig and Würsig 1980). In New Zealand, they swim at mean routine speeds between 4.54 and 12.17 km/h (Cipriano 1992). Maximum burst speeds range between 11.09 and 36.14 km/h, but are sustained only for a few minutes (Cipriano 1992). Hourglass dolphins appear to swim at speeds between seven and 29 km/h (Goodall 1997).

A radio-tagged Pacific white-sided dolphin showed little net movement over a 45-day period off the California coast (Leatherwood and Evans 1979). A satellite-tagged Atlantic white sided dolphin travelled a straight-line distance of approximately 115.3 km/day (Mate et al. 1994b). Dusky dolphins in Argentina can travel for at least 19.2 km/day during the summer, and 0.7 km/day during the winter (Würsig 1982). In a 14-day period, the range of a radio-tagged individual included 110 km along shore and approximately 50 km out to sea (Würsig and Bastida 1986).

Vocal Behavior

Dolphins of this genus produce vocalizations as low as 0.06 kHz and as high as 325 kHz, with dominant frequencies at 0.3-5 kHz, 4-15 kHz, 6.9-19.2 kHz, and 60-80 kHz (reviews by Popper 1980; Richardson et al. 1995). The maximum peak to peak source level (re: 1 μPa @ 1 m) of white-beaked dolphins is less than or equal to 207 dB and that of Pacific white-sided dolphin sounds is 180 dB (review by Richardson et al. 1995). The mean source level of Atlantic white-sided dolphins is approximately 154 db (re: 1 µPa @ 1 m), with a maximum value of 164 dB re: 1 µPa @ 1 m (Kaschner et al. 1997). Sounds of Peale's dolphins are of low frequency (1 - 5 kHz), low level (about 80 dB re: 1 µPa @ 1 m), and mostly inaudible at more than 20 m (Schevill and Watkins 1971).

Pacific white-sided dolphins have a simple pulse waveform characteristic of most echolocating odontocetes and their underwater sounds are predominantly whistles (Fahner et al. 1998).

Hearing Range

Pacific white-sided dolphins listen underwater to sounds equal or softer than 120 dB (re: 1 µPa @ 1 m) in the range of about 0.5 kHz to 135 kHz (Tremel et al. 1998). At a frequency of 1 kHz, Pacific white-sided dolphins listen to pure tones that have an intensity of at least 106 dB re: 1 µPa @ 1 m (Tremel et al. 1998). This species listens to pure tones less that have an intensity less than 90 dB (re: 1 µPa @ 1 m) in the range of two to 128 kHz (Tremel et al. 1998).

Known Impacts of Human Activities

There were no significant differences in the number of sightings of Pacific white-sided dolphins when the ATOC sound source, located at 980 m depth and transmitting at a level of 195 dB re 1uPa @ 1 m, was on or off (Calambokidis et al. 1998; Gedamke et al. 1998).

There appears to be no significant effect of the presence of boats and swimmers or different numbers of boats on behavior of dusky dolphins at Kaikoura, New Zealand (Barr 1998). Yet, Yin and Würsig (1998) recorded in the same area short-impacts of the presence of boats: changes in speed, behavioral state, direction and group cohesion of dolphins. It appears that dusky dolphins in Kaikoura are not habituated to tourist boats after nine year; however, the impact of such short-term behavioral reactions is unknown (Würsig et al. 1997). Negative effects of boat traffic on Peale's dolphins have not been reported, rather dolphins appear to be attracted by engine noise (Goodall et al. 1997b).

COMMON DOLPHINS (*DELPHINUS* SP.)

Summary

The genus *Delphinus* is comprised of two species, the short-beaked common dolphin (*D. delphis*) and the long-beaked common dolphin (*D. capensis*), that occur sympatrically in the Southern California Bight, and perhaps in other areas as well (Heyning and Perrin 1994). In the eastern tropical Pacific, five stocks of common dolphins have been defined: Baja neritic, northern, central, southern, and Guerrero (Evans 1975, 1982; Perrin et al. 1985). The Baja neritic stock is the newly recognized long-beaked common dolphin, the next three stocks refer to the short-beaked common dolphin, the Guerrero stock has not been studied in detail and could belong to either one of the two species (Perrin et al. 1985; Heyning and Perrin 1994). Common dolphins are distributed worlwide in temperate, tropical, and subtropical oceans, primarily along continental shelf and bank regions. They feed on surface schooling fishes and on organisms in the migrating deep-scattering layer; however, they do not appear to be deep divers. Common dolphins produce sounds as low as 0.2 kHz in frequency; however, limited data suggest that their ability to listen to low-frequency sounds is limited.

Their small size, probable diving habits, and potential hearing abilities make it unlikely that common dolphin will be vulnerable to LFA activity. However, their distribution and vocalizations make the species vulnerable to LFA activity. Since distribution and movements of this species are relatively well-known in some regions, it may be possible to quantify any negative impacts of LFA activity.

Protected Status

Common dolphins are not federally listed under the U. S. Endangered Species/Marine Mammal Protection acts (kingfish.ssp.nmfs.gov/tmcintyr/spec_idx.html). The two species are listed as lower risk/least concern species by the Cetacean Specialist Group of the International Union for the Conservation of Nature (www.wcmc.org.uk/data/database). Common dolphins are one of the most prominent by-catches of both the world-pelagic purse-seine and drift net fisheries, particularly in the eastern Pacific, Indian Ocean, Mediterranean Sea, northeastern Atlantic, and western Africa (IWC 1992; Evans 1994). The stock in the Black Sea has been seriously depleted by over-hunting (IWC 1992). In the eastern tropical Pacific, all three stocks have been significantly reduced by the tuna fishery (Reeves and Leatherwood 1994). But by 1995 management efforts have reduced the take of common dolphins to only nine and 192 individuals (95% bootstrap CL= 61-186 and 143-171) from the northern and central stocks, respectively (Lennert and Hall 1997). Relative mortality for that year was estimated at less than 0.01 and 0.05% (95% bias-corrected percentile CL= 0.001-0.004 and 0.025-0.093) for the northern and central stocks, respectively (Lennert and Hall 1997). Common dolphins are also killed incidentally in fishing gear or taken deliberately by artisanal dolphin hunters in many areas in addition to those already mentioned (Read et al. 1988; Leatherwood and Reeves 1989; Van Waerebeek and Reyes 1990; Waring et al. 1990; Chivers et al. 1997; Romero et al. 1997; Tregenza et al. 1997b; Van Waerebeek et al. 1997b; review by Reeves and Leatherwood 1994).

Distribution

Common dolphins are one of the most widely distributed cetaceans, they are found world-wide in temperate, tropical, and subtropical oceans, from about 66°N to 55°S (review by Evans 1994). However, common dolphins appear to be more common from 40° N to 40°S in the coastal waters of the Pacific Ocean, typically beyond the 200 m isobath, and north of the 50°N in the Atlantic Ocean (review by Evans 1994). In the northwestern Atlantic, the relative abundance of common dolphins decreases towards 36°N and south of Cape Hatteras (CETAP 1982; Gaskin 1992c). In the northeastern Atlantic, common dolphins are more common off continental shelves and banks of the United Kingdom and Ireland (Sigurjonsson and Gunlaugsson 1988 in Gaskin 1992c; Heimlich-Boran et al. 1998). Although common dolphins are found in the Caribbean and Mediterranean seas, there are no confirmed records of them in the Gulf of Mexico (Jefferson and Schiro 1997).

Long-beaked common dolphins are restricted to near-shore tropical to temperate waters of eastern Asia, the eastern Pacific, the southwestern Atlantic, South Africa, Madagascar, western Africa, and the northwestern Indian Ocean (Heyning and Perrin 1994). In the eastern Pacific, long-beaked common dolphins have been observed only within about 200 km from shore, while the short-beaked common dolphin appears to range from shallow coastal waters to thousands of kilometers from shore (Perrin et al. 1985). It has been suggested that long-beaked common dolphins are more common than short-beaked dolphins in California during periods of relatively warm water (Banks and Brownell 1969).

Common dolphins appear to be primarily inhabitants of continental shelf and bank regions (review by Gaskin 1992c). Their distribution is correlated with water temperature and bottom topography, with the species preferentially traveling over underwater escarpments (Evans 1975, 1982; Hui 1985; Polacheck 1987; Selzer and Payne 1988). In the western tropical Indian Ocean, 26% of the variance in the distribution of common dolphins is explained by their association with shallow, saline waters, high in sea surface cholorophyll and with a weak thermocline (Ballance et al. 1998). In the eastern tropical Pacific, 42% of the variance in the distribution of common dolphins is explained by their association with dense surface waters that are high in sea surface cholorophyll and have a shallow and weak thermocline, suggesting that dolphins prefer cool upwelling habitat (Reilly and Fiedler 1994). In the northwestern Atlantic, common dolphins are concentrated between the 100 and 200 m depth contours, and in warm, saline waters (CETAP 1982; Selzer and Payne 1988).

Seasonal movements of these species are not well-known. In the northwestern Atlantic, common dolphins appear to move north towards Nova Scotia and Newfoundland, Canada, during the summer (CETAP 1982; Gowans and Whitehead 1995). In waters of the United Kingdom, common dolphins are usually recorded between June and

December, in association with movements of mackerel and with presence of warm water (Evans 1980). In California, common dolphins are more common during the winter than during the summer (Forney and Barlow 1998). There is also some evidence of autumn-migration leading out of the Mediterranean Sea (Hashmi 1998).

Abundance

There are no worldwide population estimates. However, short-beaked common dolphins are the most numerous species in the eastern tropical Pacific (Wade and Gerrodette 1993).

A total of 3,093,300 (CV= 0.217-0.367) short-beaked common dolphins have been estimated for the eastern tropical Pacific (Wade and Gerrodette 1993). Overall density values in the eastern tropical Pacific were estimated from Wade and Gerrodette (1993) as mean population size divided by study area, results are 0.162 dolphins/km^2; however, density values vary within the study area. Ship surveys give an estimate of 225,821 short-beaked common dolphins (95% bootstrap CL= 143,026-419,911) in California (Barlow 1995). Estimated density was 3.248 dolphins/km^2 (Barlow 1995). A total of 96,000 ± 30,500 short-beaked common dolphins have been estimated for the Black Sea (Sokolov et al. 1997). Approximately 31,124 ± 95%CL 36,151 short-beaked common dolphins are found in the northwestern Atlantic (CETAP 1982).

A total of 127,342 long-beaked common dolphins along the west side of the Peninsula of Baja California, México (Valles and Gendron 1995). Ship surveys give an estimate of 9,472 long-beaked common dolphins (95% bootstrap CL= 0-27,029) in California (Barlow 1995). Estimated density was 0.136 dolphins/km^2 (Barlow 1995).

Diet and Foraging Behavior

Common dolphins appear to feed at both the surface and the deep-scattering layer (Sekiguchi 1994). In the eastern Pacific, they feed on surface schooling fishes and on organisms in the migrating deep-scattering layer, mostly myctophids and some cephalopods (Norris and Prescott 1961; Fitch and Brownell 1968; Jones 1981; Evans 1994). This layer migrates from a depth of 300-400 m during the day to 0-100 m at night, when it is located just above the thermocline (Fiedler et al. 1998b). In the northwestern Atlantic, stomach contents of common dolphins captured in pelagic drifnet fisheries were dominated by both epi- and mesopelagic fishes (Gannon et al. 1998a). In South Africa, common dolphins appear to feed at night and early morning on the deep-scattering layer and at mid-day on surface schooling prey (Sekiguchi 1994). In the same region, they are considered to be opportunistic feeders (Young and Cockcroft 1994). Based on a small sample, it has been suggested that short-beaked common dolphins may feed more extensively on squid than the long-beaked species (Heyning and Perrin 1994).

Off southern California, common dolphins start feeding at dusk and continue feeding throughout the night (Evans 1994). They have been observed feeding in a coordinated manner in the Gulf of California, México (Gallo-Reynoso 1991). In addition, there are records of common dolphins feeding in association with trawls (review by Fertl and Leatherwood 1997).

Diving Behavior

The deepest dive recorded on a common dolphin is 260 m (Evans 1971). However, the majority of dives are to 9-50 m, with dives deeper than 20 m occurring after 1800 h (Evans 1994).

Social Behavior

Common dolphins are found in groups that can reach thousands of individuals; however, the basic social unit may be less than 30 dolphins (Evans 1994). In the western North Atlantic group size averages 46.8 dolphins (CETAP 1979). In the Gulf of California, groups range from a mean of 129.2 dolphins (maximum of 650) in the central portion to a mean of 254.3 dolphins (maximum of 1,100) in the northern region (Breese and Tershy 1993; Silber et al. 1994). In the eastern tropical Pacific, groups average 385.9 dolphins, with a maximum of 4,000 individuals (Wade and Gerrodette 1993). In the eastern tropical Pacific, it has been suggested that increases in group size during the morning and subsequent declines in the later afternoon or night are related to reducing the risk of predation and direct competition for food, respectively (Scott and Cattanach 1998). In the same region, common dolphins are frequently associated with yellowfin tuna (*Thunnus albacares*) (review by Scott and Cattanach 1998). Common dolphins also associate with other cetacean species (review by Evans 1994).

Male common dolphins tend to be slightly larger than females (review by Evans 1994). In the eastern tropical Pacific, the modal length of short-beaked common dolphin males is 1.06 times that of females, while the modal length of long-beaked common dolphin males is 1.05 times that of females (Perrin et al. 1985).

Reproduction and Population Parameters

In the Black Sea, males of the short-beaked common dolphin attain sexual maturity at average body lengths of 1.78 m, while females do so at average lengths of 1.70 m (Perrin and Reilly 1984). In the Atlantic coast of France, females reach sexual maturity at 1.95 to 2.08 m in length, while males become sexually mature at two m in length (Collet and Harrison 1980; Collet and Girons 1984). In the North Pacific, females reach sexual maturity at 1.71 to 1.73 m in length and eight years of age, while males become sexually mature at around 1.82 m in length and 10.5 years of age (Ferrero and Walker 1995). Apparently both males and females go through seasonal patterns of sexual activity (Ridgway 1972; Collet and Girons 1984). Gestation appears to last about 10 to 11.1 months (Perrin and Reilly 1984; Ferrero and Walker 1995), while lactation in captivity lasts six months (Evans 1994). Mean calving interval varies between 1.3 and two years (review by Gaskin 1992c).

Breeding Areas

There are no apparent breeding areas. In the northeastern Atlantic and in the North Pacific, calving apparently peaks during May and June (Collet 1981 in Gaskin 1992c; Ferrero and Walker 1995). In the Black Sea, calves are usually observed in the summer months (Sleptsov 1940 in Gaskin 1992c). In eastern tropical Pacific, the timing of reproduction appears to be different between stocks (Perryman and Lynn 1993).

Speed of Travel and Movements

Common dolphins swim at routine speeds of 5.8 km/h and maximum steady speeds of 16.2 km/h (Hui 1987). They have been recorded swimming as fast as 37.1 km/h during a 7 s period (Gray 1936). Common dolphins are able to travel as far as 120 km/day (Evans 1974). On one occasion, a female moved close to 490 km in ten days (Evans 1982).

Vocal Behavior

Common dolphins produce vocalizations as low as 0.2 kHz and as high as 150 kHz, with dominant frequencies at 0.5-18 kHz and 30-60 kHz (Caldwell and Caldwell 1968; Moore and Ridgway 1995; reviews by Popper 1980; Au 1993). Vocalizations produced include clicks, squeaks, whistles, and creaks (Evans 1994). The maximum peak to peak source level of common dolphin sounds is 180 dB re: 1 µPa @ 1 m (review by Popper 1980). In the North Atlantic, the mean source levels of free-ranging common dolphins was approximately 143 db (re: 1 µPa @ 1 m) with a maximum value of 154 dB re: 1 µPa @ 1 m (Kaschner et al. 1997). Sounds of common dolphins can be heard 200-1,000 m from them (Fish and Turl 1976). Common dolphins produce whistles that could be signature whistles (Caldwell and Caldwell 1968).

When echolocating, individual pulses of common dolphins are of very short duration (20-50 µs), are of narrow band, and exhibit most energy between 15 and 100 kHz (Wood and Evans 1980; Evans and Awbrey 1988). The target detection and discrimination ability of common dolphins is comparable with that of bottlenose dolphins (*Tursiops truncatus*) (review by Evans 1994).

Hearing Range

Based on auditory brainstem responses, common dolphins listen underwater to sounds equal or softer than 120 dB (re: 1 µPa @ 1 m) in the range of <5 kHz to 150 kHz (Popov and Klishin 1998). The best underwater hearing of the species occurs at 65 kHz, where the threshold level is 53 dB re: 1 µPa @ 1 m (Popov and Klishin 1998).

Known Impacts of Human Activities

Reactions of common dolphins to emissions from a 2,210 in^3 air gun are varied, surveys suggest that dolphins avoided the immediate vicinity of the air gun while firing was in progress; however, a specific observation revealed that dolphins were able to tolerate the seismic pulses at 1 km range from the air gun array (Goold 1998; Goold and Fish 1998). The emissions are considered to be clearly audible to dolphins at least out to 8 km range (Goold and Fish 1998).

In New Zealand, common dolphins did not avoid commercial swim-with-dolphin vessels, rather they approached the boat to bowride on 43% of approaches by the boat (Constantine 1995). Dolphins avoided swimmers 38% of swims and had a sustained interaction with them, averaging 5.3 min, on 24% of swims; however, responses of dolphins to swimmers were related to the methods used by boats to place swimmers in the water (Constantine 1995).

DOLPHINS (*STENELLA* SP.)

Summary

The genus *Stenella* comprises five species: the pantropical spotted dolphin (*S. attenuata*), the clymene dolphin (*S. clymene*), the striped dolphin (*S. coeruloalba*), the Atlantic spotted dolphin (*S. frontalis*), and the spinner dolphin (*S. longirostris*). These dolphins inhabit coastal and oceanic tropical and subtropical waters. They feed on mostly on epipelagic and mesopelagic fish and squid. They appear capable of diving at least to moderate depths to reach their food. Dolphins of this genus produce sounds as low as 0.1 kHz in frequency. Their hearing abilities, however, are unclear.

Their distribution, potential diving abilities, and vocalizations make *Stenella* dolphins vulnerable to LFA activity. Since distribution and movements of some populations are relatively well-known, it may be possible to quantify negative impacts of LFA activity.

Protected Status

The clymene dolphin, the striped dolphin, and the Atlantic spotted dolphin are not federally listed under the U. S. Endangered Species/Marine Mammal Protection acts (kingfish.ssp.nmfs.gov/tmcintyr/spec_idx.html). Although the pantropical spotted dolphin and the spinner dolphin are also not federally listed under the U. S. Endangered Species/Marine Mammal Protection acts, the northeastern offshore stock of the former and the eastern stock of the latter are listed as depleted in those acts (kingfish.ssp.nmfs.gov/tmcintyr/spec_idx.html). The clymene dolphin and the Atlantic spotted dolphin are listed as data deficient species by the Cetacean Specialist Group of the International Union for the Conservation of Nature (www.wcmc.org.uk/data/database). The striped dolphin, the pantropical spotted dolphin, and the spinner dolphin are listed as lower risk/conservation dependent species by the Cetacean Specialist Group of the International Union for the Conservation of Nature (www.wcmc.org.uk/data/database). Pantropical spotted dolphins have been taken in large numbers by the drive fishery in Japan, which apparently caused a slight decline in the mininum age attainment of sexual maturity in females (Kasuya 1985a). They are also directly taken in the Philippines, Indonesia, and the Lesser Antilles (review by Perrin and Hohn 1994). Incidental catches of this species occur in gillnets in Sri Lanka, the Philippines, Pakistan, and Australia (review by Perrin and Hohn 1994). Spinner dolphins are directly taken in harpoon fisheries in the Leser Antilles, the Philippines, and Indonesia (Caldwell et al. 1971; Barnes 1991; Dolar et al. 1994). They are incidentally caught in coastal gillnet fisheries in the Philippines, Sri Lanka, Australia, Venezuela, Pakistan, and India (review by Perrin and Gilpatrick 1994).

The tuna fishery in the eastern tropical Pacific (ETP) targets pantropical spotted dolphins, and to a lesser extent spinner dolphins, to catch yellowfin (*Thunnus albacares*) and skipjack tuna, *Katsuwonus pelamis* (review by Perrin and Hohn 1994). This fishery has produced a decline in the abundance of both pantropical spotted and spinner dolphins (reviews by Perrin and Gilpatrick 1994; Perrin and Hohn 1994). Analyses of temporal trends in several biological parameters have not provided conclusive evidence for compensatory responses having occurred in northern offshore and southern offshore stocks of pantropical spotted dolphins (Chivers and Myrick 1993). Incidental mortality of both species in the ETP due to this fishery has been reduced in recent years (reviews by Perrin and Gilpatrick 1994; Perrin and Hohn 1994). In 1994, 935 and 1,226 pantropical spotted dolphins (95% bootstrap CL= 803-1,068 and 1,120-1,342) from the northeastern and western-southern stocks were killed, respectively (Lennert and Hall 1996). Relative mortality for that year was estimated at 0.13 and 0.09% (95% bias-corrected percentile CL= 0.093-0.167 and 0.073-0.134) for the northeastern and western-southern stocks, respectively (Lennert and Hall 1996). Also in 1994, 743 and 619 spinner dolphins (95% bootstrap CL= 609-941 and 553-717) from the eastern and whitebelly stocks were killed, respectively (Lennert and Hall 1996). Relative mortality for that year was estimated at 0.12 and 0.06% (95% bias-corrected percentile CL= 0.066-0.184 and 0.038-0.084) for the the eastern and whitebelly stocks, respectively (Lennert and Hall 1996).

Striped dolphins are the major target of large drive and hand-harpoon fisheries off Japan (review by Perrin et al. 1994b). Although effort has remained unchanged, annual catches have dropped with the years: 22,000 in 1959; 16,492 in 1980; 2,830 per year between 1981 and 1989; and 1,028 per year between 1989 and 1993 (Miyazaki 1983; Kasuya 1985a; Anonymous 1992; Kishiro and Kasuya 1993). Concomitant with this decline, the fishery expanded to include pantropical spotted dolphins and other odontocetes (Kishiro and Kasuya 1993). Thus, the population of striped dolphins has apparently declined over the past 30 years (Kasuya 1985a; Kishiro and Kasuya 1993). Striped dolphins are also deliberately taken in the northeast Atlantic and the Mediterranean Sea (Collet 1983; Duguy et al. 1983a). They are incidentally caught in gill nets in the north-eastern Indian Ocean, in tuna purse seines in the ETP, in fisheries in the northeastern Atlantic, in fisheries in the Mediterranean Sea, and in drift gill nets in the North Pacific (review by Perrin et al. 1994b). Striped dolphins are also incidentally captured in gillnets in California (Chivers et al. 1997).

Atlantic spotted dolphins are taken in a direct fishery for small cetaceans in the Caribbean and, perhaps, off the Azores and West Africa (Jefferson et al. 1993). Clymene dolphins are taken incidentally in the Lesser Antilles and Venezuela by gillnets, and deliberately by the small cetacean fishery in the Lesser Antiles (review by Perrin and Mead 1994).

Distribution

Pantropical spotted dolphins and spinner dolphins are found in tropical waters worlwide, from about 40°S to 40°N (reviews by Perrin and Gilpatrick 1994; Perrin and Hohn 1994). Striped dolphins are found in tropical and warm temperate waters around the world, particularly in oceanic tropical waters, from about 60°N to 50°S (review by Perrin et al. 1994b). However, records from cold waters are probably extralimital (Perrin et al. 1994b). Recent sightings of this species have been made from waters in central Chile (Canto et al. 1994). Atlantic spotted dolphins are found only in the tropical and warm-temperate Atlantic Ocean, from about 35°S to 50°N; including the Caribbean Sea, the

Gulf of Mexico, and an unconfirmed sighting in the Mediterranean Sea (review by Perrin et al. 1994c). Clymene dolphins are found only in the tropical and subtropical Atlantic Ocean, including the Caribbean Sea and the Gulf of Mexico, but not the Mediterranean Sea, from about 35°S to 40°N (Robineau et al. 1994; review by Perrin and Mead 1994).

The pantropical spotted dolphin is primarily an oceanic species (review by Perrin and Hohn 1994). However, in the ETP the species is also found along the coast from México to Perú (Perrin et al. 1985). Spinner dolphins are associated with inshore waters, islands or banks (Norris et al. 1994; Poole 1995). However, in the ETP they occur in deep waters, hundreds of miles from shore (Wade and Gerrodete 1993). The dwarf form of the spinner dolphin appears to inhabit shallow coral reef habitat in Thai waters (Perrin et al. 1989, 1998). Striped dolphins are predominantly a deep water, offshore species (review by Perrin et al. 1994b). In South Africa and the northeastern Atlantic, they are found in oceanic waters at depths of over 1,000 m (Ross 1984; Forcada et al. 1990; Heimlich-Boran et al. 1998). In the first area, their distribution is associated with the Agulhas Current (Ross 1984). In Japan, striped dolphins arrive seasonally with the advancing front of the warm Kuroshio current (Miyazaki et al. 1974). Atlantic spotted dolphins appear to prefer waters of the continental shelf; however, they can also bee found in deep, oceanic waters (review by Perrin et al. 1994c). In the northeastern Atlantic, they inhabit the continental shelf, usually inside or near the 200 m isobath, but sometimes come into very shallow water (Perrin et al. 1994c). Clymene dolphins have been observed only in deep waters (Perrin and Mead 1994).

The distribution of *Stenella* species tends to be complementary. In the ETP, spinner and pantropical spotted dolphins tend to occur in tropical surface water, characterized by stable thermocline ridging and relatively small annual variation in sea surface temperature, while striped and common dolphins (*Delphinus* sp.) inhabit areas with seasonal upwelling and large seasonal changes in surface temperature and thermocline depth (Au and Perryman 1985; Reilly and Fiedler 1994). Spatial separation between common and striped dolphins is maintained by the oceanographic preferences of striped dolphins, which are intermediate between those of common dolphins and those of spinner and pantropical spotted dolphins (Reilly 1990). In the western tropical Indian Ocean, pantropical spotted dolphins and spinner dolphins, segregated with respect to habitat affinities, contrasting with what has been documented for this species pair in the ETP (Ballance et al. 1998). In the north-central Gulf of Mexico, mean water depth of Atlantic spotted dolphin sightings was less than 400 m, while mean water depths of striped, spinner, clymene, and pantropical spotted dolphins were greater than 700 m (Mullin et al. 1994a). Seasonal and annual shifts in the distribution of pantropical spotted an spinner dolphins are found in the ETP (Reilly 1990; Reilly and Fiedler 1994). Striped dolphins are encountered in some areas throughout the year, while in others their distribution is seasonal and related with the fronts of warm oceanic currents (review by Perrin et al. 1994b).

Pantropical spotted dolphins in the ETP have been assigned to three stocks: coastal (subspecies *S. attenuata grafmani*), northeastern offshore, and western/southern offshore (Perrin et al. 1985; Dizon et al. 1992). However, the geographical boundaries of the offshore stocks need to be redrawn (Perrin et al. 1994d). Five distinct morphotypes of the spinner dolphin have been described in the Pacific Ocean: the eastern, the Central American, the whitebelly, the pantropical and the dwarf (Perrin et al. 1985, 1989; Perrin 1990). The first three forms are endemic to the ETP, the pantropical form occurs in Hawaii and throughout most of the subtropical and tropical waters of the world outside the ETP, and the dwarf form occurs in shallow waters off the Gulf of Thailand and Northern Australia, possibly also the Java Sea and other shallow waters throughout inner Indonesia and Malaysia (Perrin et al. 1989; Perrin 1990; Perrin et al. 1998). The most recently proposed form of the spinner dolphins is termed Tres Marías and is found along the edge of the continental shelf north of Cabo Corrientes, México, in the ETP (Perryman and Westlake 1998). The current population size of the eastern form of the spinner dolphin apparently ranges from 0.32 to 0.58 (best estimate of 0.44) of its historical population size (Wade 1993). High average heterozygosity indicates that there is no population subdivision in striped dolphins from the western Mediterranean Sea (García-Martínez et al. 1995). In the western North Pacific, however, striped dolphins appear to occur in two concentrations, one north and one south of 30°N; offshore and an inshore stocks are found in the north concentration area (Kasuya and Miyashita 1989 in Miyashita 1993).

Abundance

There are no worldwide population estimates for any of the five species in this genus.

The following information on abundance is not separated by stocks. Dolphins of this genus are among the most abundant cetaceans in the ETP (Wade and Gerrodette 1993). Striped dolphins are the most abundant species in the Mediterranean Sea (review by Perrin et al. 1994b). A total of 2,059,100 pantropical spotted dolphins (adding 95% bootstrap CL from different stocks= 1,522,500-2,675,300); 1,651,100 spinner dolphins (adding 95% bootstrap CL from different stocks= 1,083,900-2,394,500); and 1,918,000 striped dolphins (95% bootstrap CL= 1,531,800-2,249,300) have been estimated for the ETP (Wade and Gerrodette 1993). Overall density values in the eastern tropical Pacific were estimated from Wade and Gerrodette (1993) as mean population size divided by study area, results are 0.108 pantropical spotted dolphins/km^2, 0.086 spinner dolphins/km^2, and 0.100 striped dolphins/km^2; however, density values vary within the study area. Ship surveys give an estimate of 19,008 striped dolphins (95% bootstrap CL= 8,234-45,864) in California (Barlow 1995). Estimated density was 0.273 dolphins/km^2 (Barlow 1995). In the northwestern Pacific, a total of 438,064 pantropical spotted dolphins (95% log-normal CL= 312,285-614,503) and 570,038 striped dolphins(95% log-normal CL= 397,435-817-602) have been estimated (Miyashita 1993). However, attraction to boat may have caused an upward bias on population estimates (Miyashita 1993). Overall density values in the western North Pacific were estimated from Miyashita (1993) as mean population size divided by study area, results are 0.145 striped dolphins/km^2 and 0.081 pantropical spotted dolphins/km^2; however, density values vary within the study area. In the outer continental shelf and continental slope waters of the northwestern Gulf of Mexico, a total of 5,876 pantropical spotted dolphins (CV= 42.3%) and 2,285 Clymene dolphins (CV= 60.8%) has been estimated (Jefferson 1996). In the western Mediterranean Sea, total numbers of striped dolphins during the summer were estimated at 117,880 (95% CL= 68,379-214,800); the highest densities were found in the Alboran Sea and the Ligurian Sea (Forcada et al. 1994). In the Corso-Ligurian Basin, 25,614 striped dolphins (95% CL= 15,377-42,658) have been estimated during the summer (Forcada et al. 1995).

Diet and Foraging Behavior

Pantropical spotted dolphins feed on epipelagic and mesopelagic fish and squid, during the day and night (Robertson and Chivers 1996; review by Perrin and Hohn 1994). They are considered opportunistic feeders (Robertson and Chivers 1996). Compared with pregnant females, lactating females increase the proportion of squid in their diet and the quantity of food consumed (Robertson and Chivers 1996). Spinner dolphins feed at night primarily on small mesopelagic fishes and squids, diving to at least 200 to 300 m (review by Perrin and Gilpatrick 1994). Mesopelagic prey of both species is associated with the deep-scateering layer, which in the ETP migrates from a depth of 300-400 m during the day to 0-100 m at night, when it is located just above the thermocline (Fiedler et al. 1998b). The dwarf form of the spinner dolphin feeds on benthic and coral reef fishes and invertebrates (Perrin et al. 1998). Feeding habits of striped dolphins vary with geographical region. In Japan and southeastern South Africa, they appear to feed mainly on mesopelagic prey (Miyazaki et al. 1973; Ross 1984). Because 75 to 80% of prey in both areas had organs of luminiscence, feeding depths of striped dolphins may extend to below 200 m (review by Perrin et al. 1994b). Along the southern African coast they might have both inshore and offshore feeding habits, or feed at the continental shelf break (Sekiguchi 1994). In the Mediterranean Sea, they feed on a variety of squid, including oceanic and pelagic or bathypelagic species, crustaceans, and fishes (Wuertz and Marrale 1993; Blanco et al. 1995). Atlantic spotted dolphins feed on epipelagic and mesopelagic fish and squid, and also on benthic invertebrates (review by Perrin et al. 1994c). Clymene dolphins are thought to feed on mesopelagic small fish and squid at moderate depths, presumably at night (Perrin and Mead 1994). However, one of the prey species does not migrate close to the surface even at night (Perrin and Mead 1994). *Stenella* dolphins have been observed feeding in a cooperative manner (Martin 1986; Fertl and Würsig 1995; Fert et al. 1997). They are also known to feed in association wih trawlers (review by Fertl and Leatherwood 1997).

Diving Behavior

Radio-tagged pantropical spotted dolphins have been recorded diving to a maximum depth of 100 m (Scott et al. 1993). They can dive for as long as 3.4 min (Leatherwood and Ljungblad 1979). Diving pattern during apparent feeding consists of dives longer than 1.5 min followed by dives shorter than 10 s (Scott and Wussow 1983). Resting and feeding dives of spinner dolphins last about 3 and 3.5 min, respectively (Norris et al. 1994). A satellite-tagged Atlantic spotted dolphin spent 76.2% of its time at a depth of less than 10 m and dove to a maximum depth of 60 m (Davis et al. 1996).

Social Behavior

Dolphins of this genus are very gregarious and their groups are of varying size. The smallest group sizes have been reported for the Atlantic spotted dolphin, while the largest for the striped dolphin. In pantropical spotted dolphins, groups average 26.0 individuals, with a maximum of 148 animals in the Gulf of Mexico (Jefferson 1995). In Golfo Dulce, Costa Rica, mean group size is 35.6 individuals, and the largest group size is 300 dolphins (Acevedo-Gutiérrez and Burkhart 1998). In the Choco, Colombia, groups average 45.0 dolphins, with a maximum of 500 individuals (Suárez-C. et al. 1994). In the ETP, mean group size is 115.9 individuals, and the largest group size is 2,400 dolphins (Wade and Gerrodette 1993). In the western North Pacific, groups average 226.0 dolphins, with a maximum of 2,500 individuals (Miyashita 1993). In striped dolphins, groups average 60.9 individuals in the ETP (Wade and Gerrodette 1993). In the western North Atlantic, mean group size is 64.9 individuals, and the largest group size is 500 dolphins (CETAP 1982). In the western North Pacific, estimates vary from an average of 302.0 dolphins, with a maximum of 2,136 individuals (Miyazaki and Nishiwaki 1978) to an average of 121.4 dolphins, with a maximum of 1,500 individuals (Miyashita 1993). In spinner dolphins, groups average 37.6 individuals, with a maximum of 100 animals in the northern Indian Ocean (Alling 1986). In French Polynesia, groups average 39.0 dolphins, with a maximum of 95 individuals (Poole 1995). In Hawaii, mean group size is 77.0 individuals, and the largest group size is 300 dolphins (Östman 1994). In the ETP, mean group size is 134.1 individuals, and the largest group size is 1,700 dolphins (Wade and Gerrodette 1993). In Atlantic spotted dolphins, groups average 6.0 individuals, with a maximum of 50 animals in the Bahamas (Dudzinski 1996). In the Gulf of Mexico, mean group size is 10.0 individuals, and the largest group size is 65 dolphins (Mills et al. 1993). In clymene dolphins, groups average 41.6 individuals, with a maximum of 100 animals in the Gulf of Mexico (Mullin et al. 1994b).

In the ETP, pantropical spotted and spinner dolphins are frequently associated with each other, with yellowfin tuna, and with other cetaceans (review by Scott and Cattanach 1998). It has been suggested that increases in group size of spinner and pantropical spotted dolphins during the morning and subsequent declines in the later afternoon or night are related to reducing the risk of predation and direct competition for food, respectively (Scott and Cattanach 1998). Striped dolphins also associate occasionally with yellowfin tuna in the ETP (Perrin et al. 1994b). Clymene dolphins are known to associate with other dolphin species (Perrin and Mead 1994)

Striped dolphins in the western Pacific segregate by age and sex into juvenile, breeding adults, non-breeding adults, breeding mixed, and non-breeding mixed groups (review by Perrin et al. 1994b). Pantropical spotted, spinner and clymene dolphins appear also segregate by age and sex (Hohn and Scott 1983; Chivers and Hohn 1985; Perrin and Mead 1994).

Males of this genus appear to be slightly larger than females. The modal length of males is 1.02-1.04 that of females in pantropical spotted dolphins, spinner dolphins, and striped dolphins (Miyazaki et al. 1981; Perrin et al. 1985). The maximum length of males is 0.99 that of females in Atlantic spotted dolphins (review by Perrin and Reilly 1984). The maximum lenght of males is 1.04 that of females in clymene dolphins (Perrin et al. 1981). The modal weight of males is 1.06 that of females in striped dolphins (Miyazaki et al. 1981). The maximum weight of males is 1.15 and 1.26 that of females in clymene dolphins and spinner dolphins, respectively (Perrin et al. 1981, 1985). Based on estimates from minimum weight-length curves, the modal weight of pantropical spotted dolphin males is 1.20 that of females (Miyazaki et al. 1981). Based on estimates from a minimum weight-length curve for adult males, the modal weight of Atlantic spotted dolphin males is 0.97 that of females (Perrin et al. 1994d). Although there is no significant sexual dimorphism in striped dolphins from the Mediterranean, males are longer and heavier than females in the Atlantic (Di-Meglio et al. 1996). There is sexual dimorphism in cranial features of pantropical spotted dolphins from the ETP (Perrin et al. 1994d).

Groups of pantropical spotted dolphins appear to be stable units in the short term, although there is fluidity in composition (Pryor and Shallenberger 1991). Spinner and Atlantic spotted dolphins appear to have a fluid group structure (Herzing 1993; Norris et al. 1994; Dudzinski 1996). Spinner dolphin groups are composed of family units and of learned associations beyond the family group (Norris et al. 1994). In female Atlantic spotted dolphins, changes in reproductive state have a significant impact on female/female association patterns (Herzing and Brunnick 1997). Coefficients of association between mothers and calves are high until the birth of subsequent siblings, at which time association values decrease (Herzing and Brunnick 1997). Juvenile females display strong associations with other females in the same age class; however, these values drop upon sexual maturity and between years of changing reproductive condition (Herzing and Brunnick 1997). Pregnant females form significant associations with previously unassociated females who also give birth the same year (Herzing and Brunnick 1997). Some of these latest associations remain stable for two or more years (Herzing and Brunnick 1997). The breeding system of pantropical spotted, spinner and striped dolphins appears to be promiscuous (Norris et al. 1994; Perrin and Hohn 1994; Perrin et al. 1994b).

Reproduction and Population Parameters

In pantropical spotted dolphins from the ETP, the mean estimate of age at sexual maturity is significantly higher for the northern offshore stock, 11.1 years, than for the southern offshore stock, 9.8 years (Chivers and Myrick 1993). Males reach maturity at about 12 to 15 years (review by Perrin and Hohn 1994). In spinner dolphins, females and males appear to reach sexual maturation at 1.65 to 1.70 m and 1.60 to 1.80 m in length and four to seven years and seven to ten years in age, respectively (reviews by Perrin and Reilly 1984; Perrin and Gilpatrick 1994). In female striped dolphins, age of sexual maturation in Japan has declined from 9.7 to 7.2 years, apparently a response to decreased density caused by hunting (Kasuya 1985a). Males become sexually mature at between seven and 15 years of age (review by Perrin et al. 1994b). In the western Mediterranean Sea, estimates of sexual maturity in females range from 5-6 to 12-12.3 years of age, and from 1.60-1.75 to 1.87 m in length (Calzada et al. 1996, 1997). Males become sexually mature at eight to nine years and at 1.70 to 1.81 m (Calzada et al. 1997). In Atlantic spotted dolphins, females appear to become sexually mature at about 1.74 to 1.93 m (review by Perrin et al. 1994c). Age at sexual maturation in females is estimated to range from eight to 15 years (Herzing 1997).

Gestation in pantropical spotted dolphins is estimated at 11.2 to 11.5 months, with a calving interval of about three years (review by Perrin and Hohn 1994). In spinner dolphins, gestation and lactation extend for 10.5 months and one to two years, respectively (reviews by Perrin and Reilly 1984; Perrin and Gilpatrick 1994). Calving interval lasts about three years (reviews by Perrin and Reilly 1984; Perrin and Gilpatrick 1994). Spinner dolphins can live to at least 20 years (reviews by Perrin and Reilly 1984; Perrin and Gilpatrick 1994). A realistic rate of population increase might be between 2 and 6% for both pantropical spotted and spinner dolphins (Smith 1983). Gestation in striped dolphins lasts about 12 months (review by Perrin et al. 1994b). Calving interval has declined from four to three years in Japan (review by Perrin et al. 1994b). In the western Mediterranean Sea it averages four years, with a pregnancy rate of 25% (Calzada et al. 1996). Striped dolphins can live up to 57.5 years (review by Perrin et al. 1994b). Rate of population increase appears to be as low as 2% (Smith 1983). In Atlantic spotted dolphins, lactation can last up to five years (Herzing 1997). Average calving interval in Atlantic spotted dolphins averages 2.96 years with a range of one to five years (Herzing 1997). Females whose calves survive the first year have a mean calving interval of 3.56 years (Herzing 1997). Annual average birth rate is 0.08 (range= 0.06-0.14), average fecundity is 0.23 (range= 0.13-0.30), and average recruitment is 0.06, with a range 0.03 to 0.08 (Herzing 1997). Most females who lose a calf conceive the same or following year (Herzing 1997).

Breeding Areas

There are no apparent breeding areas. Pantropical spotted dolphins arre diffusely seasonal breeders, with two to three calving seasons in the spring, fall and possibly summer (review by Perrin and Hohn 1994). Breeding in spinner dolphins is seasonal, with geographic variations in the strength of seasonality (Barlow 1984). Analyses of back-projected birth dates revealed a broad pulse in reproduction for striped dolphins in the eastern Pacific extending from the fall through the spring (Perryman nd Lynn 1994).

Speed of Travel and Movements

Pantropical spotted dolphins, clymene dolphins, and striped dolphins are fast swimmers and often engage in aerial behavior (Jefferson et al. 1993). Spinner dolphins are one of the most aerial cetacean species (Norris and Dohl 1980; Norris et al. 1994). Top speeds of 39.7 km/h for 2 s have been recorded in pantropical spotted dolphins (Lang and Pryor 1966). However, this value may be an overestimate (Kooyman 1989). Radio-tagged individuals move at average speeds of about 4 to 19 km/h , with burst speeds close to 21 km/h (Leatherwood and Ljungblad 1979). In Hawaiian bays, spinner dolphins move at speeds ranging from 2.6 to 5.9 km/h (Norris et al. 1994). Mixed schools of pantropical spotted and spinner dolphins can move to speeds of more than 15 km/h (Au and Perryman 1982).

Pantropical spotted dolphins are able to swim long distances in a relatively short time, ranging from 9.25 to 164.6 km/day with an average of 100 km/day (Perrin et al. 1979). In another study, an individual travelled 100.5 km in 11 h (Leatherwood and Ljungblad 1979). Spinner dolphins travel less distances than pantropical spotted dolphins in a similar amount of time (review by Perrin and Gilpatrick 1994). Spinner dolphins usually spend the daytime hours resting in shallow bays near deep water and move offshore at dusk to feed (Norris and Dohl 1980; Norris et al. 1994). Some individuals, however, move slowly along the shore between successive nights (Norris et al. 1994). A satellite-tagged Atlantic spotted dolphin move an average 72 km per day (Davis et al. 1996).

Vocal Behavior

Dolphins of this genus produce vocalizations as low as 0.1 kHz and as high as 160 kHz, with dominant frequencies at 5-60 kHz, 40-50 kHz, and 130-140 kHz (Busnel et al. 1968; Caldwell and Caldwell 1971b; Caldwell MC et al. 1973; Watkins and Schevill 1974; Watkins 1980; Steiner 1981; Zanardelli et al. 1990; Mullin et al. 1994b; Norris et al. 1994; Wang Ding et al. 1995a; Au et al. 1998; reviews by Popper 1980; Ketten 1992; Richardson et al. 1995). Peak-to-peak source levels can be as high as 210 dB (re: 1uPa@1m) have been measured (Au et al. 1998).

Spinner dolphins produce several sounds: two types of burst pulse signals, echolocation clicks, whistles, and screams (Norris et al. 1994). Burst-pulse calls from spinner dolphins have been recorded up to ranges of 1.6 km (Norris et al. 1994). Free-ranging spinner dolphins use the ultrasonic range (up to 70-100 kHz) extensively for social signals (Lammers et al. 1998). Burst-pulse squeals and squawks are also produced by Atlantic spotted dolphins when excited (Caldwell and Caldwell 1971b). In spinner and Atlantic spotted dolphins, vocalizations are associated with underwater behaviors (Norris et al. 1994; Dudzinski 1996; Herzing 1996). In the Gulf of Mexico, free-ranging *Stenella* dolphins that are nocturnal feeders produce higher click trains at night than during the day (Stienessen and Evans 1998). It has been hypothesized that acoustic communication allows spinner dolphins to coordinate feeding movements of their large groups (Norris and Dohl 1980; Norris et al. 1994).

Whistles that could be signature whistles have been recorded in Atlantic spotted, pantropical spotted, and spinner dolphins (Caldwell MC et al. 1973; Steiner 1981; Wang Ding et al. 1995a). Directional echolocation-type clicks have been recorded from Atlantic spotted dolphins and spinner dolphins (Caldwell and Caldwell 1971b; Watkins and Schevill 1974; Norris et al. 1994). The echolocation-type signals of Atlantic spotted dolphins in Bahamas have bi-modal frequency spectra with a low-frequency peak between 40-50 kHz and a high-frequency peak between 130-140 kHz (Au et al. 1998). The low-frequency peak dominates when the signal source level (signal amplitude 1 m from the dolphin) is low and the high-frequency peak dominates when the source level is high (Au et al. 1998). The characteristics of echolocation signals of Atlantic spotted dolphins are similar to those of bottlenose dolphins (*Tursiops truncatus*) and false killer whales (*Pseudorca crassidens*) measured in open waters during controlled conditions (Au et al. 1998).

Hearing Range

Based on auditory brainstem responses, striped dolphins listen underwater to sounds equal or louder than 120 dB (re: 1uPa@1m) in the range of <10 kHz to >100 kHz (review by Popper 1980). The best underwater hearing of the species appears to be at 50-70 kHz, where the threshold level is 30-40 dB (re: 1uPa@1m; review by Popper 1980).

Known Impacts of Human Activities

In the northern Gulf of Mexico, repetitive signals generated by seismic exploration, classified as <200 Hz and >200 Hz, did not appear to have a negative impact on the large scale distribution or overall abundance of delphinids (Rankin and Evans 1998). Spinner dolphins reduced their use of a Hawaiian bay after the start of a noisy construction project for a water pipeline (Shallenberger 1978).

In the tropical Pacific, dolphins of this genus avoid approaching ships when at five to 12 km from them, and strongly avoid when at two to five km (Norris et al. 1978; Au and Perryman 1982; Hewitt 1985). It is probable that these dolphins have been sensitized by previous harassment during tuna seining (Norris et al. 1978; Pryor and Norris 1978). In the Gulf of Mexico, most dolphins of this genus approached survey vesels; however, striped dolphins showed avoidance towards the vessels (Würsig et al. 1998). Spinner dolphins dive in response to small aircraft circling overhead (Mullin et al. 1991; Würsig pers. comm. in Richardson et al. 1995). They have been injured or killed while attempting to bowride hydrofoils (Hudnall 1978).

ROUGH-TOOTHED DOLPHIN (*STENO BREDANENSIS*)

Summary

The rough-toothed dolphin (*Steno bredanensis*) is a poorly known, small dolphin. It is found in deep oceanic tropical to subtopical waters. They feed on fish and squid, yet their diving habits are unknown. This species produces sounds as low as 0.1 kHz; however, most sounds are concentrated at mid-frequencies.

The distribution of the rough-toothed dolphin distribution makes this species susceptible to LFA activity, but its vocalizations suggest that it is less vulnerable than other cetacean species. However, because rough-toothed dolphins have been studied in very few areas, it would be difficult to detect any negative impacts of LFA.

Protected Status

The rough-toothed dolphin is not federally listed under the U. S. Endangered Species/Marine Mammal Protection acts (kingfish.ssp.nmfs.gov/tmcintyr/spec_idx.html). This whale is listed as a data deficient species by the Cetacean Specialist Group of the International Union for the Conservation of Nature (www.wcmc.org.uk/data/database). Rough-toothed dolphins are taken in small numbers in drive fisheries in Japan, the Solomon Islands and Papua New Guinea, and in harpoon fisheries in Japan, Lesser Antilles and West Africa (Caldwell et al. 1971; Mitchell 1975; Perrin 1985; Anonymous 1989). A total of 23 individuals were captured in Japan between 1976 and 1981 (Nishiwaki and Uchida 1977; Miyazaki 1983). Rough-toothed dolphins are also taken incidentally in purse seines in the eastern tropical Pacific, 21 were estimated killed between 1971 and 1975 (Perrin and Walker 1975; Horwood 1981b), yet 36 died in a single net haul in 1982 (Wahlen et al. 1986). They are also incidentally taken in gillnet and driftnet fisheries in Sri Lanka, Brazil, the Central North Pacific, and probably in other areas (review by Miyazaki and Perrin 1994). More than 50 dolphins have been captured live for public display in Hawaii, the Mediterranean Sea, Madeira, and Japan (Miyazaki 1980a; Collet 1984).

Distribution

The rough-toothed dolphin is a tropical to subtopical species that inhabits deep oceanic waters from 45°S to 55°N, including a year-round presence in the Mediterranean Sea (review by Miyazaki and Perrin 1994). However, new records have extended the range of this species further south in the Atlantic, into Brazilian waters (Ott and Danilewicz 1996).

In the eastern tropical Pacific this species inhabits the Tropical Surface Water north of the equator, being absent in the coldest parts of the Peru and California currents (Wade and Gerrodette 1993; review by Miyazaki and Perrin 1994).

Abundance

Worldwide population is unknown.

A total of 145,900 rough-toothed dolphins (95% bootstrap CL= 89,400-256,800) have been estimated for the eastern tropical Pacific (Wade and Gerrodette 1993). Overall density values in the eastern tropical Pacific were estimated from Wade and Gerrodette (1993) as mean population size divided by study area, results are 0.008 whales/km^2; however, density values vary within the study area.

Diet and Foraging Behavior

Rough-toothed dolphins feed on fish and squid (Layne 1965; Clarke 1986; Shallenberger 1981). Although stomach contents from Hawaii included only nearshore fish species (Shallenberger 1981), it is considered that other, larger fishes may be taken in deeper water (Miyazaki and Perrin 1994). Cooperative food gathering has been reported (Smeenk and Richards 1995; Steiner 1995). In captivity, one individual consumed 59.5 kcal/kg/day (Van Dyke and Ridgway 1977).

Diving Behavior

Rough-toothed dolphins have been labeled as primarily a diving species (Norris et al. 1965; Norris and Evans 1967). Groups can stay submerged for as long as 15 min (Miyazaki and Perrin 1994). Based on rubbing of individuals against a hydrophone, rough-toothed dolphins can dive as deep as 70 m (Watkins et al. 1987b). A trained dolphin was able to dive easily to 30 m of depth (Norris et al. 1965).

Social Behavior

Rough-toothed dolphins are typically found in groups of 10-20 individuals, although groups of more than 100 dolphins have been recorded (Shallenberg 1981; Watkins et al. 1987b; Leatherwood et al. 1988a; Wade and Gerrodette 1993). In the eastern tropical Pacific, groups average 14.7 dolphins (Wade and Gerrodette 1993). In the North Pacific, mean group size is 40.0 individuals, and the largest group size is 53 dolphins (Nishiwaki 1975). Rough-toothed dolphins often associate with other small odontocetes (Perrin and Walker 1975).

Based on a sample of less than ten individuals per sex from Japan, the modal length of males is 1.07 times that of females, while their modal weight is 1.15 times that of females (Miyazaki 1980a). However, the asymptotic length is the same for males and females (Miyazaki 1980b). Based on 82 males and 94 females from different areas, the maximum length of males is 1.04 times that of females (review by Miyazaki and Perrin 1994). Epimeletic behavior has been reported in this species (Lodi 1992).

Reproduction and Population Parameters

In Japan, males reach sexual maturity at a mean length of 2.25 m and mean age of 14 years; females reach sexual maturity at a mean length of 2.10-2.20 m and mean age of 10 years (review by Miyazaki and Perrin 1994). Maximum age is estimated at 32 years (review by Miyazaki and Perrin 1994). A hybrid between this species and the bottlenose dolphin (*Tursiops truncatus)* was born in captivity in Hawaii (Dohl et al. 1974).

Breeding Areas

No data available.

Speed of Travel and Movements

Rough-toothed dolphins show variable travel speeds (review by Jefferson et al. 1993).

Vocal Behavior

Rough-toothed dolphins produce vocalizations as low as 0.1 kHz and as high as 200 kHz (reviews by Popper 1980; Miyazaki and Perrin 1994; Richardson et al. 1995). Clicks of this species are highly directional (Norris and Evans 1967). Clicks have a duration of 50-250 μs and peak energy at 25 kHz; whistles last 100-900 μs and have a maximum energy at 2-14 kHz and at 4-7 kHz (Busnel and Dziedzic 1966b in Richardson et al. 1995; Norris and Evans 1967; Norris 1969; Popper 1980). The same individuals can produce both broad-spectrum clicks and whistles at frequencies of 3-12 kHz (Watkins et al. 1987b).

Hearing Range

No data available.

Known Impacts of Human Activites

No data available.

BOTTLENOSE DOLPHIN (*TURSIOPS TRUNCATUS*)

Summary

The bottlenose dolphin (*Tursiops truncatus*) shows considerable variation along geographical and ecological lines. Although other species have been proposed for this genus, only *T. aduncus* (Ross 1977) appears to be gaining acceptance among scientists. Bottlenose dolphins are distributed worldwide in coastal and oceanic temperate, tropical, and subtropical waters. They feed on nearshore, epipelagic, and mesopelagic fish and squid. Although not regarded as deep divers, they can reach great depths. Bottlenose dolphins produce and hear sounds as low as 0.05 and 0.15 kHz in frequency, respectively.

Their distribution, diving potential, vocalizations, and hearing abilities make offshore bottlenose dolphins vulnerable to LFA activity. However, the lack of knowledge of this species in oceanic waters make is difficult to assess any negative consequenes of LFA activity on this species.

Protected Status

Although the bottlenose dolphin is not federally listed under the U. S. Endangered Species/Marine Mammal Protection acts, the western North Atlantic coastal stock(s) is listed as depleted (kingfish.ssp.nmfs.gov/tmcintyr/spec_idx.html). This species is listed as a data deficient species by the Cetacean Specialist Group of the International Union for the Conservation of Nature (www.wcmc.org.uk/data/database). Bottlenose dolphins are directly killed by harpoon, drive, gillnet, and purse seine fisheries (Miyazaki 1983; Kasuya 1985b; Bloch and Hoydal 1989; Van Waerebeek et al. 1990, 1997b; IWC 1992; Kishiro and Kasuya 1993; Romero et al. 1997). The largest direct kills occur in the Black Sea (reviews by Leatherwood et al. 1983a; Jefferson et al. 1993; Reeves and Leatherwood 1994). Bottlenose dolphins have also been shot as a nuisance to fishermen (Leatherwood et al. 1983a; Reynolds 1985). The species is incidentally taken in gillnets, anti-shark nets, shrimp trawls, and, in the eastern tropical Pacific, purse seiners (Chivers et al. 1997; reviews by Baird et al. 1993; Jefferson et al. 1993; Reeves and Leatherwood 1994). Incidental mortality by collisions with vessel propellers has also been recorded (Reynolds 1985; Fertl 1994). Live captures occur in USA, Hawaii, South Africa, Japan, México, Cuba, the Philippines, Bahamas, and the Mediterranean Sea (reviews by Leatherwood et al. 1983a; Jefferson et al. 1993). Trips that take humans to feed dolphins in the wild are conducted in USA and apparently in other countries as well.

Distribution

Bottlenose dolphins are found primarily in coastal and inshore regions of tropical and temperate waters of the world, from 50°S to 45°N, up to 60°N around the United Kingdom and northern Europe (reviews by Leatherwood et al. 1983a; Jefferson et al. 1993). However, they also inhabit some pelagic waters, such as the eastern tropical Pacific (Wade and Gerrodette 1993).

In the western Atlantic, bottlenose dolphins have been recorded from southern Greenland to Patagonia, including the Gulf of Mexico and Caribbean Sea. In the eastern Atlantic, they are found from southern Norway to the tip of South Africa, including the Mediterranean Sea. In the eastern Pacific, they have been recorded from Washington State to Chile, including the Gulf of California. In the western Pacific, bottlenose dolphins occur from northern Japan to Australia and New Zealand. They also inhabit the Indian Ocean from South Africa to Australia (reviews by Leatherwood and Reeves 1982; Leatherwood et al. 1983a; Baird et al. 1993; Jefferson et al. 1993).

Bottlenose dolphins occur in very diverse habitats. They can be found in rivers, coastal channels, waterbays, and protected bays (Gunter 1942; Irvine and Wells 1972; Shane 1980; Scott et al. 1990; Sudara and Mahakunlayanakul 1998). In Golfo San José, Argetina, they spend 92% of their time in waters less than 10 m deep (Würsig and Würsig 1979). In the north-central Gulf of Mexico, mean water depth bottlenose dolphin sightings was less than 400 m (Mullin et al. 1994a). This species regularly occurs over the continental shelf in the Gulf of Mexico (Jefferson and Schiro 1997). Bottlenose dolphins are also found around oceanic islands and in the open ocean (Scott and Chivers 1990; Acevedo 1996). Although they are more frequently found close to shore in the eastern tropical Pacific, they also occur throughout the open ocean (Wade and Gerrodette 1993). Seasonal movements have been reported in some populations (Shane 1980; Kenney 1990; Hashmi 1998).

In some areas, a coastal and an offshore form have been described based in morphology, blood chemistry, feeding habits, parasite loads, and genetic variability (Walker 1981; Duffield et al. 1983; Hersh and Duffield 1990; Mead and Potter 1990; Hoelzel et al. 1998a). In the western North Atlantic, offshore bottlenose dolphins of both sexes are significantly longer than inshore bottlenose dolphins (Hohn et al. 1998). Mitochondrial DNA data support the hypothesis that the sympatric inshore and offshore bottlenose dolphin populations in the western North Atlantic and the Gulf of Mexico are reproductively isolated (Curry et al. 1998). In the western North Atlantic, the coastal stock is defined as a single stock occurring from New Jersey to Florida; however, photoidentification data suggest that perhaps two groups with a low level of intermixing occur along the coast of North Carolina (Rittmaster and Thayer 1998). The offshore form of the bottlenose dolphin is found primarily between the 200 and 2,000 m isobaths, in two distinct stocks, Gulf of Mexico and western North Atlantic (Wells et al. 1998).

Abundance

There are no worldwide population estimates.

A total of 243,500 bottlenose dolphins (95% bootstrap CL= 190,900-409,900) have been estimated for the eastern tropical Pacific (Wade and Gerrodette 1993). Overall density values in the eastern tropical Pacific were estimated from Wade and Gerrodette (1993) as mean population size divided by study area, results are 0.013 dolphins/km^2; however, density values vary within the study area. Ship surveys give an estimate of 1,503 bottlenose dolphins (95% bootstrap CL= 499-3,819) in California (Barlow 1995). Estimated density was 0.022 dolphins/km^2 (Barlow 1995). A total of 168,792 bottlenose dolphins (95% log-normal CL= 102,001-279,045) have been estimated for the western North Pacific (Miyashita 1993). However, attraction to boat may have caused an upward bias on population estimates (Miyashita 1993). Overall density values in the western North Pacific were estimated from Miyashita (1993) as mean population size divided by study area, results are 0.044 dolphins/km^2; however, density values vary within the study area. A total of 6,900 ± 2,600 bottlenose dolphins have been estimated for the Black Sea (Sokolov et al. 1997). It is estimated that 451(CV= 36.5%) and 520 (CV= 56.3%) bottlenose dolphins are found in outer continental shelf and continental slope waters, respectively, of the northwestern Gulf of Mexico (Jefferson 1996). Seasonal averages from point estimates indicate that the northeastern US population of bottlenose dolphins contains between 10,000 and 13,000 individuals (Kenney 1990). A minimum estimate of 2,000 to 3,000 bottlenose dolphins has been made for Shark Bay, Australia (Preen et al. 1997).

Diet and Foraging Behavior

In South Africa, diets of inshore bottlenose dolphins are coastal squid and fishes, while offshore dolphins feed on mesopelagic and pelagic fishes found over the continental slope (Ross 1977; Cockcroft and Ross 1990; Sekiguchi 1994). Similar dietary differences have been reported in other areas (Walker 1981; Takemura 1986 in Sekiguchi 1994; Barros and Odell 1990; Mead and Potter 1990). However, in Sarasota Bay, USA, dolphins appear to be exclusively piscivorous, feeding on fishes that are primarily associated with seagrasses (Barros and Wells 1998). Differences in feeding habits between females and males have been reported in some areas (Barros and Odell 1990).

Feeding behavior is highly diverse and ranges from individual feeding on fish along exposed mudflats to group feeding on schooling fish in the open ocean, from feeding on fish buried in the sand to using sponges as a foraging tool, and from feeding in association with trawls to feeding in cooperation with fishermen (Hoese 1971; Bel'kovich et al. 1991; Acevedo-Gutiérrez 1997; Rossbach and Herzing 1997; Smolker et al. 1997; reviews by Würsig 1986; Shane 1990; Fertl and Leatherwood 1997).

Diving Behavior

The deepest dive recorded in a bottlenose dolphin is 535 m, reached by a trained individual (McSheehy 1981 in Ridgway 1986). The species apparently can dive for as long as ten min (Ridgway 1986). A free-ranging female in Tampa Bay, USA, spent an average of 87.1 (SE = 0.6)% of the time submerged, with a mean dive duration of 25.8 (SE = 0.5) s (Mate et al. 1995). During the early morning the animal spent more time at the surface, averaged shorter dives, and was submerged less than other times of day (Mate et al. 1995).

Social Behavior

Bottlenose dolphins are found in groups of diverse size. From 32 studies in coastal lagoons (n=8), protected shores (n=4), bays (n=11), open coasts (n=6), islands (n=1), and open ocean (n=2), in which at least 30 sightings were made in each area and group size was defined as total number of dolphins on sight, the average number of dolphins per group ranges from 3.1 to 140.3, with maximum values between 18 and 5,000 individuals; the median value is 10.7 dolphins. In Galveston, USA, groups average 3.1 dolphins, with a maximum of 27 individuals (Jones 1988). In Golfo Dulce, Costa Rica, mean group size is 5.8 individuals, and the largest group size is 25 dolphins (Acevedo-Gutiérrez and Burkhart 1998). In eastern Australia, mean group size is 10.2 individuals, and the largest group size is 80 dolphins (Lear and Bryden 1980). At Isla del Coco, Costa Rica, groups average 10.8 dolphins, with a maximum of 70 individuals (Acevedo-Gutiérrez 1997). In the Gulf of Guayaquil, Ecuador, mean group size is 16.2 individuals, and the largest group size is 61 dolphins (Félix 1994). In the eastern tropical Pacific, groups average 57.0 dolphins, with a maximum of 5,000 individuals (Scott and Chivers 1990). In the western North Pacific, mean group size is 66.9 individuals, and the largest group size is 500 dolphins (Miyashita 1993). In South Africa, mean group size is 140.3 individuals, and the largest group size is 1,000 dolphins (Saayman and Tayler 1973b). This species commonly associates with other cetaceans (review by Baird et al. 1993).

Females tend to be smaller than males. In Florida, the asymptotic length of males is 1.05 times that of females, while their asymptotic weight is 1.39 that of females (Read et al. 1991). In Sarasota Bay, it has been suggested that females may mate with many males and a promiscuous mating system has been proposed (Wells et al. 1987; Scott et al. 1990).

Bottlenose dolphins inhabiting near-shore areas exhibit fission-fusion grouping patterns in which individuals move in small schools that change in composition (Würsig 1978a,b; Wells et al. 1987; Smolker et al. 1992). A short-term study in Bahamas indicated that associations between offshore dolphins are more stable than those between near-shore dolphins (Rossbach and Herzing 1998). In Shark Bay, Australia, male bottlenose dolphins exhibit three types of alliance formation (Connor et al. 1992; Connor et al. 1996; Connor et al. 1998b). First, males form strong bonds with one or two other males that may be stable for over ten years; males in these pairs and trios cooperate to form aggressively maintained consortships with individual females, while producing pop vocalizations during consortships (Connor et al. 1992; Connor and Smolker 1996). Second, each alliance form moderately strong bonds with one or two other alliances, usually with only one, and cooperate to take or defend females from other alliances (Connor et al. 1992). Third, some males may form a large alliance that at times splits into pairs and trios that are very unstable, but that are always formed with males from the large alliance (Connor et al. 1998b). Captive studies indicate high rates of male antagonism, male dominance over females (even when males are physically smaller), and greater stability of dominance relationships among females (Samuels and Gifford 1997). In Scotland, recent evidence suggests that bottlenose dolphins engage in infanticidal behavior (Patterson et al. 1998).

Reproduction and Population Parameters

It is likely that estimates of reproductive parameters are only applicable to certain populations (review by Baird et al. 1993). Sexual maturity is attained at an average age of 11 years in males and 12 years in females (Perrin and Reilly 1984; Kasuya 1985b). However, females can become sexually mature as early as 3.5 and as late as 14 years of age, while males do so as early as nine and as late as 20 years of age (Perrin and Reilly 1984; Kasuya 1985b). Estimates of gestation period range from 11.5 to 14 months (Perrin and Reilly 1984; Kasuya 1985b). Calving interval is estimated at 1.3 to two years (Perrin and Reilly 1984; Ozharovskaya 1990). Lactation lasts on average 18 to 20 months, with a maximum of 38 months (Perrin and Reilly 1984). Calves remain with their mothers for three to six years, sometimes longer (Wells et al. 1987; Scott et al. 1990; Smolker et al. 1992; Bearzi et al. 1997). Babysitting, in which nearby adults remain with a calf as its mother forages, has been recorded (Scott et al. 1990). However, data from Shark Bay suggest that escorts do not benefit mothers by allowing them to forage (Mann and Smuts 1998). Inexperienced females that never raised an infant are more likely to escort newborns than were experienced females, supporting the hypothesis that alloparental care is a learning-to-parent strategy (Mann and Smuts 1998). Captive studies suggest that adult individuals other than the mother also have an influential role in the development of social interactions and future choices of bottlenose dolphin calves (Bojanowski 1998; Fripp et al. 1998). Bottlenose dolphins in the wild can live to at least 46 years of age (Scott et al. 1990).

Breeding Areas

There are no apparent breeding areas. Calving is known to occur year-round; however, peaks appear to occur from early spring to early fall (Harrison et al. 1969; Ozharovskaya 1990; Scott et al. 1990). Hybrids with other odontocetes are known in captivity and in the wild (Fraser 1940; Shallenberger and Kang 1977; Nishiwaki and Tobayama 1982; Shimura et al. 1986; Herzing 1990).

Speed of Travel and Movements

Sustained swimming speeds of bottlenose dolphins vary from four to 20 km/h (Lockyer and Morris 1987). Routine speeds vary between 6.37 and 11.48 km/h, and speeds as high as 29.88 km/h have been recorded for 7.5 s (Lang and Norris 1966; Lang 1975). Bottlenose dolphins change from free swimming to wave-riding between 7.56 and 13.68 km/h (Williams et al. 1992). This change corresponds to a shift from a routine to a non-routine activity level, as indicated by several physiological variables, at a speed of about 7.92 km/h (Williams et al. 1993).

In some areas, coastal bottlenose dolphins show high site fidelity, inhabiting limited home ranges, with males having larger home ranges than females (Wells et al. 1987; Scott et al. 1990). However, dolphins in other coastal areas do not show high site fidelity (Ortega-Ortiz and Delgado-Estrella 1998). Yet in other coastal waters, there is a mix of resident and transient individuals (Félix 1997; Sayigh et al. 1998). In some open areas, such as the coastal waters of Perth, Australia, and southern California individuals may cover extensive ranges (Wells et al. 1990; Waples and Gales 1998). A male offshore bottlenose dolphin from the North Atlantic moved 3,860 km offshore in 42 days, in waters more than 5,000 m deep and against the equatorial current (Wells et al. 1998). A similar male moved 2,050 km in 41 days, nortward to off Cape Hatteras, North Carolina (Wells et al. 1998).

Vocal Behavior

Bottlenose dolphins produce vocalizations as low as 0.05 kHz and as high as 150 kHz, with dominant frequencies at 0.3-14.5 kHz, 25-30 kHz, and 95-130 kHz (McCowan and Reiss 1995a; Schultz et al. 1995; reviews by Popper 1980; Richardson et al. 1995). The maximum peak to peak source level (re: 1uPa@1m) of bottlenose dolphin sounds is 228 dB (review by Richardson et al. 1995).

Sonar clicks of bottlenose dolphins are broad band, ranging in frequency from few kHz to beyond 150 kHz, with a 3-dB bandwidth of 30-60 kHz (Au 1993). Click sounds are highly directional, both in the intensity and frequency dimensions, in a beam directed in front of the animal along its longitudinal axis (Amundin 1997). Pulses propagate in a relatively narrow beam, the average 3-dB beam width is approximately 10° in both the vertical and the horizontal plane (Au 1993). A recent review of echolocation in dolphins is presented by Au (1997). The frequency spectra of echolocation signals are dependent on the output intensity of the signals and not on any fine tuning by the animals (review by Au 1997). When the output intensity is low, the center frequency of the click tends to be low; as the output intensity increases, the center frequency also tends to increase (review by Au 1997). Echo-locating dolphins can detect targets at ranges of approximately 100 plus meters, depending on the size of the targets (review by Au 1997). Target discrimination experiments have shown that dolphins can discriminate the shape, size, material composition and internal structure of targets from the echoes (review by Au 1997). Target discrimination experiments on shells suggest that processing of echoes by dolphins takes advantage of certain fundamental resonance principles to show which echo features contain information about the size, shape, wall thickness, and material composition of both the object and its filler substance (Gaunaurd et al. 1998). The broadband, short duration properties of the signal allow the echoes to have high temporal resolution, so that within the structure of the echoes a considerable amount of information on the properties of the target can be conveyed (review by Au 1997). Although the performance of the angular localization of the echolocation system of bottlenose dolphins may be limited by noise, in some environments it might be constrained by signal fluctuations (Dobbins 1997). In the first case, there will be a failure to detect targets; in the second case, detection will not be inhibited but erroneous localization and degradation of angular resolution will occur (Dobbins 1997). It has been reported that weak sounds suppressed the brain responses to much stronger sounds in bottlenose dolphins (Popov et al. 1997). This phenomenon prevents weak sounds from being masked by stronger ones and may help a dolphin to perceive weaker echo-signals in the background of stronger emitted pulses (Popov et al. 1997). Dolphin signals are designed to be tolerant of Doppler effects (review by Au 1997). Echolocation clicks of a wild, solitary bottlenose dolphin significantly different among four categories of its feeding behavior: foraging search, target detection, target interception, and capture phase (Lucke and Goodson 1997).

Bottlenose dolphins also produce whistles, the most widely known being the so-called signature whistle. Signature whistles are stereotyped, have a narrow-band sound, frequency modulated between 4 and 20 kHz, with a duration of 0.1-3.6 s, and a source level of 125-140 dB re 1uPa @ 1 m (Caldwell et al. 1990). Each individual has its own fixed, unique FM pattern, or contour, composed of similar, repetitive elements called loops (Caldwell et al. 1990). Signature whistles appear to be stimulated when individuals are isolated or separated (Caldwell et al. 1990). There is a sex difference in the tendency of calves to produce whistles similar to or different from those of their mothers. Most female calves produce whistles that are different from those of their mothers, whereas male calves are more likely to produce whistles that are similar to those of their mothers (Sayigh et al. 1995). Not only identity but also context-related information is available in the whistles of a bottlenosed dolphin (Janik et al. 1994). A captive bottlenose dolphin was able to discriminate among the presumed signature whistles of six free-ranging individuals (Harley 1998). Recent studies indicate that whistles other than signature whistles can predominate in some contexts, particularly during reunion between individuals (Tyack 1986; Smolker et al. 1993; McCowan and Reiss 1995b; Veit 1998; Janik and Slater 1998). The ability to mimic the whistles of other individuals has been reported in both captive and free-ranging bottlenose dolphins (Tyack 1986; Janik 1995). One possible role for whistle-matching is to allow individuals to learn of the location of others by producing a copy of an individual’s whistle and listening for a response (Connor et al. 1998a).

Differences in whistle structure have been identified between several bottlenose dolphin populations (Wang Ding et al. 1995b; Bazúa-Durán 1998). The differences become larger as distance between populations increases (Wang Ding et al. 1995b). Data from captive females suggest that social familiarity influences whistle acoustic structure and may be one mechanism behind regional dialects in bottlenose dolphins (McCowan et al. 1998).

Low-frequency sounds of bottlenose dolphins are produced during social contexts, typically at frequencies less than 1 kHz (Schultz et al. 1995). It is unknown whether the sounds are affiliative or agonistic (Schultz et al. 1995). In captivity, dolphins produce low-frequency sounds called thunks that have a harmonic structure with an energy peak between 273 and 350 Hz, and range from 129 to 5,556 Hz in frequency and from 21 to 171 ms in duration (McCowan and Reiss 1995a). They appear to function as aggressive contact vocalizations produced by mothers and other adult females toward infants in order to maintain infant proximity (McCowan and Reiss 1995a).

Level of aggressive response between captive dolphins increases with the production and subsequent duration of burst-pulse emissions (Overstrom 1983). It has been suggested that such escalation of aggression is related to auditory or tactile discomfort from the reception of intense burst-pulse emissions (Overstrom 1983).

Although clicks, whistles, and pulsed sounds are produced in the nasal region, bottlenose dolphins can also produce other sounds by breaching, slapping the water surface with their flukes and flippers, hitting fish, clapping together of the jaws or by means of cavitation in connection with the fluke beats (Marten et al. 1988; Smolker and Richards 1988). All these sounds have a low frequency peak (0.1-5.6 kHz) and a duration of 9-300 msec (Marten et al. 1988).

Hearing Range

Bottlenose dolphins listen underwater to sounds equal or softer than 120 dB (re: 1 µPa @ 1 m) in the range of 0.15 kHz to 135 kHz (Johnson 1967; Ljungblad et al 1982b). At a frequency of 1 kHz, botlenose dolphins listen to pure tones that have an intensity of at least 90-100 dB re: 1 µPa @ 1 m (Johnson 1967). The best underwater hearing of the species occurs at 15 kHz, where the threshold level is 42-52 dB re: 1 µPa @ 1 m (Sauerland and Dehnhardt 1998). Some old dolphins have impaired high-frequency hearing or are deaf (Ridgway and Carder 1993, 1997). However, the cause of hearing loss is unknown.

Bottlenose dolphins and humans have the best frequency discrimination abilities of all marine and terrestrial mammals that have been tested behaviorally (Fay 1988). At low frequencies (2-16 kHz) the frequency-resolving-power values of bottlenose dolphins are close to those of humans, at high frequencies (90-128 kHz) these values are several times higher, indicating very sharp frequency tuning (Tarakanov et al. 1996). Tone pulses longer than 0.1 to 0.2 s elicit similar hearing thresholds regardless of pulse duration (Johnson 1968a). In the case of shorter pulses, hearing thresholds increase as pulse duration decreases (Johnson 1968a).

A pure-tone signal at 6 kHz had to exceed spectrum level noise by 22 dB to be detected, while a 70-kHz tone had to exceed spectrum level noise by about 40 dB (Johnson 1968b). Bottlenose dolphins also have good sound location abilities, with their hearing being most sensitive when sounds arrive from the front (review by Richardson et al. 1995).

Known Impacts of Human Activities

Bottlenose dolphins appear to tolerate boat traffic, at least in some areas. During a seven-month study in the United Kingdom, the movement of a fast speed ferry boat with sound levels of 102-138 dB (re: 1 µPa @ 1 m) at a frequency 500 Hz did not produce a significant change in the timing or frequency of bottlenose dolphin sightings compared to previous years (Browning et al. 1997). In the Sado estuary, Portugal, underwater noise level, rated on a subjective scale, did not appear to influence acoustic emissions of bottlenose dolphins (dos Santos and Almada 1998). In México, bottlenose dolphins exposed to frequent boat traffic show little reaction unless a boat came within approximately 5 m (Acevedo 1991). However, surfacing patterns of dolphins in a population that have been exposed to boats for a long time are altered by an approaching boat in Scotland (Janik and Thompson 1996). In Florida dolphins are often seen near small boats; however, individuals that have been captured fled when the capture boat was more than 400 m away (Irvine et al. 1981).

Free-ranging bottlenose dolphins apparently detect but do not consistently avoid entering slick oil, and may not detect sheen oil, thereby increasing their vulnerability to potentially harmful exposure to oil chemicals (Smultea and Würsig 1995).

RISSO’S DOLPHIN (*GRAMPUS GRISEUS*)

Summary

Risso’s dolphins (*Grampus griseus*) are medium-sized delphinids that inhabit deep oceanic and continental slope waters from the tropics through the temperate regions. They feed mostly on squid. Based on their distribution and feeding habits, they may be at least mid-water divers. This species produce sounds as low as 0.1 kHz and its best underwater hearing occurs at around 8 kHz.

Its distribution, potential diving habits, and vocalizations make this species susceptible to LFA activity. On the other hand, its size and underwater hearing make it less vulnerable to LFA than other cetacean species. However, because Risso’s dolphins have been studied in very few areas, it would be difficult to detect any negative impacts of LFA.

Protected Status

The Risso’s dolphin is not federally listed under the U. S. Endangered Species/Marine Mammal Protection acts (kingfish.ssp.nmfs.gov/tmcintyr/spec_idx.html). This dolphin is listed as a data deficient species by the Cetacean Specialist Group of the International Union for the Conservation of Nature (www.wcmc.org.uk/data/database). This species has been taken by small whale fisheries in Europe, Sri Lanka, the Lesser Antilles, USA, Japan, Indonesia, the Indo-Australian archipelago, the Philippines, the Solomon Islands, and China (Caldwell et al. 1971; Duguy and Hussenot 1982; IWC 1984b; Reeves and Leatherwood 1984; Kishiro and Kasuya 1993; Aragones 1994). They have been taken around Iki Island, Japan, to reduce competition with fisheries (Kasuya 1985b). Risso’s dolphins are also caught incidentally in fishing nets (review by Baird and Stacey 1991).

Distribution

Risso’s dolphins are widely distributed, they inhabit deep oceanic and continental slope waters from the tropics through the temperate regions, from 55°S to 60°N (Leatherwood et al. 1980; review by Jefferson et al. 1993).

In the western Atlantic, they occur from Newfoundland to Argentina, including the Gulf of Mexico (Mitchell 1975; Goodall and Galeazzi 1987; Mullin et al. 1994a). In the eastern Atlantic, they have been reported from the Orkney Islands to South Africa, including the Mediterranean Sea (review by Baird and Stacey 1991). In the eastern Pacific, they are found from the Gulf of Alaska to central Chile (Aguayo 1975; Braham 1983). In the western Pacific, they are found from the Kurile Islands to New Zealand (Mitchell 1975). They are also found throughout the Indian Ocean, including Australia (review by Baird and Stacey 1991)

In the northwestern Atlantic, the average depth over which Risso’s dolphins are sighted is 1,092 m, with a range of 20 to 4,938 m (CETAP 1982). In the north-central Gulf of Mexico, mean water depths of sightings of Risso's dolphins are between 400 and 600 m (Mullin et al. 1994a). In the same area, they prefer to utilize the steep sections of the upper continental slope, perhaps in relation to oceanographic mechanisms that may concentrate prey (Baumgartner 1997). Around Scotland, particular habitats are favored on a seasonal basis, offshore and deep waters between May and July, nearshore waters or coastal bays in August and September (Atkinson et al. 1998).

In the north-central Gulf of Mexico, Risso's dolphins are the most frequently encountered species (Mullin et al. 1994a). In the northwestern Atlantic, they are the fifth most commonly sighted small whale, being less common in waters west of 70°W (CETAP 1982). The U. S. continental shelf is considered a high-use area (Hain et al. 1981; Kenney and Winn 1986), and in the eastern tropical Pacific they appear to concentrate in the shelf waters off Mexico and Guatemala, in the Gulf of Panama, and in the Peru Current (Polachek 1987; Wade and Gerrodette 1993). Along the California coast, Risso's dolphins are more abundant in the winter (Forney and Barlow 1998).

This species has been recorded in waters with surface temperatures ranging from 4.5 to 28°C (review by Baird and Stacey 1991). However, in the northwestern Atlantic sightings occurred in water temperatures between 21.3° and 25.1°C, while in the Pacific sightings have been reported in water temperatures between 10° and 28° C (Leatherwood et al. 1980; CETAP 1982)

Long-term fluctuations in the geographical ranges of Risso's dolphins may occur due to long-term environmental changes (Leatherwood et al. 1980, 1987). In the north Pacific, increases in number of sightings during summer are correlated to the warming of surface waters (Leatherwood et al. 1980). In the northwestern Atlantic, increases in number of sightings and individuals also occur during the summer (CETAP 1982). Seasonal migrations have been suggested for Japan and the North Atlantic (Kasuya 1971; Mitchell 1975). Seasonal variation in relative abundance has not been recorded in the eastern tropical Pacific or in Monterey Bay, USA (Kruse 1987; Polachek 1987).

Abundance

Worldwide population is unknown.

In the northwestern Atlantic abundance varies with season, from 3,543 dolphins (± 4350, 95% CL) in the summer to 364 dolphins (± 1,254, 95% CL) in the winter (Hain et al. 1985). A total of 175,800 Risso's dolphins (95% bootstrap CL= 90,000-375,400) have been estimated for the eastern tropical Pacific (Wade and Gerrodette 1993). Overall density values in the eastern tropical Pacific were estimated from Wade and Gerrodette (1993) as mean population size divided by study area, results are 0.009 whales/km^2; however, density values vary within the study area. Ship surveys give an estimate of 8,496 Risso's dolphins (95% bootstrap CL= 4,236-21,676) in California (Barlow 1995). Estimated density was 0.122 dolphins/km^2 (Barlow 1995). A total of 83,289 (95% log-normal CL= 58,764-118,049) Risso's dolphins have been estimated for the northwestern Pacific (Miyashita 1993). Based on this data, overall density values in the northwestern Pacific were estimated as mean population size divided by study area, results are 0.023 dolphins/km^2; however, density values vary within the study area.

Diet and Foraging Behavior

Risso's dolphins feed mostly on cephalopods and, sometimes, small fish (Mitchell 1975; Cockcroft et al. 1993; González et al. 1994). Squid-beak scars may explain some of the scratches found on the bodies of these cetaceans (Leatherwood et al. 1988a). In addition, it has been proposed that some of these scars are intraspecific and that they act as an indicator of male quality during aggressive interactions to avoid costly and dangerous fights (MacLeod 1998). Diversity of prey species differs for males and females and also between dolphin size classes, suggesting a partitioning of food resources between sub-groups (Cockcroft et al. 1993). Risso's dolphins probably feed off South Africa in the Agulhas current in coastal waters where the continental shelf is narrow (Cockcroft et al. 1993).

Diving Behavior

No data available on diving depths.

Social Behavior

In general, groups of Risso's dolphins average between 6 and 63 individuals. In the northeast Atlantic, groups average 6.3 dolphins, with a maximum of 20 individuals (McBrearty et al. 1986). In the northern Indian Ocean, mean group size is 8.7 individuals, and the largest group size is 100 dolphins (Alling 1986). In the eastern tropical Pacific, groups average 11.8 dolphins (Wade and Gerrodette 1993). In the western Northh Atlantic, mean group size is 17.2 individuals, and the largest group size is 400 dolphins (CETAP 1982). In the western North Pacific, mean group size is 32.6 individuals, and the largest group size is 200 dolphins (Miyashita 1993). Off the California coast, mean group size is 63.0 individuals, and the largest group size is 500 dolphins (Kruse 1989). Apparently the largest group size was observed off Washington State, USA, numbering more than 2,000 dolphins (Braham 1983).

Risso's dolphins commonly associate with other species of cetaceans (Würsig and Würsig 1980; CETAP 1982; Polachek 1987). However, aggressive interactions with short-finned pilot whales (*Globicephala macrorhynchus*) have been observed around the Channel Islands, USA (Shane 1995).

In Scotland, groups are typically comprised of mixed ages and sex; however, some groups include only subadults/juveniles or females with calves (Atkinson et al. 1998). Based on a sample of less than ten individuals per sex from Tierra del Fuego, the mean length of males is 1.02 times that of females, while their mean weight is 2.99 times that of females (Goodall and Schiavini 1993). In Monterey Bay, Risso's dolphins appear to have a cohesive social organization in which individuals stay together for extended periods of time (Kruse 1989). In Scotland, long-term individual affiliations may exist, along with fluid group structures (Atkinson et al. 1998).

Reproduction and Population Parameters

Risso's dolphins apparently become mature at approximately three meters in length (Leatherwood et al. 1988a). Based on a group driven ashore in Japan, gestation may last 13-14 months (Kasuya 1985b). From the same group, gross reproductive rate was estimated at 6-7% (Kasuya 1985b). Individuals are believed to live at least 20 years (Leatherwood et al. 1988a).

Breeding Areas

There are no apparent breeding areas. Calving occurs throughout the year, with some differences between regions (Baird and Stacey 1991). It has been suggested that calving occurs in winter in Russia (Tomilin 1957). Based on sightings of the smallest calves, calving may peak in November in Monterey Bay (Kruse 1987). In the northwestern Atlantic, calving appears to occur throughout the year (review by Baird and Stacey 1991).

Hybrids between this species and the bottlenose dolphin (*Tursiops truncatus*) have been recorded in captivity and in the wild (Fraser 1940; Leatherwood et al. 1983a).

Speed of Travel and Movements

Risso's dolphins are often seen surfacing slowly, although they can be energetic and acrobatic (Leatherwood et al. 1988a; Jefferson et al. 1993).

Vocal Behavior

Risso's dolphins produce whistles, pulse bursts and echolocation-type clicks (Watkins 1967; Caldwell et al. 1969; Au 1993). Vocalizations are as low as 0.1 kHz and as high as 65 kHz, with dominant frequencies at two to five kHz and at 65 kHz (Watkins 1967; Au 1993). The maximum peak to peak source level (re: 1 μPa @ 1 m) of Risso's dolphin sounds is about 120 dB (Au 1993).

Hearing Range

Risso's dolphins hear underwater sounds equal or less than 120 dB (re: 1 μPa @ 1 m) in the range of 1.5 kHz to 100 kHz (Nachtigall et al. 1995). At a frequency of 1 kHz, they listen to pure tones that have an intensity of more than 120 dB re: 1 μPa @ 1 m Nachtigall et al. 1995). Based on the audiogram curve, the best underwater hearing of the species appears to occur at approximately 8 kHz, where the threshold level is close to 64 dB (re: 1uPa@1m).

Tests using the ATOC 75 Hz signal show that thresholds for a one second signal exceeded 140dB re: 1 μPa @ 1 m, indicating that the 195 dB ATOC signal would only be heard by Risso's whales if they were directly above and within 100m of the sound source (Au et al. 1997; Nachtigall et al. 1998).

Known Impacts of Human Activities

Data on reaction of Risso's dolphins to vessels is contradictory, in some instances they are attacted to ships, in others they avoid them altogether (review by Baird and Stacey 1991). Off New Jersey, this species has been observed within 18 km off drillings, with relative abundance being similar with and without rigs (Sorensent et al. 1984).

PYGMY KILLER WHALE (*FERESA ATTENUATA*)

Summary

The pygmy killer whale (*Feresa attenuata*) is a poorly known, small odontocete. They inhabit oceanic tropical and subtropical waters around the world. They feed mostly on squid and fish; however, their feeding habits are unknown. Almost nothing is known about sound production in this species.

The distribution of pygmy killer whales make them susceptible to LFA activity. Because pygmy killer whales are poorly known, it would be difficult to detect any negative impacts of LFA.

Protected Status

The pygmy killer whale is not federally listed under the U. S. Endangered Species/Marine Mammal Protection acts (kingfish.ssp.nmfs.gov/tmcintyr/spec_idx.html). The Cetacean Specialist Group of the International Union for the Conservation of Nature (www.wcmc.org.uk/data/database) lists this whale as a data deficient species. Individuals are directly taken in the Lesser Antilles and in Sri Lanka (Caldwell and Caldwell 1971c; Leatherwood and Reeves 1989; review by Ross and Leatherwood 1994). Incidental catches are known in fisheries in Sri Lanka and in other areas (Leatherwood and Reeves 1989; review by Jefferson et al. 1993). Captured animals have been held in Japan and Hawaii (Nishiwaki et al. 1965; Pryor et al. 1965).

Distribution

Pygmy killer whales inhabit oceanic tropical and subtropical waters around the world, from about 40°S to 40° N (reviews by Caldwell and Caldwell 1971, 1975b; Ross and Leatherwood 1994).

This species is frequently sighted in the Hawaiian islands (Leatherwood et al. 1988). Based on the number of whales incidentally caught in fisheries (Alling 1986; Leatherwood and Reeves 1989), pygmy killer whales are considered common in Sri Lanka (Ross and Leatherwood 1994). The species appears to be present year-round in the Lesser Antilles and in Sri Lanka (Caldwell and Caldwell 1975b; Leatherwood and Reeves 1989).

This is considered primarily a species of tropical waters (Ross and Leatherwood 1994). Most records outside the tropics are associated with strong, warm western boundary currents (Ross and Leatherwood 1994). Records from the cold-water coasts of southern Africa and Perú may have originated in nearby warm waters (Caldwell and Caldwell 1971; Ross 1984; Van Waerebeek and Reyes 1988). In the eastern tropical Pacific, this species was more frequently found close to the coast in the warmest water (Wade and Gerrodette 1993).

Abundance

Worldwide population is unknown.

A total of 38,900 pygmy killer whales (95% bootstrap CL= 11,500-109,500) have been estimated for the eastern tropical Pacific (Wade and Gerrodette 1993). Overall density values in the eastern tropical Pacific were estimated from Wade and Gerrodette (1993) as 0.002 whales/km^2; however, density values vary within the study area.

Diet and Foraging Behavior

Pygmy killer whales primarily eat cephalopods and small fish (Ross 1984; Leatherwood and Reeves 1989). But also attack other dolphins during tuna fishery interactions in the eastern tropical Pacific (Perryman and Foster 1980). Feeding rates in captivity range from 5.4 kg/day of mackerel and squid to 8 kg/day of sardines, squid, saury, and horse mackerel (Pryor et al. 1965; Nishiwaki 1966b)

Diving Behavior

An adult captive male averaged 3.9 breaths/min, with a mean time underwater of 25.6 s (Nishiwaki et al. 1965).

Social Behavior

Groups generally contain less than 15 whales (review by Ross and Leatherwood 1994). In Sri Lanka and Hawaii, groups may reach 120 or a few hundred individuals, respectively (Leatherwood et al. 1984b, 1988a). In the eastern tropical Pacific, groups average 27.9 dolphins, with a maximum of 70 individuals (Wade and Gerrodette 1993). In Hawaii, pygmy killer whales have been observed in association with other odontocetes (review by Ross and Leatherwood 1994).

Limited data indicate no difference in body length between males and females (review by Ross and Leatherwood 1994). Based on samples from different regions, the maximum length of males is 1.06 times that of females (review by Ross and Leatherwood 1994). Based on less than ten individuals per sex and on samples from different regions, the weight of males, estimated from minimum weight-length curves, is 1.18 times that of females (review by Ross and Leatherwood 1994).

Reproduction and Population Parameters

The minimum length of sexually mature male and females is 2.07 m (review by Ross and Leatherwodd 1994).

Breeding Areas

There are no apparent breeding areas. Based on fetal and neonatal growth rates of other odontocetes of equal size, it is considered that most calves are born in the summer months (Ross and Leatherwood 1994).

Speed of Travel and Movements

In comparison with the melon-headed whale (*Peponocephala electra*), which is similar in size, the pygmy killer whale is a slow and lethargic species (Jefferson et al. 1993). However, they also engage in aerial behavior (Ross and Leatherwood 1994).

Vocal Behavior

Sounds of pygmy killer whales have been described as growls and blats (Pryor et al. 1965).

Hearing Range

No data available.

Known Impacts of Human Activities

No data available.

MELON-HEADED WHALE (*PEPONOCEPHALA ELECTRA*)

Summary

The melon-headed whale (*Peponocephala electra*) is a poorly known, small odontocete. They inhabit deep oceanic tropical and subtropical waters around the world. Melon-headed whales feed mostly on mesopelagic fishes and mesopelagic squid. Based on their distribution and feeding habits, they may be deep divers. This species is very gregarious and produces sounds in the mid-frequency range.

Its distribution and diving habits make this species susceptible to LFA activity. However, the frequency of its vocalizations suggests that it is less vulnerable to LFA than other cetacean species. Because this is a poorly known species, it would be difficult to detect any negative impacts of LFA.

Protected Status

The melon-headed whale is not federally listed under the U. S. Endangered Species/Marine Mammal Protection acts (kingfish.ssp.nmfs.gov/tmcintyr/spec_idx.html). This whale is listed as a lower risk/least concern species by the Cetacean Specialist Group of the International Union for the Conservation of Nature (www.wcmc.org.uk/data/database). Drive fisheries have captured this species in small numbers in Japan and, once, in Hawaii (Nishiwaki and Norris 1966; Kasuya et al. 1984; review by Jefferson and Barros 1997). Harpoon fisheries have taken melon-headed whales in the Lesser Antilles, Cape Verde Islands, Indonesia, the Philippines, and Sri Lanka (Caldwell et al. 1976; Leatherwood and Reeves 1989; Barnes 1991; Leatherwood et al. 1992; Aragones 1994; Dolar et al. 1994; Reiner et al. 1996). Less than 10 individuals have been taken for scientific research (review by Jefferson and Barros 1997). Live captures have occurred in the Philippines, Hawaii, and Japan (Shallenberger 1981; Hammond and Leatherwood 1984; Kasuya et al. 1984). This species is taken in small numbers in purse seines in the eastern tropical Pacific, in gillnets in Sri Lanka, and in drifnets in the Phillipines (Perrin 1976; Leatherwood and Reeves 1989; Dolar 1994).

Distribution

Melon-headed whales inhabit deep oceanic tropical and subtropical waters around the world, from 35°S to 40° N; however, most records are from 20°S to 20°N (review by Jefferson and Barros 1997).

Melon-headed whales appear to be present in most areas throughout their range (Jefferson and Barros 1997). In the eastern tropical Pacific, they occur mostly in waters characterized as equatorial, although they are not restricted to such waters (Wade and Gerrodette 1993). Although an oceanic species, they occur close to shore in some areas where the water drops off quickly, such as the Philippines (Leatherwood et al. 1992). This is species is considered rare in Japanese waters (Miyazaki 1980a). Seasonal movements have not been studied (Jefferson and Barros 1997).

Abundance

Worldwide abundance is unknown

A total of 45,400 melon-headed whales (95% bootsrap CL= 34,200-110,300) have been estimated for the eastern tropical Pacific (Wade and Gerrodette 1993). Overall density values in the eastern tropical Pacific were estimated from Wade and Gerrodette (1993) as 0.002 whales/km^2; however, density values vary within the study area. Almost 2,000 whales (CV= 0.34) have been estimated in the northwestern Gulf of Mexico (Davis and Fargion 1996). Density in the Gulf of Mexico is relatively low; this species represented <1% of cetacean groups sighted during deep-water surveys (Mullin et al. 1994a).

Diet and Feeding Behavior

Melon-headed whales feed mostly on mesopelagic fishes and mesopelagic squid (review by Jefferson and Barros 1997). Since prey species are found down to 1,500 m deep, melon-headed whales appear to feed deep in the water column (review by Jefferson and Barros 1997).

Diving Behavior

No data available.

Social Behavior

Melon-headed whales are highly social, and move in large group sizes (Perryman et al. 1994). In the Gulf of Mexico, mean group size is 135.3 individuals, and the largest group size is 400 whales (Mullin et al. 1994c). In the eastern tropical Pacific, groups average 199.1 whales (Wade and Gerrodette 1993). Large groups apparently consist of many closely spaced subgroups (Mullin et al. 1994c).

In the eastern tropical Pacific, Philippines, and Gulf of Mexico, melon-headed whales are commonly associated with other odontocetes (Hammond and Leatherwood 1984; Scott and Chivers 1990; Leatherwood et al. 1992; Wade and Gerrodette 1993; Mullin et al. 1994c). Mass strandings of this species have been reported from several areas (review by Jefferson and Barros 1997). These strandings suggest strong social bonds (Jefferson and Barros 1997).

Sex rations of 1:2 or 1:1.5 (male:female) were reported for several mass strandings (review by Jefferson and Barros 1997). Based on a mass stranding in Japan, the maximum length of males is 1.04 times that of females (Miyazaki et al. 1995). There is no indication of sexual dimorphism in total body length (Perryman et al. 1994). However, there may be dimorphism in some body proportions, although sample size in the study was small (Best and Shaughnessy 1981).

Reproduction and Population Parameters

Based on a mass stranding in Japan, females reach sexual maturity at 11.5 years and at more than 2.35 m, males reach sexual maturity at 16.5 years and at least at 2.44 m (Miyazaki et al. 1995). Gestation lasts approximately 12 months (Bryden et al. 1977; Perrin and Reilly 1984). From a mass stranding in Brazil, the oldest femae had more than

30 dentinal-growth-layer groups, and the oldest male had more than 22 (review by Jefferson and Barros 1997). There is indirect evidence that females live longer than males (review by Jefferson and Barros 1997).

Breeding Areas

No conclusive data exists on seasonality of calving.

Speed of Travel and Movements

In offshore water, melon-headed whales often move at high speed, porpoising out of the water regularly (Perryman et al. 1994). However, this could be a reaction to the observation vesel (Jefferson and Barros 1997).

Vocal Behavior

Underwater whale sounds are low level, with maximum source levels estimated at 155 dB for whistles and 165 dB for click bursts re: 1 μPa @ 1 m (Watkins et al. 1997). Individual clicks and click bursts of 0.1 to 0.2 s with 40 or more clicks at repetition rates up to about 1200/s have frequency emphases between 20 and 40 kHz (Watkins et al. 1997). Dominant frequencies for whistles are 8-12 kHz, with both upswept and downswept frequency modulation (Watkins et al. 1997). The occurrence and relative level of click bursts and whistles correlate with increased level of activity (Watkins et al. 1997).

Hearing Range

No data available.

Known Impacts of Human Activities

Melon-headed whales sometimes approach survey vessels, yet at other times avoid them (Mullin et al. 1994c).

FALSE KILLER WHALE (*PSEUDORCA CRASSIDENS*)

Summary

The false killer whale (*Pseudorca crassidens*) is a medium-sized odontocete that has been well studied in captivity. They are found worldwide in tropical to warm temperate zones in deep, offshore waters. False killer whales eat primarily large fish and squid. Based on their distribution and feeding habits, they may be at least mid-water divers. False killer whales have a low reproductive rate. This species produces sounds as low as 4 kHz and its best underwater hearing occurs at around 17 kHz. However, they may be able to hear sounds below 1 kHz.

Its distribution, low reproductive rate, and apparent diving habits make this species susceptible to LFA activity. On the other hand, the frequency range of its vocalizations and underwater hearing make it less vulnerable to LFA than other cetacean species. However, because false killer whales have not been studied in the wild, it would be difficult to detect any negative impacts of LFA.

Protected Status

The false killer whale is not federally listed under the U. S. Endangered Species/Marine Mammal Protection acts (kingfish.ssp.nmfs.gov/tmcintyr/spec_idx.html). This whale is listed as a lower risk/least concern species by the Cetacean Specialist Group of the International Union for the Conservation of Nature (www.wcmc.org.uk/data/database). False killer whales are taken by drive- and harpoon-fisheries in Japan (Miyazaki 1983; Kishiro and Kasuya 1993). They are taken around Iki Island, Japan, to reduce competition with fisheries (Kasuya 1985b). Small numbers are taken in fishing nets and lines throughout their range (review by Stacey et al. 1994). A few whales have been captured live off California and Hawaii (review by Jefferson et al. 1993).

Distribution

False killer whales are found worldwide in tropical to warm temperate zones in deep, offshore waters, from 60°S to 60° N (review by Stacey et al. 1994).

In the western Pacific, they are found from Alaska to Chile (Miller 1920; Mitchell 1965; Leatherwood et al. 1988a). In the eastern Pacific, they occur from Japan to New Zealand (Gaskin 1968; Ohsumi 1972; Bryden 1978; Zhou et al. 1982). In the Indian Ocean, false killer whales have been reported from southern South Africa to southwestern Australia (Leatherwood et al. 1991c). In the eastern Atlantic, this species is found from the British Isles to South Africa, including the Mediterranean Sea (Reinhardt 1866; Fraser 1936; Duguy et al. 1983b). In the western Atlantic, they occur from North Carolina to Tierra del Fuego (Brimley 1937; Langguth 1977; Goodall 1989).

False killer whales are found in waters 9° to 30.8° C in temperature (Miyazaki and Wada 1978; Stacey and Baird 1991b). However, they are most commonly found in warm waters of their range (Kasuya 1986b). Seasonal movements into Japanese coastal waters appear to occur from February to April (Kasuya 1971; Stacey et al. 1994). Inshore movements are occasionally associated with those of food resources or to shoreward flooding of warm ocean currents (Tomilin 1957). In the eastern tropical Pacific, they are more abundant far from shore (Wade and Gerrodette 1993). In Costa Rica, this species appears to be more common around an offshore island than near the mainland (Acevedo-Gutiérrez et al. 1997). False killer whales are common in the western Atlantic (review by Stacey et al. 1994).

Abundance

Worldwide population is unknown.

A total of 39,800 false killer whales (95% bootstrap CL= 11,500-109,500) have been estimated for the eastern tropical Pacific (Wade and Gerrodette 1993). Overall density values in the eastern tropical Pacific were estimated from Wade and Gerrodette (1993) as 0.002 whales/km^2; however, density values vary within the study area. A total of 16,668 false killer whales (95% log-normal CL= 10,034-27,689) have been estimated for the northwestern Pacific (Miyashita 1993). Overall density values in the northwestern Pacific were estimated from Miyashita (1993) as 0.006 whales/km^2; however, density values vary within the study area.

Diet and Foraging Behavior

False killer whales eat primarily large fish and squid (Ross 1984; Kasuya 1985b). The species has been observed preying on small odontocetes (Perryman and Foster 1980). In addition, they have been observed attacking medium-sized and large odontocetes (Palacios and Mate 1996; Acevedo-Gutiérrez et al. 1997). They have also attacked a humpback whale (*Megaptera novaeangliae*) calf (Hoyt 1983).

False killer whales eat both during the day and at night (Evans and Awbrey 1988). Free-ranging false killer whales have been observed sharing their food (Connor and Norris 1982). Based on a captive individual, an average daily feeding rate of 4.7% (wet weight) of toatl mass has been calculated (Sergeant 1969).

Diving Behavior

No data available.

Social Behavior

Groups as large as 300 individuals have been observed (Brown et al. 1966; review by Odell and McClune 1999). In the western North Pacific, mean group size is 32.2 individuals, and the largest group size is 500 whales, however all other groups were not larger than 40 individuals, for a mean group size of 16 whales (Miyashita 1993). At Isla del Coco, Cost Rica, false killer whales move in group sizes ranging from 5 to 34 individuals (Acevedo-Gutiérrez et al. 1997).

False killer whales associate with other cetaceans (review by Stacey et al. 1994; Odell and McClune 1999). This species often strands in mass (Porter 1977; Odell et al. 1980;

Ross 1984). The sex ratio in mass strandings and shore-driven groups is approximately equal (Fraser 1949; Kasuya 1986b). However, other studies have reported more females than males (Yamada 1956).

Based on a sample of less than ten individuals per sex, the asymptotic length of males is 1.20 times that of females (review by Perrin and Reilly 1984). False killer whales are thought to form strong social bonds in the wild (Stacey and Baird 1991b). In Costa Rica, resighting data suggest that individuals maintained stable associations over a two-year period (Acevedo-Gutiérrez et al. 1997). It has been hypothesized that male and female false killer whales may remain with their natal group (Connor et al. 1998a).

Reproduction and Population Parameters

In Japan, females are sexually mature at body lengths of 3.40-3.80 m and at an estimated 8-11 years of age (Kasuya 1986b). According to Purves and Pilleri (1978), both males and females attain sexual maturity at 8-14 years of age; according to Kasuya (1986b), males attain sexual maturity 8-10 years later than females. Males are sexually mature at body lengths of 3.70-4.30 m in South Africa and at 3.96-4.57 m in Scotland (Kitchener et al. 1990). Gestation lasts about 15-16 months (Purves and Pilleri 1978; Kasuya 1986b; Perrin and Reilly 1984). Longevity is estimated at 57.5 uears for males and 62.5 years for females (Kasuya 1986b). Overall annual mortality has been estimated at 5-6% (Kasuya 1986b).

Females ovulate approximately once a year (Purves and Pilleri 1978), and ovulation may be spontaneous (Harrison et al. 1972). In Japan, gross annual reproductive rate is 6.7%, net annual reproductive rate is 1.4%, and the proportion of pregnant females is 14.5% (Kasuya 1986b). Interval between calvings averages 6.9 years and increases with age; females over 45 years of age may be postreproductive (Kasuya 1986b).

Breeding Areas

There are no apparent breeding areas. Calving season appears to be year-round (Ross 1984). In Japan, however, calving peaks in March and mating peaks from December to January (Kasuya 1986b).

Speed of Travel and Movements

False killer whales swim at an estimated speed of 3 km/h (Brown et al. 1966).

Vocal Behavior

False killer whales produce vocalizations as low as 4 kHz and as high as 130 kHz, with dominant frequencies at 4-95 kHz, 25-30 kHz, and 95-130 kHz (Busnel and Dziedzic 1968; Kamminga and van Velden 1987; Thomas and Turl 1990). The maximum peak to peak source level (re: 1 μPa @ 1 m) of false killer whale sounds is 228 dB (Thomas and Turl 1990).

False killer whales produce highly directional echolocation clicks. The 3-dB beamwidth of the echolocation clicks of false killer whales is similar to that of bottlenose dolphins (*Tursiops truncatus*, 10-11.7°), but aimed a few degrees below the body axis (Au et al.

1993). Changes in the underwater sound repertoire of false killer whales appear to be associated with different ambient noise levels or with free-ranging versus captive environments (Nester et al. 1998). As in belugas (*Delphinapterus leucas*), false killer whales emit echolocation pulses in the 20- to 60-kHz range with low ambient noise; however, they emit stronger pulses at 100-130 kHz with higher ambient noise levels (Kamminga and van Velden 1987; Thoas et al. 1988; Thomas and Turl 1990). Apparently, weak pulses can be emitted at low or high frequencies, yet strong pulses can only be emitted at frequencies larger than 100 kHz (Au 1993). The range detection threshold of a captive false killer whale was 119 m for a small sphere as target (Thomas and Turl 1990). False killer whale are able to detect nylon monofilaments through echolocation (Hatekeyama et al. 1994).

Hearing Range

False killer whales hear underwater sounds equal or less than 120 dB (re: 1 µPa @ 1 m) in the range of less than 1.0 kHz to 115 kHz (Thomas et al 1988b). At a frequency of 1 kHz, false killer whales hear pure tones that have an intensity of at least 100 dB re: 1 µPa @ 1 m (Thomas et al. 1988b). The best underwater hearing of the species occurs at 17 kHz, where the threshold level is 39-49 dB re: 1 µPa @ 1 m (Sauerland and Dehnhardt 1998).

Critical ratios of a false killer whale were 15-20 dB at 8-24 kZ, lower than for bottlenose dolphins, belugas, or humans at those frequencies, and about as good as those of humans at their best frequencies (Thomas et al. 1990b). Tests using the ATOC 75 Hz signal show that thresholds for a one second signal exceeded 140dB re: 1 µPa @ 1 m, indicating that the 195 dB ATOC signal would only be heard by false killer whales if they were directly above and within 100m of the sound source (Au et al. 1997; Nachtigall et al. 1998).

Known Impacts of Human Activities

Captive false killer whales showed no obvious reaction to single noise pulses from small (10 g) charges with a received level of ~185 dB re: 1 µPa @ 1 m (Akamatsu et al. 1993). However, they showed some avoidance upon initial exposure to pulse sequences at 0.2-2.5 kHz if the received level was ~170 dB re: 1 µPa @ 1 m. These same type of pulses have been used to drive this species and other dolphins into hunting areas in Japan (Kasuya 1985b; Akamatsu et al. 1993). Captive false killer whales also showed some avoidance when first exposed to pulse sequences at 24-115 kHz and the received level was larger than 170 dB re: 1 µPa @ 1 m (Akamatsu et al. 1993). The avoidance response of the whales diminished upon repeated exposure to strong pulse sounds (Akamatsu et al. 1993).

PILOT WHALES (*GLOBICEPHALA* SP.)

Summary

Pilot whales comprise two species of relatively large odontocetes, the short-finned pilot whale (*Globicephala macrorhynchus*) and the long-finned pilot whale (*G. melas*). These two deep water, oceanic species have been relatively well-studied in certain locations. Taken together, both species inhabit temperate and subpolar zones as well as warm temperate to tropical waters of the world. Pilot whales feed mostly on squid and fish; they appear to be deep divers. The two species are gregarious and vocalizations are correlated with behavioral state. They have a low reproductive rate. Pilot whales produce sounds as low as 0.28 kHz, although the lowest dominant frequencies do not drop below 2 kHz.

Their size, distribution, low reproductive rate, and diving habits suggest that pilot whales could be susceptible to LFA activity. However, the relatively high frequency of their vocalizations suggest that they are less vulnerable to LFA than other cetacean species. Because pilot whales have been relatively well studied in certain areas, it may be possible to detect any negative impacts of LFA.

Protected Status

Neither short-finned pilot whales nor long-finned pilot whales are federally listed under the U. S. Endangered Species/Marine Mammal Protection acts (kingfish.ssp.nmfs.gov/tmcintyr/spec_idx.html). However, the Cetacean Specialist Group of the International Union for the Conservation of Nature (www.wcmc.org.uk/data/database) has listed short-finned pilot whales as a lower risk/conservation dependent species and long-finned pilot whales as a lower risk/least concern species. Long-finned pilot whales have been exploited by drive fisheries off Greenland, the Faeroe Islands, Norway, Iceland, Shetland, Orkney, and the Hebrides (Sergeant 1962b, 1982; Mitchell 1974; Christensen 1975; Kapel 1975; Mercer 1975; Mitchell 1975; O'Riordan 1975). They were heavily exploited by the Newfoundland fishery which depleted the population in eastern Newfoundland waters from approximately 50,000-60,000 whales at the onset of the fishery to about 4,000-12,000 whales currently estimated (review by Nelson and Lien 1996). The Newfoundland stock is the only population that appears to have been depleted (review by Nelson and Lien 1996). Long-finned pilot whales are taken incidentally in trawl and gillnet fisheries in the western North Atlantic, and in swordfish driftnets in the Mediterranean (Jefferson et al. 1993). Short-finned pilot whales have been hunted in Japan by drive fisheries and in Japan, West Indies, Philippines, Sri Lanka by harpoon fisheries (Caldwell and Caldwell 1975a; Ohsumi 1972, 1975; Reeves 1988; Leatherwood et al. 1991c; Kishiro and Kasuya 1993; Aragones 1994). They were also taken in the tropical Atlantic by pelagic whaling crews (review by Leatherwood et al. 1983a). Incidental catches by different fisheries have been reported in Japan, Sri Lanka, the eastern tropical Pacific, USA, Peru, and Canada (review by Stacey and Baird 1993). Short-finned pilot whales have been captured live for captivity, a total of 226 individuals as of 1983 (IWC 1984b).

Distribution

Long-finned pilot whales occur in temperate and subpolar zones, excluding the North Pacific, from 20° to 75°N and from 5° to 70°S (Nelson and Lien 1996). This discontinuous distribution separates the species into a northern and a southern forms, which are sometimes regarded as subspecies (Davies 1960; Aguayo 1975; Mitchell 1975). Short-finned pilot whales are found in warm temperate to tropical waters of the world, from 50°N to 40° S (Leatherwood and Dahlheim 1978). Where the ranges of the two species overlap, long-finned pilot whales appear to prefer colder, temperate waters (Jefferson et al. 1993).

In the Atlantic, long-finned pilot whales are found from Greenland, Iceland, the Barents Sea, and possibly the Baltic Sea in the north, to Cape Hatteras, USA, in the west, and northwest Africa, including the Mediterranean Sea, in the east (Sergeant and Fisher 1957; Mitchell 1975; Leatherwood and Dahlheim 1978; Nores and Perez 1988). This species inhabitated the Sea of Japan until the 12th century; however, there is no recent evidence of them in the Bering Sea or North Pacific (Kasuya 1975; Kasuya et al. 1988a).

Short-finned pilot whales in the western Atlantic occur from New Jersey, USA, to São Paulo, Brazil, including the Gulf of Mexico and the Caribbean Sea (Casinos and Bou 1980; Mead and Potter 1987; Schmiegelow and Filho 1989). In the eastern Atlantic, they have been recorded from Spain and France down to 15°S on the African coast, excluding the Mediterranean Sea (Collet and Duguy 1987; Nores and Perez 1988). In the eastern Pacific, they have been reported from the Alaskan Peninsula and the Gulf of Alaska down to Perú (Orr 1951; Home 1980; Van Waerebeek and Reyes 1986). In the western Pacific, this species is known from northern Japan to Tasmania (Nicol 1987; Wada 1988). Short-finned pilot whales are found throughout the Indian Ocean (Leatherwood et al. 1991c).

Long-finned pilot whales are pelagic animals that inhabit deep waters throughout most of the year, although at times they move inshore in pursuit of prey (Leatherwood and Dahlheim 1978; Sergeant 1982; Martin et al. 1987). They appear to prefer shelf edges (Mate pers. comm. in Nelson and Lien 1996). In the Gully, a submarine canyon on the edge of the Scotian Shelf, pilot whales prefer areas with fairly flat relief and are more common later in the summer, when the waters were warmer (Gowans and Whitehead 1995).

In the eastern Atlantic, long-finned pilot whales stay offshore in West Greenland and Iceland (Sergeant and Fisher 1957; IWC 1990). They occur in large numbers between Iceland, the Norwegian coast, and Great Britain in the summer, with its maximum concentration around the Faeroe Islands (Sergeant and Fisher 1957; Leatherwood and Dahlheim 1978; IWC 1990). They appear to be rare in Italian waters, on the coasts of the Netherlands and Belgium, and the east coasts of Britain and Ireland (Evans 1980). They are common throughout the Western Mediterranean basin (Cañadas and Sagarminaga 1998). Although the Strait of Gibraltar is an area of relatively high density of long-finned pilot whales, there is some evidence of autumn-migration leading out of the

Mediterranean Sea (Hashmi 1998). It is unclear whether they are present in the North Sea (Leatherwood and Dahlheim 1978).

In the western Atlantic, seasonal movements of long-finned pilot whales occur around Newfoundland (Nelson and Lien 1996). The species is numerous in the region of Georges Bank, Scotian Shelf, outer Laurentian Channel, and Gran Bank from July to December, but is absent from inshore Labrador waters during the summer (Sergeant 1979). They seem to be abundant in the southern portion of the Gulf of St. Lawrence and along the west coast of Newfoundland (Sergeant and Fisher 1957; Sergeant et al. 1970). In the summer, long-finned pilot whales move from the edge of the shelf off the east coast of the USA onto George’s Bank and into the Gulf of Maine (Hain et al. 1981). They migrate outside the Continental Shelf in winter, and then inhabit areas on and east of the Grand Bank in North Atlantic Current waters (Sergeant and Fisher 1957; Sergeant 1962b). Sightings are most common in the southern New England mid-shelf and shelf-break in fall and winter (review by Nelson and Lien 1996).

In the Southern Hemisphere, long-finned pilot whales occur mainly north of the Antarctic Convergence in the cold Humboldt, Falkland, and Benguela currents (Mitchell 1975; Leatherwood and Dahlheim 1978; Kasamatsu and Joyce 1995). Although no strong north-south migrational patterns in the Northern Hemisphere, a seasonal movement of Southern Hemiphere whales into Antarctic waters has been postulated (Martin et al. 1987).

Short-finned pilot whales generally inhabit warm temperate and tropical offshore waters (Miyazaki and Wada 1978; Kasuya and Marsh 1984), but they are also observed in inshore areas (Home 1980). In the western tropical Indian Ocean, 35% of the variance in the distribution of pilot whales is explained by their association with a shallow thermocline (Ballance et al. 1998). In the eastern tropical Pacific, pilot whales (most likely short-finned pilot whales), were most abundant in cold, upwelling-modified waters, and were absent from the warmest tropical waters off the Mexican coast (Wade and Gerrodette 1993). Around the California Channel Islands, USA, some individuals appear to stay year-round, while others are found offshore most of the year and move inshore following seasonal movemenst of squid (Leatherwood et al. 1987).

Although there is the possibility of continuous distribution of long-finned pilot whales across the North Atlantic, there is some evidence that the western and eastern North Atlantic populations are distinct (review by Nelson and Lien 1996). In British waters, there appears to be a northern and a southern forms (Evans 1980). In short-finned pilot whales, a northern and a southern form have been described in Japan (Kasuya et al. 1988). These two forms appear to be reproductively isolated (Wada 1988). It has been suggested that there are at least two stocks, perhaps even two different forms, of short-finned pilot whales in the eastern tropical Pacific (Wade and Gerrodette 1993).

Abundance

Worlwide population estimates are not available.

It is estimated that long -finned pilot whales number 778,000 individuals (CV= 0.295) in the northeastern Atlantic (Buckland et al. 1993). Overall densities in this area were estimated from Buckland et al. (1993) as 0.064-0.282 whales/km^2; however, density values vary within the study area. A total of 13,000 whales have been estimated from the Newfoundland-Labrador area (Hay 1982). A total of 10,000-12,000 whales have been estimated from the northeastern coast of the USA (Payne and Heinemann 1993). It is estimated that 200,000 long-finned pilot whales (CV= 0.35) are present south of the Antarctic Convergence in January, with an estimated biomass of 0.16 million tonnes (Kasamatsu and Joyce 1995).

A total of 53,608 short-finned pilot whales (95% log-normal CL= 34,725-82,758) from the southern form have been estimated for the northwestern Pacific (Miyashita 1993). Overall density values in the northwestern Pacific were estimated from Miyashita (1993) as mean population size divided by study area, results are 0.020 whales/km^2; however, density values vary within the study area. A total of 5,344 short-finned pilot whales (95% log-normal CL= 819-9,669) from the northern form have been estimated for the northwestern North Pacific (IWC 1987). Pilot whales (most likely short-finned pilot whales) number 160,200 individuals (95% bootsrap CL= 112,300-198,400) in the eastern tropical Pacific (Wade and Gerrodete 1993). They are the most abundant and the most frquently encountered small whale in the area (Wade and Gerrodette 1993). Overall density values in the eastern tropical Pacific were estimated from Wade and Gerrodette (1993) as mean population size divided by study area, results are 0.008 whales/km^2; however, density values vary within the study area.

Diet and Foraging Behavior

In the northwestern Atlantic, long-finned pilot whales off Newfoundland coastal waters eat mainly short-finned squid (Sergeant 1962b; Mercer 1975). However, northern cod (*Gadus morhua*) are thought to be a common prey item when squid are less plentiful (Sergeant 1962b; Mercer 1975). Additional organisms consumed include amphipods, other species of squid, and various species of fishes (Sergeant and Fisher 1975; Mercer 1967). However, recent analyses suggest that the dominant prey item of long-finned pilot whales in the northwestern Atlantic is either the long-finned squid (*Loligo paelei*), based on stomach contents (Gannon et al. 1997a,b), or the Atlantic mackerel, based on isotopic data (Abend and Smith 1997). In any case, diet of the species in the region appears to be more diverse than previously thought (Gannon et al. 1997b).

In the northeastern Atlantic, long-finned pilot whales feed on squid and fish (Bloch 1994; González et al. 1994). In the summer, they appear to consume mostly *Illex illecebrosus* (Mercer 1975). Isotopic data suggest that western and eastern Atlantic pilot whales feed at different trophic levels (Abend and Smith 1995). Long-finned pilot whales in the southern Hemisphere feed on squid (Clarke and Goodall 1994). When squid is abundant, it has been estimated that food intake of long-finned pilot whales may be 3-6% of body weight, or as much as 41 kg/day (Sergeant 1962b). The species appears to feed as a group (Sergeant 1962b). They have also been observed feeding in association with trawl nets (Waring et al. 1990).

Short-finned pilot whales feed primarily on squid and fish (Ross 1984; Clarke 1986). However, they have been observed chasing small dolphins in the eastern tropical Pacific and attacking sperm whales (*Physeter catodon*) in the Gulf of Mexico (Perryman and Foster 1990; Weller et al. 1996).

Diving Behavior

Pilot whales are considered to be deep divers. The average number of dives of an immature long-finned pilot whale in a 12 hour period was 636-1433 dives (Mate pers. comm. in Nelson and Lien 1996). The deepest dive recorded on a short-finned pilot whale is 610 m (review by Ridgway 1986). In the Pacific Ocean, the longest dive recorded was 290 s (Norris and Prescott 1961).

Social Behavior

Long-finned pilot whales are very social cetaceans, pelagic groups may consist of about 20 animals, although they may concentrate inshore in larger numbers, sometimes exceeding 200 animals (Sergeant and Fisher 1957; Sergeant 1962b; Hay 1982; Amos and Dover 1990). Groups of long-finned pilot whales average 47.4 ± 65.47 individuals in the Alboran Sea, Spain (Cañadas and Sagarminaga 1998). Off the Canary Islands, Spain, groups average 9.3 whales, while in the Mediterranean Sea they average 12.5 whales (McBrearty et al. 1986). Off the Faeroe Islands, mean group size is 84.5 individuals, and the largest group size is 220 whales (Bloch et al. 1993a).

Short-finned pilot whales are gregarious, their groups range from single individuals to aggregations of several hundred (Irvine et al. 1979; Shallenberger 1981). Groups of short-finned pilot whales average 12.2 individuals, with a maximum of 33 animals in the Canary Islands (Heimlich-Boran 1993). In the northwestern Pacific, mean group size is 65 individuals, and the largest group size is 300 whales (Miyashita 1993).

Long-finned pilot whales and short-finned pilot whales are the two cetaceans most often involved in mass strandings (reviews by Stacey and Baird 1993; Nelson and Lien 1996).

Pilot whales often associate with other odontocete species (Sergeant and Fisher 1957; Leatherwood et al. 1976; Leatherwood and Dahlheim 1978; Bloch 1994). Short-finned pilot whales have been found to associate with various species of cetaceans, and one species of sea lion (Norris and Prescott 1961; Kasuya and Marsh 1984; Reilly and Shane 1986; Au and Pitman 1988).

A higher percentage of long-finned pilot whale females than males is found within a group (Sergeant et al. 1970; Martin et al. 1987; Amos and Dover 1990; Bloch 1994). However, mostly-male or all-male groups are also found occasionally (Sergeant 1962b; Amos and Dover 1990).

Pilot whales are sexually dimorphic. Long-finned pilot whale females are approximately 18 to 25% smaller than males (Sergeant 1962b; Martin et al. 1987; Kasuya et al. 1988b; Desportes 1990; Bloch 1994). Off the Faeroe Islands long-finned pilot whales, the mean length of males is 1.28 times that of females, while their mean weight is 1.90 times that of females (Bloch et al. 1993b). In northeastern Pacific short-finned pilot whales, the mean length of males is 1.26 times that of females, while their mean weight, estimated from growth curves, is 1.83 times that of females (Lockyer and Heyning 1998).

In long-finned pilot whales, genetic data provide supportive evidence for the argument that both sexes remain with their natal group (Amos et al. 1993). Males and females within two large groups were related and did not mate with each other (Amos et al. 1993). Further genetic and parasitological data indicate that males migrate between schools to mate (Andersen and Siegismund 1994; Balbuena and Raga 1994). Apparently, long-finned pilot whales live in stable, matrilineal groups such as those of the closely-related killer whale (*Orcinus orca*). In short-finned pilot whales from Japan, it has been suggested that females remain in their natal group, while males migrate between groups after weaning (Kasuya and Marsh 1984).

Reproduction and Population Parameters

In long-finned pilot whales, males reach sexual maturity at about 12 years of age and four to five m in length (Sergeant 1962b; Martin et al. 1987; Kasuya et al. 1988b; Bloch 1994). In the Faeroes, the average age, length and mass at the attainment of sexual maturity of males were estimated at 16.99 ± 0.30 years, 5.16 ± 0.01 m and 1.40 ± 0.005 tonnes, respectively (Desportes et al. 1994a). Females mature at six to 13 years and three to four m (Sergeant 1962b; IWC 1988; Kasuya et al. 1988b; Bloch 1994). The gestation period is about 16 months (Sergeant 1962b; Martin et al. 1987; Bloch 1994). Lactation can last 2.5 years or longer (Sergeant 1962b; Martin et al. 1987; IWC 1988; Desportes 1990; Bloch 1994). Females can be both lactating and pregnant (IWC 1988; Bloch 1994). Calving interval is about three to four years (Sergeant 1962b; Desportes 1990). Males live up to 50 years, while females can live longer than 60 years (Kasuya et al. 1988b; Desportes 1990; Bloch 1994). Off the Faeroes, females older than 25 yrs of age bear a higher proportion of female than male fetuses than do younger females (Desportes et al. 1994b).

In long-finned pilot whales, the annual pregnancy rate is approximately 30% (Perrin and Reilly 1984; Bloch 1994). Annual calf production is estimated at 10-13% (Sergeant 1962b; Harrison 1969; Martin et al. 1987; Kasuya et al. 1988b; Desportes 1990). Mortality of male foetuses is higher than that of female foetuses (Desportes et al. 1994b). Annual mortality in males older than 1 year is higher than that of females (Sergeant 1962b; Kasuya 1988b). Thus, overall sex ratio at maturity is one male to two or three females (Sergeant 1962b; Martin et al. 1987; Kasuya et al. 1988b; Desportes 1990; Bloch 1994).

In short-finned pilot whales taken by fisheries in Japan, the mean age and length at sexual maturity of females has been estimated as nine years and 3.16 m (Kasuya and Marsh 1984). The mean age and length at sexual maturity of males has been estimated as 15 years and 4.14 m (Kasuya and Marsh 1984). Gestation lasts an average of 452 days (Kasuya and Marsh 1984). Lactation occurs until at least 2.75 years of age, with some animals possibly continuing to nurse until the age of 10 to 15 years (Kasuya and Marsh

1984). Mean longevity is estimated as 22.65 years for females and 12.11 years for males (Kasuya and Marsh 1984). The age of the oldest individuals examined was estimated at 62 years for females and 45 years for males (Kasuya and Marsh 1984). The age distribution, age parameters, and size of North Pacific short-finned pilot whales from California are consistent with data for the larger northern form from Japan (Lockyer and Heyning 1998).

Adult sex ratio is biased towards females since mortality of males is greater than mortality females (Kasuya and Marsh 1984). Short-finned pilot whale females become post-reproductive at about 35-40 years of age, but may continue to lactate for up to 15 more years (Marsh and Kasuya 1991). It is unknown whether post-reproductive females nurse their own calf or the calf of another females (Connor et al. 1998a). It has been suggested that short-finned pilot whales have a poligynous mating system (Kasuya and Marsh 1994).

Breeding Areas

There are no apparent breeding areas. In Newfoundland, the breeding season of long-finned pilot whales lasts from May to November, with the maximum number of births occurring in mid-August (Sergeant 1962b). A summer breeding season is also found for pilot whales in the Mediterranean Sea (review by Nelson and Lien 1996). The whales begin to congregate in July and calve by late September (review by Nelson and Lien 1996). In the Faeroes, the average conception date is around June (Evans 1980; Amos and Dover 1990; Desportes 1990). However, some animals breed successfully year-round (Desportes 1990).

Breeding of short-finned pilot whales off Japan is weakly seasonal, with a sleight peak in parturition in july-August (Kasuya and Marsh 1984). Calving in short-finned pilot whales peaks in spring and autumn in the Southern Hemisphere, and varies with stock in the Northern Hemisphere (Jefferson et al. 1993).

Speed of Travel and Movements

An immature long-finned pilot whale had daily movements of up to 234 km, with a mean of 80 km/day (Mate pers. comm. in Nelson and Lien 1996). The whale averaged a speed of 3.3 km/h, while speeds faster than 16 km/h could be maintained for periods over three hours (Mate pers. comm. in Nelson and Lien 1996).

Short-finned pilot whales typically travel no more than seven to nine km/h, although they are capable of rapid swimming (Norris and Prescott 1961). Off California, short-finned pilot whales appear to have high fidelity to an area, at least on a seasonal basis, with individuals being resighted within and between years (Shane and McSweeney 1990).

Vocal Behavior

Long-finned pilot whales produce vocalizations as low as 0.5 kHz and as high as 18 kHz, with dominant frequencies between 1-11 kHz (Schevill 1964; Busnel and Dziedzic 1966; Taruski 1979; Steiner 1981; McLeod 1986). Sounds include whistles, double clicks, and the ability to produce two totally different signals simultaneously (Schevill 1964; Busnel and Dziedzic 1966; Taruski 1979). These whistles are audible via hydrophones 400-1600 m away (Busnel and Dziedzic 1966; Taruski 1979). Whistles in this species form a continuum in which no mutually exclusive types could be recognized (Taruski 1979). In addition, whistles recorded from this species could be signature whistles (Steiner 1981). Sound production in long-finned pilot whales varies with behavioral and environmental context (Taruski 1979; Weilgart and Whitehead 1990).

Short-finned pilot whales produce vocalizations as low as 0.28 kHz and as high as 100 kHz, with dominant frequencies between 2-14 kHz and 30-60 kHz (Caldwell and Caldwell 1969; Fish and Turl 1976; Scheer et al. 1998). The maximum peak to peak source level (re: 1uPa@1m) of short-finned pilot whale sounds is 180 dB (Fish and Turl 1976). Their whistles are audible via hydrophones 200-1000 m away (Fish and Turl 1976). In the Canary Islands, 61 calls of short-finned pilot whales, other than echolocation sounds and grunts, had a mean maximum frequency of 10.45 kHz and a mean minimum frequency of 2.38 kHz (Scheer et al. 1998). The occurrence of these calls varied according to surface activity (Scheer et al. 1998). The clicks of this species have demonstrated echolocation abilities (Evans 1973).

Hearing Range

No data available.

Known Impacts of Human Activities

Long-finned pilot whales appear to react to sonars; echosounders are among the noise-making methods used during the Faeroese drive fishery for long-finned pilot whales (Bloch et al. 1990). Whales of this genus were seen near oil production platforms in Alaska in spite of the steady noise (Gales 1982; McCarty 1982). They did not show a reaction to an LCAC hovercraft flying less than 100 m above them (Schulberg et al. 1989). Also, many pilot whales were observed within visual range of drillships and their support vessels off West Grenland (Kapel 1979b).

During the Heard Island Feasibility Test in the southern Indian Ocean, sighting rates for pilot whales were lower during than before transmissions (Bowles et al. 1994). Sound at ~57 Hz was projected intermittently from ~175 m deep for 7.3 days, usually for periods of 1/2-1 h every 3 h; overall, source levels were initially 218-221 dB re: 1 µPa @ 1 m, later diminishing to ~205 dB (Birdsall et al. 1994). The transmitted sounds may have elicited avoidance by some whales; however, evidence was inconclusive because sample sizes were low, differences were not statistically significant, and whales probably reacted to the ships in addition to any reactions to the transmitted sounds (Bowles et al. 1994).

KILLER WHALE (*ORCINUS ORCA*)

Summary

The killer whale (*Orcinus orca*) is the largest member of the family Delphinidae and one of the best studied species. Killer whales are perhaps the most cosmopolitan of all marine mammals, being found in all the world's oceans. They have the most diverse diet of any marine mammal species. They apper to be a mid-water diving species. Killer whales have perhaps one of the most stable and cohesive animal societies, with a low reproductive rate, in which vocalizations play an essential role. They produce sounds as low as 0.1 kHz and are unusual in that their vocalizations are at lower frequencies than those of all other delphinids studied thus far. Although killer whales can hear low frequency sounds, their best underwater hearing occurs at 15 kHz.

All of the above traits make this species susceptible to LFA activity. Because killer whales have been relatively well studied in various areas, it may be possible to detect any negative impacts of LFA.

Protected Status

This species is not federally listed under the U. S. Endangered Species/Marine Mammal Protection acts (kingfish.ssp.nmfs.gov/tmcintyr/spec_idx.html). Killer whales are listed as a lower risk/conservation dependent species by the Cetacean Specialist Group of the International Union for the Conservation of Nature (www.wcmc.org.uk/data/database). Whaling fleets have been taken killer whales, particularly in the North Pacific (Nishiwaki and Handa 1958). They have been hunted in various parts of the world for human consumption, or killed as potential competitor by fisherman (Dahlheim 1981). In addition, small numbers have been taken incidentally in fisheries in many areas (review by Jefferson et al. 1993). Live captures for public display have been banned in Iceland and in most areas of the northeastern Pacific (reviews by Heyning and Dahlheim 1988; Jefferson et al. 1993).

Distribution

Killer whales are probably the most cosmopolitan of all cetaceans, they have been observed in all seas of the world, from about 80°N to77°S (Leatherwood and Dahlheim 1978). However, they appear to be more common within 800 km of major continents in cold temperate to subpolar waters (Mitchell 1975; Dahlheim 1981).

In the eastern Pacific, they have been documented from the Chukchi and Beaufort Seas to Tierra del Fuego, including the Gulf of California (Goodall 1978; Silber et al. 1994; review by Heyning and Dahlheim 1988). In the western Pacific, they occur from the sea of Okhotsk to Australia and New Zealand (Tomilin 1957; Bryden 1978). In the eastern Atlantic, they are known from Greenland and the Barents Sea to South Africa, including the Mediterranean Sea (Tomilin 1957; Casinos and Vericad 1976; Ross 1984). In the western Atlantic, they occur from the Labrador Sea to Tierra del Fuego, including the Gulf of Mexico and Caribbean Sea (Sergeant and Fisher 1957; Caldwell et al. 1971;

Goodall 1978; Jefferson 1995). Killer whales have also been sighted in the Indian Ocean (review by Heyning and Dahlheim 1988). In the Antarctic they occur mainly in the very southernmost areas, as far south as the Ross Sea (Tomilin 1957; Kasamatsu and Joyce 1995).

Three types of killer whales have been distinguised in the eastern North Pacific, from Washington State to Alaska, referred as residents, transients and offshore (Bigg 1982; Bigg et al. 1990; review by Jefferson et al. 1993). Residents and transients differ in morphology, behavior, genetics, and ecology, supporting the hypothesis that they are reproductively isolated (Bigg 1982; Bigg et al. 1990; Baird et al. 1992; Baird and Dill 1995; Barrett-Lennard et al. 1996; Hoelzel et al. 1998b).

Abundance

Worldwide population of killer whales is probably at least 100,000 individuals (review by Reeves and Leatherwood 1994).

A total of 8,500 killer whales (95% bootstrap CL= 4,700-15,900) have been estimated for the eastern tropical Pacific (Wade and Gerrodette 1993). Overall density values in the eastern tropical Pacific were estimated from Wade and Gerrodette (1993) as mean population size divided by study area, results are 0.0004 whales/km^2; however, density values vary within the study area. Ship surveys give an estimate of 307 killer whales (95% bootstrap CL= 0-2,340) in California (Barlow 1995). Estimated density was 0.004 whales/km^2 (Barlow 1995). It is estimated that 80,400 (CV= 0.15) killer whales are present south of the Antarctic Convergence in January, with an estimated biomass of 0.32 million tonnes (Kasamatsu and Joyce 1995). In northern Norway, it is estimated that 550 killer whales (95%CL=507-593) inhabit the area during fall and winter (Similä and Ugarte 1998).

Apparently, 286 killer whales are found in Prince William Sound and southeast Alaskan waters, and 260 in the intracoastal waterways of British Columbia, Canada, and Washington State, USA (Bigg 1982; Leatherwood et al. 1984c). It has been suggested that five killer whale pods are permanent or temporary inhabitants of the Gulf of California (Guerrero-Ruiz et al. 1998). Along the California coast, there are no seasonal variations in abundance of killer whales (Forney and Barlow 1998).

Diet and Foraging Behavior

Killer whales have perhaps the most diverse food habits of any marine mammal. As a species, they are known to feed on fishes, cephalopods, pinnipeds, sea otters, whales, dolphins, seabirds, and marine turtles (Nishiwaki and Handa 1958; reviews by Hoyt 1981; IWC 1982b; Gaskin 1982; Jefferson et al. 1991). Recent attacks on various cetaceans species have been reported from different regions (Brennan and Rodriguez 1994; Dahlheim and Towell 1994; Florez-González 1994; George et al. 1994; Goley and Straley 1994). Killer whales also prey on elasmobranchs, including benthic-foraging on rays in New Zealand (Fertl et al. 1996, Visser 1998). However, populations appear to have well-defined diets, with preferred prey items. It is estimated that individuals consume 4% of their body weight every day (Mitchell 1975).

Movements of killer whales appear to be related to their food supply (review by Heyning and Dahlheim 1988). It is believed that movements in eastern Canada are related to migration of seals and rorquals (Sergeant and Fisher 1957). Apparently, movements in the northeastern Atlantic are dependent upon migration of herring (Jongsgård and Lyshoel 1970; Similä et al. 1996). Killer whales use the area around southern Vancouver Island, Canada, primarily during the harbour seal (*Phoca vitulina*) weaning-postweaning period (Baird and Dill 1995). In British Columbia, movements of certain pods of so-called resident killer whales correlate with seasonal movements of certain salmon species (Nichol and Shackleton 1996).

Young killer whales are believed to be taught the feeding techniques that are characteristic of the area where they live, such as intentional stranding to feed on pinnipeds (Lopez and Lopez 1985; Guinet and Bouvier 1995). Killer whales have been observed hunting cooperatively in various areas (Ljunblad and Moore 1983; Similä and Ugarte 1993; Similä 1997). In the late 1800s and early 1900s killer whales developed and unusual cooperative relationship with shore-based whalers in Australia (Wellings 1964). Killer whales feed also in association with trawl nets (review by Fertl and Leatherwood 1997). In addition, they are known to take fish from longlines in the Bering Sea and southern Brazil (Yano and Dahlheim 1995a,b; Secchi and Vaske 1998).

In Washington State and British Columbia, so-called resident killer whales are thought to feed primarily on salmon (Bigg 1982; Bigg et al. 1990). However, recent data suggest that residents also feed regularly on bottom and mid-water fish (Baird et al. 1998b). These whales appear to benefit from communal food searching, but not necessarily from communal food capture (Hoelzel 1993). So-called transient killer whales eat mostly marine mammals (Bigg 1982; Bigg et al. 1990; Baird and Dill 1995, 1996). The group size of transient killer whales that maximizes energy intake of individuals is three, which is the typical number of whales observed together (Baird and Dill 1996).

Diving Behavior

The deepest dive recorded in a killer whale is 265 m, reached by a trained individual (review by Ridgway 1986). In southern British Columbia and in northwestern Washington State, so-called resident killer whales spend more than 70% of their time in the upper 20 m of the water column (Baird et al. 1998b). During periods that resident killer whales were thought to be foraging, they dove to 100 m or more, with a maximum recorded dive depth of 201 m (Baird et al. 1998b). In the Bering Sea, there is some suggestion that killer whales prey on fish at water depths of 200-300 m or more (Yano and Dahlheim 1995a).

Dive durations as long as 10 min have been reported(Lenfant 1969). In the Pacific Ocean, killer whales take three to five short dives of ten to 35 s duration followed by a longer dive lasting one to four min (Norris and Prescott 1961). In British Columbia, there are significant differences in mean dive times between males and females (Williams et al. 1998). Night-time dive parameters suggest that resting may occur more frequently at night than during the day (Baird et al. 1998b).

Social Behavior

Killer whales are typically found in small numbers, although at times they are found in aggregations of several hundred individuals (review by Heyning and Dahlheim 1988). In British Columbia, so-called transient killer whales average 2.5 individuals per sighting, with a maximum of five animals; while so-called resident killer whales average 9.8 individuals per sighting, with a maximum of 15 animals (Morton 1990). In the United Kingdom, mean group size is 4.6 individuals, and the largest group size is 100 whales (Evans 1988). In Monterey Bay, USA., mean group size is 4.8 individuals, and the largest group size is 60 dolphins (Ternullo et al. 1993). In Alaska, mean group size is 12.0 individuals, and the largest group size is 35 whales (Hall and Cornell 1986). Mass strandings of killer whales are not very common (review by Heyning and Dahlheim 1988).

There is sexual dimorphism in body length, weight, and the size and shape of the dorsal fin. A 6.04 m weighed 1.29 times more than a 6.35 female (Hoyt 1981). In Japan, the modal length of males is 1.05 times that of females (Nishiwaki and Handa 1958).

In British Columbia and Washington State, males and females of the so-called resident killer whales do not disperse but continue to travel as adults with their mothers in stable matrilineal groups that average three to four individuals and include up to four generations (Bigg et al. 1990). Closely related matrilineal groups preferentially associate with one another in subpods, which in turn often travel together in pods of ten to 20 or more individuals (Connor et al. 1998a). Consistent with this scenario, genetic data suggest low levels of genetic dispersal between resident whales from different areas and a pattern of genetic differentiation consistent with matrifocal population structure and small effective population size (Hoelzel et al. 1998b). So-called transient killer whales are sympatric with the residents but travel in smaller groups; however, unlike residents, they disperse from their natal group (Bigg et al. 1990). Females may disperse when they have their own calves and males disperse alone; thus forming their own groups (Baird and Dill 1996; Connor et al. 1998a). In this manner, transient groups appear to be comprised of a single matriline with one to two generations (Baird and Dill 1996). It has been proposed that so-called transient killer whales disperse due to the foraging benefits provided by small groups (Baird and Dill 1996).

Pods of killer whales have distinct dialects that are stable over time and that are likely to have been acquired culturally (Ford and Fisher 1982; Ford 1989; Strager 1995). Pods that associate tend to share certin signals; these vocally related pods are termed clans (Ford and Fisher 1982; Ford 1989). In Alaska, differences in acoustic calls between clans appear to reflect differences in maternal ancestry, suggesting that permament emigration between clans is rare (Jurk et al. 1998).

Reproduction and Population Parameters

Males attain sexual maturity at an average length of 5.2-6.2 m, while females mature at 4.6-5.4 m (Perrin and Reilly 1984). There is variation according to geographic area, with northeastern Atlantic animals maturing at the smallest lengths and Antarctic animals maturing at the longest lengths (Perrin and Reilly 1984) The best estimate of gestation period is 15 months (Perrin and Reilly 1984). Calving interval lasts three to eight years, with the higher estimates apparently more typical (review by Heyning and Dahlheim 1988) suggesting that young are dependent on the mother for of a long period. Lactation appears to last 12 months (Bryden 1972). Weaning is thought to occur when a calf reaches a length of 4.3 m (Nishiwaki and Handa 1958).

The annual pregnancy rate is probably around 13.7%; estimates of annual birth rate range from 4 to 5% (Dahlheim 1981). However, birth rate may be density-dependent (Fowler 1984; Kasuya and Marsh 1984). There is evidence that population growth rate is density-dependent (Brault and Caswell 1993). Overall sex ratios of males to females have been reported at 0.48:1 and 0.83:1 for the northeast Pacific (Balcomb et al. 1982; Bigg 1982). In the Marion Islands, these ratios are 1.34:1 (Condy et al. 1978).

Breeding Areas

There are no apparent breeding areas. Mating and calving seasons often span several months (Heyning and Dahlheim 1988). In the northeast Atlantic, calving occurs late autumn to mid-winter (Jongsgård and Lyshoel 1970).

Speed of Travel and Movements

Swimming speeds usually are six to ten km/h; however they appear to achieve speeds of at least 40 km/h (Lang 1966). Based on survey data, the speed of killer whales during 20 min was estimated at about 55 km/h (Johannessen and Harder 1960). However, it is unclear whether this result is accurate (Fish and Hui 1991). In British Columbia, there are significant differences in swim speeds between males and females (Williams et al. 1998).

Vocal Behavior

Killer whales produce vocalizations as low as 0.1 kHz and as high as 85 kHz, with dominant frequencies at 1-20 kHz (Schevill and Watkins 1966; Diercks et al. 1971, 1973; Evans 1973; Awbrey et al. 1982; Ford and Fisher 1982; Ford 1989). The maximum peak to peak source level (re: 1 μPa @ 1 m) of killer whale sounds is 180 dB (Diercks et al. 1971). Their signals carry information regarding geographic origin, individual identity, pod membership and activity level (Thomas et al. 1981; Awbrey et al. 1982; Ford and Fisher 1982; Hoelzel and Osborne 1986; Bain 1989; Ford 1989). Killer whales have the ability to echolocate (Diercks et al. 1971). However, their echolocation clicks are at unusually low frequencies, with most energy below 25 kHz (Diercks et al. 1971; Wood and Evans 1980). The pulse repetition rate for echolocation clicks is 6-18 clicks/s.

Killer whales use whistles and, more frequently, burst pulsed calls to communicate (Ford and Fisher 1982). Pulsed calls are very complex with energy at 500 Hz to 25 kHz and pulse repetition rates up to 5,000 per second (Schevill and Watkins 1966; Ford and Fisher 1982). They range from 0.05 to 10 s, but most are 0.5-1.5 s long (Ford and Fisher 1982). Although most whistles are variable, some stereotyped whistle types are produced (Thomsen and Ford 1998). These whistle types are specific to pods and are believed to coordinate close range interactions in killer whales (Thomsen and Ford 1998). Killer whale vocalizations may also be important in coordinating foraging and other activities (Hoelzel and Osborne 1986; Ford 1989).

In the northeastern Pacific, so-called resident killer whales produce click trains 27 times more often and for twice as long than so-called transient killer whales (Barrett-Lennard et al. 1996). This difference in acoustic crypticity may reflect a flexible response to the probability of alerting prey, because marine mammals have more acute hearing than fish in the frequency range of sonar clicks (Barrett-Lennard et al. 1996). Transient whales often travel or forage without discernibly echolocating, suggesting that passive listening provides cues for prey detection and orientation (Barrett-Lennard et al. 1996).

Killer whales apparently attempt to avoid masking and acoustic competition (Mossbridge and Thomas 1998). In the Antarctic, the frequency modulation (FM) point distributions of killer whale sounds in areas with many seal sounds showed a gap at 2500-3700 Hz, which is near or within the frequency range for common leopard seal sounds (2625-4662 Hz); however, no such gap was found in areas with few seal sounds (Mossbridge and Thomas 1998).

Hearing Range

Killer whales listen underwater to sounds equal or softer than 120 dB (re: 1 μPa @ 1 m) in the range of <0.5 kHz to 105 kHz (Hall and Johnson 1972; Bain et al. 1993). At a frequency of 1 kHz, killer whales listen to pure tones that have an intensity of at least 90-100 dB re: 1 μPa @ 1 m (Thomas et al. 1988b). The best underwater hearing of the species occurs at 15 kHz, where the threshold level is 34 dB re: 1 μPa @ 1 m (Hall and Johnson 1972). Critical ratios for killer whales ranged from 20 dB at 10 kHz to 40 dB at 80 kHz (Bain et al. in Bain and Dahlheim 1994).

Known Impacts of Human Activities

Reactions of killer whales to vessels are diverse. Off British Columbia, killer whales tended to move faster and towards less confined waters when whalewatching boats were within 400 m (Kruse 1991). The responses of whales did not diminish during the whalewatching season (Kruse 1991). However, a recent study in the same area found no measurable change in mean dive time or swim speed when a boat paralleled killer whales at a distance of 100 m (Williams et al. 1998). In the Southern Hemisphere, killer whales have been observed accompanying icebreakers into the Antarctic ice (Thomas et al. 1981). Killer whales were seen near oil production platforms in Alaska in spite of the steady noise (Gales 1982; McCarty 1982). Bang pipes were not effective in deterring killer whales from fishing gear in Alaska (Dahlheim in Jefferson and Curry 1994).

Vessel noise appears to impair the ability of killer whales to detect low-frequency (up to at least 20 kHZ) signals (Bain and Dahlheim 1994). It is expected that this will affect the communication of killer whales (Bain and Dahlheim 1994). It has also been suggested that estimating levels of noise exposure alone is not sufficient to assess any potential damage, this is because there is substnatial variation in the effects of masking noise of a particular level depending on orientattion (Bain and Dahlheim 1994).

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