MLA-013-Acoustic Impacts on Whales

How do we save coral reefs?

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International Whaling Commission, Scientific Committee (IWC-SC) Report

Annex K: Report of the Standing Working Group on Environmental Concerns (May 2004)

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Annex K, section 6

6. MINI-SYMPOSIUM ON ACOUSTICS

At SC55 the SWG noted the importance of the emergent threat of anthropogenic sound to cetaceans and other elements of marine ecosystems (e.g., fishes, pinnipeds) and the potential for the SC to assist in the development and interpretation of studies aimed at elucidating (assessing) the potential impacts of anthropogenic noise on cetaceans. An intersessional correspondence group was established to further develop the noise agenda of the SWG and to identify topics for future review, such as the demographic or physiological consequences of exposure to loud sound sources and possible synergistic effects. The intersessional group planned a mini-symposium on acoustics and acoustic impacts to be held at SC56. The agenda of this mini-symposium was designed to address several key components of this issue while taking advantage of previous and ongoing workshops and symposia specifically convened on this topic (e.g., NRC, ECS, SMM, NMFS, MMC)[1]. Several scientists (C. W. Clark, J. A. Hildebrand, D. R. Ketten, and R. S. Payne) with expertise in the fields of acoustics and marine mammals acoustics were invited. Special sessions were convened by the SWG during which these scientists gave presentations on acoustics, sound propagation, ocean noise, marine mammal hearing, communication behavior, synergistic effects, and noise-related mass strandings. Clark chaired the mini-symposium as part of the SWGs sessions.

Members of the intersessional group recognized that potential impacts include known increases in the deliberate deployment of powerful sound sources for probing the marine environment (e.g., seismic airgun arrays, Navy sonars) and the increasing levels of ambient noise from vessels (e.g., commercial shipping, fishing, recreational traffic). In some cases, sound sources radiate low-frequency sound over very large areas thereby exposing populations to low sound levels (< 120 dB re 1 µPa) over relatively long periods of time (weeks to years). In other cases, sound sources radiate mid- to high-frequency sound over relatively small areas and expose individual animals to high levels (> 160 dB re 1 µPa) of sound over relatively short periods of time (seconds to hours).

In this mini-symposium, examples and evidence were presented to illustrate that impacts from anthropogenic sound sources can operate over spatial and temporal scales that differ by several orders of magnitude. Some examples include low-frequency (< 1000 Hz) ambient noise levels that have increased by two orders of magnitude over the last 60 years (3-5 dB/decade) thereby significantly reducing the potential for long-range communication in mysticetes (Payne and Webb 1971, Appendix 2), and sound exposures from mid-frequency sonars that have coincided with mass strandings in beaked whales since their introduction in the 1960's (see Table 1). In addition, some members of the SWG presented evidence demonstrating specific and growing threats from exposures to seismic airguns. This included episodes of increased stranding in humpback whales along coastal Brazil in 2002 (SC/56/E28), displacement of the western North Pacific gray whale population from a primary feeding area off

[1] National Research Council, European Cetacean Society, Society of Marine Mammalogy, National Marine Fisheries Service, Marine Mammal Commission

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Sakhalin Island (SC/56/BRG39), and the increase in seismic exploration activity throughout the North Atlantic Ocean basin (SC/56/E13) and along the west coast of Africa (SC/56/E12).

Members of the SWG expressed deep concern given this collective evidence of noise impacts, noting that noise can be a source of anthropogenic removals. This is an important consideration with implications for stock assessment and management of cetacean populations. This concern is further amplified given what is known about other anthropogenic stressors such as contaminants (Busbee et al. 1999) and whaling, and the recent evidence demonstrating synergistic effects from multiple stressors (Sih et al. 2004). As a result the SWG recommends that noise remain a priority topic on future SWG agendas.

6.1 Physical acoustics and noise

Roger Payne gave a presentation on the effects of anthropogenic noise on marine animals and the possible synergistic effects between ambient ocean noise levels and other environmental stressors (Appendix 2). The presentation noted that despite a great amount of work in marine mammal acoustics, key questions remain unanswered. For example, comparative approaches are still necessary to predict which species are likely to be more impacted from exposure to anthropogenic sound sources, especially because of the difficulty of determining audiograms for marine mammal species, particularly large whales. The cumulative, large-scale, long-term impacts from increases in anthropogenic noise are not well understood, and the possibility exists that these potential impacts might combine with other stressors (e.g., persistent organic pollutants (POPs) such as PCBs, dioxins, fire retardants, heavy metals) to have negative synergistic effects on marine mammals. For example, recent publications on the synergistic effects from acid rain and habitat fragmentation on bird breeding success (Hames et al. 2002) and the synergistic effects of pesticides and the smell of a tadpole predator on tadpole mortality (Sih et al. 2004) demonstrate that very different and unrelated stressors can combine synergistically to have drastic impacts on individual fecundity and mortality rates. These results underscore the possibility that some species of marine mammals are at risk from the negative synergistic effect from anthropogenic noise exposures coupled with other stressors such as whaling and widespread pollutants.

John Hildebrand presented general background on physical acoustics and ambient noise in the ocean (Appendix 3). Sound is an acoustic wave that travels through some medium such as water, and is typically measured by the corresponding pressure associated with the vibration. Ambient noise in the ocean is the background sound that incorporates the broad range of identified and unidentified individual sources. This noise might come from both distant and nearby sources and is persistent, although contribution from individual sources is not necessarily continuous. The ambient acoustic environment of the ocean is highly variable, and location-specific conditions (e.g., sound propagation, water depth, and bathymetry) might affect how well ambient sounds are received. Natural and anthropogenic sources contribute to ocean ambient noise. Natural sources of ambient noise include: (a) wind and waves, (b) bubble distributions, (c) currents and turbulence, (d) earthquakes, (e) precipitation, (f) ice cover and activity, and (g) marine life. Anthropogenic sources contributing to oceanic ambient noise include: (a) large commercial ships, (b) airguns, (c) military sonar, (d) ship-mounted sonars, (e) pingers, (f) acoustic harassment devices, (g) polar ice-breakers, (h) offshore drilling implements, (i) research sound sources, (j) and small vessels. Several recent studies of long-term trends in ocean noise levels reveal increases of approximately 3-5dB per decade (Andrew et al. 2002; Mazzuca 2001; NMFS shipping noise workshop: http://www.shippingnoiseandmarinemammals.com). This corresponds to a doubling of noise power (3 dB) every decade for the past six decades (NRC 2003).

6.2 Biological acoustics

Darlene Ketten gave a presentation on audition and physiology of hearing in marine mammals (Appendix 4). For marine mammals, hearing is arguably their primary sensory system and cetaceans devote threefold more neurons to hearing than any other mammalian group. Out of 119 marine mammal species, audiograms (graphs of hearing

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ability conventionally displayed as frequency on the abscissa versus sensitivity measured as sound pressure or intensity on the ordinate) are available for only 10 odontocete and 11 pinniped species (all come from smaller species that were tested in captivity). Hearing ranges of species for which no direct measure or audiogram are available are estimated using models based on inner ear anatomy obtained from stranded animals, or inferred from emitted sounds and playback experiments in the wild. Data from audiograms and models indicate considerable variation among marine mammals in both absolute hearing range and sensitivity, with the composite range spanning the ultra to infrasonic. Modern cetaceans have three inner ear structural forms that coincide with acoustic groups: low to infrasonic Type M mysticetes, upper range ultrasonic Type I odontocetes, and lower range ultrasonic Type II odontocetes. Type I odontocetes have peak spectra above 100 kHz and tend to be near-shore and riverine species that operate in relatively low-light, acoustically complex waters. Type II species are primarily delphinids, which are near- and offshore animals that inhabit low object density environments, generally travel in large pods, are highly social and employ lower ultrasonic frequencies with longer wavelengths that are consistent with detecting larger objects over greater distances. Although relatively scarce, data on mysticete ears suggest they are adapted to sonic and infrasonic frequencies. Functional models indicate hearing in larger marine mammals hearing extends to 20 Hz, and is predicted to extend to infrasonic frequencies as low as 10-15 Hz in several species, including blue, fin and bowhead whales. The upper range of mysticetes is predicted to extend to 20-30 kHz.

The available data on cetacean auditory systems reveal a complex auditory architecture with specializations for extended hearing ranges and reception and localization of water-borne sound. Adaptations to the aquatic environment are most evident at the gross anatomical level. Cetaceans have no pinnae and the periotics, tympanics, and ossicles are constructed of dense, compact bone. Cetacean middle ears divide grossly into low versus high-frequency composites that follow the suborders. Inner ear anatomy varies more by species. The length of the cochlea (the portion of the inner ear responsible for hearing) correlates with animal size, but both odontocetes and mysticetes have exceptionally high ganglion cell counts and extreme basilar membrane constructions. The odontocete typano-periotic complex is isolated acoustically from the skull, which is adaptive for aquatic echolocation. The position and isolation of the odontocete bullae suggest ultrasonic signal reception via fatty acoustic wave-guides in and around the mandible. Sound reception mechanisms in mysticetes are unknown, but bony skull connections and a highly derived tympanic membrane suggest combined bone and soft tissue mechanisms. The extra-cranial location of the ear in all whales is advantageous for underwater sound localization.

It was suggested that research be conducted to study differences in cetacean sensitivities to artificial versus natural, biologically important sounds. The lack of information regarding hearing in mysticetes was also discussed. There is a need for mysticete audiograms, and it has been suggested that these can be obtained via playback experiments, but is it also possible to obtain them from auditory brain stem responses (ABR), which use surface electrodes to determine if a response to a signal is received by the auditory nerve. This is complicated in large whales because to get a good signal you have to be close to the nerve and other auditory structures. In large whales it is likely that the neurophysiological response will not be close enough to surface electrodes to be detected. Where species-specific (or even information specific to marine mammals) is lacking, other models are used when highly representative audiograms are available (e.g., humans). It was reiterated that obtaining more species-specific auditory sensitivity information with greater representation is of primary importance.

Payne presented additional information on the role of infrasound in maintaining whale "heards." He hypothesised that baleen whale populations might live in acoustic contact throughout an ocean basin where very long-range communication can take place.

Clark gave a presentation on baleen whale acoustic behaviors and the potential impacts of anthropogenic noise. The main points of this presentation complemented the presentation of Payne (see Appendix 2). Features of baleen whale sounds are well adapted for long-range communication and take advantage of two key features of the ocean environment, a) physical conditions that optimize sound transmission and b) frequency bands with low levels of ambient noise (i.e., "windows" of low ambient noise) (Clark and Ellison 2004). Blue and fin whale songs are well-adapted to features of the deep ocean habitat: their frequencies are confined to the very low-frequency band (15-30 Hz) in which sound can travel over very long distances (> 1000 km), and there is evidence of a plateau of low ambient noise (Curtis et al. 1999). In contrast to the acoustic features of these pelagic species, the calls and songs of

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coastal species, such as right and bowhead whales, are well adapted to features of shallow water habitats. Their frequencies are mostly confined to an optimal frequency band for shallow water transmission (100-400 Hz) and low ambient noise (Jensen et al. 1994).

Research on the behavioral ecology of whales, especially as it relates to direct and indirect measures of food availability, indicates that singing blue and fin whales (males) are often associated with high density food resources in which feeding is observed. This has been observed in both mid- and high latitude regions during both winter and summer periods. Such observations expand considerably the areas and periods of concern over anthropogenic impacts. In the past, emphasis has been placed primarily on low-latitude breeding areas during winter (e.g., humpbacks) or coastal areas during migrations (e.g., gray whales) than on mid- and high latitude feeding areas (shelf breaks and deep water).

Clark then presented data on anthropogenic noise as monitored in both deep water and shallow water habitats. A comparison between the Ligurian Sea (part of the multi-national Pelagos Sanctuary in the Mediterranean Sea) and the Gulf of California (Mexico) illustrated the dramatic difference between the acoustic ecology in a highly urbanized habitat (Ligurian Sea) and in a relatively pristine (Gulf of California) habitat. In the Ligurian Sea, ambient noise levels in the fin whale song frequency band (15-30 Hz) were so high as to mask all but the closest singers and were two to three orders of magnitude greater (20-30 dB) than noise levels in the Gulf of California. Acoustic monitoring in Cape Cod Bay, a critical habitat for the highly endangered northern right whale, revealed persistently elevated levels of low-frequency vessel noise from January through May, a period of relatively low fishing and recreational boating activity. Average spectrum noise levels in the 50-200 Hz frequency band were above 110 dB re 1μPa2/Hz, and Clark suggested that, in right whales, long term exposures to such levels might be considered chronic. Acoustic monitoring results from other coastal US ports showed similarly high levels of ambient, low-frequency noise.

Finally, Clark showed some results from an ongoing acoustic monitoring effort throughout a shelf-break, deep-water habitat in the western North Atlantic Ocean during a 1-week period in the late summer of 2003. The area covered is approximately 100,000 nmi2, and blue and fin whales are known to feed there. During this same period, along one edge of the region, several fishing vessels and a single seismic survey were operating. The data were presented as an animation representing the relative intensity of ambient noise in the frequency band of singing fin whales. When the seismic survey was active, ambient noise levels flooded throughout almost the entire 100,000 nmi2 region, increased by two orders of magnitude, and persisted so as to be nearly continuous for days at a time. This animation of real data contrasted with the more simplistic representations of seismic surveys that typically only consider the local area around the seismic vessel and consider a single seismic shot as lasting only a fraction of a second. Clark postulated that repeated and persistent acoustic insults to such a large area (200 by 400 nmi), that most likely contains a large portion of a fin whale population, should be considered enough to cause population level impacts.

In summary, Clark concluded that the potential impacts on baleen whales from low-frequency anthropogenic noises such as those from commercial shipping and seismic surveys are real, and that in some cases noise exposure levels are potentially chronic.

The SWG asked to what extent passive acoustics are used by marine mammals to find concentrations of prey (e.g., noises from prey itself or modifications to the ambient noise field due to prey) and, if so, is increasing anthropogenic noise impacting marine mammals' foraging success by masking these sounds. Though increasing ambient noise levels have been documented, it is difficult to attribute any impacts on feeding to noise increase because of the multitude of variables involved. It was also noted that comparisons of audiograms for species from more pristine areas with those that have greater ambient noise would be valuable (e.g., northern v. southern right whales, minke whales off Australia versus those off Newfoundland, fin whales in Gulf of California versus fin whales in the Mediterranean). Likewise, continuous monitoring of critical habitats, especially in areas of seismic profiling activities, and temporal comparisons with periods when profiling is absent would be meaningful to determine whether animals are being displaced from or further restricted within their habitats.

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6.3 Exposure, effects, and responses

Ketten provided information on the mechanisms of acoustic trauma and auditory effects on cetaceans. Noise trauma has been divided into lethal and sublethal impacts (Appendix 4). Lethal impacts result in the immediate death or serious debilitation of animals in or near an intense noise source (i.e., profound injuries related to shock wave or blast effects). Sublethal impacts are those in which a hearing loss is caused by exposures to sounds that exceed the ear's tolerance to some acoustic parameter (e.g., auditory damage occurring from loss of hair cell stereocilia). Sublethal effects might ultimately result in lethal impacts, causing death through impaired foraging, predator detection, or communication, or increased stress or mating disruption, though this type of extended or delayed impact from a sound source is not well understood. Noise induced hearing loss (NIHL) is primarily a function of three interactive factors: intensity, frequency, and sensitivity. Loss of sensitivity is referred to as a threshold shift. The extent and duration of a threshold shift depends on the synergistic effect of several acoustic features and is species-specific. The shift may be temporary (TTS – temporary threshold shift) or permanent (PTS – permanent threshold shift) depending on how the frequency, intensity and duration of the exposure interact to produce damage. In addition to direct physiological effects, impacts from noise can cause behavioral effects such as making, aversion, or attraction.

In the presentation, Ketten suggested that deafness in a whale does not necessarily lead to death. A question arose as to whether there was any information on, or examples of, complete and chronic or long-term bilateral deafness in non-captive animals. There is some evidence from stranded individuals showing a long-term condition of hearing damage and loss. Bony degradation in the jaw and infection that spread into the inner ear has been observed in stranded specimens of male beaked whales and in bottlenose dolphins with fractured jaws, and it was determine that these conditions had persisted for several years. There is also evidence of bilateral deafness in non-captive cetaceans. It was noted, however, that these conditions might have contributed to the animal's stranded state.

In addition to the presentations summarized above, the SWG reviewed the following papers related to the mini-symposium's topics.

SC/56/E18 was the latest in a series of papers, presented to the SC since 1998, summarizing information relating to noise pollution. Two issues were highlighted in the literature that had arisen in the intersessional period: i.e. (i) the exchange in *Nature* about the work by Jepson *et al*. (2003) relating to the examination of cetaceans from the Canaries and from around the UK and with potentially noise-related lesions (Fernández *et al.*, 2004 and Piantadosi and Thalmann, 2004), and (ii) the increased application of the Controlled Exposure Experiment (CEE) methodology for studying behavioral responses to noise exposure. Key issues for such CEEs include finding 'appropriate' and detectable end points as well as safe maximum exposure levels. SC/56/E18 suggests that the six recommendations in the *Oceans of Noise* review (Simmonds *et al*., 2003) intended to address noise pollution internationally - which includes the recommendation that an independent body should be established to initiate, promote, monitor and fund marine noise research - would now be expanded to include (i) an international code of conduct for CEEs and (ii) a call for the comprehensive collection of data from stranded animals during CEE research.

The SWG also reviewed SC/56/E28, which provided information on humpback whales that aggregate at Abrolhos Bank on the northeastern coast of Brazil during the spring-winter season for breeding and calving. During the 2002 breeding season, 3D seismic surveys licensed by the Brazilian Environmental Agency (IBAMA) were conducted in the southern portion of the area. These surveys were coincident with an unusual increase in the stranding rate of adult humpback whales in this region. In addition, aerial survey data revealed some changes in the distribution of humpbacks in 2002 when compared to 2001 and 2003. Because of the uncertainties regarding the relationship between seismic activities and strandings in 2003, IBAMA agreed to incorporate a precautionary approach in its recent guidelines for licensing oil exploration activities and included a prohibition of seismic surveys during the whale breeding season from July to November.

Brownell presented some information from SC/56/BRG39 on the continuing research on the western gray whale population off the northeast coast of Sakhalin Island. Two important observations related to seismic activities have been made during this research program. In 1997, various behavioral disturbances concomitant with seismic activities were observed including changes in swimming speed and orientation, respiration rates, and distribution offshore. Cumulative impacts of these short-term disturbances are not known. In 2001, seismic activities were conducted in the known feeding area of these whales. It was observed that whales left the feeding ground during these activities and moved to areas farther south. They only returned to the feeding ground after the seismic activities ceased days later. The potential impacts on these whales, especially mother-calf pairs and "skinny whales", of being displaced to the south outside the normal feeding area are not known but are cause for concern. As reported previously, whales observed to be much skinnier than normal were first observed in 1999 and continue to be observed in the population but in smaller numbers. Any disruption of feeding can be expected to impact the ability of these animals to store sufficient food reserves prior to migration. The main challenge to recovery and continued survival of this population depends on unknown cumulative impacts from noises associated with the development and production of oil and gas.

Clark presented information on a technique for estimating sound exposure levels based on a software program referred to as the Acoustic Integration Model (AIM) developed by W. T. Ellison (Marine Acoustics, Inc.) The approach combines a) validated sound propagation models that use bathymetric and sound speed profile data to predict sound transmission loss in a 3-dimensional water volume with b) characteristics of a sound source (e.g., seismic, ship, sonar) to calculate the level of the sound throughout a region of interest. These physical acoustic data are then convolved with distributions of individuals with prescribed dive-depth and horizontal patterns of movement. In its present version, there is considerable software flexibility in the type of propagation model, the number of sound sources and databases (e.g., bathymetric, sound velocity), and the biological parameters (e.g., species, population size, distribution, percentage of time at different depths, behavioral responses to received level) used to compute estimates of acoustic dosage. This model allows one to evaluate exposure levels for individuals and populations and to test for the sensitivity of the model to different parameter values (e.g., source levels and acoustic characteristics, dive patterns and responses).

Hildebrand provided information on a recently established federally authorized committee lead by the U.S. Marine Mammal Commission (MMC). The U.S. Congress directed the MMC to fund an international conference or series of conferences to share findings, survey acoustic 'threats' to marine mammals, and develop means of reducing those threats while maintaining the oceans as a global highway of international commerce in November 2003. The Commission established an Advisory Committee on Acoustic Impacts on Marine Mammals. This Committee consists of 28 members representing a broad and balanced group of stakeholder interests. In accordance with the requirements of the U.S. Federal Advisory Committee Act, background documents, public comment submissions, and summaries of all Advisory Committee meetings are available through the MMC web site (http://www.mmc.gov/sound/welcome.html). The charter describing the Committee's scope, objectives, and organizational structure, as well as the duties of Committee members is also available on this site. A series of plenary meetings of the Advisory Committee and related technical workshops sponsored by the Commission has begun in the U.S. Furthermore, because the U.S. Congress explicitly requested this be an international dialogue, the MMC, in partnership with the Joint Nature Conservation Committee (JNCC), is sponsoring an international policy workshop on the impacts of sound on marine mammals in London in September 2004. A full report of these activities as issued by the MMC, including the consensus recommendations that will be presented to the U.S. Congress, should be available in time for the SWG to review at SC57.

One of the technical workshops sponsored by the MMC under this program was held on April 13-16, 2004 to explore issues related to the vulnerability of beaked whales to anthropogenic sound. The purpose of the workshop was to bring together scientists from a range of relevant disciplines to:

(1) Assess the most current knowledge of beaked whale biology and ecology, and recent stranding events;

(2) Identify and characterize factors that may have been associated with or caused the strandings; and

(3) Identify ways to investigate more adequately the possible cause and effect relationships.

A full report of the workshop is expected be autumn 2004 and can be made available to SWG for review at SC57.

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The SWG recognized the value of the MMC Sound Committee and looks forward to receiving their report next year. It also expressed appreciation of the MMC and International Fund for Animal Welfare (IFAW) support for some of the symposium presenters to attend the SC56 meeting.

The SWG reviewed recent whale watching research in SC/56/WW6, including the effects of whalewatching boats on cetaceans. In New Zealand, Constantine et al. (2004) noted bottlenose dolphin resting behavior decreased as the number of whalewatching boats increased. Also in New Zealand, Lusseau (2003) reported bottlenose dolphins spending more time underwater as an avoidance reaction. Males showed avoidance responses as soon as a boat entered an area (often before these boats were visible), but females only showed avoidance when boats became intrusive. Hastie et al. (2003) reported that bottlenose dolphins in Scottish coastal waters significantly increased the synchronicity of their breathing in the presence of boats. The authors suggested that this might be related to an anti-predator response. In Hong Kong, Ng and Leung (2003) noted longer dives in humpback dolphins when boats were present and stronger responses were exhibited for faster vessels. Foote et al. (2004) reported that whalewatching boat traffic has increased fivefold in Washington State between 1990 and 2000. Their study showed that in recent years, and in the presence of boats killer whale call duration significantly increased. They suggested that this is an adaptation to avoid the masking effects of boat noise. Finally, in Patagonia, Coscarella et al. (2003) saw significant decreases in dusky dolphin feeding behavior in response to whale watching boats. In summary these studies demonstrate a variety of reactions for a relatively broad selection of species and locations.

Hildebrand reviewed some incidents of cetacean mass strandings associated with high-intensity sound (SC/56/E13) and recommendations for research to assess the risk of acoustic impact on beaked whale populations (SC/56/E36). Behavioral responses of marine mammals to noise are complex and poorly understood (Richardson et al. 1995) and probably depend on a variety of factors, including hearing sensitivity, behavioral context, habituation or desensitization, age and sex, presence of offspring, history of exposure and proximity to a shoreline. Responses range from subtle changes in surfacing and breathing patterns to cessation of vocalization to active avoidance or escape from the region of highest sound levels. Responses also appear to be affected by the location and motion, as well as the onset type of the sound source. Marine mammals have also been observed to have little or no reaction to some anthropogenic sounds.

Recent mass strandings of beaked whales suggest that these species, particularly Cuvier's beaked whale (*Ziphius cavirostris*), are prone to stranding following exposure to high intensity sound that is associated with naval operations and seismic exploration activities. An increased incidence of multi-animal beaked whale stranding events might correlate with the advent of high-intensity sonars that were first deployed on naval ships beginning in the early 1960s. Reports of mass strandings consisting of two or more individuals of Cuvier's beaked whales, compiled from records in the Smithsonian Institution in the USA, show that a quarter (10 of 41) were associated with concurrent naval maneuvers (see Table 1). Incidents occurring in Greece (1996), Bahamas (2000), Canary Islands (2002) and the Gulf of California (2002) were reviewed. These strandings of beaked whales in association with high-intensity sound exposure demonstrate a remarkable pattern. Although Cuvier's beaked whales are the most common species involved in these stranding events (81% of the total number of stranded animals), other beaked whales (including *Mesoplodon europeaus*, *M. densirostris*, and *Hyperoodon ampullatus*) comprise 14% of the total. Other species (*Stenella coeruleoalba*, *Kogia breviceps* and *Balaenoptera acutorostrata*) were also sparsely represented. It is not clear whether (a) *Ziphius cavirostris* is more prone to injury from high-intensity sound than other species, (b) its behavioral response to sound makes it more likely to strand, or (c) it is substantially more abundant than the other affected species at the times and places of exposure. It was noted that the geographical settings for the incidents reviewed were very similar: an island or archipelago with deep water nearby, (appropriate for beaked whale foraging habitat). Necropsies of stranded animals from these incidents suggested internal bleeding in the eyes, ears, and brain, as well as gas and fat embolisms.

The sound exposure levels modeled (Anon. 2001) at positions of beaked whale sightings (K. Balcomb and D. Claridge *pers. comm*. to J. Hildebrand) in the Bahamas do not exceed 160-170 dB re 1μPa @ 1m for 10-30 sec. Based on studies of captive bottlenose dolphins and beluga whales, these levels cannot be considered as sufficient for producing even temporary threshold shifts (hearing loss) for the affected animals. Other possible mechanisms that were discussed include physiological non-auditory impacts, or behavioral responses leading to physiological

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impact. The formation of air emboli as described in Jepson et al. (2003) and Fernández et al. (2004) either due to a behavioral response or directly induced by sound is one hypothesis currently under investigation. Concern was expressed that assessments of stranding events do not account for animals that are severly affected or died but did not strand. Based on photo-identification records of Ziphius in the Bahamas, none of the identified individuals has been resighted since the 2000 stranding event (K. Balcomb *pers. comm*. to R. Brownell).

SC/56/E37 reported that based on a review of stranding records between the late 1950s and May 2004, a total of 111 Cuvier's beaked whales, *Ziphius cavirostris,* stranded around Japan (see Table 1). Within the period between 1960 and 1995 there were ten mass strandings of Cuvier's beaked whales with 47 whales and one mass stranding of four Baird's beaked whale, *Berardius bairdii*. An US Naval operation area, as shown in Hildebrand's presentation, is offshore from where the mass strandings occurred and Brownell implicated tactical mid-frequency sonars as probably cause for these strandings. The Japanese mass stranding observations are consistent with other beaked whale strandings, mainly of Cuvier's beaked whales, associated with naval operations that also using mid-frequency sonar around Italy, the Canary Islands, and the Bahamas, as well as both LFA and mid-frequency off Greece in 1996. For beaked whales, a mass stranding is an event when two or more animals strand simultaneously in the same location. Beaked whales also mass strand at approximately the same times, but not in the same location. These strandings are "atypical" and are well documented in Italy, Greece, Bahamas, Canary Islands and Japan. In the case of Cuvier's beaked whales, no typical or atypical mass strandings are recorded before the introduction of mid-frequency sonar in the early 1960s. However both types of mass strandings were recorded in Japan since this time. The exact way these acoustic operations relate to beaked whale strandings is unclear and may vary from case to case depending on the position and diving behavior of the whales, oceanographic conditions, bathymetric details, and various sound sources. However, the worldwide increase of different underwater sounds suggests a need for retrospective reviews of other beaked whale mass strandings, especially in areas of naval activities (e.g. Puerto Rico), in order to better assess the possible world-wide magnitude of this problem. Once such information is available, it should be easier to develop possible mitigation measures to reduce such strandings in the future. In addition, it was recommended that surveys be conducted for Cuvier's beaked whales in the region off the Pacific side of Japan where these whales were once hunted and have mass stranded.

SC/56/FI23 summarizes the mass stranding of cetaceans in the Bahamas and the results of radiological examinations and cranial necropsies of the animals impacted by this incident. Detailed necropsies were performed on six of the seven animals that died. Only three of these animals (a Cuvier's beaked whale, a Blainville's beaked whale and a spotted dolphin) were sufficiently fresh to allow gross and histo-pathological examination of most of the available tissues. The necropsy of the spotted dolphin (the only animal to strand on the eastern shore of the island—the side opposite from where the naval exercises were occurring) revealed chronic, systemic, debilitating disease in multiple organ systems and no shared trauma elements with the beaked whales that died. It was therefore concluded that the stranding of this animal was unrelated to the beaked whale mass standing event. The beaked whale necropsies revealed hemorrhages in the inner ears and cranial spaces. These pathologies were considered consistent with trauma that might have compromised hearing but was not immediately lethal. Hemorrhages and contusions in the jaw fats and mandibles were also observed. Overall, the pattern of damage appeared consistent with several causes, including direct acoustic effects, diathetic (hemorrhage-enhancing) fragility, vestibular sensitivity and behavioral responses. The strandings coincided both temporally and geographically with a large-scale naval exercise involving tactical mid-range frequency sonar. This, coupled with the nature of the physiological impacts found in the dead animals, as well as the absence of any other exceptional or intense acoustic events, caused the authors to conclude that the sound field created by the combination of ocean state, topography, and the use of multiple tactical mid-range frequent sonars during the exercise, was an important factor in the stranding event. The authors also noted that organized retrospective investigations are being conducted for the recent strandings in Greece, The Bahama Islands, Maderia and the Canary Islands[2].

[2] Full details of the Bahamian stranding and results of subsequent related studies may be obtained from the following website: http://www.nmfs.noaa.gov/prot_res/overview/Interim_Bahamas_Report.pdf

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SC/56/E38 presents information on several unusual cetacean stranding events that occurred in Chinese waters in 2004 during a period when large-scale naval exercises were taking place in nearby waters south of Taiwan. Between February 24 and March 10 the following stranding events were reported: 9-10 short-finned pilot whales (*Globicephala macrorhynchus*), one ginkgo-toothed beaked whale (*Mesoplodon ginkgodens*), one striped dolphin (*Stenella coeruleoalba*), seven short-finned pilot whales, and one short-finned pilot whale. The stranding events were unusual (with respect to the species involved) compared to previous stranding records since 1994 for the region. Gross examination of the only available carcass, the ginkgo-toothed beaked whale, revealed many unusual injuries to structures that are associated with, or related to acoustics or diving. The injuries, the freshness of the carcass, its discovery location and the coincidence of the event with a military exercise suggest that this beaked whale died from acoustic or blast trauma that may have been caused by exposure to naval activities south of Taiwan. Taiwanese newspapers reported that live ammunition was used during these exercises.

Ketten commented that this pattern of injuries found in the *M. ginkgodens* was consistent with blast trauma, especially given the mention of live ammunition exercises conducted south of the stranding areas as mentioned by the authors of SC/56/E38.

In discussion of these papers and presentations, a recent hypothesis was also discussed proposing that the Canary Islands animals might have stranded with air emboli and fat emboli observed in their tissues and organs. It was suggested that these pathologies need further investigation.

Simmonds suggested that the mass and multiple strandings of ziphiid whales that occurred in 1985, 1988, and 1989 in the Canary Islands should be taken into account when considering the full history of cetacean strandings. These ziphiid whale strandings were connected with military activities during a period prior to concerns about tactical sonars. Some of these exercises involved vessels coming towards the islands through the deep waters on the African side of the islands (see Simmonds and Lopez-Jurado, 1991).

Pavan mentioned the occurrence of two atypical mass strandings of *Ziphius cavirostris* that occurred in the Ligurian Sea (Italy) in 1962 and 1963. According to newspapers, the US Navy was in the area coincident with the 1963 strandings. One stranding event involved more than 15 animals. A report and database of strandings that have occurred in the Mediterranean Sea in the last 150 years will be submitted to IWC for publication in the monographic issue on beaked whales by the end of July (Podesta et al. In Press).

One member of the SWG noted that they had just received information about recent strandings of whales off Senegal that appeared to coincide with seismic exploration in the area. Seismic activity is also occurring close to the Mauritania coast in the vicinity of a large reserve (the Parc National du Banc D'Arguin).

Several efforts are underway to compile worldwide stranding data, including any associated anthropogenic activities (e.g., Table 1, Podesta et al. In Press, Simmonds and Lopez-Jurado, 1991). The SWG appreciates these efforts and looks forward to receiving these new reports at next year's meeting.

Borsani reported on a study in the Ligurian Sea from 1999 through 2002 utilizing seafloor acoustic devices to record fin whale sounds and ambient noise. Fin whale song was detected year-round and detections peaked in March and had a minimum in July-August. Inter-note interval was generally 14s, occasionally 30s, and a rare note type, characterized in other North Atlantic locations as an "upsweep" was found (SC/56/SD6). Man-made sounds were omnipresent with a major component due to shipping noise, but minor inputs from pile-drilling, explosions and bottom-trawling. Shipping noise peaked in July. All other noises were evenly distributed during the year.

A group of authors presented information regarding seismic surveys in large whale critical habitats. Three case studies, highlighting the important nature of the issue, were presented to and discussed by the SWG; these include a Southern Hemisphere humpback whale breeding, calving, and nursing region off the coast of Brazil, a Southern Hemisphere humpback whale breeding, calving, and nursing region off the coast of Gabon, and feeding grounds for western Pacific Gray whales off Sakhalin Island.

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The SWG expressed great concern over the impacts on large whales in critical habitats from exposures to seismic sounds impulses. The potential impacts of seismic surveys on baleen whales within a critical habitat (i.e. mating, calving and nursing, or feeding areas) is deemed very high due to the high energy costs of mating, calving and nursing, or feeding activities, the likelihood of disruptions of these biologically critical activities, and the possible displacement of animals from the critical habitat.

On a local scale, the probability of a migrating baleen whale avoiding or deflecting around an area of ongoing seismic survey activity is high, although such avoidance distances would be small relative to the long migrations of many baleen species. Thus, for example, avoidance of a seismic survey area by humpback whales might be on the order of a few tens of kilometers compared to an overall migratory distance of 5000 km on each of the northward and southward migrations.

The SWG enthusiastically commended the Brazil Government for working to protect critical marine mammal habitats from seismic noise exposure. For a unique case and opportunity, the Brazil Government has undertaken ongoing consultation to define the Abrolhos Banks as a critical habitat for marine mammals. The precautionary regulations adopted by IBAMA for Abrolhos Banks are aiming for permanent exclusion of gas exploration/exploitation (see recommendations at the end of this section).

It was noted that potential impacts from seismic concerns are especially relevant to severely endangered cetacean populations such as the western population of gray whales, a population that is especially vulnerable to potential impacts from seismic surveys. It was also noted that this issue is of particular concern to developing nations. For example, the Brazilian's government response to the disturbance of humpback whales on Abrolhos Banks.

6.4 Potential impacts and summary

The SWG synthesized the information from the mini-symposium and discussions, and formulated a series of recommendations to go forward to the full SC. The SWG unanimously agreed that there was now compelling evidence implicating anthropogenic sound as a potential threat to marine mammals. This threat is manifested at both regional and ocean-scale levels that could impact populations of animals. The following listing provides a punctuated summary of these alarming concerns and represents the distillation of some existing data and observations.

(1) Cetaceans are highly adapted to perceive and produce sound.

(2) The amount of sound energy introduced into certain ocean regions by humans has been increasing by at least 3 dB/decade over the last 60 years.

(3) There has been a rise in the amount of noise from oil and gas exploration and production activities, including intense sounds from seismic airgun arrays.

(4) Since the early 1960s, there has been an increase in the use and proliferation of military, anti-submarine sonars, particularly those in the mid-frequency range (2-14 kHz).

(5) There are now several cases of impacts on mysticetes from seismic surveys.

(6) The weight of accumulated evidence now associates mid-frequency, military sonar with atypical beaked whale mass strandings. This evidence is very convincing and appears overwhelming.

(7) For terrestrial species there is now evidence demonstrating dramatic, synergistic effects from two factors acting simultaneously, as opposed to any one factor acting alone.

(8) Research on the effects of anthropogenic noise on cetacean populations should be integrated with ecosystem-based assessment and management of ocean resources, as called for in recent reviews of ocean status and health (e.g., PEW Ocean Commission Report; US Ocean Commission Report). Specifically, novel application of

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conservation tools such as designation of critical habitats, Marine Protected Areas (MPAs) and ocean zoning should be investigated as a means to protect cetacean populations from chronic and intense-episodic anthropogenic noise.

The mechanisms by which anthropogenic noises affect cetaceans are not known. The SWG recognizes the important role of science in helping to explain why whales respond behaviorally to or are injured by various sources of man-made sound. However, the SWG also recognizes and wishes to emphasize that measures to protect species and their habitats cannot always wait for ultimate certainty levels of scientific confirmation. In such cases it is appropriate to adopt the precautionary principle. Certainly, for example, in the case of slowly rising ambient noise levels, documenting the negative effect on blue whale populations would require more than a human lifetime. Cases involving the exclusion of a highly endangered population (e.g., western north pacific gray whales) from its critical habitat, or the insidious degradation of a species' critical habitat due to multiple and possibly compounding factors (e.g., noise, contaminants, food depletion), require strong, prompt action and particular vigilance.

The SWG concluded with a series of recommendations. Some of these are specific to a certain type of high intensity, episodic anthropogenic noise (e.g., seismic, mid-frequency military sonar), while others are more general.

Regarding beaked whales and military sonar, the SWG recommends:

(1) A comprehensive review of typical and atypical strandings, in particular to include beaked whales but also other species that strand at the same time,

(2) A comprehensive analysis of the stranding data relative to military activities (e.g., anti-submarine warfare sonars, live ordinance), other abiotic factors such as bathymetry, weather, magnetic anomalies, and biotic factors such as age and sex of stranded animals,

(3) Proper, standardized analyses and evaluations of dead animals. The entire animal must be examined, especially since to date none of the examined animals in these mass strandings has shown acoustic trauma, and because different pathologies might exist depending on location or behavior of the animal when the incident occurs. Also, if a single causal mechanism is operating, commonality of pathologies may be seen. However, it is possible that two or more mechanisms or conditions (e.g., trauma in an animal already compromised by stress of some sort) combine to result in a stranding.

(4) Standardized responses and protocols be developed that can be used globally for documenting and understanding mass stranding events (as recommended in the recent beaked whale workshop in April 2004).

(5) Investigate the correlation of natural sounds (e.g. earthquakes, typhoons, predators) with the mass strandings of beaked whales.

On the general topic of potential impacts from commercial oil and gas exploration and production activities (referred to as industrial activities) as well as those seismic survey activities associated with academic research (referred to as academic activities), the SWG recommends the following monitoring guidelines. These are motivated by the SWG's serious concerns over seismic survey impacts on cetaceans coupled with the increase in initiatives, particularly by the industrial community but also the academic community, to conduct seismic surveys in regions that overlap with critical habitats for cetaceans. The SWG believes there is an urgent need for coordinating and implementing mitigation and monitoring guidelines and protocols and therefore recommends:

(1) Global identification and monitoring of critical habitats for cetaceans.

(2) Access to information on timing, distribution, extent (nautical miles or kilometres for 2D surveys, or square nautical miles or square kilometres for 3D surveys), sound source, and sound source levels for past and planned seismic surveys carried out in critical habitats.

(3) Description and results of any marine mammal observer programs or other faunal observation programs carried out in conjunction with previous seismic surveys.

(4) Continuous acoustic monitoring of critical habitats on sufficient temporal and spatial scales in relation to pre- and post-seismic activity.

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(5) Independent monitoring of critical habitat (from survey vessel and from independent platforms) to evaluate displacement from critical habitat and/or disruption of important behaviours related to whale presence in critical habitat.

(6) Increased effort to monitor strandings that occur at times and in places where seismic activity is conducted.

(7) That these recommendations be presented to IWC member governments, representatives of geophysical exploration and petroleum industries, and various committees and agencies (e.g. ASCOBANS, ACCOBAMS, JNCC, MMC, NOAA-NMFS, NRC, IUCN, ICES, OSPAR)[3] and upcoming workshops (e.g., MMC and JNCC on impacts of noise on marine mammals, September 2004) exploring and addressing this important topic.

(8) That seismic operators should seek ways to mitigate their potential impacts (e.g. to reduce the power of their sources).

Furthermore, the SWG strongly recommends that:

(1) The current protection so afforded to the Abrolhos Bank, Brazil be made permanent, due to its vital importance as a breeding ground for humpback whales in the western South Atlantic Ocean,

(2) All seismic surveys in large whale critical habitats should be planned to coincide with the movement of migratory cetaceans out of phase with whale presence in their critical habitat. For example, seismic surveys could be conducted within the summer months off Gabon, December to May, when the majority of migratory baleen whales are on their southern feeding grounds,

(3) In cases when seismic surveys do occur in a critical habitat (e.g., western gray whale feeding area off Sakhalin Island), additional guidelines for seismic surveys and independent scientific monitoring should be developed, and a strict monitoring and mitigation program should be implemented. This should include independent and highly experienced shipboard marine observers and a monitoring system and platform that are independent of the seismic source vessel and seismic support vessels,

(4) In situations when displacement of whales does occur in a critical habitat, surveys should be stopped.

On the general topic of anthropogenic noise impacts on cetaceans, the SWG recommends:

(1) A workshop on the impacts of seismic exploration (including both industrial and academic activities) at the 2006 SC meeting,

(2) Integrated and coordinated international research projects to study and describe acoustic ecologies,

(3) The establishment of a working group to derive a series of hypotheses to test for synergistic impacts on long-lived species,

(4) Inclusion of anthropogenic noise assessments and noise exposure standards within the framework of national and international ocean conservation plans (e.g., consideration during designation of critical habitats, MPAs and ocean zoning).

(5) Support for multi-national programs to monitor ocean noise (e.g., IOOS) and the development of basin, regional and local-scale underwater noise budgets.

[3] JNCC (Joint Nature Conservation Comm.); MMC (US Marine Mammal Comm.); NOAA-NMFS (US National Marine Fisheries Service); National Research Council; IUCN (International Union for the Conservation of Nature-World Conservation Union); ICES (International Council for the Exploration of the Sea); OSPAR (Convention for the Protection of the Marine Environment in the Northeast Atlantic).

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