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MARINE MAMMALS AND MAN-MADE NOISE: CURRENT ISSUES

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1. INTRODUCTION

Most species of marine mammals seem sensitive to and reliant on underwater sounds. Sounds important to marine mammals may include calls from conspecifics, predator and prey sounds, and environmental sounds such as surf or ice noise. Echolocation sounds are important to odontocetes (Au 1993), and some mysticetes may also listen to reverberations or echoes from calls (Ellison et al. 1987).

Some man-made noises are known or suspected to have negative effects on marine mammals. These effects can include masking of important natural sounds and behavioral disturbance. Strong or long-lasting noise also may cause temporary or permanent hearing impairment, other noise-induced physical effects, and possibly physiological stress.

However, man-made noises do not always cause negative effects. Marine mammals are adapted to an acoustically variable and often naturally noisy environment. Even when man-made noise is well above natural ambient levels, negative effects may not be obvious. Depending on noise frequency and received level, it may be inaudible to the mammal, or audible but too weak to cause significant masking, disturbance, or other effects.

It is often said that little is known about noise effects on marine mammals (NRC 1994). In fact, many studies relevant to most topics mentioned above have been done during the past 2-3 decades. However, there are many possible combinations of noise source, marine mammal species, and environmental conditions. Only a small proportion of these combinations have been studied in detail. Also, little is known about some key topics, including masking in field conditions, long-term consequences (if any) of observed short-term behavioral effects, and thresholds for hearing damage and noise-induced physical effects. Relevant studies up to early 1995 were summarized in Richardson et al. (1995), hereafter "R+95". Since then, advances have occurred in some but not all key areas.

This paper identifies some important recent advances, topics of continuing concern, and key data gaps. I thank C.R. Greene Jr. of Greeneridge Sciences Inc. for commenting on the manuscript.

2. WHAT MAN-MADE SOUNDS ARE HEARD?

The curve relating absolute hearing threshold to frequency is called the audiogram. Audiograms have been measured for underwater hearing by several species of pinnipeds and small- to medium-sized odontocetes that can be held in captivity. The beluga whale audiogram has recently been determined in the open sea at depths down to 300 m (Ridgway et al. 1997a; see also Au 1997). In-air audiograms have been measured for the harbour porpoise (Kastelein et al. 1997) and for several pinniped species (R+95:205*ff*; see also Kastelein et al. 1996).

Hearing thresholds at frequencies below 1 kHz are difficult to measure underwater. The scarcity of data on low frequency (LF) hearing has been a significant data gap, as many man-made underwater sounds are mainly at LF. However, data on LF thresholds of several additional odontocetes and pinnipeds have been obtained recently (Kastak & Schusterman 1995; Au et al. 1997). Also, the first data on absolute hearing thresholds of a sirenian, the West Indian manatee, are now available, including LF thresholds (E. Gerstein et al., *in* Au 1997).

There is still an urgent need for direct audiometric data from baleen, sperm, and beaked whales, and from sea otters. Baleen whales presumably have sensitive LF hearing, but quantitative data are lacking. Sperm and beaked whales are of special interest as they dive into the deep sound channel, where some strong sources of man-made sound are intentionally placed.

Direct measurements of absolute hearing thresholds can be important in assessing potential effects of man-made noise. For example, ATOC acoustic tomography signals are near 75 Hz and have source levels of 195 dB re 1 µPa. Auditory thresholds of various odontocete species are high at 75 Hz: about 140 dB re 1 µPa (Au et al. 1997). The odontocetes tested by Au et al. would need to be within ½ km of an ATOC source to hear it. The ATOC sources are ~900 m deep, so odontocetes would not hear an ATOC source unless they dove to a depth ≥400 m within ½ km of the source.

On the other hand, despite the poor LF hearing sensitivity of beluga whales (Awbrey et al. 1988; Johnson et al. 1989), LF noise pulses from marine seismic exploration are so strong that belugas as much as 100 km away should be able to detect them (Richardson & Würsig 1997). Whether belugas react to weak pulses received from distant seismic operations is unknown and deserves study.

Thus, hearing threshold data can be helpful in identifying the maximum radius of potential acoustic influence, which in turn can be useful in identifying study priorities. Hearing data from baleen, sperm and beaked whales, and from sea otters, would be very valuable in identifying the circumstances in which they can hear various sources of low-, moderate-, and high-frequency sound.

3. MASKING

Masking is a natural phenomenon to which animals (and humans) are well adapted. Any sound source becomes masked and inaudible if sufficiently far away, with the specific distance depending on background noise level and other factors. Increased background noise, natural or man-made, reduces the maximum distance within which a listener can detect calls or other sounds of interest.

Quantitative data on masking of acoustic signals by background noise have been obtained for a few species of captive odontocetes and pinnipeds (R+95:226*ff*). Those data are an important starting point in assessing the severity and consequences of masking to free-ranging marine mammals (R+95:359*ff*). However, masking data are limited to a few species, not including any baleen whales, sirenians, or sea otters. Also, most data concern detection of pure tones against a white noise background. Free-ranging mammals are often exposed to non-tonal man-made noise combined with natural background noise that varies across frequency and time.

Most studies of masking in captive marine mammals are done with no angular separation between the sources of the signal and the noise. In field situations, sound signals and/or masking noise may reach a listening mammal from specific and often different directions. In these cases, directional hearing may reduce masking effects, especially at high frequencies (for recent data see Bain & Dahlheim 1994; Turnbull 1994). We need to know more about directional effects on masking.

Masking by noise from a moderately-strong and continuous source is probably more disruptive than masking by noise from an intermittent source even if the latter is stronger. For example, repeated noise pulses from seismic exploration can be very strong, but seismic pulses (duration <1 s) are usually separated by quiet periods of ~10 s. Natural ambient sounds are detectable between pulses. We find that calls from bowhead whales are often detectable to us, and presumably to other bowheads, between the seismic pulses (Richardson et al. 1986; Richardson [ed.] 1997). In contrast, steady sounds from a drillship are not nearly as strong as seismic pulses. However, sounds from a drillship and its support vessels masked most of the natural ambient noise and (apparently) most whale calls at a receiving site 11 km from the drillsite (LGL & Greeneridge 1987).

We know little about the biological effects of increased masking through exposure to man-made noise. We need more data on the importance of detecting calls and other types of natural sounds, and the consequences if these signals are masked. We especially need more information about the importance of weak acoustic signals (normally from distant sources) to marine mammals, as weak signals can be masked by even a small increment in background noise level (R+95:359).

4. DISTURBANCE

There have been many reports of situations when marine mammals show (or do not show) short-term behavioral responses to noisy human activities, including aircraft, boats, and dredges; offshore construction, drilling, and seismic exploration; acoustical oceanography research, sonars, explosions, and purposeful acoustical scaring (reviewed in R+95:241-324; Richardson & Würsig 1997).

4.1 Methodological Complications

Data on disturbance responses are limited in several ways. For most types of noise, reactions of only a few species—not representative of all marine mammal groups—have been studied in detail. Also, sample sizes are usually small, data on received sound levels are often lacking, and observations usually are limited to behaviours visible at the surface. Many species spend little time at the surface, and many aspects of behaviour are invisible to surface observers.

Sound levels to which mammals are exposed while near the surface and visible are often unrepresentative of those that they receive when they are out of sight below the surface. For underwater sources, especially those emitting LF sound, pressure release and Lloyd mirror effects often cause lower received levels near the surface than at deeper depths. In contrast, sound levels received from subsonic or supersonic aircraft passing overhead are highest at the surface and diminish with increasing depth.

A common method for assessing some aspects of subsurface behaviour during disturbance studies is to study call rates, call types, and locations of calling animals. This approach is most effective when man-made sounds are intermittent, as during seismic exploration (e.g. Richardson [ed.] 1997). Continuous man-made noise can mask calls that would be detected in the absence of the noise, complicating comparisons of call counts under "potentially disturbed" vs. control conditions.

Various telemetry tags and data loggers could provide much-needed information during disturbance studies, including data on submerged animals (Costa 1993). Time-depth recorders (TDRs), which provide data on diving behaviour, have not been widely used during disturbance studies. However, TDRs have been used during recent studies of pinnipeds exposed to acoustical oceanography sounds off California (Costa et al. 1996). Acoustic data loggers that can be attached to marine mammals show particular promise. Combined with TDRs, they could provide simultaneous data on sound exposure, animal depth, and behaviour of submerged mammals (Fletcher et al. 1996).

4.2 Variability in Reaction Criteria

Disturbance effects on marine mammals are graduated, not "all or none". When pronounced changes in behaviour are evident at close ranges and high received level (RL), subtle and less consistent changes are often present at greater distances and lower RL (e.g. Richardson et al. 1986, 1995:286). In these cases, the apparent acoustic reaction threshold and "radius of influence" depend strongly on how one defines "disturbance", on the types of behaviours recorded during the study, and on sample size. Depending on these factors, the apparent radius of influence can vary by a factor of 10, and the acoustic reaction threshold can vary by 20 dB or more! Thus, when evaluating radius of influence, "disturbance" should be defined carefully and the statistical power of the studies should be considered.

Variability in responsiveness among situations and among individual animals is another complication. Sometimes no disturbance is apparent even at short ranges with high RL. At other times there is strong disturbance even at long ranges with low RL. Observations of beluga whales provide especially clear examples, as reviewed in R+95:255*ff.* In some situations, belugas flee from ships 35-50 km away when the ship sounds seem barely detectable (Finley et al. 1990; Cosens & Dueck 1993). In other situations, belugas show extreme tolerance of boats. Even at a single place and time, different individual mammals often show much variation in responsiveness. It is common for some individuals to tolerate received sound levels 10-20 dB higher than the RLs that cause avoidance or other reactions by the more responsive individuals.

For these reasons, the sound level that elicits a given type of disturbance response should be defined on a statistical basis: 10% respond in a specified way at x dB re 1 μPa (or at x dB above ambient), 50% respond at y dB, and 90% respond at z dB (Malme et al. 1984). The percentile reaction criteria are likely to be different for different measures of disturbance, e.g. lower for altered respiration patterns than for strong avoidance.

Habituation is another phenomenon leading to variability in responsiveness. Habituation is the gradual waning of behavioral responsiveness over time as animals learn that a repeated or ongoing stimulus lacks significant consequences for the animal. Habituation to initially-disturbing stimuli is not well studied in marine mammals, but is probably common (R+95:319,396). A few cases of sensitization, i.e. increasing responsiveness over time, have also been reported (R+95:321).

4.3 Disturbance Studies on Captive Mammals

Few disturbance studies have been done with captive marine mammals. Notable exceptions include Thomas et al. (1990), Akamatsu et al. (1993, 1996) and Ridgway et al. (1997b). As compared with field studies, captive studies often allow better experimental control, more precise measurements of sound exposure, and replicated exposures (as needed to study habituation). More studies on captive mammals are desirable.

However, caution is warranted when applying behavioral reaction thresholds determined in captivity to free-ranging mammals. For example, captive belugas seem rather insensitive to some continuous and pulsed man-made sounds (Thomas et al. 1990; Ridgway et al. 1997b). Free-ranging belugas, in contrast, show highly variable responsiveness, sometimes reacting strongly to weak sounds (Finley et al. 1990; Cosens & Dueck 1993).

4.4 Recent Disturbance Studies

Disturbance effects of some noisy human activities have received considerable attention since our previous reviews were written (R+95; Richardson & Würsig 1997). Some of the notable recent work concerns disturbance by marine seismic exploration, acoustical oceanography studies, sonar, and intentional scaring. Space limitations preclude a detailed review, and in any event much of this information is still unpublished or available only in limited-circulation reports.

Seismic exploration: Recent monitoring or research studies on marine mammal reactions to pulsed seismic sounds have occurred in Alaska (Richardson [ed.] 1997), California (Arnold 1996), the U.K. (Goold 1996), and Australia (R.D. McCauley pers. comm.). In the U.S.A., there has been much recent discussion about potential hearing damage as well as disturbance during seismic work. Also, the monitoring and mitigation measures that should be applied during seismic programs have been extensively discussed (NMFS 1995b, 1997). In Alaska, the effect of seismic work on the annual subsistence hunt of bowhead whales is also a very serious issue (MMS 1997).

Acoustical oceanography studies: During the planning and permitting phase of the ATOC ocean acoustics project, much concern was expressed about potential disturbance effects (Herman 1994; Holing 1994; Potter 1994; Kineon 1996). This resulted in lengthy delays and revision of the project, including re-location of one source and expansion of the project's Marine Mammal Research Program (MMRP). The ATOC-MMRP has included several notable studies: The work of Au et al. (1997) was mentioned in §2. A year-around intensive monitoring study was done around the ATOC source operating off California (Costa et al. 1996). Also, reactions of humpback and sperm whales to ATOC-like sounds have been tested via playbacks with smaller sound projectors (Frankel et al. 1996; J. Gordon, pers. comm.). These and other ongoing studies will be helpful in reducing uncertainty about disturbance effects of projects like ATOC. Marine mammal research was also done during the recent Haro Strait oceanographic experiment, which involved numerous types of acoustic emissions (Miller & Willis 1997).

Sonar: There is increasing interest in potential effects of strong active sonar signals at low, moderate and high frequencies. Much of the concern involves potential auditory and physical effects on human divers and marine mammals (§5). However, disturbance is also an issue (Ridgway et al. 1997b). Full-scale field tests of marine mammal reactions to the U.S. Navy's Low Frequency Active (LFA) sonar are now underway.

Purposeful acoustical scaring: Acoustic Harassment Devices (AHD) operating at high source levels (e.g. 200 dB re 1 µPa-m) are widely used to reduce marine mammal "depredation" at aquaculture facilities. Acoustic Deterrent Devices (ADD) with much lower source levels (≤150 dB re 1 µPa-m) show promise for reducing bycatch of marine mammals in some fishing gear. Recent references include Jefferson & Curry (1994), Reeves et al. (1996), Goodson (1997), and Kraus et al. (1997). AHDs emit enough sound to disturb non-target animals and possibly to impair the hearing of target animals (§5). With ADDs, there is much less potential to disturb non-target animals.

4.5 What Constitutes Biologically Significant Disturbance?

When pinnipeds stampede from haul-out sites in response to passing aircraft, boats and humans, direct mortality or separation of pups from adults sometimes occurs (R+95). Also, a few cases of long-term displacement attributable to disturbance are documented or suspected (R+95:400). Long-term abandonment of an area important for feeding, breeding, or rearing the young presumably leads to reduced fecundity, carrying capacity, or both. These types of effects are biologically significant.

It is widely assumed that other forms of strong and/or prolonged disturbance may also have negative biological effects by disrupting feeding, socializing, breeding, or care of the young. The effects of feeding disruptions may be compounded by increased energy expenditure while mammals flee. However, there is little direct evidence as to whether these types of behavioral changes result in long-lasting biological effects on individuals or populations. This is an important data gap. There are potentially serious consequences for the animals if harmful types of disturbance continue and, conversely, for various human endeavours if regulatory restrictions are imposed unnecessarily.

Even less obvious is the biological significance of infrequent and minor disturbances involving only brief changes in behaviour. Examples include momentary "alert" responses, diving a few seconds earlier than might otherwise occur, or small adjustments in the paths of travelling animals to slightly increase the distance at CPA (closest point of approach). These types of minor responses to human activities resemble the responses of mammals to many natural features in their environment. These minor responses are unlikely to have significant biological consequences (NRC 1994:27*ff*).

4.6 Regulatory Implications

In the absence of specific information about the biological significance of various types of disturbance responses, even the most minor and brief behavioral changes have sometimes been considered to be "take by harassment" under U.S. regulations (Swartz & Hofman 1991). The National Marine Fisheries Service is the U.S. regulatory agency responsible for most types of marine mammals. In 1996, NMFS indicated that some brief behavioral responses would not be considered indicative of a significant "take by harassment" (NMFS 1996b). More recently, however, NMFS (1997) stated that, until ongoing discussions on the definition of harassment are concluded, NMFS recommends

> "...conservative interpretation of the statutory definition of harassment (e.g., has the potential to disturb a marine mammal or marine mammal stock in the wild by causing disruption of behavioral patterns, including, but not limited to, migration, breathing, nursing, breeding, feeding, or sheltering)."

The phrase "but not limited to" in this definition, taken from the U.S. Marine Mammal Protection Act of 1994 (MMPA), admits the possibility that any change in behaviour may be deemed "harassment".

There is an urgent need for more data, analysis, conclusions, and regulatory follow-up regarding what does and does not constitute biologically significant disturbance. At least in the U.S.A., the present state of uncertainty causes confusion and delay in planning and implementing many industrial, military, and ocean research programs. Some activities with limited potential to disturb mammals receive much scrutiny while other noisy human activities that obviously disturb marine mammals, e.g. shipping, have received little regulatory attention. Consistent, defensible, and biologically-relevant disturbance and harassment criteria are urgently needed.

5. HEARING IMPAIRMENT, PHYSICAL EFFECTS, AND STRESS

There are very few specific data concerning the circumstances when man-made noise would cause temporary or permanent hearing impairment in marine mammals, or non-auditory physiological effects such as lung resonances or vestibular problems. However, there has been much discussion and modelling, based mainly on data from terrestrial mammals (Ketten 1995; R+95:306,366; U.S. Navy 1996). Explosions can certainly cause damage to hearing and other systems. Other sources of pulsed man-made sounds that may be strong enough to cause hearing impairment or physical effects on nearby mammals include some sonars and some energy sources used for marine seismic exploration.

It is not known whether any sources of continuous or frequently-recurring underwater sound are strong enough to cause hearing impairment within the likely exposure time. AHDs placed near fish-rearing pens are one possibility (§4.4). Some pinnipeds repeatedly venture close to AHDs if they are able to obtain food despite the presence of the AHD.

The U.S. Navy is sponsoring research concerning the levels of LF sound that cause deleterious non-auditory physiological effects in human divers. The applicability of this work to marine mammals is uncertain, but it presumably will have at least indirect relevance.

Noise-induced stress is virtually unstudied in marine mammals (R+95:404). The one specific study found no evidence that noise caused elevated catecholamine levels in belugas (Thomas et al. 1990).

5.1 Temporary Threshold Shift (TTS)

NRC (1994) recommended that TTS thresholds be measured in marine mammals, as TTS thresholds provide indirect evidence about sound levels likely to cause Permanent Threshold Shift (PTS). Also, temporary hearing impairment could itself be deleterious, for reasons similar to those why masking of natural sounds could be deleterious.

The first TTS data from marine mammals are now available. Kastak and Schusterman (1996) found that, in a harbour (=common) seal, TTS occurred at unexpectedly low received levels. Their study was opportunistic, and did not determine specific TTS thresholds at particular frequencies. The first systematic TTS study of marine mammals involved bottlenose dolphins exposed to single 1-s tones at 3-75 kHz (Ridgway et al. 1997b). The dolphins began to show measurable TTS at received levels of 192-201 dB re 1 µPa, depending on frequency and individual.

These results are very useful, but TTS studies with additional exposure conditions and species are needed. TTS thresholds are expected to depend strongly on signal duration and repetition rate. They probably also vary with species and (to some degree) frequency. It is not obvious how conventional TTS data could be obtained from baleen whales and other taxa not amenable to psychoacoustic testing in captivity. TTS data from odontocetes and pinnipeds should not be assumed to apply in a quantitative way to other groups of marine mammals.

5.2 TTS Thresholds as Harassment Criteria

It has been suggested that TTS thresholds might constitute meaningful thresholds for harassment (NMFS 1995a). Under the U.S. MMPA, Level A harassment (injury) is distinguished from Level B harassment (behavioral disturbance). Given what is known about PTS in terrestrial mammals, short-term exposure of marine mammals to sounds barely sufficient to cause TTS is not expected to cause PTS (Level A harassment). On the other hand, many marine mammals exhibit strong behavioral reactions, including strong avoidance, when received levels of man-made sounds are well below anticipated TTS thresholds. Thus, the logic for treating TTS thresholds as thresholds for either Level A or Level B harassment is not immediately apparent.

One common situation in which TTS thresholds might be reasonable and conservative criteria of harassment is the case of exposure to infrequent and brief transient sounds. Such sounds often cause no more than momentary behavioral change, without "stampedes" or other major displacements. I assume that these minor behavioral effects do not constitute Level B harassment (*cf.* §4.6). If that assumption is accepted, then infrequent, brief exposure to transient sounds at received levels up to the TTS threshold would be non-harassing as long as the behavioral reactions were minor.

6. REGULATION AND MITIGATION

Mitigation measures sometimes used (or considered for use) to reduce noise effects on marine mammals include ▸ equipment design, ▸ seasonal and hourly restrictions, ▸ geographic restrictions, ▸ ramping up and other operational procedures, and ▸ real-time monitoring combined with localized mitigation when mammals are detected. Examples are given in R+95:417*ff.*

6.1 Incidental Take Authorizations

Since 1995, procedures have existed in the U.S.A. for the issuance of Incidental Harassment Authorizations (IHAs). IHAs allow non-intentional harassment of small numbers of marine mammals under specified conditions (NMFS 1995a, 1996a). Some key conditions are that no serious injuries should occur, there should be negligible impacts on the species or stock(s), and there should be monitoring to verify that the conditions were met. IHAs have been issued for missile launches, an acoustical oceanography study, seismic programs, and other nearshore projects that might disturb marine mammals. Significant effort is required to obtain an IHA and to implement its provisions. However, this process is sufficiently practical that some proponents of noisy activities in U.S. waters are choosing to seek IHAs rather than to operate without permits and risk legal action for harassing mammals.

During marine seismic exploration, it is possible that mammals close to an airgun array might suffer permanent hearing damage—a type of injury. Therefore, IHAs issued for seismic operations have required that the energy source be shut down immediately when real-time monitoring detects marine mammals within pre-defined "safety radii" (NMFS 1995b, 1997; Arnold 1996; Richardson [ed.] 1997). It is accepted that some mammals are not detected until they are well within the safety radii. However, the procedures provide some degree of mitigation. They also address the requirement to monitor the number of mammals exposed, their reactions, and the sounds to which they are exposed.

A closely-related U.S. process provides the possibility to obtain authorization for incidental takes that include injury or even mortality of small numbers of marine mammals. The application process is more complex and time consuming than for an IHA. However, this process has been used to authorize "takes" during some seismic and drilling programs, missile launches, and underwater explosions.

Both processes can be criticized on various bases, but both have the potential to benefit marine mammals. The process forces systematic scrutiny of the potential for disturbance or injury. It also requires public notice and opportunity for public comment. When deemed appropriate, mitigation measures are required. The required monitoring, if well designed, provides needed data on the nature and severity of effects. Those data can be used to refine the mitigation and monitoring procedures during future related projects.

6.2 Effectiveness of Mitigation

Ramp-up: It is often assumed that, if the source level of a strong noise source is increased gradually over several minutes ("ramped up"), marine mammals located near the source will move away before it reaches full power. This is assumed to allow any nearby mammals to move away before the received level becomes high enough to cause hearing damage or physiological effects. This concept has been applied during the ATOC project, during marine seismic programs off Alaska and California, and during operations with the LFA sonar system. However, there is not much evidence that marine mammals actually swim away during the ramp-up phase (R+95:372). This deserves study, given the reliance that is being placed on ramping-up as a mitigation measure. A related concept is the use of small *warning blasts* in advance of large explosions. The efficacy of this approach is doubtful, as some marine mammals may not move away from explosions (Todd et al. 1996).

Real-time monitoring: Visual and/or acoustical monitoring are commonly used in attempts to detect marine mammals within designated "safety zones" around strong noise sources, e.g. explosions, seismic operations, or LFA sonar. When animals are detected within the safety radius, the operation is delayed or interrupted. Visual monitoring can be from vessels, shore, or aircraft. Acoustical monitoring may or may not include localizing the positions of calling animals. Detectability varies with the specific observation procedures in use, species, distance, day vs. night, and weather. It is obvious that not all mammals present are detected. However, the specific detection probabilities under various conditions are rarely estimated. To the extent that there is risk to the undetected mammals, we need better data on effectiveness of real-time monitoring under realistic field conditions.

Safety radii and approach criteria: The distances within which potentially disturbing or injurious activities are restricted are based on the best available data about reaction or injury thresholds. However, these data are often weak or derived by extrapolation from quite different situations (§4, §5). The safety radii applied in two recent seismic programs in U.S. waters have been based on the assumption that baleen whales and pinnipeds should not be exposed to received pulse levels exceeding 180 and 190 dB re 1 μPa, respectively (rms over duration of pulse) (NMFS 1995b, 1997). In one recent 57-day seismic program, airgun operations were interrupted 135 times when seals were seen within the 190 dB safety radius (R.E. Harris et al. *in* Richardson [ed.] 1997, p. 4-36). The safety criteria used for seismic and other projects involve many subjective judgements. Better data on actual biological effects of man-made sound are highly desirable, both to ensure appropriate protection for marine mammals and to avoid unnecessary disruption of important human activities.

7. CONCLUSIONS AND PROSPECTS

Progress is being made toward understanding noise effects on marine mammals, in focusing on the most serious issues, and in devising mitigation approaches. However, the issues are complex and the needed studies are often difficult. Some major emitters of underwater sound remain reluctant to become involved in the process. It will take time, money, cooperation, and good study designs to obtain the needed data, to determine which situations need mitigation, and to devise, test and implement effective yet practical mitigation measures.

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