Agenda Item 8.1 Funding of Projects and Activities

Progress of Projects Supported by ASCOBANS

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Project Report: Approaches to an Impact Indicator in the Light of Descriptor 11 (MSFD)

Action Requested

- Take note

Submitted by Secretariat / WDC

NOTE:
DELEGATES ARE KINDLY REMINDED TO BRING THEIR OWN COPIES OF DOCUMENTS TO THE MEETING

Technical Report SSFA/ASCOBANS/2011/2

Joint paper on EU MSFD descriptor 11 noise

Methodologies to Help Determine Levels of Noise Compliant with Environmental Laws [or Environmentally Sustainable Noise Levels]

Anthropogenic noise can have an adverse effect on the marine environment. Practically all marine animals use their hearing as their primary sense: for sensing their environment, orientation, communication, reproduction, finding food, and for predator and hazard avoidance. Thus, it is probable that at least some marine species will be seriously impacted by anthropogenic noise (see reviews by Hildebrand 2005; Nowacek et al. 2007; Weilgart 2007; Tyack 2008; Popper and Hastings 2009). In light of the new European Union Marine Strategy Framework Directive (MSFD) Descriptor 11 ("Introduction of energy, including underwater noise, is at levels that do not adversely affect the marine environment."), the impact of noise needs to be carefully and fully evaluated with an aim to achieve or maintain a good environmental status in the marine environment by 2020. This requires, from a scientific point of view, no risk of physical injury and no substantial interference of biologically important behavior of endangered species. The two proposed indicators by the European Commission decision on criteria and methodological standards on good environmental status of marine waters (September 2010) are based on noise output rather than on biological effects. This considerably simplifies the process of determining when indicators show good environmental status is no longer maintained or achieved. However, an estimation of good environmental status needs to be based on both sound output and the sound receptor (animal). The biological component will unavoidably add complexity, but it is ultimately what we care most about--the maintenance of healthy marine populations. We can obviate the need for introducing a biological indicator only if we are prepared to proceed in a highly precautionary manner. Even then, very modest additions of noise could, with time, be revealed to have harmed the environment. Thus, we propose methodologies here to help determine levels of noise that are compliant with environmental laws. This paper will describe an additional indicator which includes biological effects. It will review methodologies presently available and suggest a framework of standardized procedures to estimate the effect of anthropogenic underwater noise based on the already described indicator (1) "loud, low and mid frequency impulsive sounds" and (2) "continuous low frequency sound".

> **11.1. Distribution in time and place of loud, low and mid frequency impulsive sounds**
> Proportion of days and their distribution within a calendar year over areas of a determined surface, as well as their spatial distribution, in which anthropogenic sound sources exceed levels that are likely to entail significant impact on marine animals measured as Sound Exposure Level (in dB re 1µPa 2 .s) or as peak sound pressure level (in dB re 1µPa peak) at one metre, measured over the frequency band 10 Hz to 10 kHz (11.1.1)
>
> **11.2. Continuous low frequency sound**
> — Trends in the ambient noise level within the 1/3 octave bands 63 and 125 Hz (centre frequency) (re 1µPa RMS; average noise level in these octave bands over a year) measured by observation stations and/or with the use of models if appropriate (11.2.1).

The following brief review of the impacts of noise on aquatic species is meant to update readers' knowledge of this area, show the sorts of studies, along with their limitations, that can be undertaken to determine such impacts, and indicate the likelihood for population and ecosystem-wide impacts of noise.

Lethal effects

Noise has been shown to be lethal in at least some cases. The evidence linking intense military sonars with some fatal whale strandings is undeniable (e.g. Frantzis 1998; Jepson et al. 2003; Fernandez et al. 2005). Even a U.S. Navy-commissioned report stated that "the evidence of sonar causation [of whale beachings] is, in our opinion, completely convincing." (Levine et al. 2004). Often whales show bleeding around their brain and in other vital organs of their body (e.g. NOAA and U.S. Navy 2001; Fernandez et al. 2005). Seismic air guns are a possible cause of whale strandings as well (Hildebrand 2005). Even giant squid may have mass stranded because of air guns, suffering massive internal injuries and badly damaged ears (Guerra et al. 2004). Andre et al. (2011) found that even relatively low levels of low frequency sound exposure over 2 hrs. resulted in massive acoustic trauma in four cephalopod species.

Masking

Seismic airgun noise, used by petroleum companies to detect oil and gas deposits under the seafloor, originating from eastern Canada and measured 3,000 km away in the middle of the Atlantic, was the loudest part of the background noise heard underwater (Nieukirk et al. 2004). Ocean background noise levels have doubled every decade for the last four to six decades in some areas, mainly due to shipping noise (IWC 2004; McDonald et al. 2006). This would be expected to dramatically reduce the ranges at which whales can detect sounds (from hundreds of kilometers pre-motorized shipping to tens of kilometers now). Jensen et al. (2009) determined that even small vessel noise generated at moderate speeds can reduce communication ranges for delphinids by 58% at a 50 m distance. A Cuvier's beaked whale in the presence of shipping noise reduced its foraging efficiency by at estimated >50% (Aguilar Soto et al. 2006). Whale calls seem to be becoming increasingly drowned out by our noise (Nieukirk et al. 2004, Clark et al. 2009).

Sub-lethal effects

Certainly deaths of individuals are serious, particularly in endangered species. But impacts on populations, even non-lethal ones, can severely affect species survival. The International Whaling Commission's Scientific Committee noted "…repeated and persistent acoustic insults [over] a large area…should be considered enough to cause population level impacts." (IWC 2004). Slabbekoorn et al. (2010) argue that less intense noise of longer duration (e.g. shipping) will more likely impact fish than loud noise that kills outright (e.g. explosions, pile driving), and that the more low-level, chronic noise could impact whole ecosystems. Tyack (2008) concurs, stating that marine mammal populations are probably at more risk from the more subtle effects of long-term exposures. Population impacts are hard to detect in animals as difficult to study as marine mammals, but noise has been thought to contribute to several whale species' decline or lack of recovery (NMFS 2002; Weller et al. 2002). Anything that interferes with a marine animal's ability to detect biologically important sounds could have a negative effect on its survival and the health of its populations. Reef fish larvae, for instance, use sound to orient toward or select suitable habitat (Simpson et al. 2005). If settlement-stage reef fish are exposed to artificial noise, they subsequently are attracted to it, meaning noise can disrupt a vital orientation behavior through a mechanism other than simply masking (Simpson et al. 2010).

Sub-lethal impacts may be as serious as lethal effects, because they may affect more animals yet, as mentioned, be harder to detect. Because our knowledge of most cetacean population sizes is imprecise, numbers could decline due to stress responses (e.g. reduced fertility), with no observations of fatal impacts (Wright et al. 2011). Even if impacts are fatal, only 2% of all cetacean carcasses are detected, on average (Williams et al. 2011). Animals that remain in areas that are important to them despite acoustic disturbance could either be unaffected or are forced to stay because of their dependence on the habitat for prey, protection, or other resources. Such "forced tolerance", though it outwardly appears the same as no impact, may be the most stressful of all situations (Beale 2007).

Short-term responses

Short-term reactions to noise are thus not always reliable indicators for long-term population impacts. Population impacts can result even when short-term responses seem very mild or are indeed absent or undetectable (e.g. Bejder 2005). Conversely, short-term reactions may have no serious population consequences. Often, the first animals to flee from a disturbance are those that can most easily "afford" it, i.e. those with the most energy reserves or alternatives. Thus, paradoxically, sometimes the weaker the behavioral response, the greater the impact on the population, as compromised individuals must continue feeding (Gill et al. 2001; Stillman and GossCustard 2002).

Whale and dolphin responses

Clear disruptions of foraging and avoidance were observed in beaked whales exposed to naval sonar exercises, at received sound levels "well below those used by regulators to define disturbance" (Tyack et al. 2011). Beaked whales appear to leave the naval range, returning 2-3 days after the sonar has ceased (Tyack et al. 2011), and taking 1-3 days to recover from the exposure (McCarthy et al. 2011). Certain whale species, such as beaked whales, could be highly threatened by noise not only because of their apparent sensitivity, but also because they seem to occur in small isolated populations that stay in the same area all year (Balcomb and Claridge 2001; Wimmer and Whitehead 2004; McSweeney et al. 2007). Some beaked whale species also display considerable genetic isolation among oceanic and even some regional populations (Dalebout et al. 2005), making them more vulnerable to local extinctions.

Fish reactions

Seismic air guns have been shown to severely damage fish ears, most likely permanently, at distances of from 500 m to several kilometers from seismic surveys (McCauley et al. 2003). Reduced catch rates of 50-80% and fewer fish near seismic surveys have been reported in species such as cod, haddock, rockfish, herring, and blue whiting (Dalen and Knutsen 1987; Løkkeborg 1991; Skalski et al. 1992; Engås et al. 1996; Slotte et al. 2004). These effects can last up to 5 days after exposure and at distances of more than 30 km from a seismic survey. Even when fish showed only outwardly mild behavioral reactions, such as startle responses, to the addition of noise in a tank environment, more subtle shifts in attention causing poorer discrimination between food and non-food items and decreased foraging efficiency resulted (Purser and Radford 2011). Boat noise disrupted schooling structure and coordination, and increased agonistic behavior in bluefin tuna enclosed in a tuna trap (Sarà et al. 2007). Poor schooling behavior can negatively affect their migration accuracy to feeding and spawning grounds (Sarà et al. 2007). Ship noise also interfered with the ability of toadfish to hear each others' mating and agonistic signals (Vasconcelos et al. 2007).

Physiological responses

Increases in stress hormones (Santulli et al. 1999), stress responses (Smith et al. 2004; Wysocki et al. 2006; Graham and Cooke 2008), and strong behavioral reactions (Dalen and Knutsen 1987; Pearson et al. 1992; Skalski et al. 1992; Slotte et al. 2004) have been observed in fish due to noise. Cardiac output, as a sensitive measure of stress in fish, and heart rate increased with boating noise in largemouth bass (Graham and Cooke 2008). Cardiac disturbance and recovery time was greatest with exposure to outboard motor noise, followed in magnitude by trolling motor noise, with canoe paddling noise causing the least reaction (Graham and Cooke 2008). Two marine fish species exhibited increased movement and intense muscle activity when exposed to ship-like noise, with higher hematocrit and blood lactate levels (Buscaino et al. 2010). Indications of increased stress and a weakened immune system following noise broadcasts were also shown for a whale and dolphin (Romano et al. 2004). Fairly moderate levels of noise exposure have induced TTS in some fish species, at times requiring weeks for fish to recover their hearing (Scholik and Yan 2002a; Amoser and Ladich 2003; Smith et al. 2004). PTS was unexpectedly produced in a harbor seal while testing it for underwater hearing sensitivity (Reichmuth et al. 2009). Instead of following the usual pattern of gradually exhibiting greater TTS with greater sound exposure level, the animal's response suddenly jumped from no discernable effect to a dramatic threshold shift. While it recovered some of its hearing rapidly thereafter, the seal still had hearing deficits two years later. No unusual behavior accompanied the hearing loss event. Tonal noise exposures may thus be particularly dangerous (Reichmuth et al. 2009).

Interspecific variation in sensitivity and apparent tolerance

There is large variation between fish species in how they react to sound (Kastelein et al. 2008). Some fish species do not appear very sensitive to noise. Aquaculture production noise did not negatively affect rainbow trout hearing, growth, survival, stress, or disease susceptibility (Wysocki et al. 2007), and the same species showed very limited hearing damage to loud playbacks of LFA sonar (Popper et al. 2007). Bluegill sunfish also showed no significant hearing impairment with noise exposure (Scholik and Yan 2002b). There are cases of apparent tolerance as well. Some studies have shown that seismic surveys did not appear to affect hook-and-line catch rates (Pickett et al. 1994) nor caused fish to move away (Pickett et al. 1994; Wardle et al. 2001; Hassel et al. 2003).

In marine mammals, there also appears to be inter-specific variability in noise sensitivity, even between closely related species, as well as examples of apparent tolerance (though see the above discussion on "forced tolerance"). Croll et al. (2001) found that blue and fin whale distributions seemed more related to their food than LFA sonar transmissions. Sperm whales in the Gulf of Mexico also did not appear to avoid a seismic airgun survey, though they significantly reduced their swimming effort during noise exposure along with a tendency toward reduced foraging (Miller et al 2009). Adult male sperm whales off Norway did not avoid airgun noise (Madsen et al. 2002) nor detonations (Madsen and Møhl 2000) nor change their vocalizations because of either of them.

Population and ecosystem effects

In summary, whales have been displaced from some of their feeding and mating grounds for years (e.g. Bryant et al. 1984; Morton and Symonds 2002), have altered their migration route (e.g. Richardson et al. 1995), and have changed their calls due to noise (e.g. Miller et al. 2000; Parks et al. 2007). The impacts of noise can work cumulatively or synergistically with other environmental threats. Noise could interact with marine mammal by-catch or ship collisions, preventing animals from sensing fishing gear or oncoming ships (Andre et al. 1997). Whales have blundered into fishing nets (Todd et al. 1996) most likely due to hearing damage as a result of noise. Many of the stranded or entangled dolphins or toothed whales have been shown to have profound hearing loss, implying that impaired hearing could have led to their stranding/entanglement (Mann et al. 2010).

It is impossible to know what the effects of noise are on the entire marine ecosystem, but from what we know now, the consequences could be far-ranging and severe. Noise can be fatal and cause hearing impairment in marine animals, can displace them from important breeding and feeding areas, and can produce declines in fisheries’ catch rates. Because of these impacts and others, along with reduced communication space and stress responses, there is a high likelihood for population impacts in at least some marine species, which, in turn, would probably translate into ecosystem effects.

How can we determine environmentally sustainable levels of noise?

1) Passive Acoustic Monitoring (PAM)

We are able to map ocean noise, using autonomous recording devices that are either suspended in the water column or, more commonly, placed on the ocean floor. Cumulative noise levels from many diverse sound sources can also be calculated. Such passive acoustic monitoring can be used to 1) track how noise changes over time and space; 2) ensure compliance with noise regulations; and 3) examine the relationship between anthropogenic noise and marine animal acoustic output. Even when there is no direct impact on individual fitness, changes in acoustic signals can act as an early warning sign of disturbance (Laiolo 2010). Animal vocalizations can be relatively easily studied, even in the ocean, are sensitive to human impacts, and can thus play an important role in animal conservation (Laiolo 2010). Bioacoustics could perhaps even be used to monitor ecological health and biodiversity. A good diversity of biological sounds across many frequencies may prove to be an adequate proxy for biodiversity.

2) Calculations of the loss of communication space

By examining how anthropogenic noise overlaps with the sounds of a particular species, in time, space, and frequency, measures of the amount of masking can be produced (Clark et al 2009). [Chris expands on this].

3) Stress hormones

It is increasingly possible to collect hormones from whale feces, skin, or even exhalations. Stress hormones are somewhat more elusive, but inroads have been made in this area as well. It is preferable to examine tissues for hormones that would integrate the stress responses over a longer period of time than simply a few hours to achieve measures of more sustained stress, though signs of acute stress would have some value as well. This type of study is much more easily carried out in fish or invertebrates. [Chris expands re right whales and 9-11, e.g.].

4) Population models

An index for the maximum acceptable cumulative impact on cetacean populations was developed, called Potential Cumulative Impact (PCI). The PCI includes mortalities, sublethal injuries that affect survival and reproduction, cumulative lifetime exposure to long-term sublethal effects, reduced prey abundance, reduced foraging efficiency, and feeding time lost due to disturbance. The purpose of the PCI is to determine a level of cumulative effects that will keep populations in a target range specified by conservation objectives (Cooke 2011).

Following Cooke (2011), the steps and input required to implement this approach for a population are:
1) determine the dose-response relationship for each threat on each population parameter
2) map the threat levels for each type of impact
3) map the distribution of the population
4) integrate the total impact by parameter
5) determine the total cumulative impact on the population

The largest information gap is the dose-response relationship for different types of threats (Cooke 2011). While the PCI currently incorporates all threats to which cetaceans are exposed, the model could be used to only address noise threats. The input required for this model, even for just the noise threat, is considerable and will be challenging to obtain for many species. Best-studied species will be used as initial test cases, with results being applied to more data-poor species until more information is collected.

Until all of the above methodologies for determining environmentally sustainable levels of noise yield reliable results, noise levels must remain extremely precautionary.

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