Technical Support Information to the CMS Family Guidelines on Environmental Impact Assessments for Marine Noise-generating Activities

Module B.12.

Marine Invertebrates

The full CMS Family Guidelines on Environmental Impact Assessments for Marine Noise-generating Activities and the stand-alone modules are online at:

cms.int/guidelines/cms-family-guidelines-EIAs-marine-noise

B. Expert Advice on Specific Species Groups

The sea is the interconnected system of all the Earth's oceanic waters, including the five named 'oceans' - the Atlantic, Pacific, Indian, Southern and Arctic Oceans - a connected body of salty water that covers over 70 percent of the Earth's surface.

This vast environment is home to a broader spectrum of higher animal taxa than exists on land. Many marine species have yet to be discovered and the number known to science is expanding annually. The sea also provides people with substantial supplies of food, mainly fish, shellfish and seaweed. It is a shared resource for us all.

Levels of anthropogenic marine noise have doubled in some areas of the world, every decade, for the past 60 years. (McDonald, Hildebrand *et al* 2006, Weilgart 2007) When considered in addition to the number other anthropogenic threats in the marine environment, noise can be a life-threatening trend for many marine species.

Marine wildlife rely on sound for its vital life functions, including communication, prey and predator detection, orientation and for sensing surroundings. (Hawkins and Popper 2014, Simmonds, Dolman *et al* 2014) While the ocean is certainly a sound-filled environment and many natural (or biological) sounds are very loud, wildlife is not adapted to anthropogenic noise.

The species groups covered in the following sub-modules are:

- Inshore Odontocetes
- Offshore Odontocetes
- Beaked Whales
- Mysticetes
- Pinnipeds
- Polar Bears
- Sirenians
- Marine and Sea Otters
- Marine Turtles
- Fin-fish
- Elasmobranchs
- Marine Invertebrates

General principles

Building on the information from module section B.1, sound waves move through a medium by transferring kinetic energy from one molecule to the next. Animals that are exposed to elevated or prolonged anthropogenic noise may experience passive resonance (particle motion) resulting in direct injury ranging from bruising to organ rupture and death (barotrauma). This damage can also include permanent or temporary auditory threshold shifts, compromising the animal's communication and ability to detect threats. Finally, noise can mask important natural sounds, such as the call of a mate, the sound made by prey or a predator.

Table 1: Potential results of sound exposure (from Hawkins and Popper 2016)

Impact	Effects on animal
Mortality	Death from damage sustained during sound exposure
Injury to tissues; disruption of physiology	Damage to body tissue, e.g internal haemorrhaging, disruption of gas-filled organs like the swim bladder, consequent damage to surrounding tissues
Damage to the auditory system	Rupture of accessory hearing organs, damage to hair cells, permanent threshold shift, temporary threshold shift
Masking	Masking of biologically important sounds including sounds from conspecifics
Behavioural changes	Interruption of normal activities including feeding, schooling, spawning, migration, and displacement from favoured areas
These effects will vary depending on the sound level and distance	

These mechanisms, as well as factors such as stress, distraction, confusion and panic, can affect reproduction, death and growth rates, in turn affecting the long-term welfare of the population. (Southall, Schusterman *et al*, 2000, Southall, Bowles *et al*, 2007, Clark,

Ellison *et al*, 2009, Popper *et al*, 2014, Hawkins and Popper 2016)

These impacts are experienced by a wide range of species including fish, crustaceans and cephalopods, pinnipeds (seals, sea lions and walrus), sirenians (dugong and manatee), sea turtles, the polar bear, marine otters and cetaceans (whales, dolphins and porpoises)–the most studied group of marine species when considering the impact of marine noise.

The current knowledge base is summarized in the following module.

This important volume of information should guide the assessment of Environmental Impact Assessment proposals.

References

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B.12. Marine Invertebrates

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Consider when assessing

- Seismic surveys
- Civil high power sonar
- Coastal and offshore construction works
- Offshore platforms
- Vessel traffic greater than 100 metric tons
- Vessel traffic less than 100 metric tons
- Pingers and other noise-generating activities

Related CMS agreements

- Agreement on the Conservation of Cetaceans of the Black Seas Mediterranean Seas and Contiguous Atlantic Area (ACCOBAMS)
- Agreement on the Conservation of Small Cetaceans in the Baltic, North East Atlantic, Irish and North Seas (ASCOBANS)
- MOU for the Conservation of Cetaceans and their Habitats in the Pacific Islands Region (Pacific Islands Cetaceans)
- MOU Concerning the Conservation of the Manatee and Small Cetaceans of Western Africa and Macaronesia (West African Aquatic Mammals)
- Agreement on the Conservation of Seals in the Wadden Sea (Wadden Sea seals)
- MOU Concerning Conservation Measures for the Eastern Atlantic Populations of the Mediterranean Monk Seal (*Monachus monachus*) (Atlantic monk seals)
- MOU Concerning Conservation Measures for Marine Turtles of the Atlantic Coast of Africa (Atlantic marine turtles)
- MOU on the Conservation and Management of Marine Turtles and their Habitats of the Indian Ocean and South-East Asia (IOSEA)
- MOU on the Conservation of Migratory Sharks (Sharks)

Related modules

- Refer also to modules B.10 when assessing impact to marine invertebrates

B.12.1. Species Vulnerabilities

Very little is known about effects of anthropogenic noise on invertebrates (Morley *et al*, 2014). This includes more than 170,000 described species of multicellular marine invertebrates in spite of their ecological and economic importance worldwide (Anderson *et al*, 2011). Most research targets molluscs (e.g. cephalopods, shellfish) and crustaceans (e.g. crabs, shrimps, barnacles) (reviewed in Aguilar de Soto, 2016).

Molluscs:

Two atypical mass-strandings involving nine giant squids, *Architeuthis dux*, were associated with seismic surveys co-occurring in nearby underwater canyons where this species concentrates (Guerra *et al*, 2004, 2011). Two specimens suffered extensive multiorganic damage to internal muscle fibres, gills, ovaries, stomach and digestive tract. Other squids were probably disoriented due to extensive damage in their statocysts. Damage to the sensory epithelium was also observed in four species of coastal cephalopods (*Sepia officinalis*, *Loligo vulgaris*, *Illex coindetii* and *Octopus vulgaris*) by exposure to two hours of low-frequency sweeps at 100 per cent duty cycle (André *et al*, 2011, Solé, 2012, Solé *et al*, 2013). Fewtrell and McCauley (2012) reported that squid, *Sepioteuthis australis*, exposed to seismic pulses from a single air gun showed signs of stress such as significant increases in the number of startle and alarm responses, with ink ejection in many cases, increased activity and changing position in the water column.

Delayed and abnormal development as well as an increase in mortality rates in eggs and larvae of shellfish exposed to noise have been recorded in two species. New Zealand scallop larvae, *Pecten novaezelandiae*, exposed to playbacks of low frequency pulses in the laboratory showed significant developmental delays and developed body abnormalities (Aguilar de Soto *et al*, 2013). The number of eggs of sea hares, *Stylocheilus striatus*, that failed to develop at the cleavage stage, as well as the number that died shortly after hatching, were significantly higher in a group exposed to boat noise playback at sea compared with playback of ambient noise (Nedelec *et al*, 2014). In contrast, playbacks of ship-noise enhanced larval settlement in the mussel, *Perna canaliculus* (Wilkens *et al* 2012) while seemed to increase biochemical indicators of stress in adult mussels (*Mytilus edulis*) (Wale *et al* 2016).

Crustaceans:

Stress responses were observed in aquarium-dwelling brown shrimp, *Crangon crangon*, exposed to ambient noise of some 30 dB higher than normal at 25–400 Hz (Lagardere, 1982, Regnault and Lagardere,

1983). Shrimps did not seem to habituate throughout the experiment. Similarly, shore crabs, *Carcinus maenas*, increased metabolic consumption and showed signals of stress when exposed to playbacks of ship noise in the laboratory. Crustacean larvae seem to differ in their sensitivity to noise: larval dungeness crabs, *Metacarcinus magister*, did not show significant differences in survival nor in time-to-moult when exposed to a single pulse from a seven air gun array, even at the higher received level of 231 dB re 1µPa (Pearson *et al*, 1994). In contrast, larvae of other crab species, *Austrohelice crassa* and *Hemigrapsus crenulatus* megalopae, exposed to playbacks of noise from tidal turbines tended to suffer significant delays in time-to-moult (Pine *et al*, 2012) and low-frequency noise exposure inhibited settlement of early larvae of barnacle, *Balanus amphitrite* (Branscomb and Rittschof, 1984). The apparent contradiction in the larval responses from different species of crustaceans may be due, among other things, to the experimental set-up (wild versus laboratory, one pulse versus a continuous exposure), the biology of the species, or the characteristics of the sound treatment. Cellular and humoral immune responses of marine invertebrates to noise have also been examined. In the European spiny lobster, *Palinurus elephas*, exposure to sounds resembling shipping noise in the laboratory affected various haematological and immunological parameters considered to be potential health or disease markers in crustaceans (Celi *et al*, 2014).

B.12.2. Habitat Considerations

Marine invertebrates inhabit a range of habitats. Mainly, they may live associated to the seafloor (benthic or bentho-pelagic species) or free in the water column (pelagic). Many species have an initial pelagic phase as larvae, useful for dispersion, before finding suitable habitat for settling into their adult life. Sound from preferred habitats is one of the cues used by larvae to find a suitable location to settle (Stanley *et al* 2012). Once they settle, many species have limited capabilities to move fast enough at distances required to avoid noise exposure, due to morphological constrains or to territorial behaviour.

Species associated to the seafloor will be more exposed to ground-transmission of noise. This is especially relevant for intense low frequency sounds directed towards the seafloor, typical of seismic surveys. Seismic pulses coupled with the seafloor and low frequency vibrations can travel long distances through the ground and can re-radiate to the water depending on the structure and composition of the seafloor. Marine invertebrates are sensitive to the particle motion component of sound, more than to the pressure wave, they are well suited to detect low frequency vibrations because these are used, for example, to identify predators and prey.

The variability in the extent of barotrauma experienced by different giant squid stranding at the same time, in coincidence with the same seismic survey (Guerra *et al* 2004, 2011), underlines the difficulties inherent in predicting noise-induced damage to animals in the wild. Here, some giant squid suffered direct mortality from barotrauma, while the death of others seemed to be caused by indirect effects of physiological and behavioural responses to noise exposure. Direct injury (barotrauma) can be explained by some animals being exposed to higher sound levels due to complex patterns of sound radiation creating zones of convergence (Urick, 1983) of the seismic sound waves reflected by the sea surface/sea floor, and possibly by the walls of the steep underwater canyons in the area where the seismic survey took place.

Marine invertebrates often have discrete spawning periods. It is unknown if eggs/larvae have a greater vulnerability to sound-mediated physiological or mechanical stress, or even particular phases of larval development when larvae undergo metamorphosis.

Metamorphosis involves selective expression of genes mediating changes in body arrangement, gene expression is susceptible to stress, including from noise. Spawning periods are key for the recruitment of marine invertebrates and thus should be considered when planning activities.

B.12.3. Impact of Exposure Levels

There are no data about thresholds of pressure or particle motion initiating noise impacts on marine invertebrates. Studies have found a range of physiological effects (reviewed in Aguilar de Soto and Kight 2016) but there are no dose-response curves identifying levels of impact onset. Moreover, most studies report only sound pressure level, while particle motion is relevant for the effects of noise on these species. At a distance from an acoustic source (in the far-field) the pressure and particle motion components of sound are easily predicted in a free homogeneous environment such as the water column. In contrast, in the near-field animals may experience higher particle motions than would be expected for the same pressure level in the far-field. Intense underwater sound

sources such as air guns, pile driving, sonar and blasting have back-calculated peak source levels ranging from 230 to, in the case of blasting, >300 dB re 1 µPa at 1m. These activities routinely ensonify large areas with sound pressure levels higher than the thresholds of response observed in different studies of noise-impacts on marine invertebrates. For example, a seismic array with an equivalent source level of 260 dB pk-p re 1 µPa at 1m will produce levels in excess of 160 dB_{rms} over hundreds of km-squared. This level was measured in an experiment reporting noise-induced developmental delays and malformations in scallop larvae (Aguilar de Soto *et al* 2013). But the particle velocities experienced by the larvae in the experiment (about 4-6 mm s^{-1} RMS) imply higher far-field pressure levels of some 195-200 dB_{rms} re 1 µPa, reducing the potential impact zone to only short ranges from the source. However, there are several reasons why larvae in the wild may be impacted over larger distances than these approximate levels suggest. Given the strong disruption of larval development reported, weaker but still significant effects can be expected at lower exposure levels and shorter exposure durations. Moreover, low frequency sounds propagate in complex sound fields in which convergence zones and re-radiation of sound transmitted through the sea-floor can create regions with high sound levels far from the source (Madsen *et al* 2006). The sound field experienced by an organism is a complex function of its location with respect to the sound source and acoustic boundaries in the ocean necessitating *in situ* measurements to establish the precise exposure level.

B.12.4. Assessment Criteria

Benthic marine invertebrates often have little movement capabilities further than a few metres, limiting their options to avoid exposure to anthropogenic noise. In the case of intense low frequency noise, e.g. seismic or pile driving, it is essential to consider ground-transmission. For example, during a seismic survey animals will be exposed to sound received from the air gun array passing over the location of the animals, but these invertebrates will be receiving at the same time ground-transmitted vibrations originated by previous seismic pulses. Thus, animals will experience waves arising from the water and from the ground, differing in phase and other parameters. Complex patterns of wave addition mean that in some cases vibrations will sum, increasing the levels of sound exposure to the animals. Because ground vibrations may travel tens of kilometres or more, the time that benthic invertebrates will be exposed to a given threshold of pressure or particle motion will be increased when we consider seafloor transmission. An alternative source for seismic surveys (©Vibroseis) is currently being tested. In contrast to usual seismic surveys transmitting pulses every 6 to 15 s from an air gun array towed by a ship near the sea-surface, Vibroseis is towed near the seafloor and emits continuously, but at lower peak level. Thus, duty cycle increases to 100 per cent. EIA of Vibroseis and other low frequency sound sources should include modelling particle motion in the target area and consider exposures to benthic fauna.

Results of experiments about effects of noise on catch rates of marine invertebrates have not shown significant effects: Andriguetto-Filho *et al* (2005) did not find changes on catches of shrimps after the passage of a small air gun array. No effects of seismic activities on catches of rock-lobsters were found either by Parry *et al* (2006) performing a long-term analysis of commercial data. In contrast, fishermen have blamed seismic sources for mortalities of scallops and economic losses due to reduced catch rates.

Despite uncertainties about how noise may affect marine fauna and fisheries, several countries have already implemented regulations that reduce overlap between seismic surveys and fishing activities (mainly of fin-fish). However, these regulations do not address concerns of noise effects on eggs and larvae, i.e. that noise might affect stock recruitment and thereby cause delayed reductions in catch rates.

Marine invertebrates form the base of the trophic-web in the oceans, providing an important food source for fish, marine mammals and humans. In addition to direct effects to adults, noise exposure during critical growth intervals may contribute to stock vulnerability, underlining the urgency to investigate potential effects of acoustic pollution on marine invertebrates at different ontogenetic stages. Moreover, recent results investigating the effects of noise on a range of marine invertebrate species call for applying the precautionary principle when planning activities involving high-intensity sound sources, such as explosions, construction, pile driving or seismic exploration, in spawning areas/times of marine invertebrates with high natural and economic value.

B.12.5. Species not listed on the CMS Appendices that should also be considered during assessments

Some large cephalopods are migratory, including the giant squid, *Architeuthis sp* (Winkelmann *et al* 2013). Given the vulnerability of this species to acoustic sources, it should also be considered during assessments.

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