



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

Module B.7. Sirenians

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 |
| <i>These effects will vary depending on the sound level and distance</i> | |

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

- Clark, C W. Ellison, *et al* 2009. 'Acoustic Masking in Marine Ecosystems as a Function of Anthropogenic Sound Sources.' Paper submitted to the 61st IWC Scientific Committee (SC-61 E10).
- Hawkins, AD. and Popper, A. 2014. 'Assessing the impacts of underwater sounds on fishes and other forms of marine life.' *Acoust Today* 10(2): 30-41.
- Hawkins, AD and Popper. AN. 2016. Developing Sound Exposure Criteria for Fishes. The Effects of Noise on Aquatic Life II. (Springer: New York) p 431-439.
- McDonald, MA Hildebrand, JA. *et al* 2006. 'Increases in deep ocean ambient noise in the Northeast Pacific west of San Nicolas Island, California.' *The Journal of the Acoustical Society of America* 120(2): 711-718.
- Popper, AN Hawkins, AD Fay, RR Mann, D Bartol, S Carlson, T Coombs, S Ellison, WT Gentry, R. and Halvorsen, MB. 2014. Sound Exposure Guidelines for Fishes and Sea Turtles: A Technical Report prepared by ANSI-Accredited Standards Committee S3/SC1 and registered with ANSI. (Springer)
- Simmonds, MP Dolman, SJ. *et al* 2014. 'Marine Noise Pollution-Increasing Recognition But Need for More Practical Action.' *Journal of Ocean Technology* 9(1): 71-90.
- Southall, B Bowles, A. *et al* 2007. 'Marine mammal noise-exposure criteria: initial scientific recommendations.' *Bioacoustics* 17(1-3): 273-275.
- Southall, B Schusterman, R. *et al* 2000. 'Masking in three pinnipeds: Underwater, low-frequency critical ratios.' *The Journal of the Acoustical Society of America* 108(3): 1322-1326.
- Weilgart, L. 2007. 'The impacts of anthropogenic ocean noise on cetaceans and implications for management.' *Canadian Journal of Zoology* 85(11): 1091-1116.

B.7. Sirenians

Helene Marsh
College of Marine and Environmental Sciences
James Cook University

Consider when assessing

- Military sonar
- Seismic surveys
- Civil high power sonar
- Coastal construction works
- Playback and sound exposure experiments
- Vessel traffic greater than 100 metric tons
- Vessel traffic less than 100 metric tons
- Pingers and other noise-generating activities

Related CMS agreements

- MOU Concerning the Conservation of the Manatee and Small Cetaceans of Western Africa and Macaronesia (West African Aquatic Mammals)
- MOU on the Conservation and Management of Dugongs (*Dugong dugon*) and their Habitats throughout their Range (Dugong)

B.7.1. Species Vulnerabilities

Even though traditional ecological knowledge and field observations (Marsh *et al* 1978, Hartman 1979) suggest that sirenians (manatees and dugongs) have ‘exceptional acoustic sensitivity’, scientific research on their hearing and reactions to marine noise is relatively sparse. Published hearing studies are based on the Florida manatee, *Trichechus manatus latirostris*, while behavioural studies on reactions to noise are limited to the Florida manatee, the Antillean manatee, *Trichechus manatus*, and the dugong, *Dugong dugon*. Although most of this research is limited to sounds in water, behavioural observations indicate that sirenians are capable of detecting some sounds in air above the surface (Hartman 1979).

Evoked potentials recorded for Florida manatees (Bullock *et al* 1982, Mann *et al* 2005) demonstrated variable sensitivity over a range of frequencies from about 200Hz to 35–40 kHz with greatest sensitivity in the lower range at 1–1.5 kHz. In-water behavioural audiograms of four captive Florida manatees identified the frequency range of best hearing as 6 to 32 kHz (Gerstein *et al* 1999, Gerstein 2002, Gaspard *et al* 2012), with individual variation within this range. Peak hearing

sensitivity has been variously reported as 16–18 kHz (Gerstein *et al* 1999, Gerstein 2002) and 8 kHz (Gaspard *et al* 2012). Gaspard *et al* (2012) also reported that one of their test animals appeared to be able to hear loud sounds as low as 0.25 kHz and ultrasonic frequencies as high as 90.5 kHz. Gerstein *et al* (1999) speculated that the greater sensitivity to higher frequencies observed in their audiogram research may be an adaptation that enabled manatees to avoid the complications associated with perceiving sound reflections propagated from the water–air interface (Lloyd mirror effect) in the shallow depths typical of their habitats, raising the interesting question of what these animals can hear when at the surface.

Both Gerstein (1999) and Gaspard *et al* (2012) conducted in-water behavioural experiments on captive Florida manatees to measure critical ratios. The differences in their results likely reflect both their different experimental protocols and individual differences in the manatees’ responses. Gaspard *et al* (2012) found that the manatees have relatively narrow auditory filters and struggle to hear lower and higher pitched sounds above background noise. However, manatee hearing was much sharper at 8 kHz – the frequency at which manatees communicate – where they could still distinguish tones that were only 18.3 dB louder than the background. This estimate of the manatee’s critical ratio (8 kHz) is among the lowest measured in mammals (Gaspard *et al* 2012) suggesting that generic marine mammal impact guidelines may not be appropriate for sirenians.

Field studies show that both the Florida manatee (Miksis-Olds *et al* 2007) and the dugong (Hodgson and Marsh 2007) exhibit short-term behavioural responses to noise. Miksis-Olds and Wagner (2010) showed that elevated sound levels affect the patterns of behaviour of the Florida manatee and that the response is a function of the manatee’s behavioural state. When ambient sounds were highest, the manatees spent more time feeding and less time milling. In contrast, Hodgson and Marsh’s (2007) experimental and behavioural studies showed that the time that dugongs spent feeding and travelling was unaffected by boat presence, the number of boat passes and whether a pass included a stop and restart. However, focal dugongs were less likely to continue feeding if the boat passed within 50 m, than if the boat passed at a greater distance. Boats passing at a range of speeds, and at distances of less than 50 m to over 500 m evoked mass movements of dugong feeding herds, but such movements only lasted a

couple of minutes. Castelblanco-Martínez and Arévalo-González (2015) experimentally studied the effects of side-scan sonar operating 455 kHz on the behaviour of 12 captive Antillean manatees. All the observed manatees variously showed behavioural changes including stopping foraging and feeding, significantly reducing displacement and remaining still at the bottom or at the surface, and increasing displacement behaviour. One male displayed continuous spinning movements for almost the entire experimental session. Most animals avoided the area nearest to the transducer.

Sirenians are not wilderness animals (Marsh *et al* 2011). Manatees occur in the inshore waters of Florida and have continued to use the intra-coastal waterway and residential canal estates, despite a high level of vessel activity (for references see Marsh *et al* 2011). Dugongs continue to use Johore Strait between Singapore and Peninsula area, one of the most heavily-used coastal waterways in the world, and are often detected in ports and military training areas along the Queensland east coast on the basis of their feeding trails and satellite tracking (Marsh *et al* 2011, Cleguer *et al* 2016). Hodgson *et al* (2007) experimentally tested the behavioural responses of dugongs to 4 and 10 kHz acoustic alarms (pingers). The rate of decline of the number of dugongs within the focal arena did not change significantly while pingers were activated. Dugongs passed between the pingers irrespective of whether the alarms were active or inactive, fed throughout the experiments and did not change their orientation to investigate pinger noise, or their likelihood of vocalizing. Thus despite the short-term behavioural responses noted above, there is no evidence that wild dugongs or Florida manatees are displaced by underwater noise, including side scan sonar (Gonzalez-Socoloske *et al* 2009). The reaction of dugongs and manatees to plosive sounds does not appear to have been formally tested.

Both manatees and dugongs use underwater sound for communication. There have been numerous studies of sirenian communication sounds (see Marsh *et al* 2011). Characteristics of individual call notes seem fairly similar among the species of sirenians. Frequency ranges are typically from 1 to 18 kHz, often with harmonics and non-harmonically related overtones (e.g Anderson and Barclay 1995, Sousa-Lima *et al* 2002, O'Shea and Poche 2006).

Adults of both sexes produce vocalizations, but exchanges of communication calls are most common

between cows and their nursing calves. Florida manatee calves vocalize at much greater rates than adults (Sousa-Lima *et al* 2002, O'Shea and Poche 2006). Manatees other than cows and calves vocalize at rates that vary with activity and behavioural context, and are lowest during resting, intermediate while travelling, and highest at nursing and other social situations (Reynolds 1981, Bengtson and Fitzgerald 1985, Williams 2005, O'Shea and Poche 2006, Miksis-Olds and Tyack 2009). Dugongs seem to vocalize more often during dark, early morning hours (Ichikawa *et al* 2006). No data are available on vocal communication in African manatees, *Trichechus senegalensis*, although recordings and sound spectrograms of calls of an isolated captive calf in Cote d'Ivoire were similar to those of some Florida and Amazonian manatee calves (TJ O'Shea unpublished). Florida manatees may alter vocalization parameters in response to environmental noise levels (Miksis-Olds and Tyack 2009). Sakamoto *et al* (2006) attempted to quantify the effect of vessel noise on the vocal characteristics of dugongs (number of call per minute, dominant frequency and call duration). None of the changes was significant.

We know of no information regarding PTS, TTS or noise-induced auditory damage in sirenians.

B.7.2. Habitat Considerations

In the marine environment, both manatees and dugongs mostly occur in shallow waters because of their dependence of seagrass communities (Marsh *et al* 2011). Antillean and African manatees are both riverine and estuarine and in the marine environment mainly occur in water less than 5 m deep. Dugongs are strictly marine, feeding in waters up to about 35 m deep. They may occasionally cross ocean trenches (see Marsh *et al* 2011), but typically spend most of their lives in much shallower inshore coastal and island waters often commuting with the tide to or from intertidal seagrass meadows (Marsh *et al* 2011). There is increasing evidence that dugong migration corridors follow topographic features such as coastlines (Zeh *et al* 2016 in press) or reef crests (Cleguer 2015).

B.7.3. Impact of Exposure Levels

Given that the available evidence suggests that manatees and dugongs are unlikely to be displaced by noise, the most practical approach to reducing the risk of impacts is avoidance of the overlap of acute sound impacts with seasonal aggregation sites

and periods when the animals are likely to be under stress. Seasonal aggregation sites are most likely at the high latitude limits of the ranges of dugongs and manatees and typically occur as a behavioural repose to thermal conditions or prolonged periods of rough weather (see Marsh *et al*, 2002 and 2011 for details of some well-known sites in Florida, Australia and the Arabian region). Site-specific information on this topic should be a focus of the Environmental Impact Assessment process. Extreme weather events such as cyclones or prolonged cold fronts can cause substantial increases in mortality (Marsh *et al* 2011, Meager and Limpus 2013) and noisy construction impacts should be planned to avoid times of likely environmental stress.

B.7.4. Assessment Criteria

We know of no field studies on the effects of anthropogenic noise, other than vessel noise on sirenians. The effect of vessel noise *per se* seems much less than that of vessel collisions. This lack of evidence does not prove that noise has negligible consequences for sirenian conservation, and more attention should be dedicated to a better understanding of possible impacts and ways to ameliorate them. A precautionary approach to the exposure of manatees and dugongs to noise, especially at key habitats and aggregation sites, is warranted.

References

- Anderson, PK. and Barclay, RMR. 1995. 'Acoustic signals of solitary dugongs: physical characteristics and behavioral correlates'. *Journal of Mammalogy*, 76, 1226–1237.
- Bengtson, JL. and Fitzgerald, SM. 1985. Potential role of vocalizations in West Indian manatees. *Journal of Mammalogy*, 66, 816–819.
- Bullock, TH O'Shea, TJ. and McClune, MC. 1982. 'Auditory evoked potentials in the West Indian manatee (*Sirenia: Trichechus manatus*)'. *Journal of Comparative Physiology A. Sensory, Neural, and Behavioral Physiology*, 148, 547–554.
- Castelblanco-Martínez, N. and Arévalo-González, K. 2015. 'Behavioral reaction of manatees to a side-scan sonar: preliminary results'. Abstract of presentation at 21st Biennial Meeting of the Society of Marine Mammalogy San Francisco, December 2015.
- Cleguer, C. 2015. 'Informing dugong conservation at several spatial and temporal scales in New Caledonia'. PhD thesis, James Cook University, Australia.
- Cleguer, C Limpus, C.G Gredzens, C Hamann, M Marsh, H. 2015. 'Annual report on dugong tracking and habitat use in Gladstone in 2014'. Report produced for the Ecosystem Research and Monitoring Program Advisory Panel as part of Gladstone Ports Corporation's Ecosystem Research and Monitoring Program.
- Gaspard, I Joseph Bauer, G Reep, R Dziuk, K Cardwell, A Read, L Mann, D. 2012. 'Audiogram and auditory critical ratios of two Florida manatees (*Trichechus manatus latirostris*)'. *Journal of Experimental Biology* 215, 1442–1447
- Gerstein, ER. 1999. 'Psychoacoustic evaluations of the West Indian manatee'. PhD dissertation, Florida Atlantic University, Boca Raton, FL USA.
- Gerstein, E. 2002. 'Manatees, bioacoustics and boats'. *American Scientist*, 90, 154–163.
- Gerstein, ER Gerstein, L Forsythe, SE. and Blue, JE. (1999). 'The underwater audiogram of the West Indian manatee (*Trichechus manatus*)'. *Journal of the Acoustical Society of America*, 105, 3575–3583.
- Gonzalez-Socoloske, D Olivera-Gomez, DL. and Ford, RE. 2009. 'Detection of free-ranging West Indian manatees *Trichechus manatus* using side-scan sonar'. *Endangered Species Research*. 8: 249–257.
- Hartman, DS. 1979. 'Ecology and behavior of the manatee (*Trichechus manatus*) in Florida'. *American Society of Mammalogists Special Publication*, 5, 1–153.
- Hodgson, AJ. and Marsh, H. 2007. 'Response of dugongs to boat traffic: the risk of disturbance and displacement'. *Journal of Experimental Marine Biology and Ecology*, 340, 50–61.
- Hodgson, AJ Marsh, H Delean, S. and Marcus, L. 2007. 'Is attempting to change marine mammal behaviour a generic solution to the bycatch problem? A dugong case study'. *Animal Conservation*, 10, 263–273.
- Ichikawa, K Tsutsumi, C Arai, N. *et al* 2006. 'Dugong (*Dugong dugon*) vocalization patterns recorded by automatic underwater sound monitoring systems'. *The Journal of the Acoustical Society of America*, 119, 3726–3733.
- Mann, DA O'Shea, TJ. and Nowacek, DP. (2006). 'Nonlinear dynamics in manatee vocalizations. *Marine Mammal Science*', 22, 548–555.
- Marsh, H Spain, A. V. and Heinsohn, G. E. 1978. 'Minireview: physiology of the dugong. *Comparative Biochemistry and Physiology*', 61, 159–168.
- Marsh, H Penrose, H Eros, C. and Hugues, J. 2002. 'The dugong (*Dugong dugon*) status reports and action plans for countries and territories in its range.' *Early Warning and Assessment Reports*. Nairobi: United Nations Environment Programme. 162 pp.
- Marsh, H, O'Shea, TJ, Reynolds, JE III. 2011. 'The ecology and conservation of Sirenia: dugongs and manatees'. Cambridge University Press. 521pp.
- Meager JJ, Limpus C. 2014. 'Mortality of Inshore Marine Mammals in Eastern Australia Is Predicted by Freshwater Discharge and Air Temperature'. *PLoS ONE*. 9(4):e94849.
- Miksis-Olds, JL. and Tyack, PL. 2009. 'Manatee (*Trichechus manatus*) vocalization usage in relation to environmental noise levels'. *Journal of the Acoustical Society of America*, 125, 1806–1815.
- Miksis-Olds, JL Donaghay, PL Miller, JH Tyack, PL. and Reynolds III, JE. 2007. 'Simulated vessel approaches elicit differential responses from manatees'. *Marine Mammal Science*, 23, 629–649.
- Miksis-Olds, JL and Wagner, T. 2010. Behavioral response of manatees to environmental sounds levels. *Marine Mammal Science*, 27 130–148.
- O'Shea, TJ. and Poche, LB. 2006. 'Aspects of underwater sound communication in Florida manatees (*Trichechus manatus latirostris*)'. *Journal of Mammalogy*, 87, 1061–1071.
- Reynolds III, JE. 1981b. 'Aspects of the social behaviour and herd structure of a semi-isolated colony of West Indian manatees, *Trichechus manatus*'. *Mammalia*, 45, 431–451.
- Sakamoto, S Ichikawa, K Akamatsu, T Shinke, T Arai, N Hara, T Adulyanukosol, K. 2006. 'Effect of ship sound on the vocal behavior of dugongs'. *Proceedings of the 3rd International Symposium on SEASTAR2000 and Asian Bio-logging Science (The 7th SEASTAR 2000 workshop)* 69–75.
- Sousa-Lima, RS Paglia, AP. and Da Fonseca, GAB. 2002. 'Signature information and individual recognition in the isolation calls of Amazonian manatees, *Trichechus inunguis* (Mammalia: Sirenia)'. *Animal Behaviour*, 63, 301–310.
- Williams, LE. (2005). 'Individual distinctiveness, short- and long-term comparisons, and context specific rates of Florida manatee vocalizations'. MS Thesis, University of North Carolina, Wilmington.
- Zeh . DR Michelle R. Heupel, MR Hamann, M Limpus, CJ Marsh, H. 2016. 'Quick Fix GPS technology highlights risk to marine animals moving between protected areas'. *Endangered Species Research*, 30, 37–44