Cetaceans - Acoustic disturbance and noise pollution

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1. How do cetaceans communicate and why is it so important?

In the absence of touch and smell, sound is the primary sense for marine animals (Nowacek *et al*, 2007). Sound travels almost five times faster through sea water than through air (Nowacek *et al*, 2016) allowing effective and fast communication amongst individuals over long distances where sight may be limited (Nowacek *et al*, 2016). Whales and dolphins use a wide band of acoustic frequencies, from the low-frequency sounds of ∼15 Hz used by the blue whale, to porpoises at 120 – 150 kHz (Nowacek *et al*, 2007).

The cetacean ear is specialised to hear underwater and has overcome the challenge of impeded directional hearing by acoustically isolating the ears from the skull, either by decoupling the ear from the skull, as seen in dolphins, or by evolving voluminous and heavy bones around the ear cavity and inner ear, as seen in baleen whales, though the sound perception pathway in mysticetes remains unknown, (Ritsche *et al*, 2018).

Dolphins and toothed whale species (odontocetes) such as the sperm whale use high-frequency acoustics in a process known as echolocation. High-frequency ‘clicks’ are emitted and reflected off other animals or features of the marine environment, thus dolphins can use the reflections to build a picture of their environment or to alert them to potential prey objects in the water column (Nowacek *et al*, 2016). Low- to mid-frequency acoustic signals are sometimes produced during feeding, though they are not considered essential for successful foraging (Nowacek *et al*, 2016). Individual dolphins may develop a unique signature whistle developed within their natal environment and can imitate synthetic whistles in a laboratory environment showing they can learn to produce vocalisations, a rare non-human skill (Tyack, 2019). Sperm whales communicate using rhythmic patterns of clicks called codas. The short-range of codas suggests they serve as communication within a group, helping to identify a group, or individual belonging to that group. Social groups with the same codas may join one another but this is rare among units with different codas. Codas may therefore mediate affiliation between units (Tyack, 2019).

Baleen whale species such as the humpback whale (*Megaptera novaeangliae*) emit a range of vocalisations ranging from ‘grumbles’ (high-frequency) to bird-like ‘chirps’ (low-frequency) and included modulated (such as ‘cries’ and ‘moans’), amplitude-modulated (such as ‘purrs’ and ‘growls’), and broadband (such as ‘underwater blows’) sound types. Such vocalisations are heard during breeding and feeding social interactions and as with the toothed species these noises may clarify social information between individuals such as group membership and other information including sex, size, location, and the motivation of the signaller (Dunlop, 2019).

2. How does noise affect cetaceans?

Mixed in between the large range of frequencies used by cetaceans are the sounds introduced by humans (Nowacek *et al*, 2007). The primary sources of noise pollution are commercial shipping, seismic airgun exploration (for oil and gas), and naval and mapping sonars. These sources of noise have the potential to cause negative impacts over hundreds of thousands, to millions of square kilometres (Weilgart, 2018). Documented impacts include:

- fatal strandings
- hearing damage
- long-term avoidance of the noisy area
- higher energetic costs
- stress responses
- changes in vocalisations – leading to disruptions in reproduction, foraging, and migration
- the masking or obstruction of important vocalisations and sounds

Baleen whales are more sensitive to the low frequencies (20 – 200 Hz) emitted by large ships (Rolland *et al.,* 2012) whereas the high-frequency using dolphins, and some toothed whales, are affected by the energy emitted at higher frequencies (tens of kHz) (Erbe *et al*, 2019). Rolland *et al.,* (2012) investigated the effect of shipping noise on right whales (*Eubalaena glacialis*) in the Bay of Fundy, Canada, and found evidence that suggests noise can cause chronic stress in whales. After the tragic events of 9/11, 2001, a reduction in ship traffic saw a 6 dB decrease in underwater noise, with a significant reduction below 150 Hz. Of three habitats compared, whales in the habitat with the highest background levels of shipping noise were found to have significantly higher frequencies of upcalls. This alteration in vocalisation behaviour in response to noise has been previously observed in other acoustic studies. Furthermore, the reduction in noise was associated with a decrease in the baseline levels of stress-related faecal hormone metabolites (glucocorticoids) in faecal samples collected from the whales.

Cetaceans living in freshwater systems are often overlooked but are also at risk from the impacts of noise. The critically endangered Yangtze finless porpoise (*Neophocaena asiaeorientalis asiaeorientalis*) resides in the Yangtze River, China. Noise levels at 25 sites along the middle and lower sections of the Yangtze River were measured and the majority of sites were found to have spectra levels higher than the audiogram of the finless porpoises (Wang *et al*, 2020).

3. Sources of noise pollution

3.1. Shipping and watercraft

Ship noise has become the most ubiquitous source of anthropogenic noise in the oceans and is responsible for increases in ambient noise at low frequencies (10–100 Hz) at a reported rate as high as 3 dB/decade. The noise field around a ship is not uniform and is dependent upon the source frequency, the surrounding environment, and vessel direction, speed, load and size. The strongest noise source is caused by propellers when cavitation occurs (the production of vapour filled cavities 'bubbles' caused by rapid changes in pressure within a liquid) and increases with vessel speed, size, and load. The direction that noise will travel is highly variable. In shallow water, ship noise interacts with the water surface and seafloor where it is reflected, scattered, and partly absorbed. In deeper water noise moves primarily downward (Erbe *et al*., 2019).

3.2. Whale watching

In the last few decades whale-watching has garnered a reputation for being a sustainable alternative to commercial whaling and a form of green, eco-friendly tourism. Whilst whale watching can promote knowledge and pro-conservation intentions amongst tourists (García-Cegarra and Pacheco, 2017) previous studies have uncovered variable results (Erbe, 2006: Clemente *et al,* 2018: Argüelles *et al,* 2016) with responses often different between species and individuals of a species. Documented responses include changes to surfacing and dive patterns, swim speed and direction, and a decrease in the time spent feeding and/or resting (New *et al*, 2015). Sprogis *et al*, (2020) conducted controlled exposure experiments on 42 resting mother-calf pairs on a resting ground off Australia using a research vessel traveling at a speed 1.5 knots. The vessel simulated a whale-watching boat as it approached the whales Compared to control/low treatments (124/148 dB), during high noise playbacks (172 dB), the proportion of time mothers spent resting decreased by 30%, respiration rate doubled, and swim speed increased by 37%.

3.3. Ice-breaking

Icebreakers produce sounds related to pushing and crushing ice and produce broadband radiated noise levels as high as 200 dB re 1 µPa m (Erbe, 2019). Erbe and Farmer (2000) investigated the impact of a Canadian icebreaker operating in the Beaufort Sea, north of Alaska, on the Beluga whale (*Delphinapterus leuca*). The two noises investigated were those produced by the bubbler system and from propeller cavitation. Bubbler systems emit high pressure air into the surrounding water to push ice away from the vessel. A model estimated that the icebreaker would be audible to belugas over a range of 35 – 78 km, depending on the location of the individual. The icebreaker was also predicted to mask the vocalisations of belugas within a 14 - 71 km range of the vessel and furthermore, temporary hearing damage may occur if belugas stayed within 1 - 4 km of the icebreaker.

3.4. Military activity

In May of 1996, the NATO Undersea Research Centre (NURC) in La Spezia, Italy, conducted a Shallow Water Acoustic Classification research trial in the Kiparissiakos Bay in western Greece using low to mid-frequencies (centred at 600 Hz and 3 kHz). A mass stranding of Cuvier's beaked whales (*Ziphius cavirostris*) occurred in the vicinity of the sonar test shortly afterwards, a rare occurrence for this particular species. In March 2000, the U.S. Navy conducted active sonar training involving several warships in a channel near the Abacos Islands, Bahamas. Within hours, 14 beaked whales (nine *Z. cavirostris*, three *Mesoplodon densirostris*, and two species that could not be identified) were found stranded along the shores of Abaco and Grand Bahamas to the north. Three single-animal stranding's of other species were also reported nearby. Again, this was a rare occurrence considering that Beaked whales had not been known to mass-strand in this area previously (Filadelfo *et al*, 2009).

Filadelfo *et al*, (2009) investigated a historical correlation between large-scale naval activity and beaked whale mass stranding's. The stranding's took place in four regions in which there was frequent naval activity. The Mediterranean and Caribbean Seas showed significant correlations and Japan and southern California did not. The results suggested that military sonar activity alone may not lead to increased beaked whale stranding's. However, when conducted in a location with steep bathymetry that is close to an adjacent coastline, and with military sonars used seaward, sonar activity may be an important factor in the occurrence of local stranding's, as was the case with the Mediterranean and Caribbean seas.

3.5. Seismic surveys

Seismic surveys are used for natural resource exploration. Artificially generated shock waves are produced and are reflected or refracted from the different rock strata before being picked up by hydrophones near the surface. The time it takes for returning waves to reach the surface may help identify geological features that contain natural resources such as gas and oil. The intermittent sound pulses emitted during surveys are more intense than that emitted by industrial noises and the peak frequency bands overlap those used by cetacea (Monaco *et al*, 2016). The displacement of cetaceans during seismic surveys has been previously reported and there have been possible links between surveys and stranding's for a dozen events. There is an overall a lack of causal evidence between seismic activity and cetacean deaths, though this absence should be considered as the consequence of a lack of comprehensive analysis of the circumstances rather than the surveys are not an issue (Castellote and Llorens, 2016).

McGeady *et al*, (2016) investigated the effects of seismic surveying and environmental variables on deep diving odontocete stranding rates along Ireland's coast. Their analysis indicated that the occurrence of seismic surveying operations off the coast of Ireland may have increased the number of stranding events for long-finned pilot whales, as well as all species grouped together. The increased effect for long-finned pilot whales may result from their high abundance in the area.

3.6. Drilling and Dredging

Richardson *et al*, (1990) had previously found that bowhead whales (*Balaena mysticetus*) in the Canadian Beaufort Sea showed individual sensitivity to playback of industrial noise from drill ships and dredges. Some whales moved away from the source of the noise and roughly half responded when noise was 20 - 30 dB above ambient. During some of the playback tests, the call rates of whales decreased, feeding ceased, and cycles of surfacing, respiration and diving may have changed.

A more recent study by Blackwell *et al*, (2017) also investigated the behavioural response of bowhead whales in the Bering-Chukchi-Beaufort. The whales migrate westwards in late August as part of their autumn migration. This autumn migration brings them closer to the northern shores of Alaska than at any other time of the year and is associated with activities relating to the oil and gas industry. The primary result was that the calling rates of whales were affected when in an area where industrial noise was to be found. The calls of whales peaked where increasing noise was present before decreasing. This increase in calling is consistent with previous studies and is seen in many invertebrate groups when individuals wish to maintain communication in a high noise environment. To be heard above background noise, an individual may increase the amplitude of their signal, change the frequency of their signal, or increase the repetition rate of their signal. Why did call rates peak and then decrease? Even if not entirely masked, there may come a time where background noise makes communication less effective, with more errors, and simply not worth an individual's efforts.

4. How can we mitigate noise pollution in our oceans?

It is predicted that world seaborne trade will grow by a factor of 2.5% from 2020 to 2040. Policymakers in some jurisdictions have commitments for the mitigation of noise pollution but there remains no international legally binding instrument to control, mitigate, and monitor noise in the marine environment. This legal gap makes stakeholders reluctant to take the appropriate action needed to address the issue of noise pollution (Vakili *et al*, 2020).

Bröker (2019) set out the potential pathways to mitigate the impacts of noise pollution, particularly from the hydrocarbon exploration industry, on marine mammals.

- **Source** – the use of Sound Source Verification studies to measure sources of sounds such as geophysical equipment and floating oil and gas facilities, can be useful to better assess the impact of the equipment on mammals.
- **Pathway** – propagation models are good at predicting noise propagation over short to medium distances of up to several Km (if parameterised correctly). However, to improve model accuracy, more long-range propagation modelling is required and in various environmental conditions.
- **Receiver** – more audiograms and studies on a wide range of species reduces the need for interpolation between species as well as enhancing our knowledge on the severity of disruptions and their duration.
- **Monitoring** – the development and use of autonomous monitoring technologies that can detect the presence and changes in abundance of mammals can offer insight into the impacts of marine activities on behaviour and distribution.
- **Mitigation** – the modification of industry acoustic technology can help reduce the impact on groups that are more sensitive to certain frequencies e.g. modifying airgun arrays so that they have less or no unnecessary medium and high frequencies (> 200 Hz) can reduce impact on medium- and high-frequency sensitive groups.

Weilgart (2019) also suggest some useful mitigation strategies:

- **Marine mammal observers** - a common mitigation technique, this measure usually involves a 500 m observation radius around a noise source. When animals are detected within this radius, known as a 'safety zone', the sound source will be powered or shut down until the animals leave. This can be difficult as many marine mammals spend vast amounts of their time submerged where they will remain undetected. Fog, waves and wind may also reduce the chances of detection.
- **Passive acoustic monitoring (PAM)** – PAM is conducted by deploying hydrophones to detect marine mammal sounds. This works well for vocal species such as sperm whales and beaked whales however it can be difficult to determine the species and the distance of the calling animal. Despite some drawbacks, PAM has shown promise, especially when used in conjunction with the use of gliders, underwater vehicles, which move PAM devices through the water column both horizontally and vertically.

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