Constant ocean noise and cetaceans with high site fidelity

Written by: Dóra Székely
University of Groningen
MSc Marine Biology

Supervisor: Prof. Per J. Palsbøll

Abstract

Anthropogenic noise in the oceans has increased in the last few decades as maritime transportation, offshore construction and naval activities have increased. The main underwater anthropogenic noise sources are from shipping, military sonar activities and seismic surveys. Since renewable energies are a developing energy source for many countries with sea, the noise provided by offshore windfarm construction is a potential threat as well. Underwater noise is a threat to cetacean species, especially to populations that have an important habitat overlapping with anthropogenic noise sources. Anthropogenic noise can disturb vital life processes of cetaceans, as they rely on acoustic cues for foraging, communication, mating and orientation. Populations that show high site fidelity could suffer more if noise disturbance increases habitat avoidance. The long-term effects of noise disturbance on wild cetacean populations is only speculated, and there are major data gaps in the field of acoustic research on captive and free ranging cetaceans. In this study, publications on cetacean populations that show site fidelity were presented to understand the effects of the major anthropogenic noise threats. Finally, mitigation methods were assessed in order to understand the status of actions to improve underwater noise management.

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Introduction

The oceans are under different source of anthropogenic pressure. One major contributor, noise pollution has emerged since human activities have started to be more ocean based. It has increased to a point that nowadays 90 % world trade is carried on sea and it continues to expand.

The soundscape of the ocean consists of natural and anthropogenic noise sources. Natural noise sources are sea earthquakes, volcanic eruption, wind and precipitation (Weilgart 2007). Anthropogenic noise sources are underwater explosions, seismic explorations, sonar, acoustic deterrent and harassment devices, industrial activities and commercial or recreational shipping. As a conclusion, anthropogenic noise is permanently present in the oceans, especially in the Northern Hemisphere (Hildebrand 2009).

Marine species - like cetaceans – mainly rely on underwater perception. Cetaceans depend on acoustic cues for communication, social interaction, predator avoidance, orientation, feeding and mating (Finneran & Branstetter 2013). These vital, biologically important processes can be disturbed by underwater anthropogenic noise. The study of Holt et al. (2009) found that an endangered killer whale (*Orcinus orca*) population used louder calls during high season of shipping traffic. Exposure to noise disturbance can also cause displacement from important habitats either temporarily or permanently (Nowacek *et al.* 2007; Weilgart 2007). Gray whales (*Eschrichtius robostus*) in Baja California abandoned their breeding habitat during a period of offshore construction and due to increased commercial shipping noise between 1950 and 1970. After activities ceased the whales started to reoccur (Bryant *et al.* 1984).

Physiological changes include temporary or permanent hearing damage, or noise induced stress. It was found by Klinkastelein *et al.* (2015) that captive harbour porpoises have temporary reduced hearing when exposed to 60 minute playback of pile driving noise – an acoustic disturbance caused by offshore windfarm construction. Permanent hearing damage has not been induced in captive animals (Nowacek *et al.* 2007). Chronic stress was associated with shipping noise, based on the decreased stress hormone levels of North Atlantic right whales (*Eubalaena glacialis*) during shipping traffic restrictions in the Bay of Fundy (Rolland *et al.* 2012).

Experimental research of the effects of noise on wild cetaceans in an underwater environment is extremely challenging. Research on different taxonomic groups in the marine environment - like invertebrates and fish - found evidence that other marine species are also acoustically sensitive (Slabbekoorn *et al.* 2010; Popper & Hawkins 2016). Experiments on captive cetacean individuals have been conducted (Nowacek *et al.* 2007; Weilgart 2007) but research on live animals is between ethical restrictions, hence some scenarios – such as permanent ear damage – cannot be investigated. Nevertheless, the acoustic environment of a tank and the ocean differs, it is debatable if the test results on captive cetaceans could be extrapolated to free ranging wild animals (Weilgart 2007). As a result, there are major data gaps on the long-term effects of anthropogenic noise on cetaceans. It is suspected that noise overexposure might affect species with high site fidelity (philopatry) more, especially if the critical habitat of a population overlaps with excessive anthropogenic noise sources.

The aim of this essay was to review the recent research conducted in natural environment on species or populations that show high site fidelity. First, I would like to understand the severity of short term - or long term if available - effects of anthropogenic noise on smaller, philopatric cetacean populations. Second, I would like to have an insight on what sort of mitigation methods have been applied or are in the planning process in order to reduce anthropogenic ocean noise. To answer these questions, research publication on the effects of anthropogenic noise on wild cetacean populations from different oceans were assessed.

Materials and methods

Shipping noise

North Atlantic right whales (*Eubalaena glacialis*) are one of the most endangered baleen whale species in the world (Reilly *et al.* 2012). The habitat of North Atlantic right whales overlaps with important shipping routes around the east coast of North America. An unfortunate event of a terrorist attack in 2001 (9/11) and consequent commercial shipping restrictions allowed for a research opportunity to compare stress hormone levels in North Atlantic right whales in the Bay of Fundy. Acoustic and ship traffic data with faecal glucocorticoid levels (stress related hormone metabolites) were compared to assess stress levels before and after 9/11 (Rolland *et al.* 2012).

Another highly philopatric population, the endangered southern resident killer whale population is exposed to several noise impacts. Southern resident killer whales live in the coastal waters of Washington state and British Columbia (Holt *et al.* 2009). A four element hydrophone array was used at 1-5 m depth to measure the calls of individuals during the highest peak of shipping traffic (between August 23 and September 4, 2007). Background noise level measurements were assessed right before the call of an individual was recorded, and the samples were compared to previously recorded calls of the population.

Sonar and mass stranding events

One of the most – publicly and scientifically - debated anthropogenic noise threats is the military sonar (sound navigation and ranging). There is a hypothesis that mass stranding events occur in relation to noise induced trauma (Richardson 1995). The Canary Islands used to be a major mass stranding spot for several cetacean species, including beaked whale species (Fernández *et al.* 2005; Arbelo *et al.* 2013). These stranding events had a spatio-temporal overlap with military sonar activities. Necropsies were conducted to look for physical signs of noise induced trauma (Jepson *et al.* 2003; Fernández *et al.* 2005; Arbelo *et al.* 2013).

An important evidence of strandings caused by acoustic trauma is based on the analysis of hearing loss, the damage of the inner ear structure (Morell *et al.* 2017). To find evidence of permanent hearing loss, the inner ear cells of the organ of Corti needed to be analysed.

Seismic survey

Marine seismic surveys produce an intense sound emission to explore the ocean bottom, in search of natural resources of oil and gas, or for geophysical research.
Western pacific gray whale population is considered critically endangered by the international Union for Conservation of Nature and Natural Resources (IUCN)

Amongst other anthropogenic threats, the feeding ground of this population overlaps with an offshore gas and oil development area, in the Okhotsk sea, off Sakhalin Island. The study of Muir et al. (2016) surveyed gray whale abundance during a seismic survey event in 2010, to understand if the noise disturbance changed the abundance and distribution of the whales. Shore based surveys were used to calculate abundance, and underwater noise measurements were used to monitor background noise levels.

Offshore wind farms

Offshore wind farms are an important renewable energy source to support energy consumption. However, as a downside of this energy substitute there has been a global concern about the impact of the noise that offshore windfarms produce (Thompson *et al.*

2010). The biggest concern is the noise produced by construction sites and the decommissioning of wind turbines – pile driving – and it is suspected that the noise impact from pile driving could cause temporary hearing loss or could force the animals to avoid important habitats.

Thompson et al. (2010) described an underwater noise detector called T-POD (Timed Porpoise Detectors) that can be adjusted to record echolocation clicks of several species. Two main wind turbines of the Beatrice Demonstrator Project were constructed in Moray Firth, off Scotland (2006 July-August). Moray Firth is the critical habitat of a local protected bottlenose dolphin population (*Tursiops truncatus*). Thompson et al. (2010) applied the T-POD to assess the abundance of echolocating cetacean species during the construction. The acoustic monitoring took place between 2005 and 2007 and was complemented with visual observations to monitor marine mammal occurrences near the construction area.

Results

Shipping noise

The study of Rolland et al. (2012) found decreased stress level in North Atlantic right whales during the shipping restrictions in the Bay of Fundy during the 9/11 terrorist attack. Decrease in faecal glucocorticoids in 2001 was highly significant compared to the results of samples from other years.

Commercial shipping noise can mask the voice produced by toothed whales. The study of Holt et al. (2009) found that killer whales increased the amplitude of their calls, as the noise produced by vessel traffic increased. As the background noise increased with 1 dB, the individuals raised their call level with 1 dB.

Sonar and mass stranding events

Stranded cetaceans seldom present symptoms similar to decompression sickness also found in humans (Jepson *et al.* 2003). Necropsies of mass stranding events in the Canary Islands described by Arbelo et al. (2013) have shown gas bubbles and fat emboli, that are consistent with the decompression sickness of humans. The presence of gas emboli was found in beaked whale species only, during the mass strandings occurring at the Canary Islands between 1999 and 2005, consistently overlapping with military sonar activities (Arbelo *et al.* 2013). Other species were also found with gas bubble lesions – Risso's dolphin (*Grampus griseus*), common dolphin (*Delphinus delphis*), harbour porpoise (*Phocoena phocoena*) but only occasionally, during mass stranding events in Britain (Jepson *et al.* 2003).

Seismic survey

The study of Muir et al. (2016) found that gray whales of the Okhotsk Sea, off Sakhalin Island showed higher occupancy at areas with moderate sound exposure levels, however low sound exposure areas were barely occupied. An avoidance response was likely –based on land observations - if the whales were exposed to long period of disturbance.

Offshore windfarms

The results of the study of Thompson et al. (2010) have not described major long-term changes in cetaceans related to the wind turbine construction sites. Short time responses were presented by porpoises within 1-2 km of the site. Bottlenose dolphins were detected on T-PODS less than 10 % of the monitored days. However, based on surveys common dolphins were more often sighted around the area of the construction than bottlenose dolphins.

Discussion

Anthropogenic noise is a threat to cetaceans that rely on acoustic cues for vital processes. Little is known about the effects of man produced noise impacts, but evidence shows that it is an important conservation management issue. In this study the focus was on the effect of anthropogenic noise on cetacean populations that show high site fidelity, as it is assumed that high site fidelity calls for special attention when planning mitigation actions (Forney *et al.* 2017). In this study, I compared four different anthropogenic noise sources (shipping, sonar, seismic survey and offshore windfarms) that threaten populations that rely on important habitats, compared the results and assessed the planned or implemented mitigation methods.

Populations that rely on habitats that are overlapping with important shipping routes can be disturbed by the constant noise impacts of commercial shipping noise. The study of Rolland et al. (2012) have found decreasing stress in North Atlantic right whales with decreased noise levels. However, as this study was unplanned and the replication is not possible, there is no possibility to compare noise levels of the Bay of Fundy with other years. The difference in faecal glucocorticoids was highly significant compared to other years, the sample size collected after September was low due to unfavourable weather conditions.

The study of Holt et al. (2009) has proven that southern killer whales have increased their call amplitudes proportionally to the increase of background noise. This phenomenon is called the Lombard effect (Lane & Tranel 1971), and has been documented with Beluga whales in the Gulf of St. Lawrence (Scheifele *et al.* 2005). It is unknown how would a change in vocal behavior could affect the fitness of individuals. However, southern resident killer whales are listed endangered by the Endangered Species Act, identifying chemical pollution, noise pollution and prey depletion as the three major threats. In 2011 regulations were enforced to restrict boats to approach any killer whale's path within 200 yards (183 m, NOAA 2011). A follow-up study of Holt et al. (2017) found no significant noise level change in the area – comparing noise disturbance before and after the vessel regulations. Another, five-year action plan (vessel restriction, prey recovery, revision of critical habitats) is in implementation at the moment to stop the decreasing trend of the population (NOAA 2016).

Military exercises often occur at important cetacean habitats, just like in case of the Canary Islands. Gas bubble formation is a possible indicator according to Jepson et al. 2003, but it is not always found during necropsies conducted on stranded animals (England 2001; Southall *et al.* 2013). Fernández et al. (2005) stated when stranded animals are found with gas bubbles sonar exposure should be suspected, but data should be collected from unexposed controls to understand the underlying mechanisms of gas bubble formation. In order to find direct evidence of permanent hearing loss caused by sonar, post-mortem analysis of the inner ear structure and the inner ear cells of the organ of Corti needs to be conducted. This procedure is quite challenging as the inner ear cells get destroyed by quick autolysis within a few hours after death (Morell *et al.* 2017). The U.S. Navy published a report on the mass stranding event that occurred in the Bahamas in 2000 and coincided with naval activities using mid-frequency sonar, and concluded that the mass stranding was caused by the military sonar (England 2001). Besides the mass stranding of the Bahamas, several mass stranding events coincide with sonar activities (Nowacek *et al.* 2007; Weilgart 2007) but reports and necropsies cannot confirm or deny the causality of the incidents. However, the Spanish government banned naval exercises around the waters of the Canary Islands in 2004, and no mass stranding events occurred since (Fernández *et al.* 2013).

The study of Muir et al. (2016) showed that gray whales –during a seismic survey - were only occupying moderate sound exposure areas, and had low occurrence in low sound exposure areas. On the other hand, the low sound exposure areas were shallow water habitats, which is not the preferred habitat of gray whales. The interpretation needs to be handled carefully, as only a few whales were present at the area before and during the seismic survey, thus limited abundance data was available. The absence of whales during the seismic survey is a concern, and understanding the long-term effects of seismic survey noise impacts and implementing mitigation methods are still a priority. Nowacek et al. (2015) suggests - as the noise of marine seismic survey has an international and transboundary nature - the creation of an international convention on the regulation. Another plan is to substitute airguns with a next generation marine vibroseis (MarVib), but the method is currently under development. This method suppresses higher frequency components, and expected to have less environmental impact than airguns (LGL & MAI 2011) and would be beneficial for species that are sensitive to higher frequency sounds. The main problem is data deficiency on the actual effects of this method.

Empirical assessment of the effects of offshore windfarms on cetaceans is rather challenging, as visual surveys cannot detect changes in abundance and behaviour with high power (Taylor *et al.* 2007). The results of Thompson et al. (2010) on the effects of an offshore wind turbine construction indicated no long-term effects of the noise impact produced by the construction of two wind turbines. The assessed endangered bottlenose dolphin population was concluded to be at low risk of damage by pile driving noise disturbance. The population seems to occupy more offshore habitats, further away of the noise source. On the one hand, Thompson et al. (2010) argues that sound propagation could cause effects even 40 km off the noise source. On the other hand, acoustic T-POD devices are only able to determine if the echolocation clicks were present or absent during a period of time, they do not provide information on the number of animals present in the area. Also, the absence of echolocation could be a sign of echolocation behaviour change or avoidance. Finally, the study also states low power of spatial coverage. The European Union is planning on expanding offshore wind farms until 2020, including the Baltic Sea that is the critical habitat of a critically endangered harbour porpoise subpopulation (Hammond *et al.* 2008). Constructions might take up several years, thus there is a high demand of understanding the effects and establishing adequate mitigation methods. As an example to control the noise during offshore windfarm construction, Germany adapted rules for pile driving in the German North Sea and Baltic Sea (Young *et al.* 2015) that involves reduced pile driving energy, and a bubble curtain around the noise source. Pile driving noise has been reduced successfully, although the results of the assessment were produced in shallower waters (30 m), and noise reduction decreases with increasing depth. It is a concern as future offshore windfarms are planned to be located in deeper waters, 30-60 m.

A four year project, supported by the European Union called „Achieve Quieter Oceans by shipping noise footprint reduction (AQUO) " was launched in 2012 (Audoly *et al.* 2017). The aim of the project was to mitigate anthropogenic ocean noise with a multidisciplinary approach that involved marine scientists and experts from the ship building industry. The main objective was to develop a noise footprint assessment model to predict the noise footprint of shipping activities and create a practical guide for policy makers. The work of Audoly et al. (2017) stated that the output of the model could be applied to a global scale or to a vessel level, by creating new designs for ship building companies or apply changes to the existing fleet. However, as of this moment, the implementation of recommended novel designs is merely voluntary. Further recommendations for implementation include: categorizing maritime areas and list those that are critical, defining noise limits depending on the sensitivity of the ecosystem, establishing restrictions to ships emitting intense underwater radiated noise, and give the ship traffic management to authorities to control the protected areas.

The Ocean Noise Strategy Roadmap is the project of the National Oceanic and Atmospheric Administration (NOAA). NOAA is a federal agency that manages the oceans of the USA by several legislations. The Ocean Noise Strategy Roadmap was created in 2016 to support the implementation of noise reduction strategies and management via a „cross-NOAA team", that is a group of experts connecting agencies, scientists and stakeholders (Gedamke *et al.* 2016). The planning time is 10 years, but there are current mitigation methods presented by the NOAA. First, the voluntary guideline for reducing underwater noise of commercial shipping. Second, the Marine Mammal Protection Act, that amongst other important duties investigates marine mammal strandings and their association with harmful sound exposure. Third, the National Marine Sanctuaries Act, that aims to protect important habitats and define them as sanctuaries, that allows to limit activities within the area. Finally, the Magnuson-Stevens Fishery Conservation and Management Act protects essential fish habitats, that is also important to maintain marine ecosystems.

As constant noise can be a chronic stressor that affects individuals and ecosystems, the regulation of shipping noise could be added to the mitigation methods of marine protected areas. The restoration of already degraded habitats is crucial, but Williams et al. (2015) suggested, that while waiting on the implementation of shipping noise reduction of cetacean habitats that are under a high level of noise pressure, finding habitats with high cetacean abundance that are still "quiet" and protecting them might result in faster conservation actions.

Another aspect of the challenges of underwater noise impact research is the potential conflict of interest in learning about the effects of anthropogenic noise on marine mammals (Gannon *et al.* 2004; Weilgart *et al.* 2005; Dalton 2006; Wade *et al.* 2010). Wade et al. (2010) investigated publications based on the funding agents behind the project and found a two-way bias. Publications supported by conservation groups almost concluded an effect of noise on cetaceans, while projects funded by the U.S. Navy (funds 50% of marine mammal research worldwide) either concluded no effect, but effect and no effect at the same time was the conclusion of most publications.

The two major review articles on the effects of anthropogenic noise on cetaceans claimed that major data gaps still need to be filled to have a deeper understanding on the potential consequences of increasing ocean noise (Nowacek *et al.* 2007; Weilgart 2007).

Conclusions and recommendations

Based on this review it is clear that there are major data gaps in the field of anthropogenic ocean noise research, and on the effect on cetaceans. On one hand, the underwater environment is a challenging scenario to study the effect of noise on wild cetacean individuals and populations. Based on the available literature discussing results of altered behaviour or physiological state of cetaceans, it can be concluded that anthropogenic noise is a threat to cetaceans. The level of impact, severity and the consequences are unknown. Mitigation recommendations provided by different governmental assessment projects (AQUO, NOAA) are mainly voluntary, there are no legislations providing a legal ground to control and reduce ocean noise. The only way to enforce such changes is to provide evidence of noise induced disturbance and their consequences on marine ecosystems.

It is suspected, that the biggest impact is on those species or populations that show extreme site fidelity and small population size, as they are relying on a specific habitat. Risk assessment and management should consider endangered philopatric populations with priority.

Some evidence of noise induced physical trauma has already been provided, and the U.S. Navy acknowledged in a report that their sonar caused the stranding and death of beaked whales in the Bahamas. Nevertheless, the example of the Canary Islands and the absence of mass stranding events since the ban of navy sonar activities cannot be ignored. As it is highly unlikely that underwater naval exercises will cease in the near future, it is important to come up with a solution that benefits marine mammals as well as national security.

As knowledge on the effect of anthropogenic noise is full of gaps, it would be important to put more effort and funding in acoustic monitoring methods, and in research on the effects of sound exposure on wild cetaceans.

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