Anthropogenic Noise Negatively Impacts Dolphin Communication

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Abstract

Human impacts on wildlife have become persistent since the beginning of the Industrial Revolution. In addition to habitat destruction, pollution, and climate change, noise as a result of human activity, or anthropogenic noise, has had significant impacts on marine animals (Sørensen et al., 2023). In the ocean, sound transmits over 4.3 times faster than on land, so marine creatures often utilize auditory signals to communicate across vast distances. However, ambient noise in marine environments as a result of human activity has also been increasing since the 1900s, with commercial shipping, marine exploration, and tour boats all being primary contributors (Hildebrand, 2004). Anthropogenic noise has been shown to be disruptive to animal species that use acoustic signals in order to communicate, including dolphins (Sørensen et al., 2023). Bottlenose dolphins (*Tursiops truncatus*) in particular are known to use complex vocal signals to convey information about identity, location, and food sources. Recently, bottlenose dolphins have faced increased contact with humans in the temperate and tropical waters of the Atlantic and Pacific Oceans where they live. Anthropogenic noise in these habitats significantly alters vocal behavior by masking their auditory signals, hindering dolphin whistle recognition by conspecifics, and disrupting hunting activities (Nakahara, 1999). Dolphins may alter the frequency and complexity of their whistles in response to heightened noise pollution, but even the modulations themselves pose a risk to overall dolphin health (Fouda et al., 2018). To better understand dolphin behavior and the repercussions of human marine activity, we review how bottlenose dolphins communicate during hunts, how anthropogenic noise impedes on this communication, how the dolphins acclimate to such impacts, and how dolphins' responses to these impacts can negatively impact their wellbeing, survival, and reproductive success. Furthermore, we examine ways to mitigate these impacts by reducing sources of anthropogenic noise in high conflict areas.

Introduction

a. Anthropogenic noise in the ocean

Humans have been the cause of many environmental damages and effects on wildlife, especially with increased urbanization affecting the soundscape in the ocean (Jerem et al., 2020). Anthropogenic sound (also called anthropogenic noise) is the primary cause of noise pollution in the ocean and the diminishing welfare of species that rely on auditory communication (van Ginkel, 2018). Ambient noise from wind, earthquakes, and waves are naturally occurring, but dolphins have long adapted to those factors (Ginkel et al., 2017). Anthropogenic noise in the ocean specifically has been steadily escalating and comes from many sources, including large commercial ships, seismic exploration devices, sonars, and offshore drills (Jerem et al., 2020). Though smaller scale sources of noise pollution, such as powerboats, are more inconsistent, they can nonetheless disrupt dolphin foraging behaviors on a local level (Hildebrand, 2004). Anthropogenic noise creates many issues for bottlenose dolphins as water-based industries continue to grow.

b. How dolphins communicate

Bottlenose dolphins use a variety of different acoustic signals to communicate with one another. They can vary by duration, frequency, amplitude, and complexity. Dolphins' main form of social communication are **whistles**. First, to communicate socially, dolphins produce long (0.5-0.8 seconds), high pitched whistles. For example, signature whistles are unique individual identifiers, or names, that are learned at a very early age (Janik, 2006). Because higher pitched sounds travel further distances underwater, dolphins use whistles for group cohesion and

coordinating hunting activities when they may be separated. Dolphins also produce **clicks**, short and high energy pulses of sound to navigate and hunt. For example, echolocation clicks are used to determine the location of food sources as well as any obstacles while the dolphin is swimming (Herzing, 2014). Clicks are usually used for navigation and echolocation, but it is also possible that dolphins use these sounds to arrange group foraging efforts (Morrison, 2019). Most interestingly, dolphins produce **burst pulsed sounds**, sets of rapidly repeated and especially loud clicks which are often used for direct or short-distance communication (Ryabov, 2016). Different sequences of burst pulsed sounds are used to convey distress or aggressiveness and are used in play, aggressive herding, and hostile situations, such as to stun or debilitate prey (Blomqvist et al., 2004).

c. Dolphin hunting and foraging strategies

The role of communication in bottlenose dolphin hunting has long been studied, but little is known about the effects of different vocal signals to organize group movement, since most hunting methods used by bottlenose dolphins are specific to certain regions or communities (Highfill et al., 2010). For example, females of a small pod living in Shark Bay, Australia perform sponge-carrying, a solitary form of foraging that involves sea sponges and click trains to echolocate preferred prey that do not have swim bladders and would be otherwise difficult to find using only echolocation (Fig. 1, Patterson et al., 2011). Dolphins find sea sponges and hold them to their beaks in order to dust the floor, displacing prey hidden within the seabeds. They then echolocate to determine the exact location of prey. Bottlenose dolphins in South Carolina display strand-feeding behavior in which a pod simultaneously beaches themselves in order to corral fish, then push them onto the shore (Fig. 2, Highfill et al., 2010). This is a cooperative technique that requires coordination, most likely facilitated by vocal cues such as clicks and whistles. Perhaps the most studied foraging strategy is the drive-barrier method, observed in bottlenose dolphins off the coast of Florida, where waters are murky, and acoustic communication is vital (Fig. 3). One individual slaps its tail to herd a school of fish towards other dolphins who create a barrier, forcing the fish to jump out of the water so that the dolphins can catch them (Hamilton et al., 2022). In addition to communicative clicks and whistles, these bottlenose dolphins may also use echolocation clicks in order to orient themselves and locate the approaching fish (Hamilton et al., 2022). Overall, the hunting and foraging strategies used by dolphins varies widely, in all of which auditory communication is vital. Increases in anthropogenic noise around the globe will have drastic effects on the survival of various dolphin communities.

Fig 1: Example of sponge-carrying by a dolphin. Image from: Rotating Planet Productions. (2021, June 24). *Bottlenose Dolphins Use Sponges to Protect Their Noses* [Video]. YouTube. https://www.youtube.com/watch?v=5MmBN_E3qDo

Fig 2: Example of dolphin strand feeding. Image from: greenmentch. (2017, August 17). *Dolphin Strand Feeding in South Carolina* [Video]. YouTube. https://www.youtube.com/watch?v=dXuRg6JgBIY

Fig 3: Example of drive and barrier hunting, with one dolphin creating the mud ring and others herding fish towards it. Image from: BBC. (2014, October 1). *The advanced hunting strategy of a*

dolphin - The Wonder of Animals: Episode 9 - BBC Four [Video]. YouTube. https://www.youtube.com/watch?v=-xm9PjKdf00

d. Research Question

Anthropogenic noise has been suggested to be disruptive to dolphin communication by distorting vocalizations and reducing their efficiency. Ships and boats produce sounds of similar amplitude and frequency to ones bottlenose dolphins use for communication, effectively masking and limiting the range of signals (Morrison, 2019). Even small vessels can limit the communication range by 26% for dolphins that are just 50 meters apart (Jensen et al., 2009).

However, research on the effects of anthropogenic noise on dolphin behavior is limited, leaving the question: how do dolphins acclimate their communication to human impacts, specifically anthropogenic sound, in order to successfully hunt?

Based on the existing literature and previous research demonstrating the importance of communication in bottlenose dolphin hunting, navigation, and social life, I developed the following hypotheses:

e. Hypotheses and Predictions:

i. Increases in the amount of anthropogenic noise will negatively affect dolphin communication.
   1. **Prediction:** As sound output by shipping vessels increase, vocalizations by dolphins will be masked, and their ability to communicate will be reduced.

ii. Dolphin acclimations to increased anthropogenic noise will lead to negative effects on dolphin welfare.
   1. **Prediction:** As dolphins modify their whistle characteristics in response to anthropogenic noise, their ability to coordinate hunting efforts and overall well being will decrease (decreased reproduction and survival).

iii. Reduced noise pollution will have positive effects on dolphin communication and welfare.
   1. **Prediction:** As commercial shipping vessels decrease their speed and therefore emit less noise pollution, dolphin populations increase their hunting activity and success in these areas.

Negative impacts of anthropogenic noise on dolphin communication

Even in captivity, dolphins struggle to carry out cooperative tasks when various other noises are introduced, despite the species being known for their intelligence and problem solving abilities (Sørensen et al., 2023). One such task by Sorensen et al. (2023) required two dolphins to approach buttons on opposite sides of their enclosure and press the buttons at the same time. The dolphins were able to figure out how to coordinate actions with vocal cues, but when scientists introduced increasing levels of anthropogenic sound, they found that the dolphins struggled to be successful. The ability of bottlenose dolphins to coordinate actions in the face of anthropogenic noise speaks to the severity of the disruptions caused and may extend to hunting abilities as well. As anthropogenic noise impairs basic cooperation, attempts to hunt will also be thwarted as the bottlenose dolphins' ability to use echolocation to find food

and to call for group cohesion are impacted (Nakahara, 2010). By preventing bottlenose dolphins from assigning roles or coordinating movement, anthropogenic noise lowers the efficiency of auditory signals and may decrease the survival chances of the dolphins in cases of lower food intake. This inability to find food may reduce the bottlenose dolphins' fitness, or ability to survive and reproduce. As the dolphins spend more time looking for and catching food, they face less time to socialize and reproduce, which reduces reproductive success. Therefore, anthropogenic noise can threaten population levels in the long term. As anthropogenic noise continues to impede dolphins' hunting abilities, the dolphins may develop acclimations to adjust and work around this noise.

How dolphins adapt to anthropogenic noise

a. General Dolphin Communication Adaptations

In order to cope with noise pollution, dolphins have been observed to alter vocalizations through frequency, complexity, amplitude, and duration. Ambient noise sources tend to be at lower frequencies, so increasing the frequency of vocalizations may be a strategy for avoiding masking (Ginkel et al., 2017). Furthermore, dolphins have also been observed to reduce overall frequency in cases of high frequency anthropogenic noise, indicating that dolphins are able to actively adjust to the noises surrounding them in order to successfully hunt (Gospić & Picciulin, 2016). Bottlenose dolphins also reduce the complexity of their whistle contour in order to reduce the amount of information lost through masking (Fouda et al., 2018). Contour in the context of dolphin whistles is the "shape" of the whistle, or the frequency of the whistle at different times. For example a complex whistle contour contains multiple inflection points (points at which the whistle changes in frequency and a twisting curvature (Fig. 4, Bazúa-Durán & Au, 2002). In contrast, the graphs of whistle contour in the presence of anthropogenic noise are flat graphs that indicate no changes in frequency. At the same time, dolphins increase the amplitude of these vocalizations in order to project to further distances, to avoid disruptions to sound projection by ambient noise (Candelaria-Ley, & Inez, 2001). It is also thought that dolphins shorten their calls through simplification during quieter periods to get full messages across before another wave of noise begins (Fouda et al., 2018). The types of modifications used vary by situation for the bottlenose dolphins in order to acclimate to a diverse range of circumstances that the dolphins may be faced with.

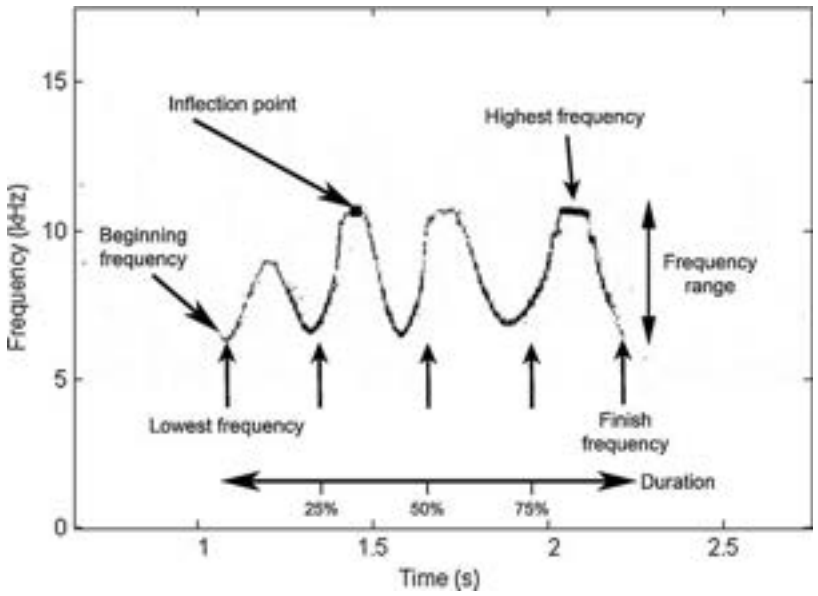

Figure 4. Labeled aspects of a bottlenose dolphin whistle spectrogram. Image from: Díaz López, Bruno. "Whistle characteristics in free-ranging bottlenose dolphins (Tursiops truncatus) in the Mediterranean Sea: Influence of behaviour." Mammalian Biology 76.2 (2011): 180-189.

b. Dolphin communication acclimation during foraging and hunting.

Specifically in the context of hunting, bottlenose dolphins rely on modified whistles in order to coordinate efforts to find food. In the presence of dolphin-watching boats, dolphins emitted more modulated and simplified whistles, which allowed them to communicate in the noisy environment (May-Collado & Quiñones-Lebrón, 2014). The communication needed among the co-members within a group about the location of food sources also requires whistles that efficiently convey information, even in the presence of anthropogenic noise (Gospić, N. R., & Picciulin, M., 2016;). In the aforementioned study completed by Sorenson et al. (2023), researchers found that in cases where anthropogenic noise impacted the ability of dolphins to coordinate learned tasks, the dolphins would adjust their vocalizations to compensate. Both dolphins in the pair significantly increased the amplitude and call duration of their whistles in response to higher levels of noise (Sørensen et al., 2023). This suggests that dolphins are able to consciously and flexibly modulate their whistles when communicating in areas of high anthropogenic noise in order to ensure coordination. This is especially important when considering hunting, where cooperation and coordination between members of a pod are important for herding fish in the drive-barrier method of hunting. Even as anthropogenic noise in marine ecosystems increases, bottlenose dolphins are able to evaluate these changes and apply them to their communication calls.

Negative effects of communication adaptations on dolphin welfare

a. Adaptations may lead to greater energy use and higher metabolism

Although these modulations to vocalizations can help mitigate the difficulties of communicating around anthropogenic noise, dolphins may suffer the consequences of making these changes. Adjustments in whistle frequency, duration, and repetition rate result in higher vocal effort, or the total acoustic energy of sounds produced (Holt et al., 2015). Holt and colleagues (2015) found that increases in vocal effort by dolphins resulted in a higher metabolic

rate (amount of energy expended) relative to that of resting states, as much as 1.2x the resting rate. Furthermore, total metabolic cost (amount of O_2 consumed) was positively correlated with vocal effort across trials. Energetically demanding behaviors such as reproduction, locating, or hunting could be harmful for individuals, especially mothers and expecting dolphins, who have used most of their energy to modulate their vocalizations.

b. Dolphins still face hardships despite adaptations

In addition to metabolic costs, bottlenose dolphins face other hardships that cannot be reduced by altering whistle frequencies. Perhaps the most critical effect of modifications is the reduced information exchange. With the changes in modulation as a result of anthropogenic noise, the now simplified vocalization may not communicate as much information as is needed for proper interaction and coordination between conspecifics. These simplified calls could also lead to inadequate vocal learning in young calves, as they grow up listening to the modulated sounds instead of proper ones (Fouda et al., 2018). In addition, the adaptations are not perfect fixes for the communication deficit caused by anthropogenic noise. As demonstrated by Sorenson et al. (2023) in their study on anthropogenic sound and dolphin cooperation, the introduction of noise caused the dolphin duo's success rates to drop by 20%. Coordinating hunts may therefore be inefficient or unsuccessful despite efforts by dolphins to overcome the noise pollution (Gospić & Picciulin, 2016). This could lead to a further lack in food intake and even lower reproductive success for bottlenose dolphin populations. Additionally, increased boat activity in bottlenose dolphin habitats creates issues separate from noise pollution. Bottlenose dolphins may move away from areas of high anthropogenic noise such as boat docks or shorelines, forcing them to seek food sources in unfamiliar and possibly dangerous areas. As humans have begun encroaching on natural habitats, bottlenose dolphins may face complications with fishing boats and fishing nets, as well as general habitat availability. Pollution of the water and deafness caused by motor noise also impact the physical wellbeing of the dolphins in the area (Gospić & Picciulin, 2016;). These concerns cannot be resolved by dolphin adaptations, and impact dolphins on a broader basis than anthropogenic noise by itself.

How we can reduce noise pollution in the ocean

a. Noise mitigation of seafaring vessels

A main suggestion for reducing anthropogenic noise in the marine environment is through the use of speed reductions and technology. Most of the anthropogenic noise produced in marine ecosystems comes from cargo ships (Findlay et al., 2023). One solution to this issue is enforcing slowdowns, where vessels purposely reduce speed whenever possible. Across all frequencies, there has been observed lower sound production and a small acoustic footprint (less area affected) with slower speeds. Concerns have been raised over the duration of exposure to anthropogenic noise for marine life, as slowdowns cause ships to pass through habitats slower and the animals are therefore exposed to noise for a longer period of time. However it has been demonstrated by Findlay et al. (2023) that slowdowns reduce the overall time during which marine life may be affected by the noise, as slowdowns reduce the time during which an animal is exposed to noise above an ambient level, around 90dB for ships approaching 300m away. Even further away, slowed vessels may not exceed the ambient noise threshold at all, having little to no effect on wildlife. In contrast, vessels not abiding by slowdown suggestions remain more than 15dB above this threshold for longer than the slow vessels (Findlay et al., 2023). Therefore, a reduction in ship source level will likely reduce the relative area over which marine mammals are affected, especially in shallow-water environments.

In addition, developing and enforcing technology can further mitigate vessel noise level, the amount of area affected, and the harm to wildlife. Many have raised concerns for slower ships due to slowdowns and reduced economic profit. However, introducing new technology allows ships to maintain speed levels and still reduce their noise footprint. One such mechanism includes the use of an electric-powered engine for boats such as tourist and small private boats. Electric motors emit an underwater noise level much lower than those emitted by the internal combustion boats, which are also harmful to the environment due to their use of diesel or gasoline as fuel, and excessive air pollution (Alfio, 2023). Conversely, electric motors can be powered through solar energy in addition to the lower noise production of such engines. Such modifications can reduce the overall noise output around 10 decibels, allowing ships to increase speed without reaching a sound level that is detrimental to wildlife (Findlay et al., 2023). Combining slowdowns with technology such as electric engines can have the largest impact on reducing anthropogenic noise in the marine setting and in turn the impact on marine wildlife. A slowdown of 25% and a technological innovation reducing the output by 8 decibels can lead to a 97% decrease in acoustic footprint for a large vessel such as a cargo ship. By both reducing the effects on bottlenose dolphins and keeping up with industrial demand, slowdowns and technology are optimal solutions to this prominent environmental issue.

b. Government involvement in boat noise regulations

Governments have the power to pass legislation that sets regulations for noise production from various sources. However, many regulations for whale watching boats, air guns, sonar machines, and construction lack consistency between nations (Markus & Sánchez, 2018). Some laws manage proximity to wildlife and time restrictions. However these measures are insufficient as they do not fully provide protection for bottlenose dolphins or are inadequate in reducing the amount of anthropogenic noise in their habitats, and bottlenose dolphins continue to be affected by anthropogenic noise in marine environments. In addition, vessels may continue to have a large acoustic footprint despite being slowed down due to older technology and poor maintenance. Thus, governments should enforce regulations on keeping vessel technology up to date and modernize or eliminate older vessel models. Limits on vessel source levels should be placed as a universal threshold to reduce the amount of vessels or vessel models that disproportionately contribute to anthropogenic noise.

Discussion

Anthropogenic noise has restricted dolphins' ability to communicate by masking vocal signals and in turn impairs their ability to successfully hunt and maintain fitness. Dolphins have learned to adapt by modifying aspects of vocal signals in order to simplify calls and increase projection. However these adjustments have led to increased energy usage and do not completely compensate. Dolphins produce a variety of vocalizations that naturally differ in frequency, duration, and amplitude. Some of these unique whistle contours are an important aspect of the dolphins' signature whistles that convey information about specific individuals. Important information as well as signature whistles may be lost as a result of oversimplifying messages. To limit the negative effects of anthropogenic noise, humans can take initiative and regulate noise production. Cargo ships can reduce speed or implement technology that allows them to minimize source noise levels, projection, and exposure duration. Governments can mitigate noise production from a political standpoint by enacting legislation that controls sources of anthropogenic noise such as underwater drills, boats, and sonar. There is much work left to be done surrounding the regulation of anthropogenic noise in marine systems.

This review paper summarizes the findings of multiple studies on the effects of anthropogenic noise on bottlenose dolphin communication and hunting and recognizes the importance of reducing noise pollution, and how doing so will have positive effects on dolphin communication and welfare. However it is important to note that current solutions are inadequate for dolphin safety and welfare, therefore further action is needed. Small modifications have shown significant decrease in noise output and effectively minimize interference with bottlenose dolphin communication. Through awareness, technology, and policy implementation, humans can successfully reduce anthropogenic noise for marine mammals such as bottlenose dolphins to ensure their well being and survival.

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