Adaptations of echolocating animals to extreme environments: A comparative study of urban and natural habitats

How do echolocating animals adapt to both natural and man-made extreme environments, such as urban areas and deep-sea living?

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Abstract
Echolocating animals such as bats and toothed whales have the unique ability to 'see' through sounds; echolocation. They evolved and adapted in such ways that they thrive in both natural and man-made extreme environments. The adaptations and evolution of echolocation is crucial for their survival, successful navigation, foraging, and communication when faced with the challenges posed by urbanization, deep-sea conditions and other human activities. This comparative analysis of animals that live in urban and natural habitats helps understand what the deficiencies of echolocation are and what the stumbling blocks for the echolocating animals are. When we better understand what these stumbling blocks of echolocation are, then we can make policy plans on how to help these animals. We can also learn from the adaptations that the animals make themselves to improve our techniques with regards to echolocation, such as sonar and bioacoustics tracking.

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Introduction

Echolocation is a biological phenomenon by which animals emit sounds and are able to locate certain objects, such as prey by listening back to the echo bounced off these objects (Jones et al., 2005). Echolocation is used by various animals to navigate, hunt and communicate (Grinall et al., 2009; Jones et al., 2005). The ability of echolocation gives these echolocating animals critical spatial information of their surroundings, when visual cues in, for instance, murky waters or dark nights, are not informative enough to navigate and hunt efficiently (Grinall et al., 2009). The most well-known echolocators are bats and toothed whales, which have evolved this ability independently indicating convergent evolution (Jones et al., 2005).

Echolocation has been extensively researched, but still there remain a lot of gaps in our understanding of how well these animals are adapted to their specific environments. Echolocating animals face unique challenges, such as dense forests with low light conditions and lots of obstacles. Or in the deep sea, where animals have evolved to thrive in an environment with high pressures, low temperatures and total darkness (Moss et al., 2023), and an expanding challenging environment in the form of urban areas, in which animals had to adapt to man inflicted challenges in the form of noise pollution and artificial structures (Moss et al., 2023). Nowadays aquatic echolocators also face similar man inflicted challenges (Heere et al., 2024).

In the deep sea, toothed whales and other marine echolocators navigate and hunt in an environment with little to no visual cues. Hence, these animals heavily rely on echolocation to detect prey and avoid obstacles. They also face the challenges of varying water densities and pressures (Jensen et al., 2018). Urban environments pose an entirely different set of challenges for bats and other terrestrial echolocators, then their other or previously inhabited environments. And since the urban areas are expanding and competition becomes a bigger influence, aerial echolocators have to adapt to also be able to survive in urban areas. The presence of buildings and other man-made structures in combination with the abundance of (artificial) noise and light can massively influence the effectiveness of an animal's ability to echolocate (Luo et al., 2015; Martin et al., 2017).

This study aims to explore how echolocating animals adapt to these extreme environments and if they are able to keep up with the rapid increase in industrialization due to humankind and thereby adapt to the new challenges that their echolocating ability faces nowadays. Understanding in what ways these animals adapt to these new challenges, not only enriches our knowledge of animal biology, but it also informs us on how we might be able to come up with conservational strategies to protect these echolocating animals while they face the new environmental challenges coming from the increasing contact with the human world.

By using a comparative approach, I try to unravel how deep-sea and urban echolocators are able to adapt to their extreme environments. I will provide insight into which selection and environmental factors shape the evolution of echolocation. By researching what strategies these echolocating animals use, and seeing uniqueness and overlap in these strategies, we will be able to look at what nature's solutions are to these ever-changing and extreme new challenges that these echolocators face in the modern world.

In this way I address the question, how do echolocating animals adapt to both natural and man-made extreme environments, such as urban areas and deep-sea living?

Echolocating animals in their natural environments

Echolocating animals have evolved the ability of echolocation over millions of years. The ability to echolocate, dates back 39 million years in toothed whales (St Lawrence, 2024), and a recent discovery of a fossil skull from a bat showed that an unknown bat species from about 50 million years ago was already able to echolocate (The University of Salford, 2023). When looking at these timeframes and how revolutionary echolocation must have been, with regards to foraging efficiency and spatial awareness, this new ability had a lot of time and great potential to evolve and become a major component in the lifestyles of these animals. So, what specific adaptations have echolocating animals undergone to be as efficient as they are in their natural environments? To answer this question, we need to take a look at echolocation signal characteristics, physiological adaptation and behavior strategies.

The deep sea is one of the natural, but extreme, environments that aquatic echolocators such as toothed whales inhabit. The reason for filling up this ecological niche in the deep sea is that there is less competition of other predators that rely heavily on visual cues. These animals occupy a new niche in the deep sea by finding a way to overcome low-light conditions or no light at all (Goldbogen et al., 2018). The echolocating toothed whales are able to echolocate at these depths by adjusting their call frequency and intensity to penetrate deeper through the water (Moss et al., 2023). These adaptations enable production of powerful, low-frequency clicks that can travel longer distances underwater than high-frequency clicks can. This ability is essential for navigating through murky and low-light waters and to eventually find prey (Moss et al., 2023). By utilizing a combination of varying click intensities and frequencies, toothed whales are able to determine the size, shape and distance of prey, even in environments with little to no visual cues (Moss et al., 2023;). Bats use echolocation in a similar way and are even able to determine in which direction a prey animal is moving through the Doppler effect (Ostdiek et al., n.d.; Moss et al., 2023). This shows how well-developed the echolocating ability is in these animals.

Some physiological adaptations were crucial in developing the echolocation efficiency that we now know of. Toothed whales have evolved enhanced auditory systems that make detection of the faintest of echoes in the deep sea possible (Ridgway et al., 2009). Aquatic echolocators possess highly sensitive inner ear structures that allow them to interpret the timing and frequency of a returning echo and this allows them to process and determine exact locations of obstacles and prey (Ridgway et al., 2009). In addition to sophisticated auditory systems, toothed whales have developed specialized structures such as the melon. The melon is a fatty organ located in the forehead and it focuses and modulates vocalizations such as clicks used for echolocation (McKenna et al., 2011). The melon increases the range and directional precision at which these animals are able to 'send' an echolocating beam in the form of a click (McKenna et al., 2011). The melon only directs the clicks and the returning echoes are received by fatty tissues located in the lower jaw (Moss et al., 2023). Bats produce and receive their echoes in different ways. They do not have a melon, but they emit ultrasonic sounds, which are relevant in echolocation, by contracting their larynx or by making clicks with their tongue ("How Do Bats Echolocate and How Are They Adapted to This Activity?," 2024). Two species are even known to produce sounds through their nostrils and use them as natural megaphones ("How Do Bats Echolocate and How Are They Adapted to This Activity?," 2024). Certain cells located on the hairs in the bat's ear make it possible that they can detect the slightest change in frequency of a returning echo and interpret these changes into relevant information ("How Do Bats Echolocate and How Are They Adapted to This Activity?," 2024). It is thought that their external ear also helps with the reception and funneling of returning echoes ("How Do Bats Echolocate and How Are They Adapted to This Activity?," 2024). The physiological changes that these animals have undergone make it possible to optimize echolocation and will be discussed more in-depth in the following section.

The rise of echolocation also brought some behavioral changes with it. The deep sea echolocators in particular started implementing hunting strategies by using their own echolocation and also passively listening to echolocating conspecifics, heterospecifics or sound emitted by a potential prey item (Johnson et al., 2004; Moss et al., 2024). They are able to maximize foraging efficiency by combining these four information sources. Passive listening is a good way to detect potential presence of prey without needing to produce sounds and be detected themselves (Johnson et al., 2004). If the potential presence of prey is confirmed, the animals switch over to active echolocation to determine their location even more accurately and capture it. Because production of echolocation is very energy consuming, this hunting strategy makes for optimal hunting success and conservation of energy. Bats use passive listening to find prey that emit sounds as well, but there is no clear evidence that they use passive listening to echolocating calls emitted by conspecifics (Moss et al., 2024). Social calls do seem to have a message and can inform about hierarchal status and sex of an individual, but if social calls and echolocating calls have any overlap is not known (Moss et al., 2024). A study has shown that bats utilize the environment by interpreting cues, traces and social calls of other animals. Because of this, animals are able to use their sophisticated auditory systems, which are also necessary for echolocation, to improve foraging efficiency and minimize predator detection (Russo et al., 2007).

What underlaying adaptations support echolocation in extreme environments?

As previously described, there are some physiological changes that are a result of evolutionary improvements of echolocators. By gaining a better understanding of what physiological changes are relevant in echolocation, we might be able to imitate some structures and maybe find new strategies to conserve (endangered) echolocating animals. The specialized auditory systems that these animals have developed helps them thrive in their respective environments (Ketten, 1992; Wang et al., 2019). The evolution of highly sensitive cochlear structures is one of the key adaptations for these specialized auditory systems (Ketten, 1992; Wang et al., 2019). The cochlear structure can be described as the spiral cavity in the inner ear containing the organ of Corti. This organ produces nerve impulses in response to the sound vibrations that it receives, returning echoes for instance (Ketten, 1992; Wang et al., 2019). Because these structures have developed to be highly sensitive, echolocators are able to detect minute differences in echo return times. That is why they can determine a potential prey item very precisely and navigate through complex environments without bumping or flying into something. Studies have shown that the cochleae of echolocating animals are finely tuned to specific ranges that correspond to their echolocation calls (Wang et al., 2019). This allows them to detect the finest details in returning echoes that they receive. It has been shown that toothed whales have shorter cochlear structures and a bonier lamina when compared to non-echolocating whales (Ketten, 1992; Wang et al., 2019). These morphological differences play a crucial role in high frequency hearing and thereby detecting returning echolocation calls (Ketten, 1992; Wang et al., 2019).

In addition to the morphological adaptations in the auditory systems of echolocating animals, genetic modifications also play a significant role in enhancing the auditory abilities necessary for echolocation. The Prestin gene is responsible for outer hair cell function in the cochlea and the variations in this gene are particularly notable in echolocators (Rossiter et al., 2011; Liu et al., 2010). Because the echolocating ability made animals more efficient at hunting and allowed them able to utilize new niches, the Prestin gene underwent positive selection in echolocating bats and toothed whales (Rossiter et al., 2011; Liu et al., 2010). The specialization of this Prestin gene to enhance high-frequency hearing sensitivity allowed early age echolocators to detect and process high-frequency sounds more efficiently and improve their echolocating ability over time (Rossiter et al., 2011; Liu et al., 2010). In one study researchers sequenced the Prestin gene, of these echolocating bats and toothed whales and their non-echolocating relatives, and made a phylogenetic tree (Rossiter et al., 2011; Liu et al., 2010). The sequencing resulted in a phylogenetic tree, that suggested that echolocating animals are the most closely related species and that they branched off from the non-echolocating animals (Rossiter et al., 2011; Liu et al., 2010). Phylogeny through DNA-sequencing reveals a phylogenetic tree in which non-echolocating cetaceans and echolocating cetaceans are most closely related and echolocating and non-echolocating bats are closely related (Rossiter et al., 2011; Liu et al., 2010). From these results, it is most likely that the positive selection for variations in the Prestin gene happened through convergent evolution, but we cannot say this with certainty. An alternative way to explain this pattern could be via horizontal gene flow. Horizontal gene flow is a process by which genetic material is transferred between different species (Keeling & Parker, 2008). It could be that the Prestin gene was transferred horizontally between the distant taxa of bats and toothed whales, enabling them to develop similar adaptations independently. It could be that they acquired the gene from a common source or directly from each other through gene transfer mechanisms like parasites, bacterial intermediates or viral vectors. Another way the evolution of the Prestin gene could be explained is via a common ancestor and that they evolved it parallel of each other after divergence of two or more new species. There has not been enough research on the Prestin gene to draw conclusions about evolution and to improve our understanding of the function of this gene in echolocation (Rossiter et al., 2011; Liu et al., 2010).

In bats, some musculoskeletal adaptations have been made in wing morphology (Frontiers, 2023). Research has shown that modifications in wing morphology are tightly correlated with echolocation call characteristics to optimize foraging efficiency for their specific diet (Frontiers, 2023). In cluttered environments or environments with dense vegetations maneuverability and speed are a necessity to forage efficiently (Frontiers, 2023). That is why certain bat species have evolved longer and narrower wings (Frontiers, 2023). These wing adaptations are often complimented with specific echolocation calls that help in specific environments by, in this case, filtering out background noise (Frontiers, 2023).

How do environmental challenges in urban and natural habitats differ and how do these differences impact echolocation?

Urbanization is one of the major threats to the habitats and lifestyles of all kinds of animals and also poses an entirely new set of challenges to echolocators. I have discussed some of the adaptations that echolocating animals have made to optimize their survival and hunting strategies in their respective environments, but these strategies might not be optimal for the urban areas, because urban areas bring new environmental challenges. In urban areas light and noise pollution are particularly challenging for echolocators, because these factors decrease echolocation efficiency drastically. Artificial light is a problem for nocturnal echolocators primarily (Seewagen et al., 2023). Echolocating bats, which are nocturnal animals, are affected because they can be disoriented by the light, making it difficult to navigate and hunt (Seewagen et al., 2023). Their biological clock can also be disrupted, but a study has shown that bats are already acclimating to the artificial lights (Seewagen et al., 2023). Noise pollution primarily comes from traffic (vehicles such as boats and cars) and industrial activities (construction work, deep sea minings, windmills). The noise pollutes the echolocation calls, reducing their effectiveness in navigation and prey detection (The Marine Mammal Center, n.d.). Noise pollution can sometimes even lead to hearing loss or complete deafness (The Marine Mammal Center, n.d.). For animals that rely on their auditory sensory system as much as echolocators do, this is detrimental. To overcome the challenges of noise pollution, animals have to adapt. Besides the noise pollution that traffic brings with it, it also claims a lot of deaths. This is because terrestrial and aerial echolocators get driven over by vehicles or aquatic echolocators that get hit by boats and die because of the injuries that are inflicted by these watercrafts (Fisheries, n.d.; Fensome & Mathews, 2016; Manville, 2015). The increase in emerging man-made structures in urban areas also increases mortality rate in echolocating animals, such as bats and birds (Manville, 2015). These aerial echolocators often fly into buildings, windmills and other structures which leads to fatal injuries or death on impact (Manville, 2015). Reflective surfaces claim the most deaths, because they mislead sensory perception (Manville, 2015). The collisions form a significant threat to the populations of these animals and the constant expansion of urban areas make that animals are forced to give up their natural habitat and adapt to their new urban habitat increasing chances of collisions even further (Manville, 2015). Echolocators in both urban and natural habitats rely on a combination of sensory input. The noise is a direct problem to echolocation, because it disturbs the signals making echolocation less or not viable.

How do echolocating animals modify their behavior and echolocation signals in urban areas?

Urban areas pose new challenges to echolocators which makes that new adaptations in behavior and echolocation signals are a necessity. Noise pollution, for instance, makes group cohesion and coordination during foraging challenging (Domer et al., 2021). In a recent study it has been observed that bats and dolphins increase volume and frequency structures of their echolocation calls to overcome noise produced by human activities (Currie et al., 2020). These adaptations help maintain effective communication and prey detection, despite high levels of background noise. Maintaining effective communication is crucial for coordinating group activities such as foraging and roosting. Increasing call volume ensures that the distances travelled by the echolocation calls are still sufficient for detecting returning echoes and changing call structures, such as frequency modulation, reduce overlap with low-frequency urban noise (Currie et al., 2020; Moss et al., 2023). This phenomenon of the Lombard effect is shown in studies about human speech and describes individuals speaking louder in noisy environments (Lombard, 1911). Aquatic echolocators also increase the rate of their clicks and vary click frequencies to overcome ambient noise produced by human activity (Currie et al., 2020; Stallard, 2023). The downside to these adaptations to urban areas is that high-frequency calls and increased call volume are very energetically costly and not effectively applicable for long distance prey detection (Currie et al., 2020). To minimize energy costs, bats have shown to alter their activity patterns to forage and communicate when human activity, and thereby noise levels, are lower. These alterations are supported by studies revealing that bats become more active during late night or early mornings and dolphins that forage at early morning or late night when boat traffic is minimal, to exploit quieter foraging times. In the future, aquatic echolocators may start to avoid heavily trafficked waters and active industrial sites located at sea. Some toothed whales have already been shown to actively leave and relocate at quieter areas, away from human hotspots (Gajbhiye, 2024). Some whales have even shown to change their migration routes to avoid areas with intense artificial acoustic noises (Gajbhiye, 2024). In response to sudden increases of ambient noise by, for instance, a boat they move away from the source and thereby minimize injury to their sensitive auditory systems. By avoiding areas with intense acoustic sources, they minimize disturbance of their acoustics.

Studies have found that urban bats now exhibit specialized flight patterns allowing them to navigate through the complex architecture of cities. These specialized flight patterns include more agile and maneuverable flight, allowing bats to avoid collisions with buildings, vehicles and other obstacles (*Modelling the Flying Routes of Bats in a Digital Twin – Tygron Platform*, 2023). The enhanced spatial awareness that echolocation provides animals enables them to forage more efficiently in urban areas than non-echolocating animals that also face new challenges. Research has shown that modifications in wing morphology are tightly correlated with echolocation call characteristics to optimize foraging efficiency to support these complex flight maneuvers (Frontiers, 2023). Man-made structures are utilized by echolocators for roosting and foraging, which is a switch-up from their traditional lifestyle preferences to the available urban environment (*Modelling the Flying Routes of Bats in a Digital Twin – Tygron Platform*, 2023). Bridges, buildings and other structures provide new roosting sites, while traffic lights and other artificial lights attract insects and thereby provide new foraging sites (*Modelling the Flying Routes of Bats in a Digital Twin – Tygron Platform*, 2023).

In aquatic echolocators, avoidance is the primary solution to areas with much human activity, but they do not fully rely on their echolocating abilities. Reliance on non-acoustic cues increases in areas with much human activity, because echolocation is heavily compromised by noise pollution (Moss et al., 2023). Dolphins, for instance have excellent vision and can use visual information to navigate and locate prey when echolocation is less effective (Moss et al., 2023). Toothed whales are also able to detect vibrations through the water supplementing their foraging efficiency (Moss et al., 2023). Passive listening also is a relevant behavioral adaptation in these waters with much human activity, while it might be more difficult to detect prey, because of the ambient noise (Moss et al., 2023).

So, urban areas present challenges to which echolocators adapt by showing flexibility. They are flexible in modifying behavior and echolocation usage, making it possible for echolocation to still be relevant and make survival of echolocators possible. Specialized call structures and sophisticated auditory systems are a primary use in natural environment, while reliance on other sensory cues such as vision and smell might become a bigger factor in the lifestyles of echolocators in urban areas.

What are the conservation implications for echolocating species in these extreme and urban environments?

It is easy to say that urbanization has a massive impact on the lifestyles and echolocation usage of animals, but it has been shown that some animals are not able to adapt quickly enough (Russo & Ancillotto, 2015). In urbanized areas, bat populations are impacted significantly (Russo & Ancillotto, 2015). This is caused primarily through habitat fragmentation and increased predation risks (Russo & Ancillotto, 2015). As urban areas expand, natural habitats are fragmented, creating isolated patches that are less hospitable for bats (Russo & Ancillotto, 2015). The habitat fragmentation leads to a decrease in suitable roosting sites and forage areas, disrupting the dynamics and thereby densities of bat populations (Russo & Ancillotto, 2015). Furthermore, urban areas often have higher densities of predators such as cats, which pose a major threat to bats (Russo & Ancillotto, 2015). Additionally, bats get disoriented by artificial lights making them even more vulnerable to predation. Conservational efforts have to focus on restoring and maintaining natural habitats and creating urban green spaces that support bat populations. (*Bats in the Anthropocene: Conservation of bats in a changing world*, n.d.)

To aquatic echolocators, deep-sea mining and noise pollution are major stumbling blocks in echolocation efficiency (Gajbhiye, 2024). The noise generated by deep-sea mining and acoustic sources such as sonar and vehicle engines inhibit effective communication, navigation and prey detection. Besides these polluters, chemical and garbage pollutions also pose a threat by degrading habitats and contaminating food sources which can lead to all kinds of health problems and reduction in their reproductive success (*Ocean Pollution and Marine Mammals | BlueVoice*, n.d.). Strict rules have to be made to mitigate the impacts of deep-sea mining activities and pollution control measures need to be taken to protect not only the aquatic echolocators but all marine ecosystems and their inhabitants. Besides all these factors the biggest threat still is the overfishing and although conservational efforts have been made to help recover prey and thereby toothed whale populations, attempts have been unsuccessful (Temple et al., 2024).

To create bat-friendly environments in and near urban areas, implementations of noise-reduction policies and strategic urban planning is required. The noise reduction is needed to interfere as little as possible with bat echolocation and communication. Urban planners can design green spaces and preserve natural habitats between and within the cities to provide safe foraging and roosting sites. Another good addition might be to implement bat boxes to provide more roosting sites. Light pollution is still a problem, because there is no real solution to this problem yet, but bats are adapting to take advantage of insect abundance near some artificial light sources. Making policies and taking these measures does not only support bat populations but it also contributes to the overall biodiversity in and near urban areas. (*Bats in the Anthropocene: Conservation of bats in a changing world*, n.d.)

To conserve aquatic echolocators, strict policies need to be made on how to protect deep-sea habitats from industrial activities such as oceanic traffic, mining and oil drilling. Establishing marine protected areas (MPAs) can help preserve essential migration routes, biodiversity hotspots, foraging ground and breeding grounds. Implementing strict environmental impact assessments before any industrial activity is allowed can also minimize potential damage. Enforcements of policies and laws need to be made internationally and are necessary to ensure the protection of the habitats of these animals. (*The Impact of Deep-sea Mining on Biodiversity, Climate and Human Cultures | IUCN NL*, n.d.)

Regular monitoring of echolocating species in and near urban environments is crucial to assess their health and population dynamics. We can indicate the quality of the habitats that these animals occupy by continuous monitoring, because it helps to identify changes in population sizes, reproductive success and individual health statuses. Studies on acoustic tracking and genetics of these animals offer good tools to monitor these species. Acoustic tracking allows researchers to monitor movements and behaviors of animals in real-time. This provides information on their responses to environmental changes and on how they maneuver and adopt new acoustical or behavioral characteristics that suit the niches that they occupy in urban habitats. Genetic studies help understand the genetic diversity and population structures, which are essential pieces of information when setting up an effective conservation plan. The data that is collected through both genetic studies and acoustic monitoring can then be assessed and give information on effectiveness of conservation measures and thus help improve or provide new insights to improve protection and conservation. (*Wildlife Monitoring – EOW*, n.d.; Moss et al., 2023)

Discussion

Echolocating animals demonstrate remarkable adaptability and flexibility in the extreme environments that nature has. They do this through behavioral and physiological modifications. These animals now face a new threat; the increasing pressures of urbanization, deep-sea mining and pollution. These pressures pose significant challenges to their survival. Effective conservation strategies must integrate policies on noise-reduction and habitat protection. To know if the conservation efforts are effective we have to monitor how population dynamics are developing, but also to know in what regions these populations are most affected and to understand what factors are most detrimental.

Bat populations are heavily affected by urbanization. This is primarily through habitat fragmentation and increased predation risks (Hormes, 2021). There also is a reduction in suitable roosting and foraging habitats which forces bats to adapt to urban environment. This results in altered flight patterns and echolocation calls to still be able to navigate and hunt effectively in these cluttered areas. The increase in artificial lighting and in noise pollution complicates navigation and foraging efforts even further, necessitating adaptations such as higher call frequencies to overcome background noise. Because this is very energy consuming, bats have to rely more on other sensory input to still forage and navigate well. These changes can increase their vulnerability to predation, lower collisions with man-made structures and lead to finding new foraging strategies.

Marine echolocators like toothed whales face other threats such as deep-sea mining, pollution and traffic of watercrafts, which disturbs their acoustic environments. These human induced activities introduce noise pollution that interferes with echolocation, communication and prey detection. This leads to increased stress levels, fatalities and altered foraging behaviors. Similar to bats, dolphins also increase the frequency of their echolocation clicks and this is also energy consuming to them affecting their overall health as well. Exposure to these threats can lead to habitat displacement and declines in population densities and populations overall. This is why there is an urgent need for protection measures.

Creating bat-friendly urban environments involves implementing noise-reduction policies and thoughtful urban planning. Preserving green spaces, installing bat houses and reducing artificial lighting can minimize the negative impact that urbanization has on bats. Constructing noise barriers and using quieter road surfaces can help reduce acoustic disturbances. It is very important to also consider the ecological needs of bats to maintain or help their populations to bounce back in urban areas, ensuring a balance between development and conservation. For protecting critical deep-sea habitats, establishing marine protected areas (MPAs) and enforcing strict regulations on deep-sea mining operations can help to protect the acoustic environment and biodiversity from industrial activities. (Chemical) pollution also needs to be kept in check strictly to make sure that the health and habitats of these animals are safeguarded.

Continuous monitoring of echolocating species in extreme environments is crucial for assessing population dynamics, individual health and effectiveness of conservation efforts. The monitoring gives insight on to how animals adapt to changing conditions and the impacts that urbanization has on their behavior and physiology. By utilizing advanced technologies such as acoustic tracking and genetic studies, we can monitor, gather information and inform relevant sources to find the best way to conserve and protect these animals. Acoustic tracking allows for study of movement patterns, habitat use and social interactions in real-time, while genetic studies provide insight into population structure, genetic diversity and evolutionary adaptations. Besides the conservational importance of monitoring echolocating animal, research on echolocation is also relevant to improve the techniques that we can use ourselves, such as sonar and bioacoustics tracking, motivating the monitoring and future studies on echolocating animals.

Unfortunately, echolocators do not yet seem to be able to adapt fast enough to the urbanizing world, so we must put in the work to help and protect these species and learn more about echolocation and the lifestyles of these animals.

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