Proceedings of the International Conference on Modern Medicine and Global Health (ICMMGH 2023)
DOI: 10.54254/2753-8818/6/20230313

Impact of transportation infrastructure on amphibians

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Abstract. In recent decades, the alarming rate of amphibian disappearance has become a pressing environmental issue. The primary cause of this decline and extinction is habitat destruction, posing a significant threat to global biological diversity. This destruction is often the result of habitat fragmentation, wherein contiguous habitats are split into smaller, increasingly isolated patches. Transportation infrastructure, particularly roads, is a significant contributor to the fragmentation. Roads have a huge impact on economic development and ecology, connecting urban areas, rural areas and countries while promoting global economic development. However, at the same time, the accelerated road construction creates barriers, leading to increased wildlife death, habitat degradation and act as a contributor of species extinction. Amphibians are notably liable to road impact because of their unique behavior traits. The relationship between habitat fragmentation, accessible habitat, and populations is complex and multifaceted, with different species responding differently. Therefore, it is crucial to continue the exploration to counteract the problems of habitat fragmentation, the decline in amphibian abundance and biodiversity caused by the development of transportation infrastructure.

Keywords: amphibians, habitat fragmentation, road mortality, edge effects, biodiversity.

1. Introduction

Amphibians have existed on Earth for more than 300 million years. However, in recent decades, certain species of these creatures have experienced a rapid population decline, leading to their disappearance. About 41% of amphibian species are deemed at risk of extinction, with the number of extinct and endangered species projected to rise annually [1]. The viability of amphibian populations is at risk due to various factors, which can be summarized into five main categories. These include habitat degradation or loss caused by urbanization, changes in land use patterns, road construction, and hydropower project construction. Pollution, mainly affecting species in still-water habitats, is another risk factor. Climate change and natural disasters also pose a threat, as amphibians have weak migration ability and their bare skin and amniotic eggs are highly vulnerable to enhanced ultraviolet-B radiation. Additionally, intraspecies factors such as weak migration ability and strong dependence on the environment, as well as interspecies effects, primarily the impact of invasive and pathogenic species, also impact amphibian populations [2].

Most scholars would agree that the principal causes of amphibian declines are habitat loss and fragmentation. The construction of transportation infrastructure, especially roads (including highways), is a key contributor that cannot be ignored. The global road construction market has been on the rise at

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a considerable rate for many years. Take China for example, China's economic and urban development has been closely tied to the improvement of its infrastructure. According to published data by the Statista research department, over the past decade, China's road network has expanded by an impressive 42% to reach 5.28 million kilometers by 2021. The density of roads has also increased, with an average of 55 kilometers per 100 square kilometers. However, this increase in road infrastructure posed a negative impact on wildlife, particularly small and unprotected animals that are not covered by animal protection laws. These animals account for a significant portion of road-related incidents, with 79.5% of all road-killed animals falling into this category [3]. Amphibians and reptiles are particularly at risk, but since their collision with humans seldom endangers human safety, there are fewer studies and protection measures in place to mitigate the impact.

The impact of transport infrastructure on amphibians is extensive, including the creation of physical barriers that impede their movement and dispersal. Amphibian mortality is heightened by vehicle traffic on roads, particularly as they attempt to cross. Disturbances associated with transport infrastructure, including noise, visual pollution, and chemical pollution, have a more profound biological effect on amphibians. To gain a thorough understanding of the impact of roads on amphibians and their populations, it is critical to consider a range of road characteristics. This paper will examine several studies that focus on the impact of roads on amphibian abundance and diversity and also explore effective strategies and approaches for mitigating the impact of roads on amphibians.

2. Impact of road on amphibians

2.1. Overview

Assessing the impact of habitat change on amphibians can be challenging since many of them inhabit one or two terrestrial environments for most of their lives, and only migrate seasonally to breed in a different aquatic environment. Interfering with this breeding migration can result in population decline [4]. Habitat change can affect various habitats crucial to the amphibians' life cycle, including the environment they reside and the places for feeding breeding. It is important to acknowledge that amphibian populations will be affected by roads within a span of eight years since their construction. However, it may take several decades for the full scope of consequences to become apparent [5]. The complete comprehension of road impacts on amphibians could require multiple years of study due to the delayed and gradual nature of many effects.

2.2. Road effect zone shown in a case study

To partially illustrate the complicated road impact on amphibians, a study was conducted in fragmented areas in Europe by Hamer and colleagues. The European continent is significantly fragmented due to the presence of transport infrastructure such as roads. In Hungary, the construction of roads and other landscape modifications has led to the destruction of over 90% of original wetlands, with potentially negative consequences for various animal species, including amphibians that rely on connected terrestrial and aquatic habitats for dispersal. Hamer and colleagues conducted a study analyzing how roads and railways impact the population of juvenile amphibians in fragmented habitats in Central Europe [6]. They evaluated habitat factors within 1 kilometer distance surrounding freshwater ponds during breeding season. Additionally, they monitored the variation in larval abundance across seven amphibian species over a distance of 1 kilometer from the highway. Bufo bufo, a genus of true toads, was the most responsive species, exhibiting a significant negative correlation with road coverage within a 1-kilometer distance of the pond. The results confirmed that the road effect stretched up to 1 km, causing a reduction in the count of amphibian larvae in ponds situated within the same radius of the highway. As the road network becomes denser, traffic volume increases, and vehicles speed up, the area of influence expands, ultimately resulting in the fragmentation, degradation, or even total loss of appropriate habitats for wildlife. This expansion of the impact zone of road will decrease the available living space for wild animals, inevitably impacting the stability of their populations.

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2.3. Roadkill

Biodiversity is under threat from roadkill, with amphibians being particularly vulnerable. Studies have shown that these creatures make up a significant proportion of all vertebrate deaths on roads, often due to their unique characteristics such as slow movement, seasonal migrations, and a tendency to freeze in response to oncoming vehicles [7]. Amphibians require significant amounts of energy for foraging, mating, and dispersal during breeding and migration seasons, leading to an increase in traffic mortality due to strengthened movement patterns. Amphibians have a higher likelihood of perishing near roads that are situated within a range of one to two kilometers from wetlands and ponds. Research from China suggests that the hot moments for amphibian roadkill occur in April, with a higher likelihood of incidents happening at night due to increased traffic volume [8]. Hotspots for roadkill are often concentrated near breeding pools. A study in Catalonia also found that sections of roads with streams crossing under them had the highest mortality rates for Common Toads, indicating that these water bodies were crucial migratory pathways for hibernation and breeding [9]. Identifying areas with high potential mortality is crucial for reducing habitat fragmentation and implementing effective measures to protect these vulnerable creatures.

A study conducted in Ontario, Canada revealed a few significant trends with regard to amphibian roadkills [10]. Firstly, a reduction in traffic volume resulted in a decline in both the total count of amphibians and the count of carcasses discovered per kilometer. Conversely, an increase in traffic volume resulted in a higher number of dead amphibians on the road. Secondly, with further increase in traffic volume, the density of amphibians on the roadside and adjacent habitats decreased. This was attributed to the fact that high-traffic volume roads became almost completely inaccessible to slow-moving amphibians, reducing their chances of successfully crossing the road. Additionally, noise and exhaust emissions from vehicles and other disturbances made amphibians avoid roads, resulting in reduced mortality rates. The study underscores the importance of considering different traffic volumes when assessing road fatalities across different species of animals. The yearly amount of roadkill amphibians is a mystery, influenced by various factors such as counting techniques, weather conditions, and traffic flow. Harsh weather conditions make it difficult to locate deceased animals, while high volumes of traffic can cause dead amphibians to disintegrate, making them indiscernible. Even though driving to count roadkill can cover more extensive areas, it can reduce the precision of the counts.

2.4. Edge effect

The term "edge effect" in ecology refers to alterations in a population or community at the interface of a habitat, such as the intersection of a road and a wetland. It is commonly assumed that species that avoid edges are more susceptible to local extinction than those that do not, making it essential to consider the impact of edge effects when explaining the loss of biodiversity in fragmented landscapes. Amphibians, in particular, are highly sensitive to edge effects due to their physiological requirements, yet there have been limited investigations done on this subject. Since amphibians rely on environmental heat for survival and the main mode of respiration for amphibians is through their skin, alterations in temperature conditions near edges are likely to have a significant impact on their distribution. Additionally, in arid environments near edges, amphibians may be more vulnerable to dehydration. Maunoury et al. examined the responses of amphibians and reptiles to forest edges [11]. Their findings revealed that 96% of all amphibians exhibited an edge response, with 74.5% of amphibians experiencing a decrease in abundance as proximity to forest edges increased. The effects of edges on forest species were observed up to one kilometer from the edge, and the impact varied between wet and dry seasons, affecting the distribution of numerous species. Some species were found exclusively in the core interior of fragments, while others preferred areas near the edge [12]. Despite the presence of roads, some species may continue to inhabit adjacent habitats, but studies indicate that the constant noise from vehicular traffic can disrupt crucial sounds and cause species to spend more energy on staying alert, negatively impacting fitness and reproductive success [13].

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2.5. Genetic diversity

The conservation of species and biodiversity can be greatly influenced by alterations in landscape structure. Genetic diversity plays a crucial role in the ability of amphibian populations to respond to environmental changes. The range of different inherited traits in small populations is typically limited, mating between relatives are common, leading to reduced survival and fertility of offspring. Particular genes may disappear as individuals die or do not reproduce. Small population also has limited ability to eliminate harmful alleles, ultimately decreasing their long-term viability. The impact of roads on population gene flow and abundance can further decrease genetic diversity, hindering breeding migration and juvenile dispersal due to road kills. Studies have shown that road-induced isolation and reduced population size significantly impact genetic diversity, with lower heterozygosity observed in populations near highways [14]. The genetic diversity of a population can be impacted by the barrier effect of roads over an extended period. However, the population reduction because of traffic mortality has even more profound impact [15]. It is therefore essential to maintain stable populations to preserve genetic variation, regardless of barriers to gene flow.

3. Measures to reduce road impact

It is apparent that new ponds constructed near highways may not always offer favorable habitat conditions to support thriving amphibian populations, given that they fall within the road-effect zones. Within these road-effect zones, amphibian communities may be adversely affected by factors such as roadkill. Given the above-mentioned studies, there are a few solutions we can take into consideration to reduce road impact on amphibians.

3.1. Environmentally friendly construction scheme

In order to minimize adverse impacts on amphibians, the most effective strategy is to reduce road development and protect extensive natural habitats. By establishing significant, unbroken areas of land that are devoid of human intervention, amphibians can avoid being killed on roads or disturbed by the various types of vehicles. If it is impossible to avoid road construction, it is important to alter the orientation of roads and adopt an eco-friendly construction design. During the development of new roads, it is crucial to make every effort to avoid passing through areas where amphibians reside.

3.2. Establish passages

In situations where transportation infrastructure is unavoidable, creating wildlife passages (corridor, bridge, culvert, etc.) that connect fragmented areas can allow amphibians to move freely between habitats and access more abundant resources. This can be achieved by planting native vegetation along the edges of fragmented patches or constructing corridor, bridges and tunnels over or under highways and other barriers.

3.3. Strengthen surveillance and data collection

To develop effective protection strategies for different species, it is essential to conduct additional population surveys, monitoring projects, and scientific research. This is because the impact of road distance on various species varies and must be carefully studied. A novel approach to data monitoring and collection is involving the public in scientific research. This cost-effective method can help identify areas and times when roadkill is most likely to occur, making it easier to establish hotspots and patterns that require attention.

4. Conclusion

Modifying the habitat alongside roads has been proven to disrupt the behavior and activity patterns of amphibians. This, coupled with the increased risk of road mortality and mobility barriers, has led to a decline in species numbers and gene flow, ultimately impacting the overall stability and survival of populations. Within a 1 km zone around roads, pond amphibian communities were found to be negatively affected. The analysis suggests that measures to mitigate the impact of roads should focus

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on constructing sizable ponds in regions with low road density and the absence of highways. Furthermore, it is essential to ensure that these ponds are connected to adjacent habitats to maintain ecological connectivity. Though roads are a threat to amphibians because of the habitat fragmentation, edge effects, mortality and disturbance they cause. Some species have a preference for certain landscapes in fragmented habitats that benefit their populations. Consequently, upcoming studies ought to examine amphibians' utilization of these landscapes in order to more accurately evaluate the impact of decreased accessible areas resulting from fragmentation on population size. To better comprehend and alleviate the effects of roads on amphibians, we propose a series of future endeavors. Firstly, we need to conduct meticulous research to examine the impact of roads and traffic on various amphibian species, including road mortality, road effect zone, edge effect and genetic diversity over several generations. Secondly, people will gather information on roadkill sites and hotspots to enhance the effective placement of road-crossing structures. Additionally, modeling to identify key features of ecological corridors and optimize road intersection structures are useful. Lastly, humans will conduct field investigations to monitor the effectiveness of road-crossing structures. By pursuing these activities, we can gain a deeper understanding of the road's impact on amphibians and take necessary measures to mitigate them.

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