Effects of Border Fences on Wildlife: A Review

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Abstract

Physical barriers have been used to separate regions, countries, and properties for thousands of years. The Great Wall of China, the Berlin Wall, and the Dingo fence in Australia are examples of significant barriers throughout history. Since 2001, there has been an increase in fence construction around the world, mostly to dissuade refugee access. European border fences have increased in the last century to prevent refugee migration from the multiple conflicts in the Middle East. Similar construction is being completed on the United States-Mexico border fence, which is composed of incomplete sections that are distributed across the 3,145 km border. The objective of this review was to summarize the effects that these anthropogenic transboundary barriers have on wildlife species that once moved freely across borders. We hypothesized that border fences would have a significant negative effect on large bodied, terrestrial vertebrates with high mobility. Additionally, we hypothesized that results of articles reviewed would mostly reference habitat fragmentation and gene flow effects. We conducted a literature review for studies relating to effects of border fences on animals and found 40 peer-reviewed journal articles that focused on transboundary barriers and wildlife. We extracted variables relating to barrier location, construction, wildlife species, and effects of barriers on animals. We also identified whether studies examined influences of barriers on wildlife regarding habitat fragmentation, gene flow, wildlife conservation, availability of water, and climate change. We identified five challenges related to border walls and wildlife: (1) Habitat loss and fragmentation due to the inability to physically cross a barrier such as a fence or wall reduced the home range size of multiple species, (2) Reduction of gene flow due to the segregation of groups or populations on either side of the barrier, (3) Increased difficulty in transboundary conservation and research due to the inability to easily conduct studies with neighboring regions, (4)

Decreased access to water sources due to construction of border fences, and (5) Climate change and the relation of wildlife species and border fences. The articles we found represented studies from four continents (Africa, Asia, Europe, North America). Many of the articles were published after 2005, indicating concerns for wildlife have increased with the increase in border wall construction. Barrier heights ranged from 1.5 m to 8 m. Most studies focused on large mammals (>25 kg) of high mobility with >30% species with decreasing populations and at risk. We found that barriers presented an overall negative effect on mobile species and contributed to the decline of animal populations, including those identified as threatened or endangered. Mitigation to prevent further degradation of habitat included using technologically advanced surveillance instead of physical fences, placing fences in areas that would not disrupt wildlife migration routes, creating wildlife-friendly openings in fences, and wildlife-friendly fencing.

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Introduction

Around the world, transboundary barriers in the form of fences and walls have presented an issue for wildlife. The construction of borders and barriers to determine boundaries is a practice that dates back thousands of years. The Great Wall of China in 220 BCE, Hadrian's Wall in England in 122, the Dingo fence in Australia in 1859, the Berlin Wall in Germany in 1961, and the fence that separates the Gaza Strip from Palestine in 2006 are notable examples (Egan et al. 2018; Rabou and Fattah 2021). However, the construction of international border walls has intensified globally with the refugee crises in Europe and Asia and after the terrorist attacks on the United States on 11 Sep 2001 (Linnell et al. 2016). Ogden (2017) estimated that there are now 30,000 km of border fencing in Eurasia alone and Titley et al. (2020) determined that 13.2% of the world's borders have a physical barrier of varying degrees.

Barriers used to demarcate political boundaries vary in design and construction (Trouwborst et al. 2016, Linnell et al. 2016). With the invention of barbed wire fencing in the late 1800s, countries had an easy and affordable way to identify boundaries of their lands (Poor et al. 2014). Today, border fences can be classified into three categories: almost fully fenced, partially or of unknown extent, and planned or under construction (Linnell et al. 2016). Single or combinations of materials may be used, including chain link, barbed or razor wire fences, electrified fences, steel fences, concrete or mud or sand walls, trenches, or underground metal walls (Trouwborst et al. 2016). The effectiveness of fencing has improved in the last decade, reducing permeability and further limiting animal movement (Linnell et al. 2016). In addition to physical barriers, infrastructure associated with fences such as roads, railroads, canals, power lines, and pipelines can have negative effects on wildlife as these also alter animal behavior (Jakes et al. 2018).

Wildlife interactions with fences can be physical or behavioral, both of which have negative consequences (Jakes et al. 2018). Animals may experience loss of habitat connectivity resulting in fragmentation or loss of habitat, limitations on dispersal thereby reducing gene flow, blocked migratory paths, changes in spatial distribution of species, altered community structures, and even injury or mortality from fence entanglement, poachers, landmines, or predators (Trouwborst et al. 2016, Pokorny et al. 2017).

Habitat fragmentation had a negative effect on snow leopard (*Panthera uncia)* populations in Asia as their home ranges exist across multiple international borders, fenced and unfenced (Li et al. 2020). In addition, the lack of gene flow in snow leopard populations is leading to genetic erosion in segregated populations (Li et al. 2020). The near-threatened European bison has faced similar challenges in Belarus, where a border fence constructed in 1980 divided the population into multiple groups, which has led to inbreeding depression and reduced number of offspring (Daleszczyk et al. 2009).

Barriers can also result in injury or mortality to wildlife. During a 10-month study that focused on the 178 km Slovenia-Croatia Border, Pokorny et al. (2017) found that 13 red deer (*Cervus elaphus*) and 8 roe deer (*Capreolus capreolus*) were killed due to fence entanglement. Safner et al. (2021) found in the two years after installation of the Hungary-Croatia border fence, 38 red deer, 23 roe deer and three wild boar (*Sus scrofa*) had been killed due to entanglement. The authors determined that these numbers equated to a mortality rate of 0.47 ungulates per km of fencing.

Border fences can also cause unintended increases in predation and entrapment. Both African wild dogs (*Lycaon pictus*) and coyotes (*Canis latrans*) chased fast moving prey into fences to trap and kill them. Hunters and poachers may use the same techniques to harvest animals (Trouwborst et al. 2016). Wildlife-human conflicts have increased in Bangladesh as a result of a border fence. Locals expressed their concerns over the destruction of agricultural land and homes by Asian elephants (*Elephas maximus*). Interruption of the historical migration routes of elephants by the wall results in trapping animals in populated rural areas (Aziz et al. 2016).

Another example of a transboundary barrier that is concerning for wildlife conservation is the United States-Mexico border. In 1993, the United States completed its first section of the southern border wall between San Diego, USA and Tijuana, Mexico (Harriss 2018). In 2005, the United States Congress passed the Real ID Act, which granted the newly developed Department of Homeland Security full rights to waive any environmental laws that would slow development of a border wall. Waived laws included the Endangered Species Act (ESA) and the National Environmental Policy Act (NEPA). The disregard of these guidelines allowed construction to be completed without environmental impact analysis, conservation-oriented development, and post-construction environmental monitoring (Peters et al. 2018). By 2017, one-third of this southern border had barriers. These included vertical steel posts, wire fencing, and low-height vehicle barriers (Ogden 2017). Although the design of the United States-Mexico border fences varies, the most common design exceeds four meters in height, has 5 to 10 cm wide vertical gaps and is surrounded by a 25 m wide clearing for access roads (Flesch, 2009). In 2017, United States policymakers urged for completion of the border wall and construction efforts increased. To complete the border, the Department of Homeland Security estimates it will require 21 billion dollars, which can decrease budgets meant for wildlife conservation (Harriss 2018).

Intensified construction has reduced the area, quality, and connectivity of wildlife habitat in the southern United States (Chambers et al. 2022). Barriers along the southern border decreased the abundance of puma (*Puma concolor*) and coati (*Nasua narica*). Further construction is likely to negatively affect endangered species that reside along the border such as the Mexican gray wolf (*Canis lupus baileyi*), ocelot (*Leopardus pardalis*) and the Sonoran pronghorn (*Antilocapra americana sonoriensis*) (Titley et al. 2020). In addition to the negative effects on wildlife, a continuous barrier would compromise more than a century of binational conservation between Mexico and the United States (Peters et al. 2018).

The goal of this study was to summarize known effects of transboundary fences on wildlife. We hypothesized that border fences would have an overall negative effect on animal species. Furthermore, the higher the mobility of the species, including species with long-distance migration habits and nomadic species that shift for seasonal food availability, the larger the negative effect we expected. To investigate our hypothesis, we conducted a literature review with the intent of describing barriers, wildlife species, and summarizing five main questions: (1) how does habitat loss and fragmentation disrupt the natural migratory corridors near fenced borders, (2) what effects do habitat loss and fragmentation have on gene flow of wildlife species, (3) what are conservation issues related to border fences and binational cooperation and what solutions exist to reduce the impacts of the effects, (4) does decreased access to water sources due to construction of border fences influence wildlife, and (5) how are climate change and the relation of wildlife species and border fences considered.

Methods

2.1 Literature Search

We conducted a literature review in December of 2022 using two search strategies. For the first phase, we searched *Web of Science*, *BIOSIS*, *CAB Abstracts*, *Zoological Record*, and *Agricultural and Environmental Science Collection* for publications specifically about the United States border wall with Mexico and its effect on wildlife. That search was structured as follows: (border OR perimeter OR bounda* OR transboundary) AND (wall* OR fenc* OR barrier) AND (US OR USA OR U.S. OR U.S.A. OR "United States" OR "US-Mexico" OR "United States-Mexico") AND Mexic* AND (wildlife OR animals OR biodivers* OR species OR corridor OR migrat* OR conservat* OR connect* OR fragment* OR linka* OR dispers* OR range OR "gene flow”). We then broadened the search and removed geographic restriction to look for any publications about how border barriers affect wildlife. That search was structured as follows: ("border wall" OR “border walls” OR “security wall” OR “security walls” OR “border fence” OR “border fences” OR “border fencing” OR “security fence” OR “security fences” OR “security fencing”) AND (wildlife OR animals OR biodivers* OR species OR corridor OR migrat* OR conservat* OR connect* OR fragment* OR linka* OR dispers* OR range OR “gene flow”).

We conducted a second search using Google Scholar. We sought additional sources relating to transboundary barriers, wildlife, habitat fragmentation and gene flow. We used terms “Gene flow”, “Habitat fragmentation” and “Ecological segregation”.

2.2 Study attributes and variable extraction

Once we obtained search results, we determined which articles to include in our review based on three criteria. (1) The source had to include information regarding one or more wildlife species and a barrier. We defined "barrier" as an impassible, human-made obstacle, such as a fence or wall, designed to restrict movements of wildlife species or humans. Additional criteria included: (2) peer-reviewed journal articles in English, and (3) information involving conservation issues, climate change, and background or historical information regarding wildlife species and border walls or fences. We also differentiated between types of studies by determining whether an article reported empirical data on effects of an international border wall or fence on wildlife species. Results that did not include the required criteria were not included in the data extraction and results, but pertinent information was used in the introduction and discussion sections of the review to further express ideas.

From each paper, we obtained information regarding barriers in regards to their effects on wildlife and collected 26 variables. Four characterized the article, 8 the barrier, and 14 related to wildlife species and effects of the barrier (Table 1). Some information on wildlife species was obtained from web-based searches (e.g., mean mass of the wildlife species) or sources such as Natureserve (NatureServe 2023). The International Union for Conservation of Nature (IUCN) (IUCN 2023) was used to determine species conservation status and population trend (Table 1). We also recorded mitigation suggestions or solutions to decrease negative effects of barriers on wildlife presented by article authors.

Results

The first phase of our search identified 257 results including 205 journal articles, 22 theses, 1 blog post, 8 newspaper articles, 7 books or book sections, and 4 conference papers. The second phase yielded 7 peer-reviewed journal articles. Based on our criteria, we retained 40 articles. Articles ranged in publication year from 2007-2022 (Figure 1) and were conducted in 28 countries and four continents (Figure 2). Many of the results (43%) focused on the US-Mexico border wall. The fences described in these studies consisted of various construction and ranged from 1.5 to 8 m tall, with 8%, 20%, 22%, 30%, 3%, and 17% of studies describing fences that were 1-2 m, 2-3 m, 3-4 m, 4-5 m, 7-8 m, and unknown fence heights, respectively (Figure 3). The number of fences represented by these articles was lower; for example, although 12 articles discussed fences that were 4-5 m tall, these represented only 2 unique fences (Figure 3).

Although 5 taxa were represented in these studies (Mammalia, Aves, Reptilia, Amphibia, Pisces; Figure 4), all articles used for data extraction mentioned mammals, other taxa were less frequently represented. Of the 32 wildlife species described in articles included in this review, 78% weighed >25 kg (Figure 5) and 84% (Figure 6) were considered mobile (Table 1). Additionally, 34% of species were considered non-migratory, 34% were short-distance migrators, 22% were long-distance migrators, and 10% were nomadic (Figure 7). Barriers had an overall negative effect on wildlife species, with 95% of papers finding a negative effect, and only 5% indicating a positive effect (Figure 8). Thirty seven percent of the species in this review are classified as decreasing and 31% considered at risk under the IUCN (Figures 9a and 9b). Eighty-five percent of articles mentioned the effects of fragmentation due to an international border fence, 50% mentioned effects on gene flow, 75% mentioned issues related to conservation, 20% mentioned water as a reason for animal movement, and 20% mentioned climate change and the potential future effects it could present (Figure 10).

Discussion

4.1 Overview

We found a clear and negative effect on wildlife species that have had their historical geographic ranges, travel corridors, or migratory routes intersected by border fences. Additionally, many borderland regions reside in biodiverse habitats where endangered or threatened species are present, putting these at greater risk from habitat alteration or loss (McCallum et al. 2014). In this discussion section we will highlight the results of our review in six sections: (1) overview, (2) border wall effects on habitat fragmentation, (3) border wall effects on gene flow, (4) conservation issues and mitigation strategies, (5) water use and availability, and (6) future climate change effects on wildlife.

Fences have been used for tens to thousands of years, but there are negative consequences that are now accentuated with the dramatic increase in border fence construction. The installation of border fences in highly biodiverse vegetation types resulted in habitat loss and fragmentation, reduction or loss of gene flow and increased difficulty in species conservation and research due to limited access (Daleszczyk and Bunevich 2009, Flesch et al. 2010).

The articles we found generally involved short-term studies (e.g., Olson et al. 2009, Pokorny et al. 2017) and thus may lack important long-term information. Furthermore, studies were conducted independently of one another with no strict guidelines, which may not allow for follow-up studies to determine long-term changes. We also had difficulty finding fence descriptions. Given many of these barriers mark binational boundaries and were constructed for security reasons, some nations are reluctant to provide details on barriers (Linnell et al. 2016). Many studies mentioned mitigation strategies, and we compiled the most feasible of these from multiple peer-reviewed sources. These mitigation measures can be referenced during the planning phase of future barrier construction projects.

4.2 Habitat Loss and Fragmentation

Habitat fragmentation is defined as the separation of habitat into small, isolated fragments separated by a matrix of human-transformed land cover and reduces wildlife (mammals, birds, insects, and plants) biodiversity by 13 to 75% (Haddad et al. 2015). Fragmentation can cause habitat loss, direct and indirect mortality, and alteration of natural ecosystem processes for many species (Cypher et al. 2021). Large, migrating carnivores and herbivores are especially at risk of fragmentation because they require large, continuous travel corridors to complete a migration (Kaczensky et al 2011). For example, there has been a notable shift of wild camel (*Camelus bactreanus*) home ranges in Mongolia due to fragmentation (Xue et al. 2021). Eighty-five percent of our studies identified fragmentation as an important consideration.

On a global scale, many of the historic migration corridors have been lost or reduced due to anthropogenic factors leading to fragmentation. Accessibility of food and water and productive breeding grounds is a primary concern regarding fragmentation as wildlife species that track high quality forage or productive and safe breeding areas throughout their migrations have been limited due to the implementation of fencing (Poor et al. 2014). Additionally, young animals that cannot negotiate these fragmentation barriers can become stranded and prone to exposure and predation, therefore reducing future recruitment and limiting population size (Jakes et al. 2018).

One very common result of habitat fragmentation is habitat loss, which can lead to areas that lack appropriate habitat and can be as restrictive as a wall or fence. Habitat fragmentation can impede movements of wildlife, limit population expansion, increase exposure to human land uses along fragmented edges and isolate populations that were once continuous (Kaczensky et al. 2011, Haddad et al. 2015). These factors are compounding because as habitat fragmentation increases, the level of species mobility must increase to traverse a less connected habitat corridor. Without connectivity, population dynamics and distributions will be altered (Gonzalez-Saucedo et al. 2021). When habitat area was reduced, wildlife species experienced decreased residency, increased isolation of sub-populations, and reduced movements via historical migration routes, often disturbing the composition of entire communities (Haddad et al. 2015). The effects of habitat fragmentation have severe consequences for many wildlife species and natural ecosystems and have been a major factor driving research and mitigation (Jakes et al. 2018).

A well-studied example of fragmentation effects is the China-Mongolia border fence. The border barrier is 4,710 km long and is an almost fully fenced area that intersects the Gobi Desert and the Mongolian Steppes, one of the largest remaining temperate grasslands in the world (Olson et al. 2009). Both China and Mongolia have experienced a large loss of steppe habitat due to agriculture and overgrazing (Olson et al. 2009). Mongolian gazelle (*Procapra gutturosa*), the Asiatic wild ass (*Equus hemionus*), and the wild camel are negatively affected by the border fence as it divides habitat and restricts movement as the species follow seasonal food sources. The wild camel is critically endangered and is currently restricted to the Mongolian side of the border; it can no longer access resources across the border (Xue et al. 2021). The Mongolian gazelle is considered a species of least concern with a stable population (IUCN 2023) with estimates of one million individuals; however, it faces similar threats due to migration restrictions. The gazelles make annual movements of up to 600 km, making them the fifth most mobile animal (Olsen et al. 2009). McCain and Childs (2008) used Global Positioning System (GPS) locations of migrating gazelles to determine whether the border fence affected their movements. They concluded that 80% of gazelles encountered the border fence at least once and, on average, would move parallel along the fence for 1 to 59 days and distances that averaged 11 km.

Another significant barrier in the region is the fully fenced Ulaanbaatar–Beijing Railroad, which traverses 1,500 km from Beijing, China to Ulaanbaatar, Mongolia. The railroad fence cuts off 17,000 km^2 of Asiatic wild ass habitat to the southwest into China (Kaczensky et al. 2011). Although many animal crossings exist for livestock herders, these are not positioned or designed for wildlife use (Kaczensky et al. 2011). This was confirmed by Takehito et al. (2013) when they tracked Mongolian gazelle and Asiatic wild ass movements in the region for 3 years. No gazelles or Asiatic wild asses crossed the railroad during the study. They inferred that species mortality would increase due to the inability to reach productive forage areas in the winter season and this would become a much larger issue as environmental factors degraded. Olson et al. (2009) suggested that minor fence modifications would be enough to allow species to retain historic nomadic movements.

There are many notable global examples of fragmentation effects due to border fences. The Cape hare (*Lepus capensis*) population in Israel has lost access to habitat on either side of the political border fence installed in 1948 (Rabbou and Fatah 2021). Border fences in northern Bangladesh have become barriers to migrating Asian elephants, resulting in increased human-elephant conflicts and elephant and human mortality (Aziz et al. 2016). Brown bear (*Ursus arctos*) populations in Europe are expected to decline in response to newly installed refugee borders which prevent cross-boundary movements (Linnell et al 2016, Reljic et al. 2018). Li et al. (2020) described the change in historical snow leopard movements and how nearly all of the linkages across their range have been divided due to anthropogenic disturbances such as fences and highways.

The United States-Mexico border traverses 3,145 km across six ecoregions and is considered to have some of the most biodiverse habitats in the world, bisecting the ranges of 62 critically endangered, endangered, or threatened wildlife species (Peters et al. 2018). Several species of concern include the mountain lion (*Puma concolor*), black bear (*Ursus americana*), Mexican gray wolf (*Canis lupus baileyi*), and jaguar (*Panthera onca*), all of which have home ranges intersected by the border fence (Gonzalez-Saucedo et al. 2021). Ongoing construction of the border wall has resulted in 8,000 km of official roads, lights, and operation bases. Roads, vegetation removal, barriers, and light pollution will likely increase habitat fragmentation where fences are installed (Lasky et al. 2011). Regular patrols by vehicle, horseback, and foot travel have made the fragmentation effects (i.e., disturbance) even greater (Ogden 2017). Roads associated with the border have a width of 12 to 20 m, which is the equivalent of 12 to 20 hectares destroyed per kilometer of barrier (Fowler et al. 2018). A continuous border wall will cut off 34% (n = 346) of native mammals from their habitat to the south, and 59 of those species would have dramatically decreased geographic ranges that would put them at risk of extinction (Peters et al. 2018).

Species with large home ranges will likely be more affected by a border fence. For example, the mountain lion is a species with a large dispersal area that needs migration corridors to react to environmental variability or disturbances such as wildfire, drought, and food availability (McCallum et al. 2014). Similarly, the federally protected jaguar was tracked in a study by McCain and Childs (2008). They found that the movements across the border were mostly in key connective areas, and they suspect that a thinly distributed population links habitats from Arizona, USA to Sonora, Mexico. No known jaguar breeding has occurred in the United States since 1910, thus they reproduce exclusively south of the United States border. Male jaguars have been known to migrate into their historical range in Arizona and New Mexico (Chambers et al. 2022). This implies that the subpopulation in the United States would be cut off from breeding grounds in Mexico, therefore preventing any chance of recovery in the United States population (Fowler et al. 2018).

Movement habits of large predators are based on energy expenditure. When a species with a large home range, such as the jaguar, loses habitat connectivity, small obstructions can increase energy expenditure resulting in a higher need for food and water (Gonzalez-Saucedo et al. 2021). Gonzalez-Saucedo et al. (2021) stated that although jaguars had the ability to move their home ranges in response to the border wall, factors such as energy expenditure and resource availability could limit those abilities. For example, when exposed to a wall, a jaguar would walk an average of 6 km further to access a water source than in the unwalled areas, which equated to a 4% increase in daily energy expenditure. Energy expenditures increased due to the interference of a direct route to springs on opposite sides of the border.

4.3 Gene Flow

Half of the papers we reviewed indicated border fencing influenced gene flow. A major effect of habitat fragmentation is geographic isolation and the reduction in gene flow (Peters et al. 2018, Li et al. 2020). Geographic isolation is defined as a population or species that resides in regions that are close, but regions do not overlap due to barriers or obstacles (Li et al. 2020). Border fences that limit dispersal can alter gene flow and lead to genetic isolation of subpopulations (Safner et al. 2021, Lasky et al. 2011). Connectivity between genetic populations is essential for maintaining diversity and population fitness, and to prevent extinction risks within smaller subpopulations as more genetically diverse individuals and populations often have higher fitness (Buchalski et al. 2015, Jakes et al. 2018). Loss of connectivity in subpopulations is often deleterious, leaving fragmented populations prone to a reduction in diversity and increased extinction rate (Lasky et al. 2011). Isolated subpopulations lose genetic variation because of random sampling, meaning not every allele is represented in offspring, causing the population to lose alleles over time (Ogden 2017). Extinction rates are more likely to increase due to stochastic factors, such as small population size and inbreeding depression. Inbreeding depression refers to the reduced fitness of offspring due to the mating of closely related individuals instead of randomly selected mates (Daleszczyk and Bunevich 2009). When present for multiple generations, inbreeding is likely to cause an increase in the expression of recessive, deleterious genes in a population (Li et al. 2020). Furthermore, inbreeding can reduce evolutionary potential in the long term by limiting the ability of a population to adapt to changes in biotic and abiotic factors, such as climate change or ecological shifts due to the border fence (Epps et al. 2005). The likelihood of inbreeding can be increased when historical movement corridors are altered, causing a funneling effect when the remaining individuals have to congregate into a new core area (Egan et al. 2020).

Shurtliff et al. (2013) stated that mating opportunities between species were determined by the distribution of habitat and the degree to which species are restricted to these habitats. This is especially true for species near the edge of their home range as populations are often already low, meaning even a slight hindrance can have large consequences such as extinction of subpopulations (Lasky et al. 2011). Loss of diversity caused by anthropogenic factors will have important implications for long term conservation of the affected subpopulations (Li et al. 2020).

The negative effects of gene flow were demonstrated by Aspi et al. (2007) using gray wolf (*Canis lupus*) alleles to determine the influence of the Soviet Era fences on the Russian-Finnish border. The Russian populations lost multiple rare alleles and genetic differences between the Russian and Finnish wolf populations were significant. They determined that the overall proportion of migrants between the two populations was only 2.7%, which they attributed to the sections of the border fence that remained. Similarly, Daleszczyk and Bunevich (2009) found that European bison (*Bison bonasus*) along the Belarusian border fence lacked gene exchange and required a future exchange of genetic material to prevent population extinctions.

Rapid construction of a border fence on the United States-Mexico border will likely drive genetic division in wildlife species by intersecting and eliminating historical migration corridors between Arizona and Mexico Sky Island ranges (Atwood et al. 2011). Sky Island ranges are mountains rising from the lowland valleys that harbor high biodiversity and serve as habitat for many migrating wildlife species (Ogden 2017). These Sky Islands contain high quality corridors linking subpopulations in the Sierra Madre mountain range that extends from central Sonora, Mexico to the Mogollon Rim in Arizona and New Mexico (Atwood et al. 2011).

The completion of the border fence will likely affect multiple species, including the black bear as it will present a physical barrier between the Sky Islands and increase genetic isolation in subpopulations (Atwood et al. 2011). Gould et al. (2022) stated that border security in unfinished sections could also decrease gene flow and sever populations due to the heavy human use of roads that have been built for security purposes. Gould et al. (2022) described how roads have influenced movement patterns and habitat selection of black bears, leading to genetic substructures throughout the population.

Several studies have concluded that the completion of the wall would disrupt populations of bighorn sheep (*Ovis canadensis*) by weakening linkages between populations on either side of the border. Bighorn sheep populations near the United States-Mexico border are often small and fragmented, so connectivity amongst them is necessary (Flesch et al. 2009). Flesch et al. (2009) identified dispersal corridors of bighorn sheep and estimated that nine populations throughout Sonora, Mexico and the United States were linked by gene flow. One radio collared female crossed an unfenced portion of the border nine times. This study showed that a border fence would disrupt the 10 female transboundary dispersal corridors (Flesch et al. 2009). The ability for the female bighorn sheep to move among subpopulations was necessary to ensure continued population viability (Ogden 2017). Buchalski et al. (2015) found that one population would be divided in half, causing a risk of local extinction due to the reduction of access to suitable habitat. Flesch et al. (2009) determined the border fence would weaken linkages between populations, both transboundary and on the same side of the fence. They also estimated that an impermeable barrier will cause a 0.4% per year decrease in genetic diversity, leading to a 40% decrease over 60 years. They further explained how gene flow among populations was strongly and negatively correlated with barriers at interpopulation distances of less than 15 km.

4.4 Climate Change

Despite the increasing awareness about changing climate over the past 20 years, few papers (20%) described the effects of climate change on wildlife, yet climate change is likely to add even more complexity to transboundary conservation of wildlife species. Historically, as a region aridifies, vegetation types shift along a north-south gradient which will significantly affect migrating species by creating a poleward home range transition (Thornton et al. 2107, Titley et al. 2020, Gould et al. 2022). Climate change has the potential to increase home range size, insect outbreaks, and fire frequency, as well as alter water regimes (Ogden 2017). A shift in species distributions could cause an impermeable border wall to have an even more significant negative effect on wildlife species, emphasizing the importance of landscape connectivity (Flesch et al. 2010). Titley et al. (2020) stated that effects to wildlife species along the United States-Mexico border would increase due to climate change and that it could be one of the worst affected areas in the world if a continuous wall is constructed due to the multiple shifting habitat types and high number of species that reside in the region. Climate change will cause a need for significant binational cooperation as many species ranges will be pushed across international borders (Titley et al. 2020).

4.5 Water

Only 20% of studies identified water as an important factor in border fencing; however, it is critical in some environments. Wildlife species residing in arid climates are required to constantly move to access seasonal, changing water sources. A lack of habitat connectivity caused by a border fence can impede this process and reduce the ability to attain this necessary resource (Ogden 2017). Due to different management techniques throughout a species' range, wildlife species that are forced to change their geographic range could be in competition with livestock for resources like water (Kaczensky et al. 2010). Livestock that frequent water access points can pose a high amount of competition for naturally occurring wildlife species.

Additionally, home ranges of individuals within many species show a negative relationship between distance to water and occupancy and this can increase the distance and energy required to reach the source (Atwood et al. 2010). Liu et al. (2020) described a study where jaguars were greatly influenced by border fences, causing a 4% increase in daily energy expenditure that was related to searching for accessible water sources. Energy expenditure of many wildlife species will likely increase when a border fence is implemented and cuts off access routes to certain portions of a species geographic range.

4.6 Conservation

Two-thirds of the papers we reviewed emphasized the role conservation planning has in mitigating negative effects of border walls. Predicting the implications associated with a border fence is a challenge that affects scientists and policymakers worldwide (Egan et al. 2018). The effects of a border fence may be difficult to control given transboundary conservation efforts likely differ on either side where security issues, policies, and conservation efforts may be viewed differently (McCallum et al. 2014). Transboundary species with a large portion of their range on one side and a small portion on the other side of the border may be more at risk of mismanagement due to multiple management techniques that differ between countries, compared to species whose geographic range is completely within one country (Thornton et al. 2017).

Commonly, border fences are built for security reasons and access is restricted at or near the fence. Additionally, environmental policies are often waived to proceed with construction efforts (Egan et al. 2018). Although many border regions are considered highly biodiverse, they generally lack biodiversity surveys because of difficulties accessing remote and roadless areas and complications regarding military control of the regions (Liu et al. 2019). Worldwide, lands contain tens of thousands of kilometers of fencing that present major effects on wildlife species, yet fences are typically unregulated, unmapped, and constructed without considering ecological effects (Jakes et al. 2018). Fences can cause heightened stress of wildlife species due to negotiating the obstacle, obstructed movements, separation from the group and entanglement. These impacts can accumulate over time and negatively affect species by increasing energy expenditure, mortality rates, and decreasing fitness (Jakes et al. 2018).

There are many issues related to administrative and political differences between countries with shared borders. In Europe, small countries delegate environmental issues to multiple, smaller autonomous regions, decreasing the amount of cooperation, and making it difficult to enact broad-scale policies (Reljic et al. 2018). Border wall construction and subsequent management policies on the Israel-Palestine border placed residents of both countries on opposite sides of the wall, negatively affected wildlife populations, and prevented the natural flow of water in many areas (Swaileh 2011, Rabou and Fattah 2021).

Border fences that are installed with no regard to scientific, traditional, or behavioral knowledge may result in a negative effect on the wildlife species near border fences. Aziz et al. (2016) discussed border fences installed in northern Bangladesh and their effects on elephants, which often resulted in human conflicts. Elephants were forced to follow the fence for long distances to find a crossing point. Instead of crossing, elephants destroyed 228 houses in one year, killed 78 humans between 2000-2015, and destroyed unknown hectares of crops and agricultural lands. Between 2008-2015, 19 elephants died because of conflicts with humans.

Olson et al. (2009) described hundreds of dead Mongolian gazelle trapped in border fences between Russia and Mongolia. Prior to 2008, Normalized Difference Vegetation Index (NDVI) estimates of available green biomass eaten by gazelle had declined between 27 and 37%.

Due to this lack of vegetation, thousands of gazelles attempted to migrate north into Russia but were prevented by fences. Olson et al. (2009) found that gazelles generally spent days in the vicinity of the fence before turning another direction. In May 2008, Russian border guards were seen temporarily dismantling fences to allow safe passage of gazelles.

The United States-Mexico fence has sparked concerns of eminent domain, in which the US government can exercise the power to pay a landowner "just compensation" to turn private property into public land for border fence operations (Harriss 2018). Additionally, a treaty signed between the United States and Mexico in 1889 prevents the disruption of the Rio Grande River. This has led to sections of the border fence being moved and forcing some U.S. citizens to be on the opposite side of the border (Harriss 2018). Some are worried that the wall has undermined conservation efforts and diverted funds towards barrier construction instead. Many United States and Mexican scientists have shared stories of being threatened, harassed, and delayed by border officials on both sides, making study efforts even more difficult (Peters et al. 2018).

Binational collaboration between the United States-Mexico border could be imperative to the future success of many endangered species (Gould et al. 2022). Important species that will benefit from collaboration include the jaguar, which used corridors to cross into the southern United States for decades, ocelot, Mexican gray wolf, black-tailed prairie dog (*Cynomys ludovicianus*), black bear, mountain lion, mule deer (*Odocoileus hemionus*), and others (Dinah, 2009). The Janos-Hidalgo bison (*Bison bison*) herd is an example of a species requiring binational collaboration efforts (List et al. 2007). In Mexico, the herd is protected by federal law whereas in New Mexico the bison are considered livestock and are hunted on private land for additional income (List et al. 2007).

The endangered ferruginous pygmy-owl (*Glaucidium brasilianum*) is an avian species likely to be affected by the border fence. Flesch et al. (2009) showed that flight heights averaged only 1.4 m above the ground with maximum flight heights of 4.6 m. Because the border fence had an average height of 4 m, some birds could cross and gene flow would not be eliminated completely but would be significantly reduced. This would affect demographics, particularly for the small population in the United States. Large vegetation gaps and a physical barrier would limit transboundary movements, reducing dispersal speeds by up to 116 times below normal. Additionally, ferruginous pygmy-owls that used corridors with large vegetation openings changed direction 2 times more than those without, causing increased energy expenditure.

Effects of fencing are often negative, but there are some positive outcomes of fencing in relation to wildlife. When used as a tool in wildlife management, fencing can protect sensitive areas, deter poaching, reduce predation (Hameed et al. 2012), limit disease transmission, and prevent invasive species colonization (Jakes et al. 2018). Liu et al. (2020) stated that there were higher proportions of protected areas near international borders. They also described how border fences could prevent wildlife from crossing into countries with weak or nonexistent hunting laws, such as the Mongolian Asiatic wild ass population which is prevented from crossing into China where poaching is abundant (Ogden 2017).

In the following section, we provide suggestions on how to mitigate many negative effects of fences on wildlife. Although not all options may be realistic, managers can consider these suggestions to improve wildlife habitat across fenced borders.

Crossing Approaches

This approach mitigates habitat fragmentation and reduced gene flow from impermeable barriers. During border fence construction, there is generally little consideration for permeable crossing points because fences are often built to deter human immigration, which leaves no gaps or crossings. The strategies below would result in a decrease in human immigration deterrents and a significant increase in wildlife crossing capabilities.

- Wildlife crossing structures where security requirements allow (Trouwborst et al. 2016)
- Seasonal removal of border fences to permit movement of migratory species (Linnell et al. 2016)
- Maintanence of connective corridors between seasonal habitats (Nandintsetseg et al. 2019)

Fence Construction

The design of border fences are meant to prevent human crossings. This presents issues to many wildlife species as they can be the same size or larger than humans. The design of border fences can be modified to prevent human and vehicle passage while maintaining wildlife movements through the region. Strategies to increase wildlife crossings are included below.

- Plan fence routes to mitigate resource exclusion (Trouwborst et al. 2016)
- Use wildlife friendly fencing (Linnell et al. 2016)
- Remove bottom strands of barbed wire from fences (Olson et al. 2009)
- Remove border fencing and restore degraded land (Bradby et al. 2021)
- Use plain, high tensile fencing wire instead of barbed wire (Van Der Ree 1999)
- Use technological monitoring systems instead of border fences (Linnell et al. 2016)
- Increase size and frequency of openings in fences and walls to promote transborder dispersal. If adding additional barriers, determine the combined effect of all barriers (Lasky et al. 2011)
- Reduce or eliminate artificial lighting (change the spectra of the lighting, use direct light sources so artificial light is not directed widely, switch off lighting when area not in use or light not needed) (Gregory et al. 2021)

Conservation Focused Planning

Conservationists and wildlife biologists should be involved in planning processes for border fences. This would allow for increased knowledge of effects on wildlife species in the region. Additionally, the involvement of wildlife experts in the planning phases of fence construction could reduce the overall impacts presented by international border fences and prevent many issues that we are observing. The methods below include conservation focused planning efforts that can be involved in the planning processes.

- Increase the presence of biologists in the national and international debates around border fencing (Linnell et al. 2016)
- Use landscape genetics modeling or analysis to optimize dispersal and corridor models (Kaczensky et al. 2011)
- Translocate individuals to counter genetic fragmentation (Trouborst et al. 2016)
- Involve decision-makers, academics, and civil society in making decisions to improve binational plans and agreements for conservation (Gonzalez-Saucedo et al. 2021)
- Create transboundary reserves in areas that have high biodiversity to protect wildlife (Liu et al. 2020)
- Raise public awareness, clear land use plans, ecotourism, protected areas, and put an economic value on natural resources (Abdallah and Swaileh, 2011)
- Identify locations with high species richness and species most at risk, then identify effects of barriers on species most at risk (Lasky et al. 2011)
- Follow sound scientific and legal frameworks of US environmental laws (ESA, NEPA) (Peters et al. 2018)
- Facilitate research to assist in environmental evaluation and mitigation efforts (train Border Patrol agents about research and notify them when researchers working near the border) (Peters et al. 2018)

Information regarding the direct effects of border fences on many wildlife species is lacking. There has been a dramatic but recent increase in border fences globally (Linnell et al. 2016). To conserve species, it is important to identify priority areas around the world and ensure proper planning and management decisions are implemented (Thornton et al. 2017, Liu et al.

2020). Lastly, it is necessary to take immediate conservation actions as some effects may take decades or longer to present themselves (Sayre and Knight, 2009).

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Tables and Figures

Table 1. Definitions and descriptions of variables obtained from 40 peer-reviewed articles identifying effects of transboundary barriers (fences, walls) on wildlife.

Variable	Definition
Information about the paper	
ID	Numeric identifier of article, in order of search results
Keep	Appropriate to keep in literature review? Includes one or more wildlife species and a barrier such as a fence (yes/no)
Fence	A physical barrier (fence or wall) is included or mentioned in the paper but may not be the focus of the study (yes/no)
Focus	A physical barrier (fence or wall) is embedded in the study design (or review of studies) with a specific test of fence effects (yes/no)
Wildlife	Wildlife species listed with response to barrier (yes/no)
Empirical	Original empirical data for wildlife and barrier (not citing other studies) - a direct test of barrier effect on wildlife (yes/no)
Review	Is the paper a review of literature? (yes/no)
Publication year	Year that article was published (Example: 2009)
Author/s	Author names
Paper title	Title of article
Journal title	Journal in which article was published
Information about the barrier	
Barrier effect	Fence effects on wildlife species as described in the article: - = negative effects, 0 = no effects detected, + = positive effects
Border	Type of border: transboundary = separates international or regional boundaries, NA = Fence not related to international border
Type of barrier	Structure of fence: wire, razor wire, wall, combination (e.g., wall and wire)
Height	Height of barrier (m)
Length	Length of section of barrier (km)
Continent	Continent where barrier is located: Africa, Antarctica, Asia, Australia, Europe, North America, South America
Location	Specific location within continent (city, state, country, region, or border)
Reason	Reason for barrier placement (e.g., control illegal immigration, prevent wildlife movement)
Information about wildlife species	
Taxa	Taxa/on of species identified as influenced by border (Mammalia, Aves, Reptilia, Amphibia, Pisces)
#Species in paper	Number of species studied in the article
Species	Taxonomic identification of wildlife species (genus and species)
Mobility	Species has physical ability to travel to neighboring regions or farther (Yes/No)

IUCN status	Extinct (EX), extinct in the wild (EW), Critically endangered (CR), Endangered (EN), Vulnerable (VU), Near threatened (NT), Least concern (LC), Data deficient (DD), Not evaluated (NE)
Average mass	Average mass (kg) of wildlife species
Migratory	Historical or current seasonal movement of species: Non = non migratory, Short = <100 km in search of food, breeding opportunity or to escape austere conditions, Long = >100 km in search of food, breeding opportunity or to escape austere conditions, Nomadic = Species is constantly changing range
Fragmentation	Article contains information regarding habitat loss or fragmentation effects on wildlife species (yes/no)
Gene flow	Article contains information regarding gene flow of wildlife species (yes/no)
Conservation	Article contains information regarding conservation of wildlife species (yes/no)
Water related	Wildlife species moves due to seasonal water demands (yes/no)
Climate change	Article contains information regarding effects of climate change on wildlife species (yes/no)
Notes	Additional observations

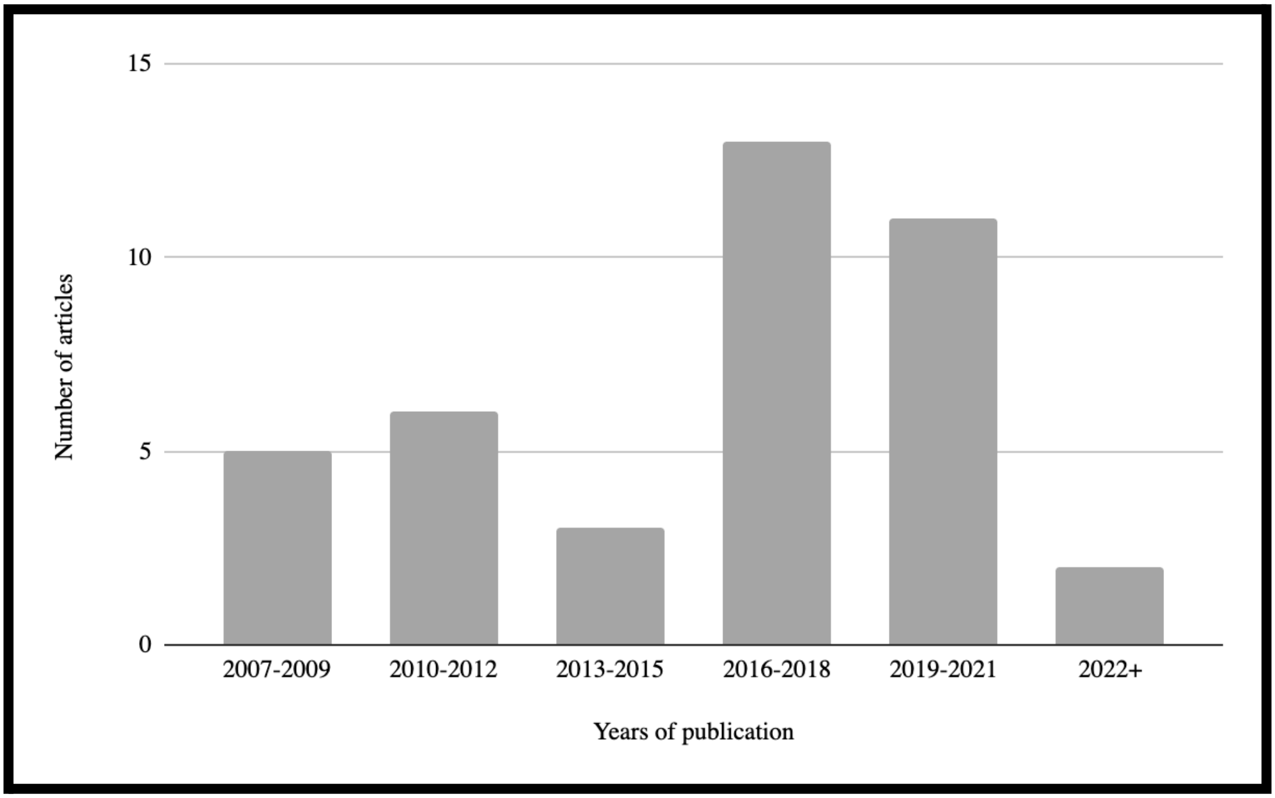


Figure 1. Number of articles identifying the effects of transboundary barriers (fences, walls) on wildlife and the years they were published. Time periods were categorized into six 3-year periods: 2007-2009, 2010-2012, 2013-2015, 2016-2018, 2019-2021, 2022 and newer.

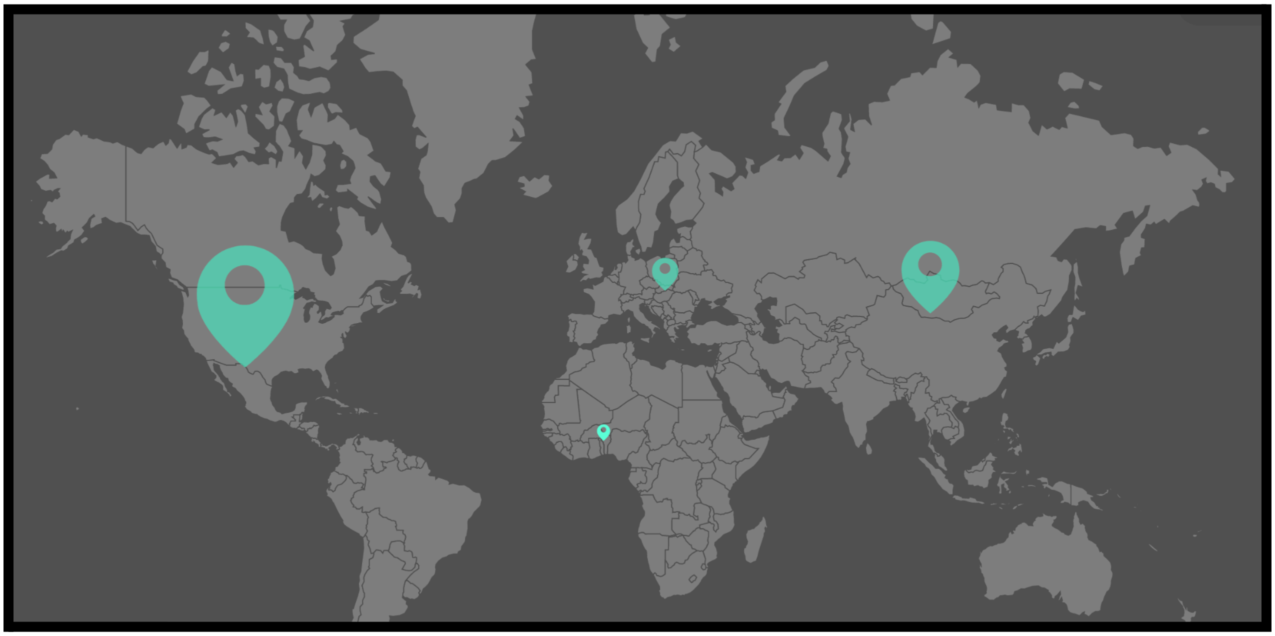


Figure 2. Representation of study locations by continent conducted around the world identifying effects of transboundary barriers (fences, walls) on wildlife. Size of marker is proportionate to the number of articles used in the review (i.e., larger markers indicate more papers).

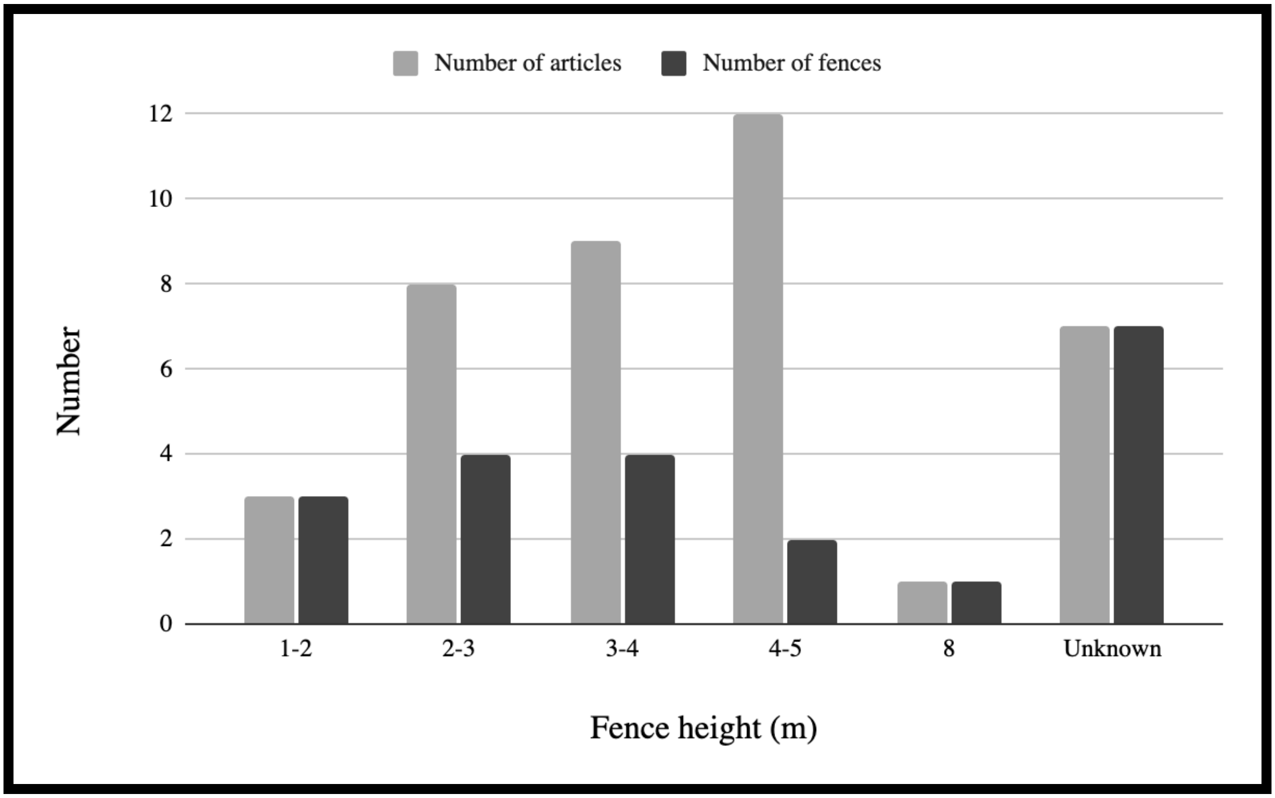


Figure 3. Fence heights (categorized in 1-m increments: 1-2 m, 2-3 m, 3-4 m, 4- to 5 m, 8 m, or unknown) in articles identifying effects of transboundary barriers (fences, walls) on wildlife (light gray) contrasted with number of physical fences that exist (without recurrence) in the 40 studies (black).

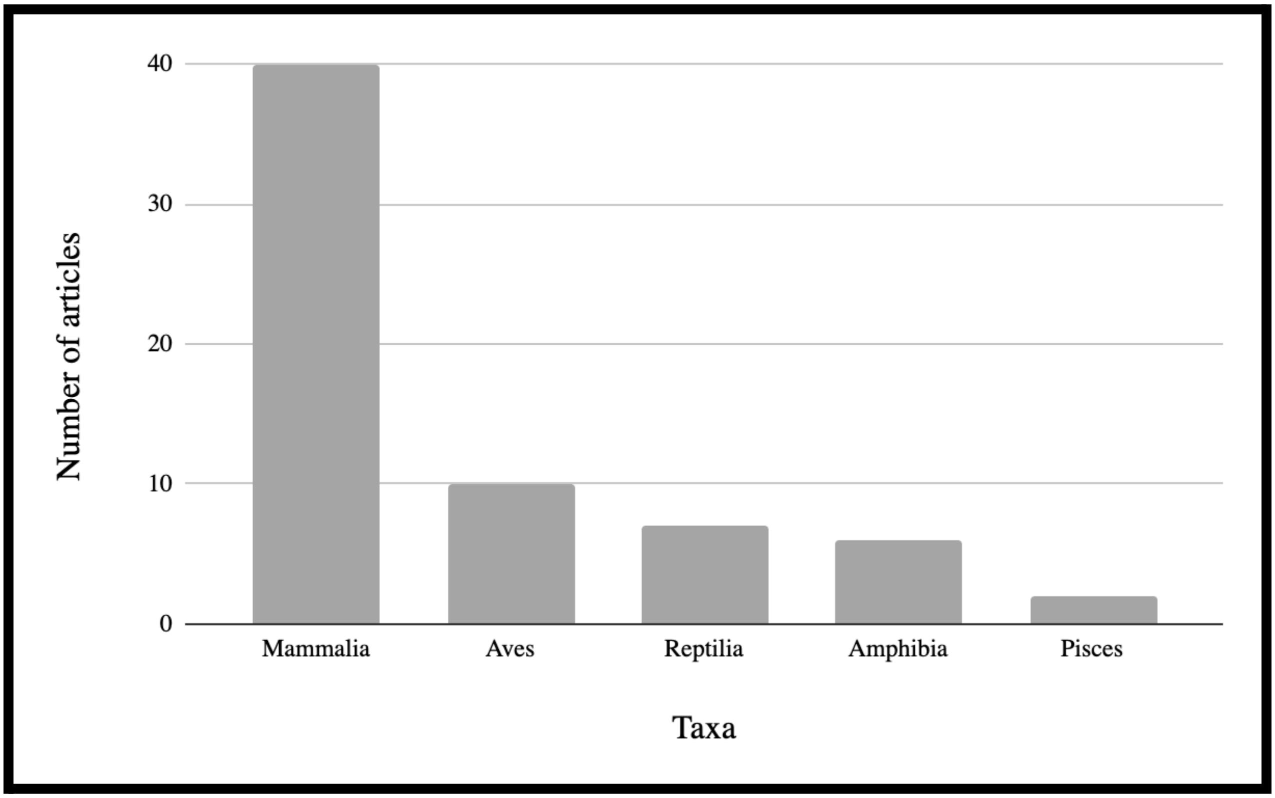


Figure 4. Numbers of articles identifying the effects of transboundary barriers (fences, walls) on wildlife by taxa.

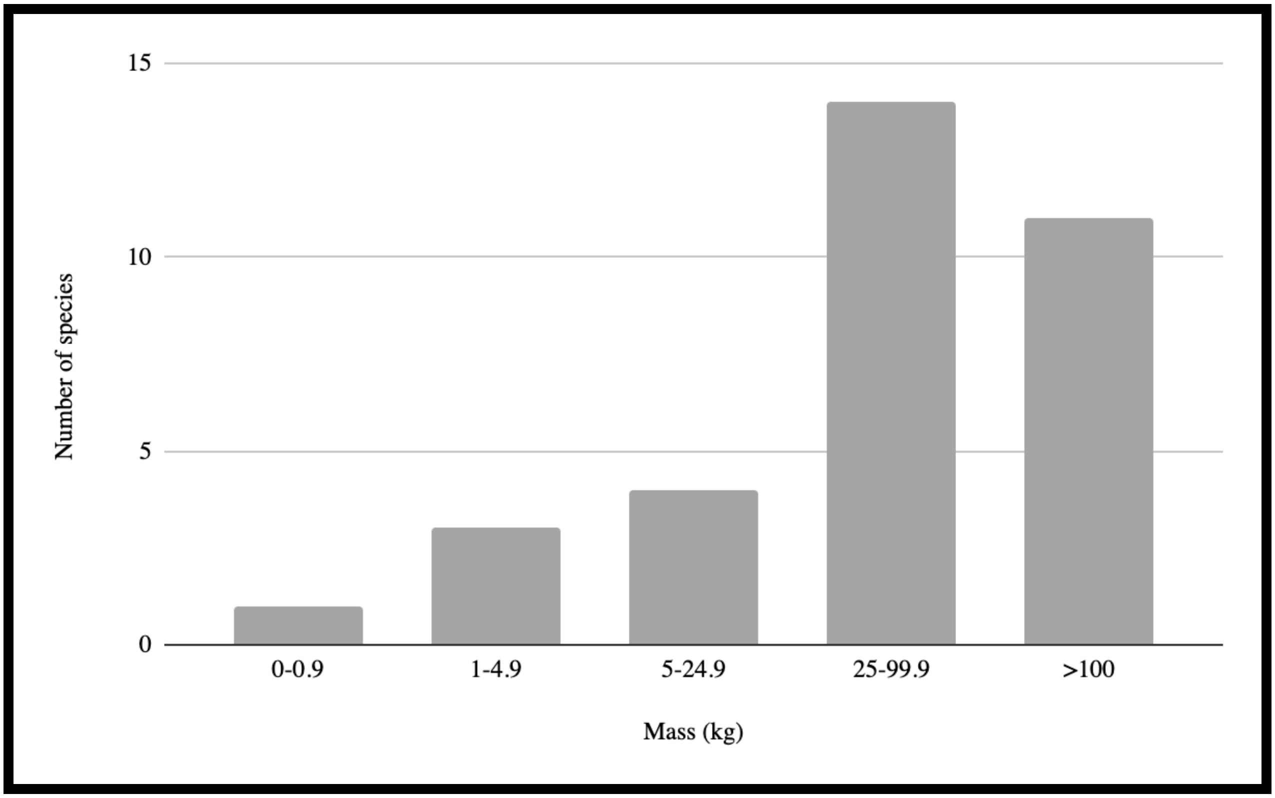


Figure 5. The mass (categorized as 0-0.9 kg, 1-4.9 kg, 5-24.9 kg, 25-99.9 kg and >100 kg) of each of 32 wildlife species included in articles identifying effects of transboundary barriers (fences, walls) on wildlife.

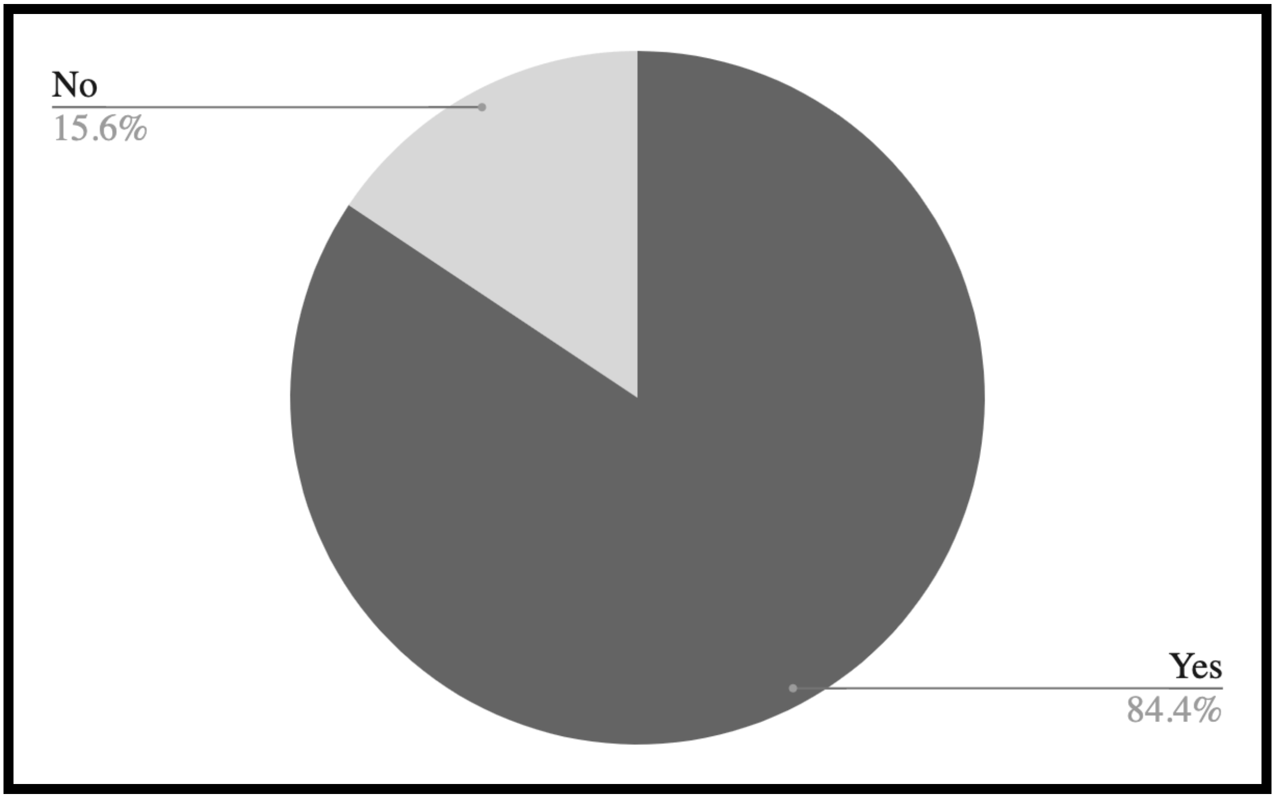


Figure 6. Mobility of 32 wildlife species from articles identifying effects of transboundary barriers (fences, walls) on wildlife. Yes = species has physical ability to move to neighboring regions, state or countries, No = species does not have physical ability to travel to neighboring regions, state or countries.

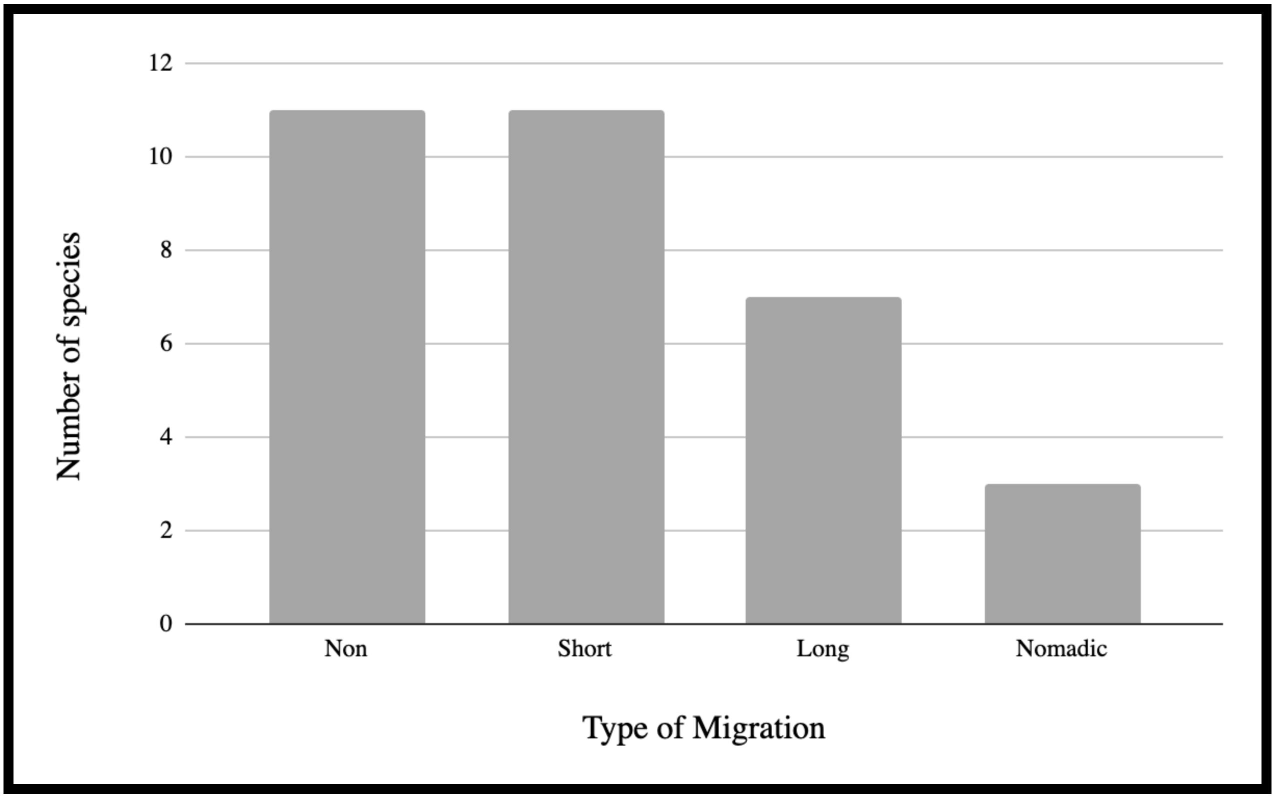


Figure 7. Types of wildlife migrations and the number of species from articles identifying effects of transboundary barriers (fences, walls) on wildlife. Categories are non = non migratory, short = <100km, long = >100km, and nomadic = species constantly changing home range.

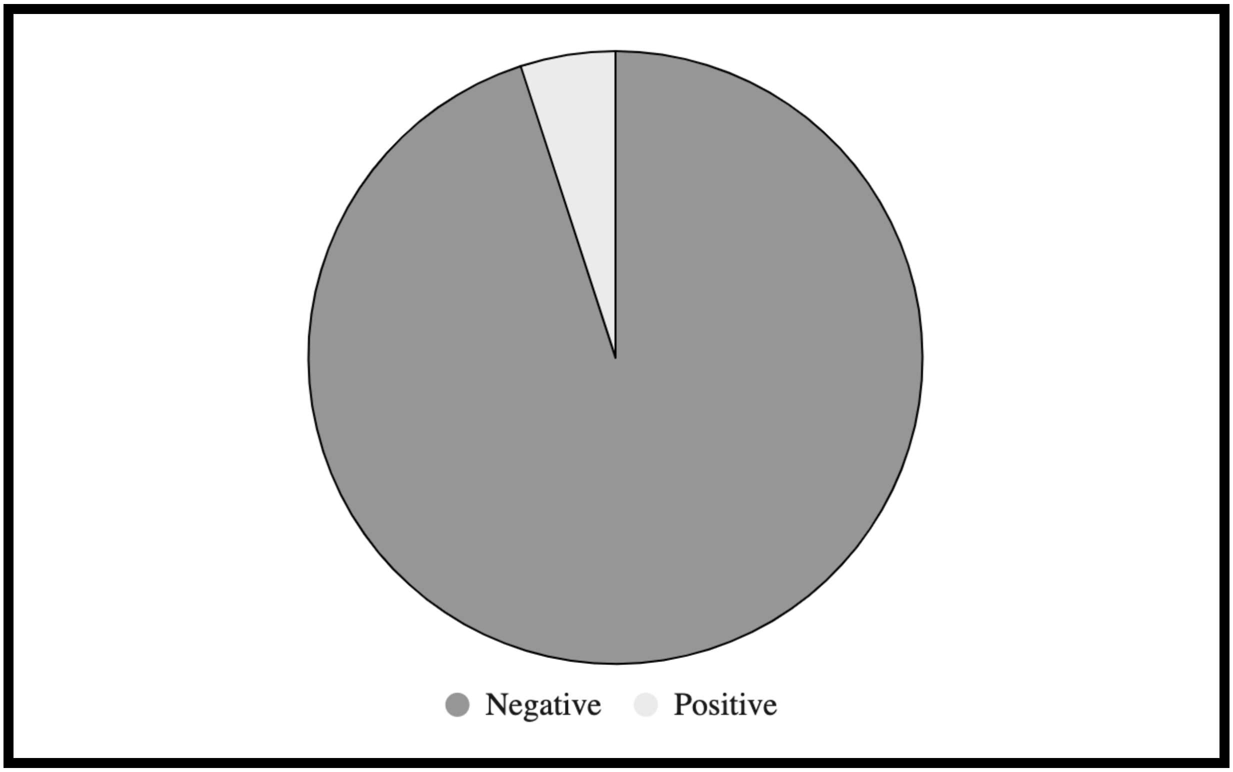
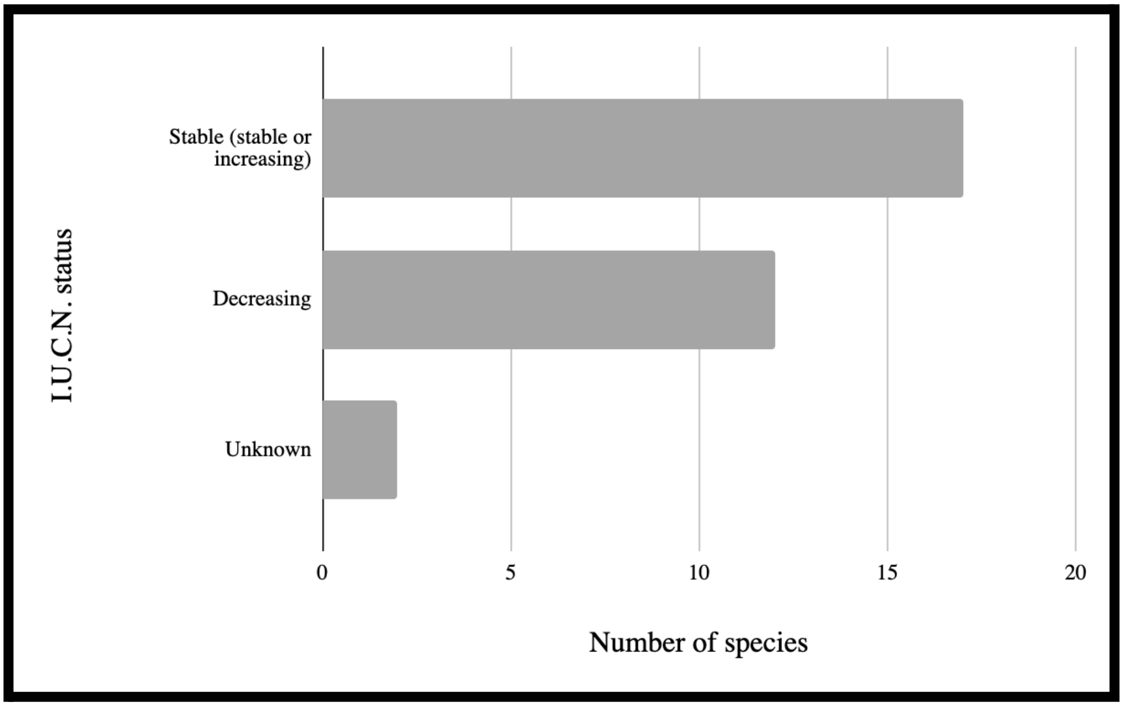


Figure 8. Effects of transboundary barriers (fences, walls) on wildlife derived from 40 articles (white = positive effects on wildlife, black = negative effects on wildlife).

A.



B.

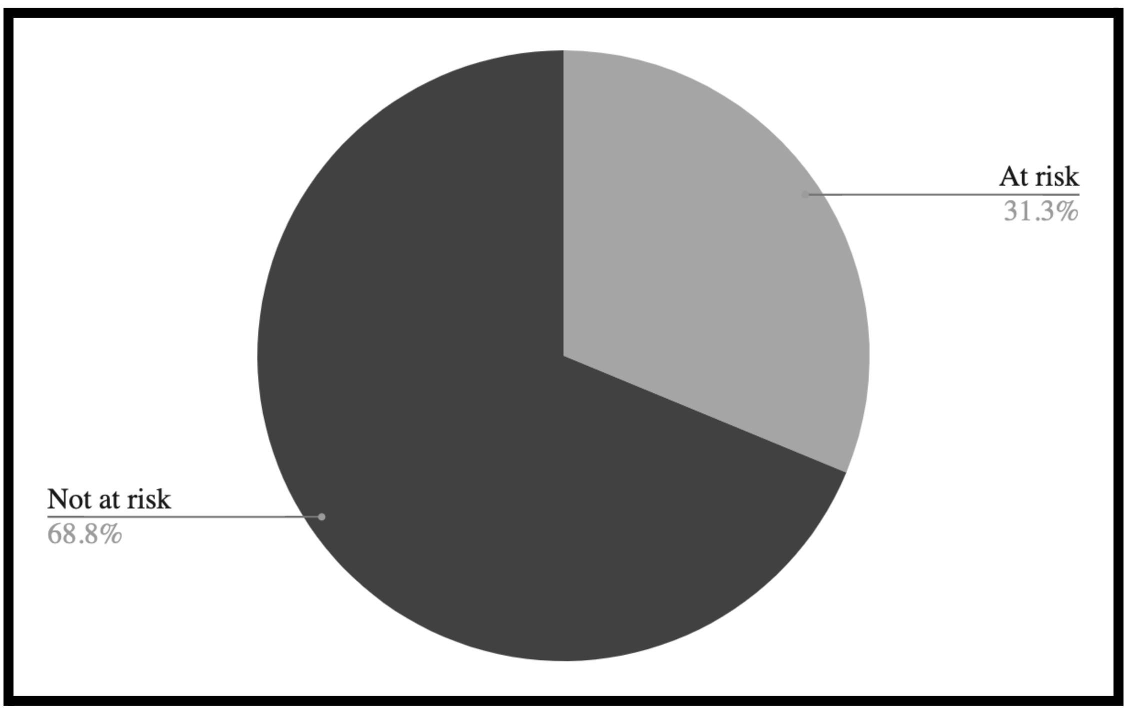


Figure 9. A. Wildlife species (n = 32) studied in articles identifying effects of transboundary barriers (fences, walls) on wildlife by IUCN status and **B.** by their IUCN risk status (at risk = CR+EN+NT+VU, not at risk = LC).

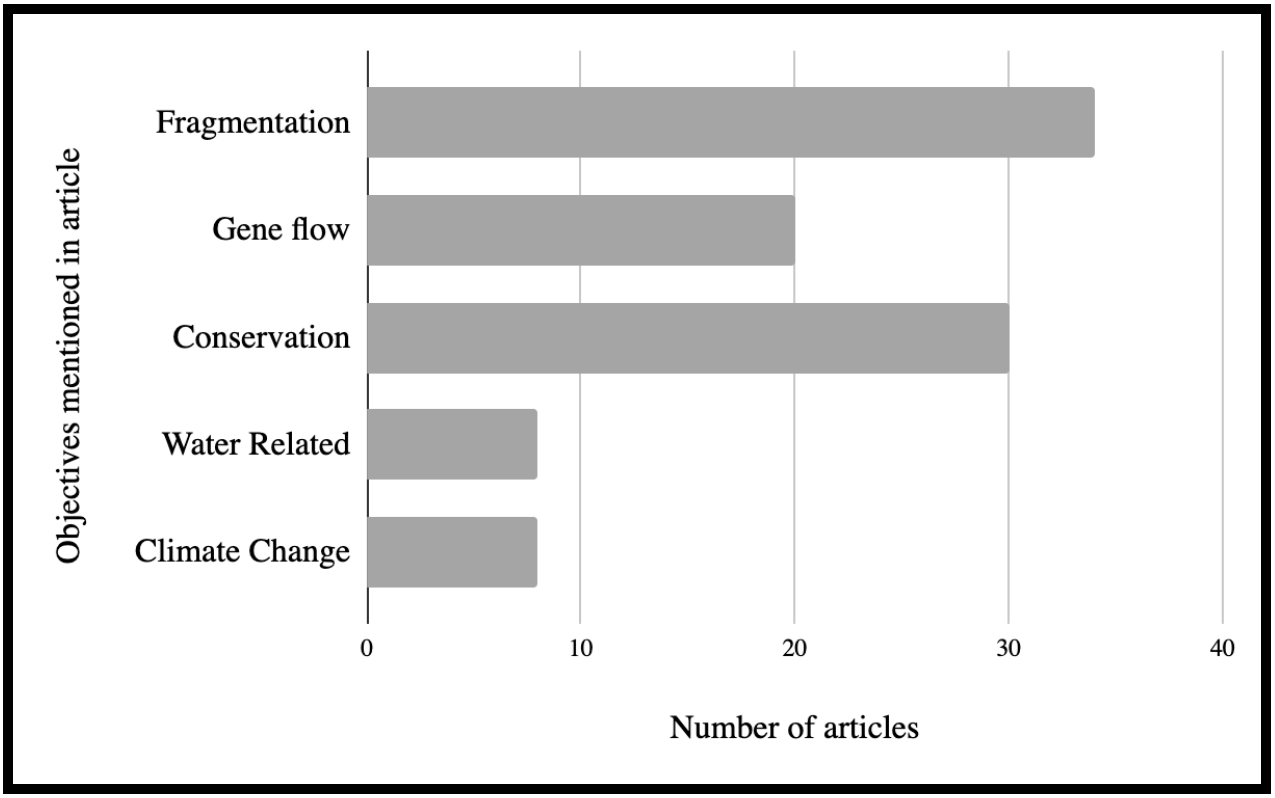


Figure 10. Objectives included in articles identifying effects of transboundary barriers (fences, walls) on wildlife by the number of articles.

Ethics Statement

Our statement of ethics is based on the standards produced by The Wildlife Society. We conducted our research while ensuring that results were unbiased, ensuring honesty within results and representing the authors' work in a respectful manner. The information obtained from other authors was cited properly to ensure correct representation of their work. Participation by all contributing members was voluntary and authors were given the opportunity to provide information of their choice. We conducted this research in the interest of promoting wildlife species that are negatively affected by the transboundary border fences around the world. Additionally, we aimed to provide information that drives science-based management and benefits all wildlife species involved. We believe that the information provided will promote a better understanding of the methods needed to ensure proper management of transboundary regions.

While adhering to the standards of The Wildlife Society, we followed guidelines involving the standards for professional conduct, including:

- Abstaining from plagiarism and using primarily up-to-date information obtained from our own research.
- Avoiding results that are biased or falsified.
- Ensuring information provided was used to benefit wildlife species involved.
- Ensuring the public is aware of all resources and methods used to obtain information.
- Maintaining confidence where requested.
- Using the information provided for the sole purpose of informing the public and avoiding monetary gains from the research.
- Ensuring that information is public and available to all participants and interested readers.

- Providing correct contact information of all authors for interested persons.