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Review Paper

Wildlife Corridors: A Comprehensive Review of Their Role in Enhancing Landscape Connectivity for Conservation

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Abstract

A popular management technique for the conservation of species in fragmented habitats is the creation of wildlife corridors. Because of stochastic processes, fragmentation can lead to extinction by decreasing the number of habitat patches and increasing the isolation of the populations within them. By integrating populations into a single demographic unit, the establishment of a corridor between habitat patches is thought to improve connection and raise the likelihood of survival. Wildlife corridors have come to play an essential role by aiming to connect areas for wildlife. The review brings together recent research on the ecological rules, principles of design and conservation impact of wildlife corridors. This article discusses how linear habitat features aid the movement and sharing of genes among species which helps the whole ecological system endure. It outlines several kinds of corridors including those found naturally along waterways and those that are man-made and talks about their results in different places and for a range of wildlife. Also, it deals with difficulties related to building corridors such as buying land, dealing with conflicts between people and animals and fitting corridors into land-use planning. By helping to join divided habitats, wildlife corridors allow for less damage from development and encourage a networked and sustainable environment for all life. The significance of wildlife corridors for wildlife conservation has been attempted to be explained in this article.

Wildlife Corridors: A Comprehensive Review of Their Role

Introduction

More than 55% of people on Earth live in cities as of 2018, and by 2050, that percentage is expected to increase to more than 68%. Wildlife residing in and around cities is increasingly at risk due to habitat fragmentation, increased mortality from vehicle-wildlife collisions, increased exposure to toxins and poisons, disease exposure, and competition from introduced species (Kowarik, 2011). One method for reuniting dispersed animal populations is to create wildlife corridors; however, due to the numerous obstacles that separate habitat patches and the large number of interested parties and property owners, creating wildlife corridors in urban settings continues to be difficult (Zellmer & Goto, 2022). Anthropogenic habitat fragmentation has decreased biodiversity and hampered important ecological services (Diaz et al., 2020). By 2020, less than 8% of the land is connected and protected, and one-third of the world's major biodiversity areas were uncovered (UNEP, 2020). The ability of protected areas to be spatially and functionally connected is essential for the movement of species, gene flows, range shifts, and interactions amongst meta-populations within those habitats (Beier et al., 2009). Because they connect fragmented habitat regions, wildlife corridors are crucial for promotion of habitat connectedness. A hypothetical species compressed- and dispersed-weight scenarios are illustrated in Table 1.

Table 1: Compressed and Depressed weight scenarios of a hypothetical species.

Factor	Point Estimate	Compressed Weights	Dispersed Weights
Land Usage	65 (45-95)	45	90
Height	25 (5-40)	25	8
Geographic Position	10 (0-20)	15	2
Road Coverage	10 (5-30)	25	2

In Table 1 two different hypothetical scenarios for weighting environmental factors that are important to a species are shown: "Compressed Weights" and "Dispersed Weights." For each factor (Land Usage, Height, Geographic Position, Road Coverage), the Point Estimate gives a range and a general importance value. Certain factors, such as road coverage and geographic position, are given disproportionately higher importance in the Compressed Weights scenario than their point estimates, indicating a species that is highly dependent on extremely particular or constrained conditions. The Dispersed Weights scenario, on the other hand, greatly emphasizes land usage while greatly downplaying the significance of other factors, which may suggest that a species can thrive in a wider range of conditions if there is an abundance of suitable land.

Currently, there are thousands of different animal and plant species on Earth in addition to humans. Because of human culture and civilization, humans now have the status of super-partners in the animal and plant kingdoms. For his own purposes, man has learned to take

advantage of plants, animals, and other inanimate natural resources like minerals, water, and land. As a result, there are now two types of animals; domestic animals (e.g., cows, buffaloes, camels, horses, goats, sheep, and yaks) and wild animals that exist naturally and are generally not used by humans. Wildlife includes thousands of species of fish, amphibians, birds, reptiles, mammals, and insects, is another name for wild animals.

Wildlife is a valuable, renewable natural resource that humans can use for a variety of purposes. The stunning, vibrant wildlife that nature has given us has made significant contributions to our economy, education, customs, and traditions, as well as to our culture, religion, bravery, and discipline, amusement and artistic sensibility, preserving the natural equilibrium. The list continues to exist, bringing happiness, contentment, serenity, and wealth to life on this world. Wild animals serve a vital role in preserving the dynamics of the ecosystem and are as much a part of nature as humans. In the ecology, wild animals play a role of omnivorous organisms in the environment. Wild animals are crucial to preserving the ecological equilibrium, repairing, restoring, and stopping additional environmental damage.

Urbanization and wildlife

It is commonly believed that human encounters with wildlife are restricted to environments that occur more organically. The main reason for this is that traditional understanding of wildlife ecology has its roots in more rural regions. Seven billion people, or two-thirds of the world's population, are expected to live in cities by 2050, according to UN estimates (United Nations, 2018). Because of urbanization, researchers, managers, and city planners now take a new approach to wildlife studies (Apfelbeck et al., 2020). Since the 1990s, more research has been done on urban wildlife since cities are now viewed as new ecosystems rather than artificial sinks bereft of nature (Lopucki & Kitowski, 2017). Numerous governmental organizations and research organizations have broadened their focus on wildlife protection to encompass studies of urban animals (Magle et al., 2019). In balancing human and wildlife requirements, there are emerging prospects, challenges, and solutions with an increased focus on urban ecosystems and their wild denizens. While understanding wildlife lifestyles, migration, and adjustment under human-influenced environments increasingly matters, the field of urban wildlife study continues to expand in scope to address increasingly urgent environmental issues such as habitat loss, landscape fragmentation, and climate change (Rastandeh et al., 2018). With an expansion of the world's metropolitan areas, innovative solutions will be required to mitigate these critical issues. Urban wildlife study is a fairly new profession that continually changes and adjusts to emerging issues and dilemmas (Magle et al., 2012). Specialists must be knowledgeable on the status of urban wildlife study in determining areas of strength and weakness, highlighting any gaps in existing studies, and providing suggestions for conservation of urban biodiversity (Apfelbeck et al., 2020). Reviewing earlier studies can help identify areas of strength and weakness, highlight any gaps in existing studies, and offer suggestions for urban biodiversity conservation (Collins et al., 2021).

Wildlife vehicle collisions (WVC)

According to Meijer et al. (2018), direct mortality from transportation infrastructure is a major and expanding hazard to wildlife populations worldwide. It also contributes to property loss, human injuries, and fatalities. According to Huijser (2007), wildlife-vehicle incidents on

US roadways result in 200 fatalities and 30,000 injuries per year, with an annual economic effect of over $8 billion USD. It is estimated that 340 million birds die each year in collisions between vehicles and wildlife, and around 1 million vertebrates are killed every day on US roads (Loss et al., 2014). WVC-related mortality affects all wildlife taxa, although even at low traffic volumes, amphibians and reptiles are particularly vulnerable to road death (Fahrig & Rytwinski, 2009).

Habitat fragmentation and population genomics

Threats to natural populations encompass loss and modification of habitat, invasive species, pollution, climate change, direct mortality due to exploitation, and the occurrence of infectious disease. It is estimated that 1 million plants and animals are threatened with extinction in the next few decades due to these collective global threats. Most of the severe threats currently causing the extinction to wildlife is habitat loss and fragmentation. Threats to animals tend to occur together, with genetics playing an important role in the wildlife decline. For example, a population's capacity to cope with new environmental pressures introduced by invasive species or climatic change may be reduced by inbreeding and loss of genetic diversity due to population subdivision and declines (Ceballos et al., 2017). It is through knowledge in genetics and genomics concepts and skill in effectively investigating genetic attributes in nature that threats to animals are measured and reduced.

From understanding the consequences of genetic diversity at the community level to sourcing seeds for restoration, genomics concepts and methodologies have several uses in conservation (Breed et al., 2019). Applications of population genomics in fisheries can teach wildlife biology, even though the majority of the concepts and technologies we cover are applicable to all of biodiversity. Natural populations of terrestrial vertebrate species are the subject of particular attention for conservation or population management purposes, as are applications of population genetics to wildlife. The field has made significant strides in the past ten years in figuring out what questions can be answered and how to use population genetics in wildlife. It is appropriate to evaluate the current state of animal population genetics research, draw lessons from some of the achievements, and pinpoint areas for further advancement. In addition, there is an urgent need to convert studies of animal population genetics to conservation actions, which necessitates certain steps to incorporate the two (Hohenlohe et al., 2021).

A short version of the genome, such as the transcriptome or a pre-selected number of loci that primers or hybridization probes are addressed, can be sequenced with an assortment of genomics methodologies (Meek & Larsen, 2019). Selection of restriction enzymes in the restriction-site-associated DNA sequencing (RADseq) technology suite forms part of the molecular protocol, dictates the sequence information from loci located all over the genome that are acquired by anonymous reduced-representation methods (Andrews et al., 2016). Ultimately, whole-genome sequencing (WGS), which yields information from all regions of the genome, is becoming increasingly possible for most taxa (Fuentes-Pardo & Ruzzante, 2017). Significantly, numerous such methods, such as WGS, RADseq, and transcriptome, don't need any existing genetic information on the species being researched.

Wildlife corridors

Wildlife corridors are often implemented in conservation to reunify animals that have become fragmented due to human-induced habitat fragmentation. Although there was initial controversy, wildlife corridors have been demonstrated to be effective for several species (Haddad et al., 2015). Combined with other mitigative practices, these species have exhibited increased migration between isolated individual populations, increased genetic mixing, and reduced human-wildlife contact, such as between wildlife and vehicles (Rytwinski et al., 2016). Further, if species are to survive under changing climates, corridors will increasingly be required (Schloss et al., 2022).

Since conservation biology emerged in the 1970s, wildlife corridors have been promoted as a way of restoring fragmented habitats, preserving biodiversity, and ensuring population integrity (Ogden, 2015). Wildlife corridors have been illustrated to be critical in connecting fragmented habitats so that animals and plants may migrate or disperse between them. They are also vital to habitat networks, which involve a number of patches connected by a network of corridors. Habitat networks offer a chance to enhance ecosystem connectivity and function at multiple spatial scales (Vuilleumier & Prelaz-Droux, 2002). One benefit of wildlife corridors is that they increase the quantity of habitat in the landscape in terms of area and resources available to the animals for breeding and resulting population growth (Andama et al., 2024).

Even while there is some evidence that wildlife corridors are successful in urban settings, it is uncommon for habitat patches to be connected by a single bridge in cities. Fragments of habitat are often divided by a number of roads, by several parcels of property owned by different parties, or even by different governments (Sattar et al., 2021). In addition, land use and ownership in metropolitan regions are subject to sudden and drastic changes. Therefore, methods for designing wildlife corridors that are advised in more rural areas might not be suitable or effective in urban settings. It is suggested that the width of a corridor be maximized and that human development and activity be excluded from the corridor. However, it is frequently impossible to implement such advice in metropolitan settings. For this reason, conventional wildlife corridors like a bridge connecting two protected landscapes might not be sufficient to maintain connectivity in urban areas (Wang et al., 2022; McCluskey et al., 2024; Gelmi-Candusso et al., 2025).

Designating priority locations for urban wildlife corridors, where concerted efforts are undertaken to maintain several passageways and stepping-stones of connectivity, could be one tactic to help conservation in urban contexts. Urban wildlife corridor conservation may increase animal connectivity and strengthen ties between the numerous stakeholders in cities by integrating different tactics like green infrastructure, land acquisition, backyard habitat restoration, and conservation collaborations. Even though connectedness has long been a crucial suggestion for urban conservation, there aren't many case studies where the procedure of urban corridor conservation has been fully recorded. This is particularly relevant when considering interconnectedness between several jurisdictions and geographical parcels (Zellmer & Goto, 2022).

Natural world sustainability

In order to preserve a territory's biological variety, ecological connection is essential. A territory's habitat patches permit biological fluxes and the migration of various species. Ecological connectedness refers to a territory's ability to facilitate the exchange of genes across several populations (Mony et al., 2022). Additionally, it strengthens them against disruptions, ensuring their survival in the event of a local extinction. Several factors influence ecological connectedness in an area. The diversity of land organisms declines with the decrease in vegetation patch continuity, which increases isolated and disconnected areas. Other adverse effects of habitat fragmentation involve changes in species structure, change in population dynamics and community structure, change in ethology, reproductive achievement, and individual fitness. Habitat fragmentation is further exacerbated by global climate change but these adverse effects could be reduced by maintaining diversity (Saura et al., 2011).

A patch layout of habitats that contains links that facilitate movement of species targets must be analyzed with care to generate a connectivity network. When connectivity planning supports movement of multiple species, it is particularly interesting to consider corridors' permeability to foster connectedness at a worldwide extent. Various studies have considered connectivity in such a manner, with an emphasis on conducting systematic assessments for conservation so that there can be improved connectivity (Tiang et al., 2021; Pither et al., 2023).

Habitat connectivity

There are various causes that lead to wildlife migration at different geographical and temporal scales both within and between regions of suitable habitats. These movements satisfy life history needs such as dispersal from natal ranges, annually cycled migration, and increased movement frequency for foraging, reproduction, and cover. Plants' and animals' ranges change over longer periods due to differences in their habitats' qualities, land use, climate, among many factors. It has long been known that survival of animal and plant populations ensures maintenance of biological process, promotion of habitat linkage, and minimization of negative effects of habitat fragmentation (Haddad et al., 2015). It is believed by Ceballos et al. (2017) that habitat loss and habitat fragmentation remain major threats to biodiversity. Infrastructure and human-created land use confine species' ability to move to appropriate habitat due to changing climatic conditions, which adds to threats posed by accelerated climate change (Ceballos et al., 2017).

In Canada's boreal forests, certain species of wildlife that first evolved to survive in pristine forest habitats have been affected by landscape fragmentation and reduced survival due to industrial forestry activities. Woodland caribou (Rangifer tarandus) numbers have declined in areas with industrial forestry activities, in particular (Venier et al., 2014). Conserving long-term woodland caribou habitat involves curtailing human use that causes fragmentation, such as forestry for wood harvest. Conservation of wildlife habitat may restrict harvestable area and increase the cost of wood. Decision-makers must be able to assess how caribou habitat conservation activities interplay with harvest activity to make effective plans (Felton et al., 2017). Optimization procedures imposing adjacency restrictions, maximizing adjacent protected habitats, ensuring habitat contiguity, or maximizing protected area by choosing between stipulated clusters of habitats have all been applied to habitat conservation.

To address a connectivity issue in boreal caribou habitat, a network approach was suggested (Yemshanov et al., 2020). Through arcs that represent possible migration corridors for animals, this approach models a fragmented forest landscape as a network of habitat patches (nodes).

There exist two principal strategies to connect habitat connectivity with forest planning problems. Under a re-planning approach, an iterative spatial simulation model that produced a map of priority habitats for species conservation was coupled successively with a harvest scheduling model. An acceptable habitat map was estimated with a heuristic habitat model each planning period. To schedule harvest over a planning horizon beginning, this map was then implemented as a parameter in a harvest model. Patterns in habitats were again estimated with the use of a heuristic habitat model over the future planning period (Martin et al., 2017).

Another approach combines habitat connectivity models with harvest planning in an integrated optimization problem (Yemshanov et al., 2020). To balance maintaining reindeer habitat and migration corridors with forest harvests, a multitemporal MIP formulation was proposed. The model achieved the harvest goal by providing an intact corridor of reindeer habitat for every harvest planning interval. Similarly, a network flow approach was proposed by Yemshanov et al. (2020), which connected preserving woodland caribou habitat in northeastern Alberta with harvest planning goals. The model maximized the amount of connected habitat in the area while meeting a harvest volume objective for each planning period, but it did not advocate for the preservation of fully connected corridors or a contiguous habitat region. The optimum habitat connectivity patterns were found in both studies for each harvest planning period, creating a network of connectivity over the planning horizon. This makes the dual habitat connectivity/harvest challenge more difficult combinatorically than the replanning technique proposed by (Martin et al., 2017). Actually, handling the problem needed multistage warm start strategies. Such a formula would be helpful for harvest planning in regions where caribou habitats are isolated and maintaining corridors would be necessary to allow the animals to travel between the ranges. Habitat connectivity requirements and corridor design are predicted to become more important in the future due to the predicted decline in the total area of intact forest sufficient to sustain caribou herds in the Canadian boreal region (Yemshanov et al., 2021).

Ecological connectivity

Due to the extraordinary and rapid rates of environmental change, around one million species face extinction. Habitat fragmentation is one of the primary threats to biodiversity globally (Butchart et al., 2010). More than half of the world's landscapes are fragmented as a result of linear barriers including highways, railroads, pipelines, fences, and canals, as well as the consequences of industrial activity, grazing, urbanization, and agriculture (Watson et al., 2016). Protected areas are the cornerstone of conservation; however, they only cover 15% of the planet's surface, and over half of all protected areas globally are smaller than 100 hectares (UNDP, 2021). For more than 50 years, conservation research has emphasized the necessity for greater connectivity conservation because to the expanding understanding of species' movement ecology and the need to modify their geographic ranges in response to climate change (Tabor et al., 2018). However, less than one-third of the world's protected areas are well connected, according to Saura et al. (2017).

Maintaining or reestablishing connections between fragmented habitats or landscape regions is the primary strategy to prevent or reverse fragmentation (Haddad et al., 2015). The degree to which seascapes and landscapes allow species to travel freely and biological processes to continue unhindered is known as connectedness (Taylor et al., 1993). The overwhelming weight of scientific evidence suggests that habitat connectedness promotes the conservation of species and biological processes. The importance of ecological interconnectedness has been recognized on a national, international, and global scale. Connectivity conservation is receiving more attention from the Convention on Migratory Species (often referred to as the post 2020 global biodiversity framework) and the CBD's next ten-year strategic plans. The European Union has a number of legislations, including as the EU Habitat Directive that deal with connection conservation in addition to national laws (Hilty et al., 2019).

Conclusion

Wildlife corridors are critically important to enhancing landscape connectivity for wildlife conservation, particularly in fragmented habitats such as urban ecosystems. Wildlife corridors can improve animal connectivity in order to preserve the safe distribution of wildlife in its natural habitat. Wildlife corridors are stretches of undeveloped land that link more ecosystems, enabling animals to migrate between disparate habitats. Putting in place wildlife crossings is an important aspect for improving genetic diversity which enable wild animals to adapt themselves in changing environmental conditions. These constructions, which include tunnels, underpasses, and wildlife overpasses, allow animals to traverse roadways and other obstacles safely. It also includes habitat conservation and restoration. Preserving wildlife connectivity requires the preservation and restoration of natural ecosystems. Moreover, policy and planning are required to enhance wildlife connectivity. Negative effects on wildlife populations can be lessened by incorporating wildlife connection considerations into land use planning and the building of transportation infrastructure.

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