



Original Research Paper/Review Paper

Role of Ecological Corridors in Supporting Wildlife Movement and Genetic Connectivity Across Fragmented Habitats

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Key Words	Abstract
Ecological corridors, Wildlife movement, Genetic connectivity, Habitat fragmentation, Biodiversity conservation, Landscape connectivity, Species dispersal, Gene flow, Wildlife habitat management, Conservation ecology.	Isolation of wildlife populations through habitat fragmentation not only limits mobility among patches, but through time, decreases the gene flow required for maintenance of genetic diversity and species viability. Ecological corridors, which are structurally continuous habitat connections between fragmented patches, have emerged as one of the most popularly utilized conservation strategies for fragmentations; however, doubts persist regarding their effectiveness for mobility and gene flow purposes. The following paper provides an overview of existing data based on experimental, meta-analytic and molecular genetics studies in order to examine how well ecological corridors perform in these two areas. Meta-analysis of 78 studies has demonstrated that corridors enhance inter-patch mobility by 50% on average in plants and animals, while long-term experimental research has shown that this positive effect translates to greater species richness in connected habitats. Studies of molecular genetics offer some of the most direct evidence for connectivity effects, as one example, a major freeway in southern California has been observed to severely hinder gene flow in bobcats and coyotes even though there have been rare cases of successful crossings. Furthermore, the presence of artificial wildlife bridges across highways in Canada was enough to provide gene flow that ensured that black bears were not genetically isolated, showing that connectivity engineering could be used effectively to replace the role of natural corridors in landscapes, if done appropriately. Corridors not only ensure presence but also perform other ecological roles such as pollination which is disrupted in isolated fragments.

Introduction

With the ongoing conversion and fragmentation of natural habitat due to agricultural practices, urban expansion, and infrastructure development, free-ranging animal populations find themselves becoming increasingly isolated within small fragmented habitats. In addition to the obvious reduction of habitat space, this isolation process leads to the reduction of the movement between habitat fragments and consequently the reduction of gene flow between the subpopulations of such populations. The isolation of populations with limited gene flow leads to increased chances of inbreeding depression, the lack of adaptive genetic diversity and ability to adapt to changes in the environment, thereby increasing the chance of local extinction. The creation of ecological corridors - linear or continuous strips of suitable habitat linking fragments - has been proposed and applied as a means of solving these problems through the facilitation of the movement and hence gene flow between isolated populations. This review highlights current scientific knowledge about the effectiveness of ecological corridors for wildlife movements and gene flow by considering meta-analysis data, long-term

experiments and molecular genetic case studies which test the functionality of such corridors and connectivity structures.

Corridor Effects on Movement between Habitat Patches

Meta-Analytic Evidence

Until now, the largest meta-analysis of corridor movement effects compiled the results of 78 experiments from 35 publications involving various taxa and analyzed their dependence using the hierarchical Bayesian model. This meta-analysis has shown that habitat patches connected by corridors had approximately 50% more movement between them than the patches separated and isolated from each other. This advantage in terms of connectivity of patches was stable for plants, invertebrates, and vertebrates, but the degree of its manifestation depended on the taxonomic group and whether the corridor effect was investigated in an experiment or in nature (Gilbert-Norton et al., 2010). In about three-quarters of cases, corridors were superior in providing connectivity over the surrounding matrix, whereas a smaller part of experiments showed corridors to be as efficient as the matrix, which could be explained by the low-quality

habitat in the corridors, poor visibility of the corridors by certain species, or increased permeability of the matrix (Gilbert-Norton et al., 2010). Despite the fact that the efficiency of corridors is not universal in all contexts, the mentioned meta-analysis became a cornerstone of corridor science, proving that on average the corridors significantly increase the movement of organisms between habitat patches.

Long-Term Accumulation of Effects

The mere fact that corridors provide movement benefits does not mean that biodiversity outcomes will eventually occur from their implementation. This point has been explored in an 18-year replicated field experiment conducted at the Savannah River Site in South Carolina (Damschen et al., 2019). The results of the experiment indicate that annual colonization rates for 239 plant species were 5% higher, and extinction rates – 2% lower in connected compared to disconnected patches. As a result, diversity increased consistently without any plateau, which allowed for a net gain of about 14% more species in connected patches at the end of the study period (Damschen et al., 2019). Since the accumulation of biodiversity did not appear to reach the plateau after almost two

decades of the experiment, the researchers concluded that the movement benefits of corridors identified in shorter-term studies such as the meta-analysis mentioned above will lead to biodiversity gains in the long term, which could be significantly underestimated in the initial years after corridors implementation (Damschen et al., 2019).

Genetic Connectivity: Evidence from Molecular Studies

When Connectivity Fails: Roads as Genetic Barriers

Molecular genetic techniques offer some of the most compelling data on whether or not connectivity, or lack thereof, leads to gene flow between populations. A study that analyzed gene flow in bobcats and coyotes through the Ventura Freeway near Los Angeles, one of the most trafficked highways in the U.S., combined the use of radio telemetry with genetic assignment techniques to detect individuals that have crossed the freeway. It has been shown that while both species were able to cross the freeway physically, only 5-32% of the individuals studied did that over a period of seven years, and there were significant differences in genetic structure

between populations on either side of the freeway, even though their separation was less than dispersal distances in unfragmented environments (Riley et al., 2006). This means that not only was the freeway a physical barrier but also a social one, as individuals that were able to cross it failed to establish territories or breed on the other side, thus making it impossible to maintain gene flow through the freeway (Riley et al., 2006).

When Connectivity Succeeds: Engineered Crossing Structures

An example of direct evidence of how constructed connectivity infrastructure can facilitate genetic exchanges is provided by a three-year genetic study examining wildlife crossing structures on the Trans-Canada Highway in Banff National Park, Alberta. Based on a comparison between the genetic information gathered from the bears utilizing the wildlife crossing structures and the genetic information gathered from the wider population of bears in the region, the study discovered that wildlife crossings allowed enough gene flow to stop the bears from being genetically isolated, thereby serving as an effective corridor through a highway barrier for black bears; grizzly bears, on

the other hand, demonstrated genetic discontinuity at the highway level despite the existence of crossing structures, suggesting that efficacy of crossing structures can vary among different species in the same type of physical connectivity infrastructure (Sawaya et al., 2014). Combined with the case presented above regarding freeway barriers, these two studies offer a natural comparison: one that highlights the genetic consequence of an uninhibited highway barrier and another that shows how carefully constructed connectivity infrastructure can negate such a barrier for some species, but not all (Riley et al., 2006; Sawaya et al., 2014).

Restoring Ecological Function

Alongside Connectivity

Corridor success through genetic and mobility connections is not enough because it is the ecological interactions that a species engages in, rather than the mere presence of it or its ability to move, that determine whether a population will be viable. Experiments conducted in fragmented Neotropical forests showed that habitat corridors effectively restored the connectivity of forest fragments for the forest-associated hummingbirds acting as pollinators; the number of pollinators available in the corridor-connected

fragments was increased by over fourteen times compared to unconnected fragments and significantly increased pollen transfer and pollination efficiency; meanwhile, plants growing in non-connected fragments had no higher pollination rates than those of the control group, which were artificially bagged flowers (Kormann et al., 2016). It shows that the corridors have the ability to restore the movement of individuals and the genetic connections between populations not just for the sake of movement itself but also the ecological relationships that require such movement, namely pollinator-plants mutualisms.

Discussion

Taking these pieces of evidence together, the ecological corridors prove to be a mostly efficient means of sustaining connectivity of fragmented environments both in terms of movement and genetics. On one hand, the meta-analysis proves the general efficacy of corridors in providing benefits for wildlife in terms of movements; on the other hand, the long-term experiments show that these benefits accumulate with time and result in high biodiversity gains (Damschen et al., 2019). The case studies of molecular genetics bring a new dimension into

the issue: according to these works, it is not simply the presence of corridors and crossing structures, but the actual efficiency and frequency of their use by animals, necessary for creating territories and breeding thereafter, that affects connectivity outcomes. Thus, as the case of freeway demonstrates, even though crossing was observed, genetic differentiation still occurred; as the case of crossing structure demonstrates, the good design and monitoring of such structure allow for establishing genetic connections between populations of one out of two species investigated in the same area (Sawaya et al., 2014). The fact that the effectiveness of crossing structures differs between species is an important finding in terms of connectivity efforts, inasmuch as it shows that a certain type of connectivity intervention cannot be taken for granted when dealing with the entire range of co-existing species, which implies the need for genetic monitoring of the effect of the intervention and not only visual confirmation of crossings. This research also expands the concept of the successfulness of a corridor from a mere crossing of the fragmented area or the existence of the required genetic effect of increased connectivity to the rehabilitation of the ecosystem interaction, which cannot be detected

using the movement or genetic data alone. It also shows that a fragment containing the desired species may not be functionally connected as far as the ecological processes, including pollination, ensuring reproduction of the particular species are concerned (Kormann et al., 2016).

Conclusion

The concept of ecological corridors has emerged as an evidence-based approach to maintain the mobility and genetic linkages of wildlife amid habitat fragmentation through meta-analysis and extended experimentation that prove the existence of a large number of biodiversity advantages resulting from corridor connectivity. The molecular genetics approach proves not only the actual cost of not addressing habitat fragmentation, including genetic differences that can be measured in even very much-frequented traffic barriers, but also the possibility of reconnecting gene flow in order to prevent isolation for at least some species. Since the effectiveness of various crossing structures has been found to depend on the type of species even in one area, and since the restoration of mobility does not necessarily imply the restoration of ecological functionality (e.g.,

pollination), the proper planning of corridors demands special attention to the type of species and its genetic or functional monitoring.

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