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DOES STRUCTURAL CONNECTIVITY FACILITATE DISPERSAL OF NATIVE SPECIES IN AUSTRALIA'S FRAGMENTED TERRESTRIAL LANDSCAPES?

Review Report: Summary

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Cover Sheet

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Systematic Review Summary

Background

Habitat loss and fragmentation present increasingly serious problems in the context of global climate change, as smaller populations will be less resilient and isolated populations will have difficulty shifting their ranges to track changing environments. A potential solution is to provide *structural connectivity*—elements of the landscape (typically some form of native vegetation) that physically link isolated patches of habitat. According to metapopulation theory, these linkages will allow individuals and/or their genes to disperse between multiple small patches, allowing these subpopulations to collectively function as larger, more resilient metapopulations. Structural connectivity includes the concept of wildlife "corridors" (linear, continuous connections between patches), but also encompasses a wide variety of landscape elements in the form of corridors, disconnected linear elements that do not directly connect patches, and "stepping stones"— series of isolated features such as individual trees, shrubs, rocky outcrops or small clusters of these features. However, it is unclear whether structural connectivity really does facilitate the movement of native animals and plants between patches (and thus provide *functional connectivity*), or if particular characteristics of structural connectivity influence its effectiveness. Protection and restoration of structural connectivity is already being recommended across Australia, but given the lack of consensus on the relationships between structural and functional connectivity, specific guidelines for managers are lacking. The purpose of this review was to synthesise all available evidence on the relationship between structural connectivity and landscape-scale dispersal movements in Australian terrestrial landscapes in order to identify knowledge gaps and, if possible, to devise general principles for connectivity restoration.

Objectives

Our primary question was:

- Do the various landscape elements that provide structural connectivity in Australian fragmented terrestrial landscapes facilitate dispersal of native species between habitat patches or populations? i.e., do they provide true functional connectivity?

Because we were particularly interested in knowing what form structural connectivity should take in order to be most effective, we also asked the secondary questions:

- Do the various landscape elements that provide structural connectivity differ in how well they facilitate dispersal of individuals between habitat patches or populations?
- What particular characteristics make structural connectivity most effective?

Finally, the effectiveness of structural connectivity may depend not just on its form but also on the species and ecosystem in question. Thus, we aimed to consider whether the effectiveness of different types of connectivity varies among taxonomic groups or other species categories (such as habitat specialists vs. generalists), and between temperate and tropical ecosystems.

Search strategy

Electronic searching using a pre-defined series of search terms was completed in May and June of 2008 using the following databases, catalogues and web-engines: ISI Web of Knowledge (including ISI Web of Science, ISI Proceedings, Current Contents, CAB Abstracts, Zoological Record, and Web Citation Index), Directory of Open Access Journals, Scopus, Australian Agriculture and Natural Resources Online (AANRO), CSPubList (via EnCompass; official CSIRO publications), CSIRO Library Catalogue (Voyager), Australasian Digital Theses Program, ProQuest Dissertations and Theses, Google Scholar, and AllTheWeb. A special protocol was developed to search for grey literature via university libraries, departments, and state and federal governmental organisations involved in environmental research. Bibliographies of articles viewed at full text, particularly narrative literature reviews, were searched for additional relevant sources. Experts were widely consulted in the development of the review protocol, resulting in the inclusion of two sources of unpublished data in the review.

Selection criteria

Studies were included in the review if they:

- contained data on any terrestrial native Australian species;
- and had at least one study site that contained some type of structural connectivity (spatial heterogeneity) between otherwise isolated patches of native habitat;
- and contained data on movement of species through the connectivity or data that allowed inference of movement (e.g., presence in the connectivity, population genetic data, presence/absence in patches with different types or degrees of connectivity).

Data collection and analysis

The selection criteria were met by 98 sources, representing 80 different studies. As the vast majority of studies did not directly test the primary question of the review, but contained data that could allow it to be evaluated, raw data rather than statistical results were extracted for each species included in each study. These included whether or not there was evidence for movement (or presence) of the species in the structural connectivity, whether or not there was evidence for movement (or presence) of the species in the matrix if that was also studied as a control, as well as the quality of the evidence (e.g., the degree to which movement was directly assessed versus inferred based various assumptions). A suite of other variables was extracted describing the species, the characteristics of the structural connectivity, and the general environment. Additional data on gap distances crossed, either between small elements of structural connectivity or between both structurally connected and isolated patches were also extracted where possible. Almost none of the studies provided data suitable for meta-analysis, so exploratory analyses using summary statistics and hierarchical modelling were undertaken instead.

Main results

The 80 studies included in the review varied enormously in their goals, methodologies, and theoretical frameworks and they measured responses to structural connectivity using more than two dozen different response variables. Too few studies were available on plants or invertebrates to include them in most of our analyses. Almost all studies were conducted in wooded habitat patches and/or in structural connectivity consisting of trees, so relatively little can be concluded about grassland or other non-treed ecosystems. Furthermore, the vast majority of studies only assessed the presence of species within structural connectivity without directly examining movement of species through the connectivity and thus probably tell us more about the value of connectivity as habitat rather than its effectiveness at facilitating movement. Despite these limitations, our exploratory analyses were able to reveal a few clear messages as well as some interesting patterns that suggest foci for future research.

Does structural connectivity help? Native species were more likely to be present in elements of structural connectivity than in the matrix, providing reasonable evidence that these landscape features provide habitat for these species, though only weak evidence that they facilitate dispersal movements. However, studies with specific evidence of movement between patches also generally found that the presence of structural connectivity increased the rates and/or likelihood of such movement. Both simple contingency analyses and HGLM (mixed) models confirmed that increased amounts of structural connectivity were correlated with increased movement between patches. Thus, we found considerable support for a positive answer to the review's primary question (i.e., structural connectivity generally did facilitate greater functional connectivity).

Which types of structural connectivity (corridors, stepping stones, etc.) are better? All forms of structural connectivity for which there were sufficient data for analyses were effective to some degree in both providing habitat and in facilitating movement. In terms of providing habitat, our exploratory analyses suggest that while all forms were better habitat than matrix for most species, continuous corridors were better than discontinuous linear elements which were better than stepping stones. However, in terms of facilitating movement, our analyses suggest that stepping stones (generally, these were scattered paddock trees) were at least as effective if not more effective than continuous corridors.

Does the effectiveness of these different structures vary among ecosystems and species? Effectiveness of structural connectivity at providing habitat varied somewhat according to the environment and the species. Species that disperse terrestrially were less likely to be found living between habitat patches, but where they were found between patches, they were significantly more restricted to elements of structural connectivity (as opposed to the matrix) than aerial dispersers. Similarly, habitat specialists were less likely to be present between patches, but when present were significantly more restricted to disconnected linear element and corridors than habitat generalists. Corridors were less likely to be used as habitat in tropical ecosystems than in temperate ones, and disconnected linear elements were more likely to be used as habitat when they were wider. Both types were less likely to contain reptile species (relative to other taxonomic groups), possibly because most studies focused specifically on wooded landscape elements, which may not constitute habitat for many of the reptiles studied. Interestingly, width had a significant effect on the likelihood of occupancy of disconnected linear elements but no effect on occupancy of continuous corridors.

In general, there were insufficient data and/or variability in the data to assess variation in the effectiveness of the different forms of structural connectivity at facilitating movement. However, similar to our analyses of connectivity as habitat, we did find evidence that wooded corridors were less likely to facilitate movement by reptiles relative to other taxonomic groups. Birds and mammals appeared to have similar responses to structural connectivity, and both groups appeared to be slightly more likely to move through stepping stones (scattered trees) than corridors.

Are gap distances and distances between patches important? Data on critical gap-crossing and interpatch-crossing distance thresholds could be estimated for only a subset of studies and most of these estimates were based on relatively small sample sizes. Based on these limited data we calculated a mean gap-crossing threshold of 106m, indicating that many species are unable to cross open areas (i.e., matrix) that exceed this distance. We also calculated an interpatch-crossing threshold of 1100m, indicating that many species are unable to disperse between patches of habitat separated by >1100m, even where structural connectivity exists between the patches. While it must be reiterated that these threshold values are based on limited data that come primarily from bird and mammal species inhabiting wooded habitats, they should provide a useful starting point for future connectivity research, modelling and planning.

Conclusions

Research implications: Structural connectivity can serve multiple functions in a landscape, providing additional habitat but also facilitating dispersal movements and gene flow between larger patches of habitat. The distinction between these two functions of connectivity is critical because the vast majority of data on the use of structural connectivity by Australian native species have focused on presence in connectivity and thus tested whether the connectivity was providing habitat (94% of the data in this review fall into this category). Yet conclusions are often drawn and management actions undertaken as though the movement function was tested, despite the fact that such tests have rarely been performed. To redress this imbalance more research is urgently needed that examines movements of a wide range of native species (including invertebrates and plant seeds and pollen) through a wide range of heterogeneous, “real” landscapes (including grassland and shrubland systems). Studies should be designed to consider multiple forms of structural connectivity in a comparative framework, to gather data on a large sample of individuals (even where this means limiting the number of species examined in any single study) and to aim for meaningful replication with entire landscapes acting as replicates. Data collection should be particularly focused on recording the details of precise movement paths, accurately characterising all elements of structural connectivity (and the matrix itself) through which movements do and do not occur, and assessing effective dispersal (i.e., post-dispersal contribution to the gene pool). Such data will be critical for developing a meaningful understanding of how different types of structural connectivity contribute to true functional connectivity, and ultimately allow managers to accurately weigh the costs and benefits of different options for preserving or restoring such connectivity.

Management implications: Until the research gaps described above are filled, many aspects of functional connectivity will remain poorly understood. However, management efforts must continue armed with the best available knowledge. Thus, we have attempted to provide guidelines for managing and restoring structural connectivity with the caveat that more research is still needed, so all of our recommendations are intended to be applied in an adaptive management framework. It is particularly important to reiterate that most of the data on which our recommendations are based come from studies of Australian mammals and birds living in woodland and forest ecosystems. Our guidelines (see attached “Summary of Guidelines for Connectivity Management and Restoration” and the full review for more detail) should thus be most applicable in similar systems and applied more broadly only with caution.

This systematic review of available empirical evidence suggests that structural connectivity is currently providing some benefit for native species in Australian landscapes, but that with better information resulting from new research, these benefits and their cost-effectiveness could be significantly improved. Although limited, currently available data indicate that the effectiveness of connectivity initiatives could be enhanced for many species by considering diverse types of structural connectivity (particularly scattered trees separated by no more than ~100m) and by targeting patches less than 1.1km apart for connectivity protection and restoration.