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Issues of Landscape Connectivity and Maintaining Viable Amphibian Populations

Of all vertebrates in the world, amphibians have one of the highest proportions of threatened species (Cushman 2006). This may be partly because they have low vagility, high vulnerability to road mortality and narrow habitat tolerances. Amphibians also experience relatively high rates of local extinction, even in unfragmented landscapes, which emphasizes the importance of habitat connectivity for recolonization of local populations. These factors make amphibians vulnerable to habitat loss and fragmentation. Connectivity seems to be especially important for juvenile movement because of their large dispersal distances compared to adults (Cushman 2006).

One of the primary methods of collecting empirical data on amphibians and connectivity is conducting large-scale, correlative studies of distribution in relation to habitat composition and configuration at several different scales (Knutson et al. 1999, Guerry and Hunter 2002, Weyrauch and Grubb 2004). For example, Eigenbrod et al. (2008) conducted visual and call surveys to assess the independent effects of traffic and forest cover on amphibians. Other methods include mark-recapture and telemetry studies, which can track dispersal through a habitat matrix. Rothermel (2004) used mark-recpature techniques to study the migratory success of juvenile spotted salamanders and American toads. One study developed a migration zone model to assess the connectivity of a matrix with respect to amphibians (Joly et al.). Cushman (2006) argues that future research should integrate large empirical field studies with molecular genetics and simulation modeling.

Several of the papers I reviewed made reference to the concept of landscape complementation, a term coined in 1992 by Dunning et al. meaning the process by which the proximity of two critical habitat patches of different types complements occupancy, abundance or persistence in each patch. This term applies to amphibians because, due to their complex metamorphic life-cycle, they rely on both upland terrestrial habitat for foraging and migration as well as wetland habitat for breeding. Because amphibians have relatively low vagility, the proximity of these two habitats is critical. This need for proximity may mean that amphibians are especially vulnerable to habitat loss and fragmentation (Guerry and Hunter 2002). Scale becomes an important factor as migratory ability of amphibians determines the spatial scale at which landscape complementation operates (Rothermel 2004).

Most studies find negative associations with the presence of urban land near breeding habitat and generally positive associations with upland and wetland forests and emergent wetlands (Knutson 1999). Rothermel (2004) used mark-recpature techniques to study the migratory success of juvenile spotted salamanders and American toads in 18 artificial pools in replicate pastures at distances of 5–50 m from the nearest forest edges. She found that the migratory success of both species was mostly based on the distance to nearest forest. Less than 15% of the individuals released were able to reach the forest 50 m away, demonstrating the importance of proximity of breeding ponds to suitable upland habitat. Rothermel points out that the factors influencing the migratory success of amphibians, especially of juveniles, are poorly understood.

Pope et al. (2000) found that local pond habitat, availability of summer habitat, and number of occupied ponds in the surrounding landscapes were all significantly correlated with northern leopard frog density. They stress that the traditional application of metapopulation theory, which converts a heterogeneous landscape into a binary habitat/non-habitat matrix, is not effective for species that rely on landscape complementation. It is necessary to consider both breeding habitat and surrounding upland habitat that is critical for adult survival.

Not only do breeding habitat and upland habitat need to be close in proximity, there is evidence to suggest that habitat connectivity plays a key role in ensuring the regional viability of amphibians. In a review paper, Cushman (2006) suggests that the short-term impact of habitat loss and fragmentation increases with species dispersal ability. However, species with limited dispersal abilities are likely to be equally imperiled by habitat loss and fragmentation over longer time periods (Cushman 2006).

One study surveyed twenty-one glacial marshes located in urban and agricultural regions of central and southwestern Minnesota (Lehtinen et al. 1999). The surveyed wetlands were distributed across two ecoregions: tallgrass prairie and northern hardwood forest. Results showed that species richness was negatively associated with wetland isolation and road density at all spatial scales in both ecoregions. Richness was also negatively correlated with the amount of urban land at all spatial scales in the hardwood forest ecoregion. In fact, the negative correlation was strong enough to effectively negate the other land use variables in the forested area. The authors conclude that decreases in landscape connectivity due to fragmentation and habitat loss can affect amphibian assemblages. They add that amphibian conservation efforts will have greater success if they aim to protect not only the wetlands, but also their connectance with upland surroundings. Road density and traffic was also found to have a negative effect on anuran populations in northeastern North America that is at least as great as the negative effect of deforestation (e.g., Eigenbroda et al. 2008, Guerry and Hunter 2002).

There is also evidence that, in addition to habitat proximity and connectance, the extent of habitat surrounding breeding ponds is important. After conducting visual and call surveys at 116 ponds in northeastern Maine, Guerry and Hunter (2002) found that the occurrences of many amphibian species (including frogs, toads, newts and salamanders) were associated with the amount of surrounding forested area, whereas fewer species were associated with the adjacency of ponds and forest. Most of these associations were positive, but two species were negatively associated with forest area. Both findings are generally consistent with what is known about the ecology of these species.

Similarly, another study found a positive relationship between the extent of native canopy cover in the surrounding landscape and frog species richness at farm ponds, demonstrating that the area of surrounding upland habitat can be influential (Hazell et al. 2001). Again, these findings emphasize the need to consider both aquatic breeding habitat and terrestrial upland environment to develop an understanding of factors influencing frog populations in modified environments. These authors also found that relationships between habitat and abundance varied from species to species.

Several of the papers I reviewed studied the effects of both landscape composition and landscape configuration. One study found that while the richness of amphibians is positively related to heterogeneity in the landscape, richness is more closely related to the abundance of certain land-use types. This result suggests that amphibians rely on specific types of habitats more than the way in which they are configured (Atauri and de Lucio 2001).

An interesting question that surfaced a few times was whether pond characteristics or landscape variables have more of an effect on amphibian richness and abundance. Hartel et al. (2008) found no significant association between toad counts and aquatic variables (size, percentage of emergent aquatic vegetation cover, percentage of shallow water and presence of fish). They did, however, find that toad counts were positively associated with the presence of vegetated corridors between ponds and forests, the proximity of the forests to the breeding ponds, and the amount of forested area around the breeding ponds. These results highlight the role of both landscape composition and connectivity in managing toad populations.

A recurring theme during this review was the importance of species-specific research and management. Most of the studies that surveyed multiple species found varying associations between factors like species richness and relative abundance and landscape characteristics like extent of surrounding forest cover and road density (Eigenbroda et al. 2008). Thus, increasing the focus of both research and management on particular species would be beneficial for the persistence of amphibian species (Cushman 2006).

As this review demonstrates, amphibian species appear to be highly impacted by habitat fragmentation due to their reliance on connectivity between critical habitats, but better understanding of these interactions is needed. The problem of fragmentation in Rhode Island and New England, while not as intense as the Midwest where agricultural fields completely dominate the landscape, is an issue that demands increased scientific understanding at a local level. Urbanization and roads are among the primary fragmentation culprits in Rhode Island. While much of the state is still forested, urbanization and crop production are increasing. Conservation strategies could be enhanced by increased research of the effects of habitat loss and fragmentation on movement, survival rates and population dynamics of amphibians using multi-scale, species-specific approaches (Cushman 2006).

Annotated Bibliography

1) Atauri, J. A. and J. V. de Lucio 2001. The role of landscape structure in species richness distribution of birds, amphibians, reptiles and lepidopterans in Mediterranean landscapes. Landscape Ecology 16:147–159.

The authors attempted to identify the main factors that influence the distribution of species richness in the Mediterranean region and to assess specifically the significance of landscape structure. Looking at birds, amphibians, reptiles and lepidopterans in a 7,995 km^2 area of the Madrid Autonomous Region, Spain, they compared the estimated number of species per hectare to three indices of landscape parameters: the estimated number of landcover types per hactare, the equitability of land uses (i.e., the relative proportions of land uses in the landscape regardless of the number of land uses), and the number of individual patches, which indicates the degree of fragmentation. Unlike most of the other reviewed papers, the authors here did not sample populations, rather they used species richness data published in 1989, in the case of amphibians, and more recently for the other groups. They found that while the richness of amphibians is positively related to heterogeneity in the landscape, richness is more closely related to the abundance of certain land-use types. This result suggests that amphibians rely on specific types of habitats more than the way in which they are configured. The amphibian richness data may be a source of error given that it was over a decade old at the time of this study. In addition, the authors did not provide lists of which species were used in each group, negating any species-specific landscape relationships.

2) Cushman, S. A. 2006. Effects of habitat loss and fragmentation on amphibians: A review and prospectus. Biological Conservation 128:231-240.

This review paper provided a fantastic overview of the general issues relating to amphibians and fragmentation. Citing several papers in this review and some I came across but did not include here, Cushman outlines the state of knowledge, identifies key gaps in knowledge of the subject, proposes future research avenues to fill those gaps, and finally discusses conservation implications. Overall, the paper emphasizes the importance of habitat connectivity for the regional viability of amphibian populations. The most interesting part of this paper was the idea of combining molecular genetics and spatial modeling of organism movement to improve understanding of how habitat area and configuration influences dispersal, survival and population dynamics. Cushman argues that this type of integrated analysis could greatly improve the effectiveness of amphibian conservation efforts.

3) Eigenbroda, F., S. J. Hecnarb, L. Fahriga 2008. The relative effects of road traffic and forest cover on anuran populations. Biological Conservation 141:35-46.

In Ottawa, Canada, 36 ponds were surveyed to assess the independent effects of traffic and forest cover on frog and toad species. They selected sites that were at least 3 km apart and characterized the surrounding landscape (1500 m radius) as low traffic/low forest, low traffic/high forest, high traffic/low forest, or high traffic/high forest. Results suggest that the overall negative effect of traffic on anuran populations in northeastern North America is at least as great as the negative effect of deforestation. Adding to the growing pile of evidence supporting species-specific conservation, they found that the relative effects of traffic and forest cover on anuran abundance vary between species. This study stood out because instead of just using road density as many other researchers do, they obtained traffic volume data from the department of transportation and conducted their own traffic counts for the more minor roads. They were also careful in controlling for effects of pond variables.

4) Guerry, A., and M. Hunter Jr., 2002. Amphibian Distributions in a Landscape of Forests and Agriculture: an Examination of Landscape Composition and Configuration. Conservation Biology, 16(3):745-754.

In order to measure the association of amphibian occurrence with area of forest and breeding pond adjacency to forest, the authors conducted visual and call surveys of nine species at 116 ponds in northeastern Maine. They found that the area of forest and pond adjacency to forest were not associated, indicating that these factors can affect species separately. Futhermore, they found that the occurrences of many amphibian species (including frogs, toads, newts and salamanders) were associated with the amount of surrounding forested area, whereas fewer species were associated with the adjacency of ponds and forest. Most of these associations were positive, but two species were negatively associated with forest area. Both findings are generally consistent with what is known about the ecology of these species.

This is one of the few amphibian connectivity studies that has been done in the Northeast US, making it particularly useful for Rhode Island and New England amphibian management. This is one of several papers to reference “landscape complementation”, a term coined in 1992 by Dunning et al. and meaning the process by which the proximity of two critical habitat patches of different types complements occupancy, abundance, or persistence in each patch. As a point of critique, many of their sample area radii overlap which suggests a pseudoreplication issue for examining large-scale associations. Additionally, they did not take into consideration the impact of roads, but they suggest that the consistent proximity of their surveyed ponds to roads may have standardized the ponds with respect to roads.

5) Hartel, T., S. Nemes, L. Demeter, K. Öllerer, 2008. Pond and landscape characteristics — which is more important for common toads (*Bufo bufo*)? A case study from central Romania. Applied Herpetology 5:1-12.

Hartel et al. looked at the effects of aquatic and landscape characteristics on common toad counts by surveying 43 ponds in a 2600 km^2 area of central Romania. Interestingly, they found no significant association between toad counts and aquatic variables (size, percentage of emergent aquatic vegetation cover, percentage of shallow water and presence of fish). They did, however, find that toad counts were positively associated with the presence of vegetated corridors between ponds and forests, the proximity of the forests to the breeding ponds and the amount of forested area around the breeding ponds, which is consistent with other studies including the Guerry and Hunter paper reviewed above. These results highlight the role of both landscape composition and connectivity in managing toad populations. Although this study is similar to many others, I would think that Cushman would find it exemplary as it focuses on just one species at a landscape scale.

6) Hazell, D., R. Cunnningham, D. Lindenmayer, B. Mackey, W. Osborne, 2001. Use of farm dams as frog habitat in an Australian agricultural landscape: factors affecting species richness and distribution. Biological Conservation 102:155–169.

This paper presented the results of southeastern Australian study that examined correlations among the aquatic habitat characteristics of 70 farm ponds and their surrounding terrestrial habitats, frog species richness and the presence of individual species. Results showed a positive relationship between the extent of native canopy cover in the surrounding landscape and frog species richness at farm ponds, emphasizing the need to consider both aquatic breeding habitat and terrestrial upland environment to develop an understanding of factors influencing frog populations in modified environments and that these factors may vary from species to species.

What I found particularly interesting in this paper was the point about farm ponds being constructed for amphibian conservation purposes alone in the UK and Europe where natural ponds are being lost to urbanization. Hazell notes that farmers have the ability to provide frog habitat with their farm ponds by using managing their land properly and maintaining suitable pond characteristics.

7) Joly, P., C. Morand, A. Cohas 2003. Habitat fragmentation and amphibian conservation: building a tool for assessing landscape matrix connectivity. C. R. Biologies 326:S132–S139.

In this paper, Joly et al. take a unique approach to studying the impact of habitat fragmentation on amphibian migration. Using a GIS, they created a model that attempts to define migration zones for the common toad in a French floodplain while taking into account energetic costs and mortality risks from roads. After attributing each habitat type in the study area with a resistance coefficient (i.e., the energy cost of moving through that patch), they assigned a virtual population to each pond and tested the model at a migration distance of 3 km, a typical maximum distance for breeding migration. The final map shows the estimated density of toads over the entire study area. It would be interesting to conduct a field study to test the accuracy of the model. An interesting piece of this analysis was the creation of a friction map that depicts the potential costs of a toad moving through each habitat type within the study area. This approach would seem to have potential for use in conservation planning.

8) Knutson, M., J. Sauer, D. Olsen, M. Mossman, L. Hemesath, M. Lannoo, 1999. Effects of Landscape Composition and Wetland Fragmentation on Frog and Toad Abundance and Species Richness in Iowa and Wisconsin, U.S.A. Conservation Biology 13(6):1437-1446.

Using volunteer collected data, the authors studied landscape-level habitat relationships for frogs and toads by measuring associations between relative abundance and species richness based on survey data derived from anuran calls and features of land-cover maps for Iowa and Wisconsin. They found a negative association with the presence of urban land, and generally positive associations with upland and wetland forests and emergent wetlands. A possible source of error in this study is that all surveyed ponds were “roadside” ponds, but the effect of roads was not taken into consideration. These ponds were also “subjectively” chosen by volunteers, which could indicate a sampling bias. Another drawback to this study is that it surveys all anurans with no distinction between species. On the other hand, this method allowed for a significant amount of data to be collected across a large area.

9) Lehtinen R. M., S. M. Galatowitsch and J. R. Tester 1999. Consequences of habitat loss and fragmentation for wetland amphibian assemblages. Wetlands 19:1-12.

Using similar methods to other papers reviewed here, Lehtinen et al. surveyed twenty-one glacial marshes located within urban and agricultural regions of central and southwestern Minnesota to examine the impact of habitat loss and fragmentation on amphibian assemblages. In addition to visual and call surveys of adults, the authors sampled amphibian larvae in each pond. The surveyed wetlands were distributed across two ecoregions: tallgrass prairie and northern hardwood forest. Using a GIS to quantify land-use variables at three scales, they found that species richness was negatively associated with wetland isolation and road density at all spatial scales in both ecoregions. Richness was also negatively correlated with the amount of urban land at all spatial scales in the hardwood forest ecoregion. In fact, the negative correlation was strong enough to effectively negate the other land use variables in the forested area. The authors conclude that decreases in landscape connectivity due to fragmentation and habitat loss can affect amphibian assemblages. They add that amphibian conservation efforts will have greater success if they aim to protect not only the wetlands, but also their connectivity with upland surroundings.

10) Pope, S. E., L. Fahrig and H. G. Merriam 2000. Landscape complementation and metapopulation effects on leopard frog populations. Ecology 81(9):2498-2508.

This fascinating paper presented a unique idea based on a study on the effects of local pond habitat, availability of summer habitat and number of occupied ponds in the surrounding landscapes on northern leopard frog density. They conducted call surveys to assess the relative abundance of frogs in 34 "core" ponds in Ottawa, Canada. All of the factors had statistically significant effects on frog density. However, when summer habitat was excluded from the statistical model, the metapopulation structure was no longer significant. The revelation of this paper was the conclusion that the traditional application of metapopulation theory, which converts a heterogeneous landscape into a binary habitat and non-habitat matrix, is not effective for species that rely on landscape complementation. The potential for rescue and recolonization to maintain a regional population must be assessed within the constraints of the entire landscape. Conservation efforts cannot focus only on breeding habitat, but must also consider surrounding upland habitat that is critical for adult survival.

11) Rothermel, B. B. 2004. Migratory success of juveniles: a potential constraint on connectivity for pond-breeding amphibians. Ecological Applications 14(5):1535–1546.

Rothermel used mark-recpature techniques to study the migratory success of juvenile spotted salamanders and American toads in 18 artificial pools in replicate pastures at distances of 5–50 m from the nearest forest edges. She found that the migratory success of both species was mostly based on the distance to nearest forest. It is important to note that this is compared not to other landscape variables but to environmental conditions (i.e. precipitation, temperature) and body size. Less than 15% of the individuals released were able to reach the forest 50 m away, again demonstrating the importance of connectivity of breeding sites and suitable terrestrial habitat. An interesting question addressed in this study was whether juvenile amphibians possess some sort of sense that helps them find suitable upland habitat at long distances. While some salamanders did exhibit nonrandom orientation, overall there was a lack of target-oriented movement.

12) Semlitsch, D., J. R. Bodie, 1998. Are Small, Isolated Wetlands Expendable? Conservation Biology 12(5):1129-1133.

With this paper, Semlitsch and Brodie review a variety of studies that provide evidence to support the conservation of small wetlands for biodiversity and for metapopulation dynamics. I was surprised to learn that the majority of natural wetlands are small, but it did not surprise me to learn that these small wetlands are rich in amphibian species and that they serve as an important source of juvenile recruits. Several studies cited suggest that large increases in the nearest-wetland distance could impede “rescue” effects at the metapopulation level. The authors argue that small wetlands are extremely valuable for maintaining biodiversity, and that the loss of small wetlands will cause a direct reduction in the connectance among remaining species populations. The authors recommend that wetland legislation consider both size and local and regional wetland distribution in order to protect ecological connectance. As this paper was written over ten years ago, wetland legislation may have changed to reflect these recommendations.

Other References:

Van Buskirk, J. 2005. Local and landscape influence on amphibian occurrence and abundance. Ecology 86(7):1936–1947.

Weyrauch S. L., T. C. Grubb Jr. 2004. Patch and landscape characteristics associated with the distribution of woodland amphibians in an agricultural fragmented landscape: an information-theoretic approach. Biological Conservation 115:443–450.