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TOWARDS A DEFINITION OF BIOLOGICAL CORRIDOR

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Abstract: Lack of clear, unambiguous criteria that distinguishes a linear habitat patch as a corridor contributes to controversy over the value of corridors for wildlife conservation. The definitions of biological corridors have been vague or inconsistent, and often they confound form and function. Explicit criteria that can differentiate between a linear habitat patch and a biological corridor have not been formulated. We reviewed the use of the term "corridor-' in the ecological literature. and attempted to clarify the concept of biological corridor.

Resumen: La falta de claridez y criterios ambiguos para distinguir un parche de habitat linear de un corredor contribuye a la controversia de1 valor de los corredores en la conversacion de de fauna silvestre. Las definiciones de corredores biológicos han sido vagas e inconsistentes y frecuentemente confunden la forma y funcion. Un criterio explicito que pueda diferenciar entre un parche de habitat linear y un corredor biológico no han sido aun formulados. Nosotros revisamos el uso de1 termino "corredor" en la literatura ecológica en un intento de clarificar el concepto de corredor biológico.

Key words: biological corridor. connectivity, corridor, habitat corridor. habitat patch. landscape. linear patch.

The inclusion of linear landscape elements into wildlife conservation plans has gained wide acceptance as an important aspect of conservation strategy (Noss 1987, Saunders and Hobbs 199la, Mann and Plummer 1993). Arguments for the importance of corridors as landscape elements can be found in natural resource ecology and human ecology (Forman and Godron 1986:121). The use of the term corridor in a broad spectrum of disciplines has contributed to vague and sometimes contradictory definitions, and has incited vigorous debate over their importance to conservation.

In common usage, corridor has been defined as 1) "A gallery or passageway. . . one into which compartments or rooms open," 2) "A gallery or passageway connecting several apartments of a building," 3) ". . . a narrow passageway or route" (Merriam Webster and Co. 1961) and as numerous similar definitions. The common elements of these definitions most relevant to their ecological application are the terms passageway and connecting. With "passageway" there is an implicit concept that the corridor is narrow relative to the habitats being interconnected. In the ecological literature. corridors have been defined as 1 of 3 major landscape elements: patch. matrix. and corridor (Forman and Godron 1986:23). In a thorough discussion of the principles of landscape ecology. corridors were defined as ". . . narrow strips of land which differ from the matrix on either side. Corridors may be isolated strips. but are usually attached to a patch of somewhat similar vegetations" (Forman and Godron 1986:123). This definition characterizes corridors in terms of their shape and spatial context. but does not explicitly ascribe a functional role. Earlier in their discussion. Forman and Godron (1986:121) emphasized the possible transport function i.e.. movement of objects) of corridors. arising as a consequence of their shape and context. rather than as a necessary condition to ascribe the term "corridor" to a linear element.

Given the above definitions. the necessary criteria for determining if a linear landscape element is a corridor are ambiguous. One definition emphasizes function (passageway from one location to another) while others stress form and context (narrow, and contrasting with the environment on its edges,. Thus. when issues such as the significance of corridors to the maintenance of biological diversity are debated (Noss 1987. Simberloff and Cox 1987. Saunders and Hobbs 1991a). disagreement may arise simply as a consequence of divergent understandings of the corridor concept.

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USE OF THE TERM "CORRIDOR" IN PUBLISHED STUDIES

Corridors have been described as linear patches of natural vegetation that provide habitat for wildlife, either as temporary use areas (part of a home range) or as a place of permanent residence (an inclusive home range). For example. Maelfait and De Keer (1990) in their study of field edges in Belgium, concluded that corridors were effective in the conservation of invertebrates. Their conclusion was based on the observation that the "corridor" provided

habitat (both temporary and permanent) for many species that were not adapted to the surrounding pasture. They recognized the possible importance of the corridor for migration, yet their conclusion of corridor value was based exclusively on the role of providing, habitat. In a similar example, Van Dorp and Opdam (1987) assert the functional role of corridors as connecting-networks, yet describe corridors in terms of their habitat composition, not in terms of any effects on animal movement.

Linear landscape elements arising from human design, such as power-lines and roadside vegetation are sometimes referred to as corridors with an implicit assumption of ecological value. For example. Kroodsma (1987) described bird densities and distribution in brushy power-line habitat and along the edge of a forest in Tennessee (U.S.). Although data were not presented that demonstrated enhanced movement of birds. the habitat was referred to as "brushy corridor vegetation" (Kroodsma 1987: 282) consistent with the habitat definition of Forman and Godron (1986). Similarly. roadside vegetation is often considered as a corridor. For example. several papers included in Saunders and Hobbs (1991*a*) on corridors discussed the advantages of managing roadside vegetation as habitat.

There are numerous examples of "corridor" used to signify its structural attributes as linear habitat and its functional role as a dispersal conduit. In reply to a paper questioning the merits of corridors (Simberloff and Cox 1987). Noss (1987) listed first those criteria associated with the enhanced movement function. Secondarily. factors associated with habitat attributes were described and the discussion of these factors imply the habitat criteria (i.e. form) for corridors: "Scenery, recreation, pollution abarement. and land value enhancement are what usually motivate planners to draw corridors into their designs" (Noss 1987:162). Although a focus on form does not preclude a functional detinition of corridor. it suggests that either set of criteria. facilitated movement or spatial structure, context, and composition is sufficient. In summarizing the role of corridors. Saunders and Hobbs 1991*b*). followed the definition of Forman and Godron (1986). including both the habitat (form) and movement (function) role of linear patches; emphasis, however, was placed on facilitated movement. Merriam (1991:137) stated that "Corridors may or may not be involved in achieving connectivity among patches or fragments", thus emphasizing a habitat definition that may include, but does not require, a functional role of facilitating movement. Laan and Verboom (1990) are among the few researchers who recognized that the role of a strip of vegetation as habitat or as a facilitator of movement are not necessarily equivalent, and are difficult to differentiate. Failure to reconcile these 2 definitions of "corridor" have contributed to she controversy over their value.

The facilitated movement function of a linear landscape element is the most commonly assumed distinguishing characteristic of a corridor. That is, a corridor is a type of landscape element that establishes connectivity via 'a continuous narrow patch of vegetation that facilitates movement among larger habitat patches and prevents their isolation (Merriam 1984). Soule' and Gilpin (l991:3) provide a clear and concise definition: ". . . a linear two-dimensional landscape element that connects two or more patches of wildlife (animal) habitat that have been connected in historical time; it is meant as a conduit for animals." Bennet (1990: 109) defined habitat corridors as ". . . narrow connecting strips of favored habitat." Szacki (1987) limits the discussion of corridor effectiveness to the frequency of movement. without considering its vaIue as habitat. Dmowski and Kozakiewicz (1990) defined corridors similarly, and explicitly equated corridors with connectivity, and discussed the role of a narrow belt of shrubs in enhancing movement of birds between 2 (different) habitats and in directing movement. Merriam and Lanoue (1990: 124) restricted their use of the term corridor by calling it "movement corridor." thus implicitly suggesting other functions for other types of corridors. A functional definition was adopted by Reh and Seitz (1990) in their discussion of corridors as connectors among otherwise isolated populations of frogs. In this case. corridors were discussed as facilitating and directing movement.

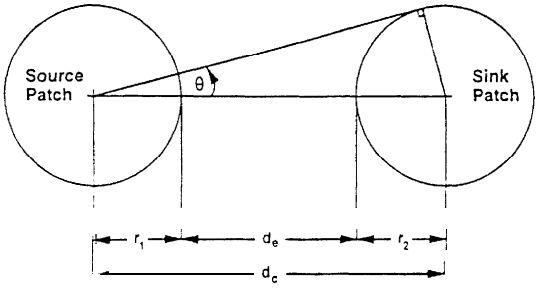
This brief Iiterature review should reveal that corridors mean different things to different authors. and this ambiguity has contributed to the current controversy over their efficacy as conservation tools. Without a clear definition of corridors. defined in terms of their functional effects on animal behavior, it is impossible to determine their value as management tools.

A MODEL TO CLARIFY THE MEANING OF BIOLOGICAL CORRIDORS

To distinguish between a linear landscape element as habitat or as a biological corridor, we need to clarify the function of such patches for the species that occupy them. Specifically, we will focus on corridors as facilitators of movement between habitat patches. To do so. we offer the foliowing operational definitions of 2 landscape elements and note that each may need to be defined on a species-specific basis.

1. Habitat: a patch that provides for survivorship, natality, and movement. If average survivorship and natality rates allow a stable or growing population that produces emigrants, it is a source patch; otherwise, it is a sink that is dependent upon immigrants to sustain its populations (Pulliam 1988).
2. Corridor: a linear landscape element that provides for survivorship and movement, but not necessarily natality, between other habitats. Thus, not a11 of a species life-history requirements may be met in a corridor.

Given the above operational definition, a corridor can be characterized by ≥ 3 key parameters:



p_r (disperse from Source to Sink Patch) = 2θ/360

$$\theta = \arctan \frac{r_2}{\sqrt{d_c^2 - r_2^2}}$$

Fig. 1. Method of estimating the angle of intersection between a source patch and an adjacent sink patch in the heuristic corridor model. The null probability of dispersing in the correct direction is a function of the combined angles of intersection of all neighboring sink patches.

Selectivity (s): the degree to which a dispersing animal can discriminate among possible corridors (pathways) between habitat patches so as to maximize its likelihood of successful dispersal.

Resistence (k): a measure of the resistence. or survival costs, per unit of time spent in a given corridor.

Velocity ($\bar{v}$): the average rate of an animal's movement in a corridor patch.

These parameters can be combined into a simple model. Consider a hypothetical landscape with 3 elements: a circular source habitat patch. 4 surrounding circular sink-habitat patches (1 aligned in each of the cardinal directions from the source patch). and a landscape matrix in which these habitat patches are embedded. Each straight-line pathway from the center of the source patch that intersects an adjacent sink patch represents a possible corridor (Fig. 1). A pool of emigrants is available in the source patch. and due to density-dependent effects. these individuals are forced to disperse. Dispersal between source and sink patches is modeled as a straight-line path moving away from the source patch at a random azimuth.

There are 2 requirements for successful dispersal. First. the dispersing animal must move in a direction that will intersect a neighboring sink patch. In our model, the probability (Pr) of intersection with an adjacent sink patch is governed by the following equation (Fig. 1):

$$\Pr(\text{disperse from source patch to a given adjacent sink patch}) = 2\theta/360,$$

$$\text{where } \theta = \text{arctangent } [r_2/d_c^2 - r_2^2)^{1/2}].$$

Second, if a correct direction is chosen, the animal must move successfully through the corridor. The likelihood of successful travel to an adjacent sink patch lying a distance *d* units away (measured edge-to-edge) is modeled by a declining exponential,

$$\Pr(\text{survive to time } t) = \exp[-k(d/\bar{v})],$$

where *k* is a constant as defined above with units of l/time, *d* is the distance between the source and a sink patch, and $\bar{v}$ is the animals average speed of movement between these 2 patches.

Under the simplest case of equally-spaced. equal size patches, and no selectivity among possible corridors, we have the following total likelihood of successful dispersal.

$$\Pr(\text{dispersal success}) = (2\theta/360) \sum_{i=1}^{4} \exp[-k_i(d/\bar{v}_i)],$$

$$i = 1, 2, 3, \text{ 4th corridor, and } \theta \leq 30°.$$

$$1, 2, 3, \text{4th corridor, and } \theta \leq 30°.$$

If we further assume that: 1) only 1 path can be chosen. 2) the 4 possible dispersal paths differ in their likelihood of success. and 3) the animal is able to discriminate among these paths. the disperser will maximize its probability of success by selecting the corridor (pathway) that minimizes $k_i/_i$. That is. for fixed *d*, survival probability is increased by selecting the corridor with the least resistence (survival cost per unit time) and the corridor where an animal achieves the largest average velocity. Importantly, these factors can have compensatory effects. We expect selectivity to evolve as natural selection should favor those dispersers that chose corridors with minimum $k_i/\bar{v}_i$ values.

If we allow non-random dispersal from the source patch and differential selection among possible corridors, equation (3) is changed to

$$\Pr(\text{dispersal success}) = (2\theta/360) \sum_{i=1} (s_i)\exp[-k(d/\bar{v}_i)].$$

where s_i = selectivity coefficient associated with corridor *i*,

$$0 \leq s_i \leq 180/\theta, \quad \text{and} \quad 4 \leq \sum_{i=1} s_i \leq 180/\theta.$$

Assuming the disperser selects a pathway that intersects an adjacent patch, s_i can be thought of as the probability (p_i) of selecting corridor *i*, with

$$p_i = s_i \Big/ \sum_{i=1}^{4} s_i.$$

In this case, equation (4) becomes

$$\Pr(\text{dispersa1 success}) = \sum_{i=1} (p_i)\exp[-k_i(d/\bar{v}_i)].$$

An individual animal maximizes its likelihood of successful dispersal by choosing, with probability 1, the corridor with minimum $k_i/\bar{v}_i$, and avoiding all other possible corridors. Additional complexity (re-

ality ?) can be added by allowing k or $\bar{v}$ to show positive, or negative, density-dependent effects.

Thus, immieration rate to a sink patch is a function of the number of animals directed to a corridor and the number that can successfully traverse the chosen corridor. By these criteria, a linear landscape element functions as a corridor when the immigration rate to the target patch is increased over what it would be if the linear patch was not present. Corridors thus exist along a continuum, defined in terms of s, k, and $\bar{v}$, and they may have equal efficiencies by compensatory relationships among these variables.

CONCLUSIONS

This preliminary conceptual model of a corridor emphasizes its functional role as a facilitator of movement. Further, we have partitioned the overall functional response into its behavioral components to provide a focus for future research. Estimation of the model parameters that determine the degree to which a linear patch functions as a corridor will be difficult. Consideration of these parameters, however, will provide a theoretical construct for assessing the degree to which a linear patch may function primarily as a biological corridor.

Our definition is similar to that of Soule' and GiIpin (1991). However, we do not require a 2-dimensional limitation. nor do we require that patches being linked to have been connected historically. This later requirement may be important when considering the original conservation value of a specific landscape pattern, but the functional significance of an extant corridor is unreiated to historical uses.

The approach we use to clarify the corridor concept is similar to that of Merriam (1991) in that we emphasize the functional aspect of corridors as mediated through their effects on an animal's behavior. In contrast. we view natality as an infrequent behavior in corridors. but a necessary condition for a habitat patch.

Our definition differs from Forman and Godron's (1986) by restricting our use of the term "corridor" to its function as a facilitator of movement and by not specifying vegetation characteristics relative to vegetation of other landscape elements. SimilarIy, our definition differs from Harris and Scheck's (1991) definition that requires the linear patch to be comprised of native vegetation and to be similar to the connected tracts (i.e., target patches). Our functional definition has no such restrictions, and, similar to Dmowski and Kozakiewicz (1990), the term "corridor" does not necessarily specify what is being connected. Our definition simply requires that immigration to the target patch via the corridor be greater than if the corridor were absent, and this is the key criterion asserted.

LITERATURE CITED

Bennet, A. F. 1990. Habitat corridors and the conservation of small mammals in a fragmented forest environment. Landscape Ecol. 4:109-l22.

Dmowski, K., and M. Kozakiewicz. 1990. Influence of a shrub corridor on movements of passerine birds to a lake littoral zone. Landscape Ecol. 4:99-108.

Forman, R. T. T., and M. Godron. 1986. Landscape ecology. John Wiley & Sons, New York, N.Y. 619pp.

Harris, L. D., and J. Scheck. 1991. From implications to applications: the dispersal corridor principle applied to the conservation of biological diversity. Pages 189-220 *in* D. A. Saunders and R. J. Hobbs, eds. Nature conservation 2: the role of corridors. Surrey Beatty & Sons, Chipping Norton, Australia.

Kroodsma, R. L. 1987. Edge effect on breeding birds along power-Iine corridors in east Tennessee. Am. MidI. Nat. 118:275-283.

Laan, R., and B. Verboom. 1990. Effects of pool size and isolation on amphibian communities. Biol. Conserv. 54:251-262.

Maelfait, J. P., and R. De Keer. 1990. The border zone of an intensively grazed pasture as a corridor for spiders Araneae. Biol. Conserv. 54:223-238.

Mann, C. C., and M. L. Plummer. 1993. The high cost of biodiversity. Science 260:1868-1871.

Merriam, G. 1984. Connectivity: A fundamental ecological characteristic of landscape pattern. Pages 5-15 *in* J. Brandt and P. Agger. eds. Proc. first int. seminar on methodology in landscape ecolo. res. and planning. Int. Assoc. for Landscape Ecol., Roskilde Univ., Roskilde. Denmark.

———. 1991. Corridors and connectivity: animal populations in heterogeneous environments. Pages 133-I42 *in* D. A. Saunders and R. J. Hobbs, eds. Nature conservation 2: the role of corridors. Surrey Beatty & Sons, Chipping Norton, Australia.

———. and A. Lanoue. 1990. Corridor use by small mammals: field measurement for three experimental types of *Peromyscus leucopus*. Landscape Ecol. 4: 123-131.

Merriam Webster and Co. 1961. Webster's third new international dictionary. Unabridged. G. and C. Merriam Co. Springfield. Mass. 2,662pp.

Noss, R. F. 1987. Corridors in real landscapes: a reply to Simberloff and Cox. Conserv. Biol. 1:159-l64.

Pulliam, H. R. 1988. Sources. sinks, and population regulation. Am. Nat. 132:652-661

Reh, W., and A. Seitz. 1990. The influence of land use on the genetic structure of populations of the common frog *Rana temporaria*. Biol. Conserv. 54:239-250.

Saunders, D. A., and R. J. Hobbs. eds. 1991a. Nature conservation 2: the role of corridors. Surrey Beatty & Sons. Chipping Norton, Australia. 442 pp.

———, and———. 1991*b*. The role of corridors in conservation: what do we know and where do we go? Pages 421-427 *in* D. A. Saunders and R. J. Hobbs. eds. Nature conservation 2: the role of corridors. Surrey Beatty & Sons, Chipping Norton, Australia.

Simberloff, D., and J. Cox. 1987. Consequences and costs of conservation corridors. Conserv. Biol. 1:63-71.

Soulé, M. E., and M. E. Gilpin. 1991. The theory of wildlife corridor capability. Pages 3-8 in D. A. Saunders and R. J. Hobbs, eds. Nature conservation 2: the role of corridors. Surrey Beatty & Sons, Chipping Norton, Australia.

Szacki, J. 1987. Ecological corridor as a factor determining the structure and organization of a bank vole population. Acta Theriol. 32:31-44.

Van Dorp, D.. and P. F. M. Opdam. 1987. Effects of patch size, isolation and regional abundance on forest bird communities. Landscape Ecol. 1:59-73.