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Abstract: We describe the important functions of wildlife corridors, identify 2 classes of corridor users, and propose a series of steps to evaluate wildlife corridors with reference to these functions and user types. Our primary goal is to provide writers and critics of environmental impact analyses with a basis for developing measures that will avoid and mitigate impacts on wildlife movements. A second and related goal is to advocate that development projects bear the cost of monitoring animal use of the corridors created by those projects, so that hypotheses about corridor design can be tested.

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"IN MY EXPERIENCE . . ."

A CHECKLIST FOR EVALUATING IMPACTS TO WILDLIFE MOVEMENT CORRIDORS

PAUL BEIER,[1] ***Department of Forestry and Resource Management, University of California, Berkeley, CA 94720***

STEVE LOE, ***U.S. Forest Service, San Bernardino National Forest, 1824 South Commercecenter Circle, San Bernardino, CA 92408***

A wildlife movement corridor is a linear habitat whose primary wildlife function is to connect ≥2 significant habitat areas (Harris and Gallagher 1989:26–27). When development projects threaten to disrupt natural patterns of wildlife movement, federal (and some state) laws mandate environmental impact analyses to address these impacts. These analyses typically include measures either to preserve a natural corridor (impact avoidance) or to create a wildlife movement corridor out of an area formerly unobstructed (mitigation). In our experience, the impact analyses and the avoidance and mitigation measures are inadequate.

For example, in the past 18 months, we have reviewed impact analyses for 8 projects in southern California. Although these analyses acknowledged impact to animal movements, only 2 analyses included a map of wildlife movement areas, and only 1 used field data on animal movements. Three tollway projects claimed to accommodate animal movement solely by underpasses under bridges (whose locations were selected to accommodate water movement or unstable soils) despite obvious habitat unsuitability in most cases. The most generous design had a corridor width of 164 m (500 feet). Agencies based their refusals to mandate wider corridors on the lack of field data. But, ironically, no agency required monitoring animal use of the planned corridors to obtain such data. The tollway analyses apparently confused corridors with underpasses (which may be narrow constrictions along a corridor) and failed to specify minimum width or other standards for the remainder of the corridor. Only 1 of the 8 impact reports proposed measures that, in our opinion, would protect or create a useful wildlife movement corridor.

We describe the important functions of wildlife corridors, identify 2 classes of corridor users, and propose a series of steps to evaluate wildlife corridors with reference to these functions and user types. Our primary goal is to provide writers and critics of environmental impact analyses with a basis for developing measures that will avoid and mitigate impacts on wildlife movements. A second and related goal is to advocate that development projects bear the cost of monitoring animal use of the corridors created by those projects, so that hypotheses about corridor design can be tested. We hope that these data will render this provisional checklist obsolete.

FUNCTIONS OF CORRIDORS

Comprehensive reviews of the literature on wildlife corridors are provided by Forman and Godron (1986:364–426), Adams and Dove

[1] Present address: School of Forestry, Northern Arizona University, Flagstaff, AZ 86011-4098.

(1989), and Harris and Gallagher (1989). We confine our attention to *dispersal corridors* and *landscape linkages* as distinguished from *linear habitats* by Harris and Gallagher (1989: 26–27). Linear habitats (such as fencerows in an agricultural landscape or streamside buffers) are valued primarily or solely as habitat. Although corridors also may have intrinsic habitat value, their salient wildlife value is that they connect more substantive patches of habitat.

The critical features of a wildlife corridor are not physical traits such as its length or width or vegetation but rather how well a particular piece of land fulfills several *functions*. In particular, corridors provide avenues along which:

1. Wide-ranging animals can travel, migrate, and meet mates (Baumgartner 1943, Wegner and Merriam 1979, Nixon et al. 1980, Farhig and Merriam 1985, Redford and da Fonesca 1986, Soulé et al. 1988, Bennett 1990, Bleich et al. 1990, Johnsingh et al. 1990, Beier 1993). Although corridors also may provide avenues for parasites, disease, and fire (Simberloff and Cox 1987), ecological catastrophes caused by the presence of corridors have not been documented. Corridors generally are used to maintain connectivity among formerly contiguous wildlands, not to connect naturally isolated units (Noss 1987), and the advantages of providing corridors outweigh the potential drawbacks (Noss 1987, Soulé et al. 1988).

2. Plants can propagate (Harlan 1963, Jain and Martins 1979, Levenson 1981, Noss 1983, but see Harlan 1983 for a discussion of unintended hybridization among plant species linked by unnatural corridors).

3. Genetic interchange can occur (Ralls et al. 1988, Harris and Gallagher 1989:15, Bennett 1990, Bleich et al. 1990).

4. Populations can move in response to environmental changes and natural disasters (Noss 1983, Redford and da Fonesca 1986, Harris and Gallagher 1989:22–23).

5. Individuals can recolonize habitats from which populations have been locally extirpated (Baumgartner 1943, Nixon et al. 1980, Diamond 1984, Farhig and Merriam 1985, Henderson et al. 1985, Redford and da Fonesca 1986, Diamond et al. 1987, Soulé et al. 1988, Bleich et al. 1990, Dodd 1990, Henein and Merriam 1990).

These 5 functions of corridors were explicitly listed by the Federal Ninth Circuit Court in 1990 in ruling on the adequacy of an environmental impact analysis (Marble Mt. Audubon Soc. vs. Rice, 914 F.2d 179) and thus constitute legal precedent for such analyses. These functions (rather than some minimum width) should be used to evaluate the suitability of land as a wildlife corridor. Indeed, this functional approach makes it clear that corridor width is determined by many factors, such as its length, the topography and vegetation of the corridor, the species of interest, and adjacent human activities (Reed et al. 1975, Harris 1984:141–152, Henein and Merriam 1990, Foster and Humphrey 1991, Harrison 1992). The most important determinant is the species of interest. For instance, a corridor that allows movement of coyotes (*Canis latrans*) may be unsuitable for cougars (*Felis concolor*) or kangaroo rats (*Dipodomys* spp.). The corridor is "wide enough" when it meets these functions for each species of interest.

Following Harris and Gallagher (1989:27), corridors perform these functions among significant habitat areas; these areas are the "rooms" connected by the corridor. This seemingly obvious point is not trivial. For example, the impact analysis for a tollway project in California stated that a planned bridge over a major creek would facilitate wildlife movement to and from an adjacent wilderness park (Anonymous 1991*a*). The planners ignored the fact that the park needed a connection to national forest land, whereas this creek led into wildlands designated for a 13,000-home planned community. The analysis for this project had proceeded with a vague notion of connecting to "vast wildlands to the east" without clearly identifying target areas on both ends of the corridor. Planning agencies now routinely devise corridors without identifying the specific parcels to be connected.

PASSAGE SPECIES AND CORRIDOR DWELLERS

From the variety of functions that a corridor must serve, we can categorize most species into 1 of 2 types of corridor users. "Passage species" need corridors to allow individuals to pass directly between 2 areas in discrete events of brief duration, e.g., dispersal of a juvenile, seasonal migration, or moving between parts of a large home range. Large herbivores and medium-to-large carnivores are typically passage species, as are many migratory animals.

For passage species, it is important to avoid assuming that anything big enough for the animals to walk through is a corridor (Harrison 1992). Although these species do not have to meet all of their life requirements within the corridor, the corridor at least must provide conditions (see below) that motivate the animal to enter and use the corridor.

In contrast to passage species, "corridor dwellers" need several days to several generations to pass through the corridor. Most plants, reptiles, amphibians, insects, small mammals, and birds with limited dispersal ability often will be corridor dwellers. Members of these species must be able to live in the corridor for extended periods, perhaps entire lifespans. Thus, the corridor must provide most or all of the species' life-history requirements, including special needs related to reproduction (e.g., soil for germination, denning areas, other breeding adults).

In our experience, environmental impact analyses focus solely on passage species; we can provide no examples relevant to the needs of corridor dwellers. Corridor dwellers are neglected partly because, except for Bennett (1990), little research has been done on their use of corridors. Also, environmental impact analyses (despite legal mandates to consider regional impacts) rarely consider areas outside the project boundaries. At this scale, many species of interest can be treated as passage species. However, when planning for larger landscapes, the needs of corridor dwellers may have to be considered.

A CHECKLIST FOR EVALUATING CORRIDORS

Step 1: Identify the Habitat Areas the Corridor is Designed to Connect

Each area will usually be in some sort of protected status, but it also may be an area of high diversity, habitat of an endangered population, or other special area that is a candidate for protection. There must be a reasonable prospect that these areas will remain suitable habitat.

Step 2: Select Several Species of Interest from the Species Present in these Areas

As a practical matter, only a handful of species can be addressed rigorously, so it is important to select "umbrella species" (Noss 1991) whose protection is expected to confer benefits on the greatest number of species and to include species that have the greatest need for a corridor (Salwasser et al. 1983, Soulé 1987:8, Noss 1991). Although these often will be area-sensitive species such as large carnivores (Soulé 1987:8, Noss 1991, Beier 1993), corridor dwellers and other less mobile species should not be overlooked. Because vegetative or topographic structures that facilitate movement for 1 species may inhibit movement for other species, the species of interest should cover an appropriate range of vagilities and habitat associations.

Step 3: Evaluate the Relevant Needs of each Selected Species

This process differs for passage species versus corridor dwellers. For passage species, identify the movement and dispersal patterns of local animals, including seasonal migrations. To identify which of several potential corridors should be protected, data from radiotagged animals could be obtained to determine actual travel routes (Beier 1993).

For corridor dwellers, identify the habitat needs of those species, including special needs for nesting, rearing of young, or germination. Identify the dispersal or migratory patterns of the animals. Because trans-corridor movement by a corridor dweller may take generations, it will rarely be possible to determine actual travel routes.

Step 4: For each Potential Corridor, Evaluate How the Area Will Accommodate Movement by each Species of Interest

During this step, some potential corridors may be judged inadequate. This may require considering additional alternatives or mandating habitat improvements. As with step 3, this process differs for passage species versus corridor dwellers.

For passage species:

A. Given the animal's movement patterns, is the topography, vegetation, and location such that the animal will *encounter* the entrance to the corridor?
B. Once an animal encounters the corridor, will the habitat within it attract the animal to *enter* it and follow it for the full length?
C. How long will it take the animal to reach the other end? Is there sufficient shelter and concealment cover, food, and water for the animal on a journey of this duration?
D. What are the current *impediments* to use of the corridor and what impediments are expected in the future? Important factors include domestic dogs and cats, noise from traffic and other human activities, outdoor lighting, type of road crossing (e.g., bridged underpass, culvert), off-road vehicles, fences, grazing and silvicultural practices, dam construction, and stream channelization.

For corridor dwellers, several other considerations arise:

A. Is the species of interest now present throughout the corridor? If not, are the gaps short enough that they would be crossed in a single event (e.g., dispersal or seasonal migration)?
B. If the species is absent from all or much of the corridor, does the habitat meet its needs (identified in step 3) so that occasional occupation might be expected?
C. Given the animal's movement patterns, are the topography, vegetation, and location such that individuals will *encounter*, *enter*, and *live in* the corridor?
D. Also address the questions related to impediments listed above for passage species.

Step 5: Draw the Corridor(s) on a Map

Each corridor should be mapped to the edge of each habitat area it is designed to link, its width should be clearly stated, and its vegetation and topography described. Clearly explain how each corridor will meet the needs of each species of interest. More than 1 corridor may be needed to meet the needs of all species of concern. Specify management guidelines for each corridor, including:

A. Prohibitions on land uses within the corridor that would prevent the area from functioning as a corridor.
B. What land uses may be permitted adjacent to the corridor. For example, a golf course or industrial park may be permitted, whereas housing may be excluded.
C. How domestic cats and dogs, off-road vehicles, outdoor lighting, and recreational activities should be controlled in and adjacent to the corridor.
D. How future road crossings should be designed. The number of road crossings should be minimized, at least where deer (*Odocoileus* spp.) or cougars are species of interest (Reed et al. 1975, Foster and Humphrey 1991). Bridged underpasses are

preferable to culverts, and where high-speed roads cross the corridor, fencing should be used to guide animals away from the road and toward the underpass. Where low-use roads cross corridors, vehicle speeds should be kept low through appropriate road design elements (speed limits, signs, speed bumps, curves, and grades). Specific recommendations for underpass design are available for mule deer (*O. hemionus*) (Reed et al. 1974, 1975) and cougars (Foster and Humphrey 1991). There are no published studies on how other species use structures to cross under or over roads.

E. Recommended changes to enhance the utility of the corridor, e.g., restoration of vegetation to a mined area.

Step 6: Design a Monitoring Program

In our experience, developers propose, and planning agencies routinely approve, corridors based on optimistic assessments of the ability of a narrow corridor to meet the needs of wildlife. In fairness to the planners, data for steps 3–5 are lacking, and it is often impossible to prove that a larger corridor is needed. Lacking data, planners are conducting experiments; each experiment is a test of the hypothesis that "This configuration of corridor length, width, vegetation, topography, and land uses will facilitate travel through the area by species *A*." Unfortunately, planners rarely require developers to monitor the results of these experiments. If animal use of each project-impacted corridor is monitored, the failure or success of various designs will yield the data needed to preserve or create functional corridors in the future.

Monitoring programs can include counts of tracks or other sign, photographic documentation of corridor use, radiotelemetry, or measures of gene flow. If track surveys are used, enhancements (e.g., spreading lime on the ground, raking) may be needed to reliably detect tracks, and sites should be checked at dawn (before nocturnal tracks become degraded). Track monitoring should take place at least twice a week for several months, including those times when rarer movements (e.g., seasonal migration, dispersal events) are most likely. The monitoring program should assess how animals use the corridor both before and after construction of the project, with equal sampling intensity in both periods. Areas outside the corridor also should be monitored to document how animals use the corridor compared to the adjacent matrix land both before and after construction.

If the corridor is intended to replace a corridor the project will destroy, preproject use of the forfeited corridor also should be monitored. In this case, ≥1 undisturbed corridor also should be monitored (both before and after construction) to provide a control for exogenous effects that might affect indices of animal movement.

DISCUSSION

We offer this checklist as a means to improve the treatment of wildlife corridors in environmental impact analyses. Research is urgently needed to give such analyses a better scientific foundation. Some of this research should be done in concert with monitoring programs, and no wildlife corridor design should be approved without mandating that the project proponent fund such monitoring (step 6). Henein and Merriam (1990:168) and Harrison (1992) provide additional recommendations for directed research based on the home range, movement, dispersal, and habitat-use patterns of focal species.

Much of this research will be designed to determine the minimum width for wildlife corridors for a given species. We have cautioned against seeking simple answers to this question and have advocated additional research. Nonetheless, intuition and observation suggest several generalizations. First, a long corridor will need to be wider than a short one

(Harrison 1992). For example, a 1-m-wide box culvert may be a passable corridor for a deer to travel the 3-m distance under a small aqueduct, but a much wider underpass is needed for the 30-m passage under a freeway (Reed et al. 1975). Radiotagged cougars have been documented to travel near the edge of housing tracts, but never for distances >100 m (P. Beier, unpubl. data).

Topography and vegetation are probably as important as corridor length in determining corridor quality and hence corridor width (Henein and Merriam 1990; P. Beier, unpubl. data). As in other types of real estate assessment, *location* also is critically important. For instance, cougars cross freeways not through the best-designed underpass, but rather through the underpass that is best aligned with a major drainage (P. Beier, unpubl. data).

Because most monitoring efforts will have a sample size of 1 corridor, they will rarely yield publishable results. To make such reports accessible to other biologists and planners, 1 of us (PB) hereby volunteers to serve as a clearinghouse for reports documenting animal use or avoidance of corridors that result from development projects.

An earlier version of this checklist was implemented in 1 environmental impact document (Anonymous 1991*b*). In this case, it greatly improved the rigor with which wildlife corridors were addressed. The analysis identified 3 large natural areas that needed to remain connected, selected 2 species of interest, used track surveys to identify probable routes, included specific prohibitions on land uses, specified design standards for roads crossing the corridors, and addressed uncertainty by providing for redundant corridors. We hope that this checklist will be used and improved by others.

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