A framework for the design of wildlife conservation corridors with specific
application to southwestern Ontario

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Abstract

Natural disturbances and human development can cause habitat fragmentation. Plant and animal populations can become isolated, but wildlife corridors can potentially alleviate the problem by providing linkages between isolated patches of natural areas. These connecting corridors need to be designed to create habitat appropriate for target species.

This study developed a framework for design of wildlife corridors which considered both critical corridor attributes and target species. It provided a methodology for use in designing corridors to ensure appropriate species composition. Objectives included identifying and analyzing attributes which constitute a corridor. An 'ecosystem approach' for selecting guilds of target species was used. The framework was applied to a fragmented landscape case study in southwestern Ontario, Canada.

Results indicated that, by applying this framework to a fragmented landscape, ecologically appropriate corridors could be designed when corridor attributes and target species were carefully analyzed. In addition, it was shown that optimal corridor designs could be altered to fit a landscape's opportunities and constraints.

1. Introduction

As urban areas expand they cause fragmentation of natural environments. A major consequence of habitat fragmentation is that faunal and floral species populations become isolated in the fragmented patches, leading to inbreeding, demolition of existing food sources and, in some cases, population extinction (Thomas, 1991).

Wildlife corridors have been identified as one solution to overcome problems of fragmentation by providing linkages between these isolated habitat patches (Ness, 1993). The resultant faunal interchange may increase the ecological value of the patches in two ways: (1) by reducing the vulnerability of insular populations to extinction, and (2) by providing a means for recolonization to occur should local extinctions take place (Bennett, 1990). Much of the literature regarding wildlife corridors, including the attributes which define them, is theoretical (e.g. Noss, 1993).

There is no precedent methodology for use by landscape architects which would allow translation of the theoretical information into a format usable in the design and development of high quality wildlife corridors. The goal of this study, then, was to develop a framework for the design of high quality wildlife corridors utilizing the wide range of information available in the literature on specific components of corridors. The objectives of this study were: (1) to identify and analyze attributes defined as critical to the quality of corridors, (2) to select and analyze target species in response to the critical design attributes, (3) to develop a framework for use in the design of wildlife corridors, and use it to design generic wildlife corridors, (4) to apply the framework to a specific fragmented landscape, to test its applicability, and (5) to evaluate the results to determine if the framework was helpful in designing high quality corridors for the target species in the target location.

2. Corridors in landscape ecology

A corridor can be defined as a strip of land or vegetation that differs from the matrix through which it runs (Barrett and Bohlen, 1991). Corridors can be classified into five types based on their origin: planted, disturbed, regenerated, environmental resource, remnant (Barrett and Bohlen, 1991). Corridor 'quality' has been defined by design attributes and the ability of species to utilize the corridor for movement between patches (Henein and Merriam, 1990; Thome, 1993).

The major functions of corridors include: (1) a habitat for certain species, (2) a conduit for movement, (3) a barrier or filter separating areas, (4) a source of environmental and biotic effects on the surrounding matrix (Forman and Godron, 1986). This study will focus on the first two functions.

3. Framework for the design of wildlife corridors

There are two primary considerations in corridor design: (1) including corridor attributes that can contribute to corridor quality (Schroeder et al., 1992), (2) tailoring corridors to the needs of the species it was designed to serve (Soule, 1991).

Although there is no methodology to assist designers in utilizing the information in the literature regarding these two issues, there exists a flexible model for the design of ecological greenways that could be used for various types of greenways (Hellmund, 1993). Four broad stages were defined in the design process: (1) understanding the regional context, (2) selecting project goals and a study swath, (3) defining greenway boundaries, (4) creating and implementing site designs and management schemes. Hellmund's study (Hellmund, 1993), however, did not apply the method to an actual landscape with specific species in mind.

The framework for the design of wildlife corridors (FDWC) developed in this study has combined the ideology of a flexible method with the theories associated with wildlife corridors. This framework is designed to provide corridor designers with an approach to process existing scientific information and synthesize it for application in design. The framework is, in essence, an extension of Hellmund's final step of creating and implementing site designs (Hellmund, 1993).

The FDWC outlines one method for landscape architects to consider habitat quality in the design of corridors in a rural-urban fringe area (see Fig. I). The framework examined issues and their relation to high quality corridor designs. The first issue was corridor purpose. A corridor could have a social or

Fig. 1. Framework for the design of wildlife corridors.

ecological purpose. A social corridor is primarily concerned with the recreation needs of humans, while an ecological or wildlife conservation corridor views wildlife movement as a priority. This study focused on ecological corridors.

It has been shown that successful corridors are related to corridor attributes and species utilizing the corridor (Bennett, 1990; Schroeder et al., 1992). Three components therefore comprise the second tier within the framework: the definition of the critical corridor attributes, the identification of target species and a biophysical inventory of the landscape in question.

3.1. Definition of critical corridor attributes

Critical corridor attributes are those characteristics which affect corridor quality and, in turn, can be affected by design. These attributes were selected from the literature concerning wildlife corridors. The critical corridor attributes have been organized from the broadest landscape scale to the most specific

design issue. In summary, the critical corridor attributes as identified from the literature are: matrix, patch, network connectivity, barrier, length, width, shape, edge, structure, composition.

3.1.1. *Matrix*

Often, a matrix is obvious; for example, it may be easy to describe an area as primarily agricultural. The matrix, therefore, would be agricultural in nature. A corridor exists within a matrix; the matrix either presents a barrier or an alternative, but penetrable, space for the species utilizing the corridor. Management of the matrix can help to make it less hostile for the dispersion of animals, or enhance its lethality (Franklin, 1993). For example, many small mammals find certain crop types to be inhospitable for movement. However, the matrix may provide food, water or shelter for other fauna utilizing the wildlife corridor as a travel lane.

3.1.2. *Patch*

The size and shape of patches within the landscape are important in the ecological process. Edge effects are maximized or minimized depending on these characteristics of a patch (LaGro, 1991).

Table 1
Patch size and benefit

	Circular patch	Rectangular patch
Problem of barriers within patch	Less	More
Problem of habitat diversity	Less	More
Functions as movement corridor	Less	More
Species diversity	More	Less
Foraging efficiency	More	Less

Source: Forman and Godron, 1986. p. 111.

The orientation of a patch also affects its success as habitat for species. Patches should be oriented perpendicular to the corridor to 'catch' as many species as possible (Gutzwiller and Anderson, 1992). Species richness and nest abundance by migratory birds have been shown to increase in patches oriented perpendicular rather than parallel to migratory direction (Forman, 1995). Two general shapes of patches can be identified within the landscape: circles and rectangles. Circular patches are more effective than rectangular patches in protecting their internal resources from such forces as wind penetration. As well, interior species and species richness should be higher in a circular patch than in an elongated patch (Forman, 1995). The benefits of circular and rectangular patches are presented in Table 1. In general, patch shape should be as circular as possible, oriented perpendicular to the corridor. and as large as possible within the particular landscape.

3.1.3. *Network connectivity*

Connectivity in the landscape refers to the degree that all nodes in a system are connected by corridors. This function of the landscape is important to the movement of animals between multiple patches in order to minimize population decline in patches that are too small to support minimum critical populations. Alternative corridors or loops within the system are important in minimizing potential barriers to movement, such as roads or other human impacts. When wide and internally diverse corridors are not possible, a network of corridors may collectively encompass a range of habitat types. This network may also preclude against any catastrophic event that could potentially destroy a single travel corridor (Ness, 1993).

An important structural characteristic of the network is the type of connection in which corridor lines intersect or end (Forman and Baudry, 1984). Corridor intersections are important, as the microclimate at intersection points has been shown to differ from that of the corridor in general. In shape, corridor intersections may be 'T', 'L' or '+' shape, and generally have a small break near the intersection (Forman and Baudry, 1984). Constant et al. (1976) reported that a wider variety of bird species exist near the intersections of hedgerows than in the remainder of the corridor. No single intersection type has been shown to be preferred by all species.

3.1.4. Barriers

A barrier to the movement by species in a corridor is undesirable as it lowers the quality of the corridor, when an animal encounters a break in the corridor, movement may be halted. This lack of movement increases the chance that a predator may locate the species. As well, this break may increase the effects of fragmentation, as species cannot reach their patch destination. In effect, the corridor has become an isolated patch.

Barriers or breaks in a continuous corridor in a fringe or agricultural area are often caused by roadways. Roads more often than not run through many areas of similar habitat and may be the most destructive cause of fragmentation. Because of this tendency to interrupt connectivity, roads require special solutions by designers of greenways (Ness, 1993).

Species most likely affected by the fragmentation caused by roads include: (1) those that do not do well in edge environments, (2) species that are sensitive to human contact, (3) those species that exist at low densities, (4) species that are unlikely or unable to cross roads, (5) species that seek roads for heat or food, (6) species that require large amounts of territory, more than can exist in any single road-created fragment (Schonewald-Cox and Buechner, 1990, p. 375). Table 2 outlines some reasons why roads and traffic represent sources of mortality for wildlife.

For most small mammals, studies have shown that roads up to 30 m in width can be crossed, but this is not encouraged due to the high mortality rates of the animals attempting to cross (Wegner and Merriam, 1979). Roads also remove habitat directly by occupying space within the ecosystem; a 30 m wide road covers 30000 m² for each kilometre of its length. Other landscape elements that act as a barrier to wildlife movement include streams and water courses, and unsuitable habitat. Streams greater than 3-4 m wide and deeper than 10-40 cm were shown not to be traversable by small mammals in southern Ontario (Henderson et al., 1985).

Several bird species have been reported as not crossing unsuitable habitat that was greater than 1-2 km in width (Wegner and Merriam, 1979). Larger species have greater difficulties with barriers to their movement, as their home ranges are large. White tailed deer prefer to be at least 400 m away from moving traffic and 800 m from human activity if possible (Ministry of Natural Resources, 1990).

In general, any break or discontinuity within the composition of a corridor should be avoided. If necessary, the barriers should be as narrow as possible to minimize the edge effect and habitat fragmentation.

Table 2
Why roads represent mortality for wildlife

Reason	Example
Roads bisect natural migration routes and death results when animals attempt to cross the traffic stream	Black bear on US 19 near Homosassa Springs
Roads provide a deceptively easy movement opportunity and animals intermingle with traffic	Panthers and bears in wetlands such as the Everglades
Roads bisect established home range or territory	Panthers in Big Cypress National Reserve
New food resources made available, e.g. spilled grain, nutritious forage and carrion	Marsh rabbits consume forage, bald eagles eat carrion
New habitat is attractive and serves as an ecological trap	Cattle egret, marsh rabbit
New environment serves as habitat for residence	Gopher tortoise, Florida mouse, love bugs

Source: Harris and Scheck, 1991, p. 192.

3.1.5. Length

This critical corridor attribute is species specific. The mortality and speed of the species determine the maximum length of a corridor (Soule, 1991). Speed depends on the style of movement. Burrowing animals can take hours or days to move 1 in. whereas a dispersing bird might cover 100 km or more in the same time interval. Likewise, a 10 km corridor would be too long for a frog, especially where raccoons are present. Therefore, the longer the corridor, the faster the animal must move to make it successfully to the other end.

Bennett (1990) has concluded that forest patches that are separated from other patches by less than 1 km do not necessarily preclude movements by small mammals, if suitable habitat is available within the corridor.

In general, the shorter the corridor, the more likely that a higher success rate will ensue, but species use is the major determinant of this attribute.

3.1.6. Width

The corridor must be wide enough to shelter the animal species from predators, allow for movement and also providing nesting and feeding opportunities. A very narrow corridor has a high ratio of edge (high mortality for certain species) to interior (low mortality) habitat. A very wide corridor has a high rate of occupancy, and allows for 'wandering'. In a simulation by Soule and Gilpin (1991), corridor width was measured against success (see Fig. 2). In theory, there should have been conditions where the curve would resemble an inverted 'U', but no such optimal width emerged in this study.

Wider corridors have always been assumed to be more effective than narrow corridors. A guideline does not exist which suggests how wide is wide enough (Loney and Hobbs, 1991.)

In a workshop conducted in Australia (Friend, 1991), all participants felt that both width and

Fig. 2. Simulation of corridor width measured against species success (after Soule and Gilpin, 1991).

composition affected corridor quality. However, all participants agreed that there is little or no empirical evidence to show that corridors facilitate movement per se, let alone how width and composition may influence such movement.

The length to width ratio may be more important than width alone. Optimum width is difficult to specify generally because width is species specific, time specific, habitat specific and landscape specific. It is suggested that the requirements of species that are high on the food chain should be utilized as a 'minimum estimate' of necessary width. In this application, those species that will be identified as 'highly dependent' on corridors for movement will be the keystone species on which width is determined.

3.1.7. Shape

The shape of a corridor can directly affect the quality. The shape that is most often associated with corridors is that of a rectangle. Other alternatives to this shape are present in the landscape, often with disastrous results for species utilizing the corridor.

In 1991, Soule and Gilpin developed a computer simulation which was designed to mimic the behavior of some kinds of animals (including insects, some vertebrates and perhaps gallinaeous birds). In this simulation of corridor design, two shapes (funnel/horn and rectangle) were tested for their effect on

Fig. 3. Examples of funnel and dogleg shaped corridors.

organisms' success rate within the corridor (Fig. 3). First, the funnel shape was simulated. The funnel was wide at the entrance and narrow at the exit. This shape was particularly harmful for species entering the corridor, as individuals kept running into the edge as they proceeded through the corridor. A success rate in the funnel shape was documented at 16% compared to 43% in a rectangular corridor.

The second shape simulated was that of a horn. All individuals entered at the middle, but because the corridor increased in width with distance and time from the origin, the chance of entering edge habitat was relatively small. The horn, however, was not significantly better than the rectangle, especially considering that it would appear to be funnel shaped if entered from the opposite end.

A variation within the rectangular corridor had a dogleg within it. A dogleg greatly reduced corridor capability for the species simulated, as the wall acted as a barrier, temporarily stopping virtually all the animals. The success rate of a corridor with a dogleg in it was less than half of that in the rectangular corridor with the same area. (Soule and Gilpin, 1991).

Soule (1991) presented some general conclusions about corridor shape. Firstly, any departure from linearity could be deleterious, as more time is spent in an edge environment. Secondly, corridors were shown to be most effective with straight sides and a constant width. Some contradiction exists, however, as it has been suggested that small bulges or nodes throughout the corridor can allow the migratory route to become habitat for certain species (Lynch and Saunders, 1991). Also, edge effects could be minimized if a feathered edge was utilized, as opposed to an abrupt edge of a corridor (Reese and Ratti, 1988).

3.1.8. Edge

An edge is defined as an outer band or ring, which differs significantly from the interior of the patch or corridor. Different species and vegetative composition is found in this edge, representing the 'edge effect'

(Forman and Godron, 1986.) If corridors are too narrow, they may be completely 'edge', and so fail to act as permanently populated strips between habitat patches (Thomas, 1991).

Research has examined the impacts of increased proportions of edge due to forest fragmentation. Several authors have debated whether this edge effect is beneficial or not to an overall ecosystem, and to what extent this effect penetrates into the interior of a patch (Reese and Ratti, 1988).

Major vegetational changes at habitat edges are often apparent for only 10-30 m into a forest, but animal edge effects often show changes over distances of a few hundred metres to a kilometre. Therefore, for habitat interior species, a corridor that is to provide permanently populated habitat must contain a core of populated habitat as well as an edge on either side (Thomas, 1991).

Models by Buechner (1987) and Stamps et al. (1987) have attempted to identify parameters for edge. The first parameter is the edge-to-size ratio itself. The probability of emigration for habitat-interior species is low when the edge-to-size ratio is low. That is, species are unlikely to emigrate from wide corridors or large patches. As well, species are unlikely to emigrate if the edges are 'hard'. In summary, habitat-interior species are least likely to leave habitat patches or corridors if they are large, have easily detected edges, and if those species have strong preference for the interior habitat. Short wide corridors, therefore, will likely be adequate for all interior species, but long thin corridors will only be suitable for species with a strong habitat preference and if the corridors have easily detected edges (Thomas, 1991).

3.1.9. Structure

Generally, a corridor has an internal structure, including its width, vertical stratification and height. The definition of this corridor attribute as used in this study is that of vegetative vertical stratification. Vegetation structure, as measured by the number of layers present in a corridor or hedgerow, has been related to faunal diversity (Forman and Baudry, 1984). The type of vegetation and arrangement found within the corridor can affect quality. A structurally diverse corridor is of much greater benefit to a greater number of species than a simple corridor, diversity is described as a corridor with several layers in a cross-section. These layers could consist of grasses, small shrubs, tall shrubs, and a mixture of deciduous and coniferous trees (Merriam and Lanoue, 1990).

Fig. 4. Brush piles can provide nesting site and protection for a variety of species.

Capell (1988) provided a description of a structurally diverse windbreak for the Great Plains of North America. His windbreak comprised five basic rows with two rows of evergreens to the north or west side to provide winter wind and snow protection. The middle row was described as having one or more species of tall deciduous trees to provide vertical habitat, nesting cover and added wind protection. The remaining two rows should be shrubby material which would offer the greatest food availability and food production potential. In more extreme situations, large block plantings or snow drift buffers 15-35 m or more to the north of the plantings are beneficial.

Other elements which add to corridor diversity include brush piles, rock piles and snags and burrows. When constructed properly, these elements provide nesting and protection for a variety of wildlife (see Fig. 4). A rock pile can provide habitat for a variety of species. Rabbits, snakes, lizards and many insects utilize these structural elements in their daily routines. The core of the pile should be constructed of 1-3 large boulders, 1-4 m in diameter, surrounded by smaller rocks 1m in diameter or less. (Tessman, 1982, in Green and Salter, 1987). Rock piles should be 1-4 m high and occupy an area of 10 m². Reptiles prefer rock piles with south-facing entrances.

A snag, which is defined as a dead or dying tree, is beneficial to many forms of wildlife. Over 85 species of North American birds use cavities in dead or deteriorating trees (Sobkowiak, 1990). Large snags also provide singing perches and look-out branches for several bird species. As well, bats, squirrels, raccoons and several insects use these elements of a corridor for habitat and as a food source (Fig. 5). After a snag has fallen, or has been cut down, the dead logs and stumps should not be removed. These logs should be oriented perpendicular to the slope if on a hill in order to serve as a sediment and moisture trap. Large diameter logs are preferable, as the value to wildlife increases with log diameter. As the log decays, different species utilize this element. If use by raptors is intended, the logs should be placed near the hilltop and on the leeward side of prevailing winds (Maser, 1979).

In summary, the more structurally diverse the corridor is, the more benefits to wildlife it can offer. A variety of deciduous tree and shrub species, mixed with conifers, provide a habitat structure with a large selection of vertical and horizontal nesting and foraging sites. The conifers provide winter wind

Fig. 5. Snags can provide singing perches, nesting sites, and food sources for a variety of species.

Table 3
Species guild

	Insects	Reptiles and amphibians	Birds
Matrix	Diversity of insects is greatest where corridors border field of beans or pasture	n.a.	Land use surrounding conservation corridors for birds does not seem as critical for birds as for other mammals. Generally, locating near a pond or water source was stated specifically for 20% of species studied. A cover crop for winter food supply, or corn fields is also a requirement. Only four of 32 species were stated as being tolerant of human habitation near the corridor
Patch	n.a.	n.a.	n.a.
Network	n.a.	n.a.	n.a.
Barriers	Eddies created by a corridor may be a barrier to certain wind dispersed insects	n.a.	Limited information. One reference indicated that distances of 1-2 km of suitable habitat kept birds from colonizing
Length	n.a.	Shown to move 2 km along hedgerow	Two examples. blue jays are found only within 100 m of a forest patch; ring necked pheasants can cruise up to 1 mile per day. No overall length for all bird species was indicated
Width	n.a.	n.a.	Little information existed on required width for birds. Ranges were found, however, between 4 and 90 m. Of the eight species where width information was found, six of those listed width required as between 4 and 15 m. As well, more than four rows of trees
Shape	n.a.	n.a.	n.a.
Edge	n.a.	n.a.	15 of the 34 species analysed were classified as edges species, who utilize the corridor edge for feeding, reproduction purposes or both
	Small mammals	Medium mammals	Large mammals
Matrix	Corn and small grain fields will be crossed, hay and pasture fields will not. Dense forbs are avoided, as small mammals cannot forage or move quickly to avoid predator. Locating a corridor near a water source is necessary for certain small mammals	A non-competing legume such as red clover adjacent to the corridor will help prevent eastern cottontails from browsing on trees within the corridor. Corn fields can be traversed, and the corn eaten, but hay and oat fields are avoided. A corn field provides high canopy and good cover. Water source is required	The land use surrounding the corridor for these mammals should contain woody brushy areas intermixed with open spaces. Optimum habitat includes the presence of water within 0.8 km. Fields or food plots containing green winter wheat, alfalfa or sweet clover are excellent options for winter food sources
Patch	Small mammals prefer habitats of woody brushy areas, especially beech-maple forests	n.a.	Patch size recommended for large mammals (white tailed deer) has been stated at 183-366 m in diameter to provide adequate shelter and thermal cover
Network	n.a.	n.a.	n.a.

Table 3 (continued)

Barriers	Roads of up to 30 m do not represent an impenetrable barrier. Streams 3-4 m wide and 10-40 cm deep were shown to be not crossable by most small mammals	One study indicated that a skunk will cross a road with a narrow clearance (less than 15 m)	Habitat patches and travel corridors should optimally be located more than 400 m from traffic, and 800 m from pedestrians
Length	Average travelling distance along hedgerows were recorded at 18-50 m	Two examples of distance travelled by medium sized mammals was found: eastern cottontails will travel approximately 100 m while skunks can travel up to 1000 m along a corridor. No overall length for medium-sized mammals was found	No information was found for large mammals and the distance they travel along a corridor. It should be noted, however, that this large mammal has only minor dependence on corridors for movement
Width	These small mammals prefer corridors which are greater than 2 m wide at the base. Chipmunks can establish breeding populations at widths as narrow as 3 m	Two studies referred to width specifically and suggested that corridor width should be greater than three rows of trees and wider than 2 m	n.a.
Shape	n.a.	n.a.	n.a.
Edge	n.a.	n.a.	n.a.
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	Insects	Reptiles and amphibians	Birds
Structure	Two layered hedges have been shown to support high insect diversity	Large rock piles, rock crevices gravel banks, earth dams, logs and stumps are required. Rock piles that are south facing are desirable	Structurally important elements for birds include a diversity of shrub species, multitude of horizontal limbs, dense overall woody vegetation, leaf covered woodland floor, and a mixture of deciduous and coniferous trees. As well, snags and cavities are important for nesting and loafing. Recommended height for trees was between 2 and 40 feet, or between 1 and 80 feet if possible
Composition	Oak and hawthorn hedges support diverse insect habitat in England. Native species in general support higher diversity	No particular vegetative species listed in literature	The following vegetative species should be included in southwestern Ontario corridors. Shrubs: honeysuckle, dogwood, hawthorn, blackberry, chokecherry, grape, sumac, holly, rose, raspberry, serviceberry and bayberry. Trees: alder, apple, aspen, birch, cherry chestnut, cottonwood, elm, maple, oak poplar and willow. Conifers: balsam fir, pine, larch, spruce, red cedar and juniper
Predators	Insects which control damaging pests include wasps, flies, lacewings, beetles, spiders and mites	Raccoons, chipmunks, many birds, including owls, pheasants, and weasels	Snakes, housecats, birds and humans
Minimum critical population	n.a.	One 0.8 ha pond per population of amphibians; various sizes for reptiles	n.a.
Feeding	n.a.	Reptiles: frogs, sparrows, robins, thrushes, warblers, mice, chipmunks, shrews. Amphibians: live insects and invertebrates	Insects, vegetative matter, seeds, nuts, sup, wheat, corn, and some small mammals

Table 3 (continued)

	Small mammals	Medium mammals	Large mammals
Structure	Small mammals prefer structurally diverse corridors with dense cover in the form of trees, shrubs, fallen logs and rocks. This increased vertical stratification minimizes predator risk	Medium-sized mammals require shrubby vegetation, multiple rows of trees, and shrubs with good ground level density. Rocks, stumps, snags and brush piles are required for nesting. Interior rows of conifers with low sweeping branches are encouraged. Three or more rows of trees is considered minimum	Large mammals require vegetation that is greater than 1.5 m with 75% canopy closure. Conifers are required which allow for ease of movement in the winter
Composition	Habitat preference for this guild includes beech and maples in a mixed deciduous forest	Vegetation recommended for this species guild includes redcedar, blue spruce, pines, apple, chestnut, hawthorn, multiflora rose, honeysuckle, black raspberry, gooseberry and sumac	Preferred vegetation includes hemlock cedar, pine, spruce, red maple, sugar maple, birch, elm, oak, ash
Predators	Hawks, owls, snakes, foxes, weasels, house cats	n.a.	Humans
Minimum critical population	n.a.	Home range of this species guild varied greatly from approximately 600 ha per pair of foxes to 1 acre for one cottontail rabbit. No overall figure for species guild	n.a.
Feeding	Small mammals survive on acorns, grasses and sedges, seeds, vegetative matter and some insects. Required vegetation includes chokecherry, hawthorn, apple and nannyberry	Medium mammals exist on bark, twigs, buds and shoots of various vegetative matter including raspberry, blackberry, black cherry, apple, hawthorn, rose and staghorn sumac. Insects, fruit, and berries are also required. Foxes	Clover, green winter wheat and alfalfa are important. These mammals graze on green plants, acorns, beechnuts in the summer and shoots and twigs of serviceberry dogwood and willow in the winter

protection. The existence of a well-developed understorey of shrubs is the single most important vegetation related factor that increased the carrying capacity of corridors for small passerine animals (Lynch and Saunders, 1991). In addition to vegetation, snags, rock and brush piles and burrows provide additional nesting and foraging habitats within the corridor for a variety of species, thus increasing corridor quality.

3.1.10. Composition

The composition of a corridor is defined in this study as the specific flora required to enhance corridor quality. Food and shelter requirements must be provided in the corridor.

In general, the trees and shrubs that are required need to provide sustenance for animals, birds and insects to eat, especially during the winter months. Their branches must provide shelter during the winter from snow and wind, and nesting opportunities in the spring and summer.

Choices for corridor plant material should be made by comparing lists of desired plant material to the particular forest region where the corridor is desired. As well, intended animal USC will determine necessary faunal composition.

3.2 Identification of target species

The capability of a habitat to support different populations can be determined through the monitoring of guilds of animals rather than through all species or through indicator species (Werner, 1983).

Fig. 6. Critical corridor attributes for reptiles.

A guild has been defined as “groups of species that exploit the same class of environmental resources in a similar way” (Hellmund, 1993, p. 135, after Root, 1967).

There are various ways to group species into guilds. In this study, the guilds were defined based on size for mammals, and habitat requirements for all other species groups. These groupings relate directly to three of the critical corridor attributes. Habitat requirements can be translated into corridor structure and composition, while size of species has been shown to relate directly to corridor length. The identification of species guilds allows corridor designers to consider individual species where little specific information on corridor requirements exists. The species guilds identified for use in this study were: (1) insects, (2) reptiles and amphibians, (3) birds, (4) small mammals, (5) medium mammals and (6) large mammals (see Table 3). What these guilds have in common are the use of the corridors for specific activities including, primarily, movement followed by feeding, nesting and resting.

3.2. Biophysical inventory

It is necessary to conduct an inventory of the biological and physical characteristics of a site in order to best match proposed corridor composition and distribution to the existing environment. Characteristics to inventory and map include geology, soils, slope, vegetation type and structure, and faunal description.

4. Generic corridor design requirements

The species guilds table shown in Table 3 illustrates the species guild requirements regarding critical corridor attributes. This table is an amalgamation of all literature sources found in the reference section of

Fig. 7. Critical corridor attributes for birds.

this study. By using this table format, a corridor designer has an opportunity to organize each guild into a consistent set of characteristics to facilitate cross-species comparison. It ensures that any corridor designed would address a complete set of design parameters. Illustrations of various attributes of the species guilds tables are provided for clarity (Figs. 6-10). These graphical representations indicate to the designer how critical corridor attributes could be implemented at the site scale. Greater details than those provided by these illustrations can be found throughout the references cited in the species specific tables.

Within the guilds, variation in the amount of dependence on corridors might exist (see Table 4). Where this occurs, species with high dependence on corridors should be considered first in the design process. In most landscapes, the corridor will be designed for more than one species guild. Therefore, it is necessary to amalgamate design requirements for each species guild into a single corridor design. In reviewing the corridor requirements of species guilds, certain minimum requirements for a given

Fig. 8. Critical corridor attributes for small mammals.

corridor attribute existed, under which the corridor would not be defined as having quality. However, it was also found that, for most attributes, there was some level above the minimum which improved the corridor to its 'desired' level of quality. For this reason, both these minimum and desirable requirements are illustrated in Table 5. Where practical, designers should implement the desired corridor design parameters. However, in no case should the corridor design fall below the minimum requirements. This

Fig. 9. Critical corridor attributes for large mammals.

Fig. 10. Critical corridor attributes for medium-sized mammals.

desired design, however, is not yet site specific. None of the constraints or opportunities that exist in an actual landscape are considered at this point in the design decision.

Table 4
Dependence of mammals on wildlife corridors

Species	Dependence
White footed mouse (<i>Peromyscus leucopus</i>)	High dependence
Eastern chipmunk (<i>Tamias striatus</i>)	Minor dependence
Meadow vole (<i>Microtus pennsylvanicus</i>)	Minor dependence
Red backed vole (<i>Clethrionomys gapperi</i>)	High dependence
Red squirrel (<i>Sciurus vulgaris</i>)	Moderate dependence
Woodchuk (<i>Marmota maza rufescens</i>)	Moderate dependence
Grey squirrel (<i>Sciurus carolinensis</i>)	High dependence
Eastern cottontail (<i>Sylvilagus floridanus</i>)	Minor dependence
Striped skunk (<i>Mephitis mephitis</i>)	n.a.
Red fox (<i>Vulpes vulpes</i>)	Minor dependence
Long tailed weasel (<i>Mustela frenata</i>)	Minor dependence
Raccoon (<i>Procyon lotor</i>)	n.a.
White tailed deer (<i>Odocoileus virginianus</i>)	Minor dependence

(After Johnson and Beck, 1988).

5. Case study of Hanlon Creek Watershed

The applicability of the FDWC is shown through a case study application in southern Ontario. In order to test the applicability of the FWDC, a case study approach was undertaken. A biophysical inventory of the

study area was prepared to gain an understanding of the regional context and, more specifically, the composition of flora and fauna. The second step was to identify existing patches and corridors within the watershed, as these would form the basis of enhanced corridor design and connectivity. Thirdly, utilizing Table 5 (desired corridor requirements) for species guilds in southwestern Ontario, wildlife corridors were designed, or existing corridors enhanced, to provide a higher level of connectivity in this fragmented landscape. These designed corridors were then examined in order to determine if a high quality connection could be created within specific locations of the watershed.

Table 5
Minimum and desired corridor design requirements

Critical design elements	Minimum corridor requirements	Desired corridor requirements
Matrix	Avoid matrices where major land use is hay or pasture fields. A water source is required, and a cover crop of food for winter feeding	Optimum matrix would consist of corn fields, water source within 0.8 ha, cover crop of winter food supply (green winter wheat) or alfalfa, with some brushy areas along the ecotone between matrix and corridor
Patch	Difficult attribute to summarize, as information was not available for all species. Minimum patch size appears to be approx. 200 m in diam. As well, the patch should be as circular as possible and oriented as perpendicular to the corridor as possible	Optimum patch size would be large, 400 m in diameter, woody and brushy in character
Network connectivity	A network of corridors is preferable to a single route	More than one alternative route allows for catastrophes and the escape from predators. These loops can encompass small patches of diverse habitat
Barrier	No breaks caused by road. No streams greater than 3 m should divide the corridor	No breaks at all along length clearances should exceed 15 m of corridor, as this greatly affects corridor integrity. Optimally, locate corridors for wildlife 400 m from traffic and 800 m from pedestrians
Length	In general, the corridor should be as short as possible for safe travel. In the case of southwestern Ontario, a corridor should not exceed 50 m without a patch or node. Very difficult attribute to summarize since very landscape, time and species specific	The shorter the corridor, the more likely that all species can move successfully between patches of suitable habitat; 50 m appears to be an acceptable length for all species researched
Width	Information on this attribute was not available for insects, reptiles or large mammals. Therefore, the minimum width for those species groups where information was available was 2 m. These corridors could be utilized by some small and medium-sized mammals	A corridor should be as wide as possible to allow for the maximum diversity of habitats. For birds, the maximum width specified was 90 m, but even wider than this is desirable where possible in the landscape
Edge	Edge effects can be minimized if a feathered edge is utilized as opposed to an abrupt edge	Edge effects need to be mitigated against the surrounding matrix, as an inhospitable matrix allows for greater edge effects
Structure	Diversity of structure is very important to the success of a corridor. The necessary requirements for a corridor are rock piles, logs and stumps, snags and a good mixture of conifers and deciduous trees. These structural components are necessary for reptiles, birds and all sizes of mammals	The optimum corridor would be multilayered and structurally complex. This means, in addition to those elements listed as necessary, that the corridor would contain gravel banks, earth dams, a wide diversity of shrubs, horizontal limbs for nesting, overall dense woody vegetation and cavities. The height range would also be great, ranging from 1 to 80 feet
Composition	Necessary vegetation for a corridor in southwestern Ontario is: Shrubs: honeysuckle, rose, raspberry, sumach. Deciduous trees: apple, beech birch, chestnut, elm, maple, oak and hawthorn. Coniferous trees: pine, spruce and red cedar	An optimum corridor in southern Ontario contains, in addition to those species listed as necessary: dogwood, blackberry, chokecherry, grape, holly, viburnum, serviceberry, gooseberry, bayberry, alder, aspen, ash, cherry, cottonwood, poplar, willow, balsam fir, larch, juniper and hemlock

5.1. Biophysical inventory of Hanlon Creek Watershed

The Hanlon Creek Watershed is a 16.6 km² area located in the southern portion of the City of Guelph, Ontario, Canada (Fig. 11). The site contained a diverse mixture of land uses, including residential,

industrial, commercial, agricultural and open space. Future development plans for the area were to increase the amount of housing, industry and commerce, while decreasing open space containing

Fig. 11. Hanlon Creek Watershed, Guelph, Ontario, Canada.

agriculture and recreational areas. In a regional context, the Hanlon Creek Watershed is an important facet in preserving the floral and faunal biodiversity.

5.1.1. Geology, soils and slope

The Hanlon Creek drainage basin lies within two physiographic regions. These are the Guelph Drumlin Field, and the Horseshoe Moraines. The Guelph Drumlin Field comprises the northern part of the watershed. It is characterized by a drumlinized till plain containing elongated northwest trending drumlins, separated by a lower-lying till plain, and spillway channels and outwash plains of glaciofluvial origin. Slopes on the drumlins are typically less than 10%, whereas the lowland areas, including the Hanlon Creek Wetland, is level to gently undulating.

The Horseshoe Moraines physiographic region comprises the Paris Galt Moraine in the study areas. The Paris Galt Moraine trends northeast-southwest across the southern portion of the watershed. Hummocky topography characterizes this region, and drainage tends to be into depressional areas. Local relief on these moraines is typically 10-15m.

5.1.2. Vegetation description

Much of the upper portion of the watershed is agricultural in nature, with the forested areas remaining around wet depressions in the landscape. Many wetlands form the large part of the natural habitat within this area. Vegetation within the wetland portions of the watershed is diverse and multilayered. These areas are heavily forested with understorey ranging from dense undergrowth to little or no understorey. Groundcover is also diverse, from graminoids to herbs and forbs. Mixed coniferous woods occur in drier portions of the watershed. The canopy in these woods tends to be fairly open. Within the upland areas of the watershed, deciduous forests are found. All of these communities are very attractive to several bird, mammal and reptilian species.

5.1.3. Faunal description of Hanlon Creek Watershed

The wildlife of the Hanlon Creek Watershed has been inventoried several times over the last 20 years. The most comprehensive was that of the Hanlon Creek Ecological Study, conducted in 1971-1972 (Hanlon Creek Ecological Study, 1971). The complete list of birds, mammals and reptiles found in the watershed was compared to literature discussing faunal use of corridors. All species studied are shown in Table 4.

The central portion of the creek valley has also been identified as a provincially significant deer wintering site. It is ideal in that the required closed canopy is provided, and winter browse is available. It is estimated that 6-20 deer utilize this habitat.

Commonly observed species in the watershed include short-tailed shrew, little brown bat, European hare, eastern cottontail, woodchuck, white-footed mouse, meadow vole, muskrat, raccoon, beaver and mink, as well as the white tailed deer. Of these 12 common species, five were shown through the literature to utilize corridors and are therefore included in this study.

Within the watershed, several common reptiles and amphibians have also been identified. These include spring peepers, northern chorus frogs, wood, leopard, and green frogs, red-bellied salamanders and the eastern garter snake. One uncommon species, the northern brown snake, was observed in the Hail's Pond area. Several of these species are also included for study.

5.1.4. Implications for corridor design

This agricultural matrix provides many opportunities for corridor design. Many desirable vegetative species currently grow in this forest region, and are indigenous to the area. Due to crop rotation, it is difficult to determine from the information available what the current crops in the agricultural fields are. Water sources exist within the matrix, which are desirable by many species. Existing corridors appear in the form of riparian habitat or hedgerows. It appears from air photo analysis that the existing hedgerows will need upgrading to encourage them to function as high quality corridors for the species groups specified.

The topography of the Hanlon Creek Watershed does not appear to pose any problems for the implementation of wildlife corridors. The slopes are manageable, and no climatic change is evident from the change in altitude. The soils are also suitable for corridor development. Existing and proposed development for the Hanlon Creek Watershed may act as a hindrance to the strategic placement of desirable corridors. It is necessary to consider these constraints and ensure that corridor designs do not fall below the minimum standards for a quality corridor. As well, the corridor purpose needs to be considered, ensuring that ecological goals are met before a social purpose of human recreation.

6. Corridor design for Hanlon Creek Watershed

6.1. identification of matrix, patches and corridors

Through air photos and topographic maps, the matrix, patches and corridors within the watershed (Fig. 12 and Table 6) were identified and mapped (e.g. Forman and Godron, 1986). Proposed corridor locations

were identified by utilizing the information from the biophysical analysis of the landscape. For the purposes of this study, only those patches to the east of the Hanlon Expressway were examined. This is because, currently, only one small underpass/culvert connects the Hanlon Creek Swamp to the Speed River Wetland. Until a larger wildlife underpass is constructed, a quality connection cannot exist.

Table 7 indicates how the generic corridor design can be adjusted to fit a landscape, considering the existing land cover and future development. Each new corridor designed is compared to the critical

Fig. 12. Hanlon Creek Watershed patches, 1993.

corridor attributes. Each pair of patches within the watershed is connected by at least one corridor, as identified on Fig. 13, and a description of each corridor is provided. In total, six corridors (A-F) were designed or existing corridors enhanced to increase connectivity in this study area. At the time of publication, none of these corridors had been brought into existence, although the Hanlon Creek Watershed Plan (Marshall et al., 1993) identified similar corridor locations.

6.1.1. Design of Corridor A

As shown on Fig. 13, a corridor was required between the Paris Galt Moraine and the Hall's Pond Wetland ESAs. The matrix between these two patches comprises mainly herbaceous material, and a few small open patches of deciduous trees. A network of hedgerows exists which is connected to the Hall's Pond Wetland. These hedgerows need to be extended across Gordon Street, to connect with the Paris Galt Moraine. Open water is present within the matrix, and patches exist which could act as nodes along the corridor length. A greater mixture of vegetation needs to be provided, as well as other structural elements. The proposed corridor width is approximately 50 m.

6.1.2. *Design of Corridor B*

The second corridor connection occurs between the unclassified wetland in the southernmost portion of the study area with Hall's Pond Wetland and ESA. Two connections will be made between these two patches, as shown on Fig. 13. Corridor B joins a small patch of deciduous trees of intermediate height across an agricultural matrix to a patch of herbaceous material. There is open water at this point in the corridor. The basis of the corridor is existing hedgerows which will be enhanced and widened

Table 6
Description of environmentally sensitive areas (ESA) in Hanlon Creek Watershed

Location of wetland	Description
Speed River Wetland (ESA 13)	This wetland is a provincially significant (Class 1) wetland, and covers a total of 546 ha. This wetland is very important to wildlife because of its high diversity of vegetative communities. It has regionally significance as winter habitat for deer, and the Speed River itself is an important staging area for waterfowl. Most of the floodplain is forested swamp, with pockets of slippery elm, basswood and white ash. As well, the portion of the ESA within the Hanlon Creek valley is mostly forested swamp, containing blocks of willow, cedar swam, and mixed cedar/maple/ash swamp.
Hall's Ponds Wetlands Complex (ESA 15)	The Hall's Ponds Wetland is a Class 2 provincially significant wetland. This 34.4 ha wetland consists of open water ponds and marsh habitat, with some deciduous forested and fen areas. The entire area covers 133 ha with many provincially and regionally rare breeding birds. Muskrat and raccoon inhabit the area, as well as the northern brown snake
Hanlon Creek Swamp (ESA 14)	This ESA totals 272 ha and contains most of the Hanlon Creek Swamp Wetland. The wetland is currently classified as regionally significant (Class 3) wetland. Several Cooper's hawk sightings have been reported in the area in recent years, and is recognized by COSEWIC as a vulnerable species.

After Marshall et al., 1993.

through structural and compositional elements. A small patch of existing development occurs in close proximity to the open water; the corridor will therefore angle slightly towards the southeast, where it connects with Hall's Pond. The enhanced hedgerows will be approximately 30-100 m in width. Unfortunately, due to the existing development, not all of the hedgerows can be incorporated into this wildlife strategy of corridor design.

6.1.3. *Design of Corridor C*

Corridor C joins the unclassified wetland with Hall's Pond in a more southern location. There are no existing hedgerows within this area, so a new corridor will need to be constructed. This corridor will join a patch of deciduous trees of intermediate height across an agricultural matrix to another patch of deciduous trees with an open canopy. No road need to be crossed in this scheme, and open water exists within the patches at either end, This corridor is fairly short, approximately 200 m long by 300 m wide.

6.1.4. *Design of Corridor D*

This corridor also connects the unclassified wetland to Hall's Pond in the southernmost portion of the study area. There are no existing hedgerows in this area that could connect these two patches, so a new corridor will need to be implemented. At this point, the vegetation in the wetland is a combination of trees and shrubs, all deciduous in nature. While there is no open water along the length of the corridor, this attribute does exist within the patches. Currently, a dogleg patch of trees exists which needs to be altered to encourage successful movement between the patches. Two hedgerows currently run northwest to southeast which could connect to this new corridor if enhanced. The new corridor will measure approximately 600 m long by 200 m wide.

6.1.5. Design of Corridor E

This corridor runs southwest to northeast, connecting the northern portion of the unclassified wetland to the Hanlon Swamp Wetland. Much of the area surrounding this corridor is already developed, in the form of residences. Developing and maintaining a high quality corridor in this location will be difficult, due to the pressure from the residential land use and the presence of Clair Road. Two small existing patches of trees, one coniferous and one mainly deciduous, will form the basis of this corridor. It will be fairly wide in an attempt to compensate for the inhospitable matrix and barriers, and will measure 150 m X 400 m. No open water exists within this corridor.

Table 7
Application of generic corridor design requirement to Hanlon Creek Watershed

Critical corridor attribute	Optimum corridor design	Corridor A	Corridor B
Matrix	Optimum matrix would consist of corn fields, water source and winter food source. Brushy areas would exist within the matrix	The optimum matrix can be achieved between these two patches	The optimum matrix does exist here; agricultural land is present, as are herbaceous material and deciduous trees
Patch	Optimum patch size would be large, > 300 m in diameter, woody and brushy in character	Optimum patches are to be connected	Optimum patches are to be connected
Network connectivity	Loops of corridors can encompass diverse habitat and compensate should catastrophic events occur	Two hedgerows will be extended between these two patches, allowing for a circular route between them	Two alternative routes are proposed within this corridor
Barrier	No breaks along the corridor length, approx. 400 m from traffic and 800 m from pedestrians	The northwestern portion of the corridor is fairly close to the road, but the opposite side of the corridor is approximately 400 m from the road. The corridor must cross Gordon Street to connect with the Paris Galt Mofaine	There are no breaks along the corridor length, but residential development does butt up against the open water which acts as nodes within the corridor
Length	50 m in length with small nodes present	This length cannot be achieved in this location. As it exists, the corridor is approx. 400 m long connecting two patches. Small nodes should be encouraged at shorter distances along the length	Total length of this corridor is approx. 700 m, but wide enough to act as habitat for many small mammals and birds
Width	As wide as possible; maximum required is 90 m	In enhancing the existing hedgerows to an optimum, agricultural land must be sacrificed. However, in the interest of wildlife, these hedgerows could be expanded to a width of approx. 20 m. The total natural area, which buffers the two corridor loops, measures approx. 400 m	Overall corridor width is approx. 200 m, with the existing hedgerows being expanded to approximately 90 m in width. Small areas of agricultural fields still persist.
Shape	Straight sides and a constant width	The optimum shape is achievable in this location	The optimum shape is achievable in this location
Edge	Feathered edge	The optimum edge is achievable in this location	The optimum edge is achievable in this location
Structure	Multilayered, structurally complex	Currently, the hedgerows comprise deciduous trees with a closed canopy and are between 15 and 20 m in height. In order to achieve the optimum, coniferous trees and other structural elements would need to be included	The existing hedgerows comprise deciduous trees 5–25 m in height. Herbaceous material is present. Coniferous trees and shrubs need to be added to enhance corridor quality
Composition	Optimum composition would include a wide variety of trees and shrubs; honeysuckle, multiflora rose, black raspberry, sumach, dogwood, blackberry, chokecherry, grape, holly, viburnum, serviceberry, gooseberry, bayberry, apple, beech, birch, chestnut, elm, maple, oak, hawthorn, alder, aspen, ash, cherry, cottonwood, poplar, willow, pine, spruce, red cedar, balsam fir, larch, juniper and hemlock	The hedgerow network between these two patches consists of very tall deciduous trees with a fairly open canopy. Species include maple, poplar, cherry, ash and linden. An existing shrub patch contains raspberry, honeysuckle and some maples. Added to this to meet the desirable level would be rose, dogwood, chokecherry, grape, holly, gooseberry and bayberry, as well as more deciduous and coniferous trees	The hedgerow network that forms the basis for the corridor consists of deciduous trees of intermediate height with a closed canopy. Compositional diversity can be achieved by adding those species listed under the desirable corridor requirements. Coniferous trees and more shrubs are required

Table 7 (continued)

Critical corridor attribute	Optimum corridor design	Corridor C	Corridor D
Matrix	Optimum matrix would consist of corn fields, water source and winter food source. Brushy areas would exist within the matrix	The matrix here is not optimum, as no open water exists. A small patch of agriculture exists, which may contain corn	The optimum matrix cannot be achieved here as no open water exists. An agricultural field does exist which could provide winter food. Brushy vegetation does exist
Patch	Optimum patch size would be large, > 300 m in diameter, woody and brushy in character	Optimum patches are to be connected	Optimum patches can be connected
Network connectivity	Loops of corridors can encompass diverse habitat and compensate should catastrophic events occur	This corridor is one of three alternative routes between these two large patches. However, within this corridor, only one route exists	This corridor does not have alternate loops within it, but is wide enough that catastrophic events should not destroy it
Barrier	No breaks along the corridor length, approx. 400 m from traffic and 800 m from pedestrians	The optimum corridor with regards to barriers can be achieved, as no roads or development currently exists	No breaks in the form of roads exist along the length of the corridor. No other breaks exist. It is designed to contain the optimum structural elements
Length	50 m in length with small nodes present	This corridor is longer than the optimum, but also wide enough to act as habitat if necessary	This length is exceeded in the corridor, but it is wide enough to provide habitat for those species that require it
Width	As wide as possible; maximum required is 90 m	The corridor width in this location is approximately 200 m, which is desirable	200 m wide
Shape	Straight sides and a constant width	The optimum shape is achievable in this location	This optimum attribute is achievable in this corridor if the existing dogleg is corrected
Edge	Feathered edge	The optimum edge is achievable in this location	This attribute is achievable
Structure	Multilayered, structurally complex	Given that no existing hedgerows occur in this location, composition can be designed to the optimum level	This optimum attribute will be strived for in the creation of the new corridor
Composition	Optimum composition would include a wide variety of trees and shrubs: honeysuckle, multiflora rose, black raspberry, sumach, dogwood, blackberry, chokecherry, grape, holly, viburnum, serviceberry, gooseberry, bayberry, apple, beech, birch, chestnut, elm, maple, oak, hawthorn, alder, aspen, ash, cherry, cottonwood, poplar, willow, pine, spruce, red cedar, balsam fir, larch, juniper and hemlock	No existing hedgerows occur in this location, so this corridor will take a longer time to become established as a high quality corridor. Some intermediate height trees exist, and need to be complemented with coniferous trees and shrubs and black raspberry	The existing hedgerow which a forming the basis for this corridor consists of spruce, pine, elm, cherry and dogwood. This suggests that several other types of trees and shrubs could be added. To reach the minimum corridor requirements the following vegetative material should be added: sumach, apple, beech, birch, maple, oak, red cedar, honeysuckle, multiflora rose, and black raspberry
		Corridor E	Corridor F
Matrix	Optimum matrix would consist of corn fields, water source and winter food source. Brushy areas would exist within the matrix	The optimum matrix cannot be achieved here, as development has already encroached into the area. The two patches of trees will be enhanced to create the highest quality corridor possible	The agricultural matrix provides a good background for this corridor, but no open water exists along its length

Table 7 (continued)

Critical corridor attribute	Optimum corridor design	Corridor E	Corridor F
Patch	Optimum patch size would be large, > 300 m in diameter, woody and brushy in character	Optimum patches can be collected	Optimum patches can be connected
Network connectivity	Loops of corridors can encompass diverse habitat and compensate should catastrophic events occur	Two hedgerows form the beginnings of this corridor, which then join to form a wider travel route	Two loops are provided along this corridor, with habitat nodes provided
Barrier	No breaks along the corridor length, approx. 400 m from traffic and 800 m from pedestrians	Clair Road divides this corridor, and human activity exists on either side. Likely, this corridor will not be utilized to a great extent by white tailed deer, but if the road clearance is kept to a minimum, small and medium-sized mammals and birds will be able to cross with minimal mortality	Two major breaks occur along the length of this corridor, Clair Road and Gordon Street
Length	50 m in length with small nodes present	This length is exceeded, but the corridor is wide enough not to act as a sink for mammals utilizing it	The optimum length is exceeded, but two patches have been provided along the corridor length
Width	As wide as possible; maximum required is 90 m	This corridor averages 200 m wide	This corridor averages 50 m wide, with nodes provided
Shape	Straight sides and a constant width	This attribute is achievable in this design	One dogleg exists at the northeast end of the corridor, but this could be altered if another patch existed outside of the watershed
Edge	Feathered edge	This attribute may not be achievable given the amount of existing residential development	This attribute is achievable
Structure	Multilayered, structurally complex	This attribute is achievable, given that deciduous and coniferous trees currently exist	If coniferous trees were added to the existing corridors, this attribute is achievable
Composition	Optimum composition would include a wide variety of trees and shrubs: honeysuckle, multiflora rose, black raspberry, sumach, dogwood, blackberry, chokecherry, grape, holly, viburnum, serviceberry, gooseberry, bayberry, apple, beech, birch, chesnut, elm, maple, oak, hawthorn, alder, aspen, ash, cherry, cottonwood, poplar, willow, pine, spruce, red cedar, balsam fir, larch, juniper and hemlock	One patch to be connected contains maple, beech and hawthorn. The corridor should contain some coniferous trees and a greater variety of shrubs	The existing hedgerows which are to form the basis for this corridor consist of tall, deciduous trees with a fairly open canopy. To this, shrubs and coniferous trees should be added for compositional diversity, and to close the canopy

6.1.6. Design of Corridor F

This corridor will run parallel to Clair Road and create an alternate route or loop to the entire system. This corridor will connect the Hanlon Swamp Wetland to Hall's Pond Wetland. The basis of this corridor system is existing hedgerows, and patches of woodland. This corridor will be narrower than the previous links, but two routes parallel each other, with nodes existing every 500 m. Two major roadways will need to be crossed, Gordon Street and Clair Road. Coniferous trees will need to be added to both the hedgerows and the forest patches to achieve composition diversity.

Fig. 13. Hanlon Creek Watershed patches and corridors, 1993 and proposed.

6.2. Evaluation of corridor designs

The outcome of applying the desirable requirements to an actual site are summarized in Table 7. These corridors were evaluated to determine if the goal of high quality design was achieved.

In total, six corridors were designed for the Hanlon Creek Watershed area utilizing the FDWC. Of these six, none meet all of the desirable requirements in all of the ten critical corridor attributes. Matrix, barriers and length were the three attributes that were most difficult to effect through design.

The matrix within this area is heavily manipulated by human activity, in the form of agriculture and residential development. It is difficult to determine what crop types exist in the watershed. Open water is fairly prevalent in the area, but only two of the six corridors have open water within the immediate area of the corridor. Water is available, however, throughout the landscape.

Barriers in this area are represented by the roads which cross the landscape in a grid-like pattern. This geometric form presents a distinct problem to achieving connectivity between the patches. Three of the six corridors have breaks along their length due to roadways. Corridor F, which crosses Gordon Street, poses the greatest threat to wildlife, due to the heavy amounts of traffic to and from Highway 401 into Guelph.

Length is generally determined by the distance between the natural areas. The level of development in the Hanlon Creek Watershed area make these distances quite great. Bennett (1990), however, suggests that corridor lengths of less than 1 km are manageable by most small mammals if hospitable habitat were to exist along the corridor length. This is achievable in all of the corridors. None of the corridors were able to achieve the desirable maximum corridor length of only 50 m.

However, of the six corridors designed for the eastern portion of the watershed, none fall below the minimum requirements of corridor design. The corridor which meets the greatest number of desirable corridor requirements, and is therefore of the highest quality, is Corridor B. The corridor which is closest to the minimum requirements is Corridor F, with its undesirable matrix, long length, breaks in the form of roads, and existing dogleg shape.

7. Conclusions and suggestions for future research

The Framework for the Design of Wildlife Corridors (FDWC) was reasonably successful and should prove to be quite valuable to landscape architects charged with the creation of corridors to enhance the landscape ecological integrity of a landscape. However, more than anything, this study has demonstrated that much research remains to be done. Most of the principles employed are theoretical and remain to be proven. The species specific information might not hold when considered in combination with other factors. The FDWC is a valuable framework in that, whenever new ecological information is discovered, it can immediately be employed by practitioners.

Certainly there is a need for more biological studies documenting a specific species use of a wildlife corridor for travel. This would indicate what attributes within the corridor truly affect quality. Given that the matrix, barriers and length were the most difficult to account for in design within a rural fringe area, it is necessary to know if these attributes contribute to quality. As well, more information on the length to width ratio would allow for easier design decisions.

Each biological study that is conducted will provide information for the individual species tables or the species guilds tables which in turn lead to more informed decisions regarding corridor design. Considering that landscape ecology is a combination of several disciplines, input from ecologists and biologists into the species specific tables would provide a more complete analysis of the existing information.

Landscape architecture is a combination of theory and design, and more studies examining the integration of these two areas of study would be useful. More emphasis should be placed on the application of theory and the evaluation of such designs in order to further the growth of this professional body of knowledge.

Once a corridor is implemented, evaluation of its success as a travel route needs to be conducted. This will ensure that corridor designs will continue to improve and mistakes at the cost of wildlife will not be repeated.

The integration of humans and wildlife within the same matrix needs to be further examined given the increased pressure on the landscape. If the idea of a conservation ethic is to succeed, it will likely include the needs of humans to recreate in conjunction with the need to encourage wildlife movement. Presently, there is not enough information available to make informed design decisions regarding this integration.

As society attempts to heal the wounds on the landscape created by generations of human exploitation, landscape ecology is a discipline that has the potential to make a significant contribution. Patches of natural areas connected by appropriately designed corridors that provide habitat as well as conduit for movement will provide a framework for this healing. The FDWC, outlined in this paper, will provide landscape architects with the most up-to-date theories and information about appropriate design of corridors for wildlife.

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