THE ECOLOGICAL EFFECTS OF A TYPICAL HOUSING DEVELOPMENT ON BIRD SPECIES DIVERSITY WITHIN A FOREST FRAGMENT

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ABSTRACT

THE ECOLOGICAL EFFECTS OF A TYPICAL HOUSING DEVELOPMENT ON BIRD SPECIES DIVERSITY WITHIN A FOREST FRAGMENT

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Human manipulation of the form and function of landscapes has led to a significant decrease in species diversity in Southern Ontario. To conserve species diversity, it is necessary for landscape architects to understand the ecological effects of the spatial patterns they create. Here, a post occupancy assessment of a typical housing subdivision reveals the ecological effects of its design on a forest fragment in London, Ontario. Prior to development, this fragment within Middlesex County was one of the last remaining upland patches large enough to have interior habitat. Development significantly reduced this interior habitat.

The number and composition of bird species were compared, using the same methodology, before and approximately 10 years after development. A greater sampling effort recorded a greater number of bird species, but the composition of the bird community had changed substantially. This result is consistent with observations elsewhere and was predicted by opponents of the subdivision development prior to its development in 1977. The observed number of interior forest specialist species declined, while the observed number of interior-edge and edge generalist species increased - a result that is in keeping with findings published in ecological literature. This study has

demonstrated that site-scale design can have a substantial effect upon species diversity at a local scale, which may have implications for conservation at coarser scales. The relationships between the diversity of species and the spatial attributes of the site must be identified and tested if landscape architects are to develop spatial patterns that conserve species diversity.

...no pattern is an isolated entity. Each pattern can exist in the world, only to the extent that it is supported by other patterns: the larger patterns in which it is embedded, the patterns of the same size that surround it, and the smaller patterns which are embedded in it. This is a fundamental view of the world. It says that when you build a thing you cannot merely build that thing in isolation, but must also repair the world around it, and within it, so that the larger world at that one place becomes more coherent, and more whole; and the thing which you make takes its place in the web of nature...

Christopher Alexander
A Pattern Language

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Introduction

Over the last 200 years in Southern Ontario, human manipulation has changed the landscape pattern from one dominated by forest, to one dominated by agricultural fields and large areas of human structures and surfaces. The once contiguous forest has been reduced to small and fragmented patches and corridors (Riley and Mohr 1994). As a result of this transformation and confounded by the speed at which it has occurred, the number and composition of species have altered within the remaining forest fragments and in the landscape overall. Species that are adapted to the new landscape patterns often thrive at the expense of others whose populations become smaller and subdivided and, as a result, more prone to local extinction (Wilcox 1980; Wilcove, McLellan and Dobson 1986; McNeely, Miller, Reid, Mittermeier and Werner 1990; Saunders, Hobbs and Margules 1991). It is estimated that, in Ontario, at least 50 species of plants and animals have been extirpated, and a further 215 have been identified as being vulnerable to extirpation (Riley and Mohr 1992).

Landscape architecture deals with the manipulation of spatial patterns. Every design on the landscape changes the spatial pattern of the ecosystem, and therefore, potentially, its function. The patterns formed at one scale may be influenced by those at finer scales and, in turn, may determine the patterns and function of the ecosystem at coarser scales (Allen and Starr 1982; O'Neill, DeAngelis, Waide and Allen 1986). Yet, landscape architects and planners are often unaware of the ecological effects of the patterns they create. In addition, they manipulate patterns defined at site boundaries and are not always cognizant of their effects at other scales. Landscape architects and planners are just beginning to incorporate information about the ecological implications of spatial patterns into their design processes (Kreiger 1991; Thorne, Huang, Hatley and Mathur 1991; Knaapen, Scheffer and Harms 1992; Federowick 1993; Sauer 1993; Post 1994; Rodiek and DelGuidice 1994; Carr, Lambert, Zwick 1994; Yahner, Korostoff, Johnson, Battaglia and Jones 1995). However, study of the connection between spatial form and ecological function is in its infancy and ecologists are still working to understand these relationships (Harris 1984; Forman and Godron 1986; Bierregaard, Lovejoy, Kapos, Augusto dos Santos and Hutchings 1992). In many cases, the effects of form on function are unknown and hypotheses regarding their relationships remain inadequately supported.

Landscape architects and planners are uniquely positioned to play a major role in the exploration and testing of spatial forms and their ecological functions so that spatial patterns can be developed that conserve, rather than undermine, species diversity. Accordingly, this thesis determines the ecological effects of a spatial pattern on species diversity, explores the ecological relationships that may be responsible for these effects and develops design criteria that may combine to conserve species diversity.

In order to achieve these goals, a number of objectives are accomplished. A post occupancy assessment is performed of a housing development within a forest fragment in Southern Ontario. The number and composition of bird species within the fragment prior to development are compared with those identified in the post occupancy assessment to determine the effects of the development on the species diversity of the forest fragment. A literature search is performed to reveal the ecological relationships that are currently believed to determine bird species diversity within forest fragments. The spatial pattern of the study area is analysed for its expression of these ecological relationships in order to identify those that may be responsible for the change in diversity within the study area. Design criteria are then proposed that may lead to the conservation of species diversity within similar forest fragments.

Bird species are being used as indicators of the effects of the development on forest species in general. Although different plants and animals have different habitat requirements and respond differently to fragmentation, bird species are considered particularly good indicators of the effects of fragmentation on forest species (Morrison 1986; Martin and Finch 1995). They are widespread in the landscape and include a large number of co-existing species with varying ecologies. They are easily studied, and more is known about them than almost any other species. In addition, they are among the most sensitive in the forest to disturbance.

Study Area

In 1977, prior to development, Warbler Woods was an approximately 84 ha upland deciduous forest fragment situated on kame moraine landforms located just outside the City of London, Ontario (Figure 1). The site consisted of three successional seres: forest, shrubland and grassland, with the forest being further subdivided into late and middle successional seres. The topographic complexity of the site, together with that of the soils and drainage regimes, led to the growth of a large number and variety of rare and common plants, a diversity of plant communities and associations and a large number of bird species (Hough, Stansbury and Michalski Ltd. 1982; McIlwraith Field Naturalists of London 1977).

Warbler Woods lies within Middlesex County, a landscape that originally was approximately 85 percent forest (Larson, Riley, Snell and Godschalk 1999). 87 percent of the land in Middlesex county is either class 1, 2 or 3 agricultural land, and over the last 150 years the original forest has reduced to relatively small and isolated forest fragments (Hilts and Cook 1982). In 1981, prior to development, about 6 percent of the County remained in forest (Min. of Agriculture and Food 1982). Warbler Woods was one of the largest remaining upland forest fragments within this landscape (Hilts *et al.* 1982).

In 1977, Proctor and Redfern Ltd. was hired by the principal landowner to conduct an 'Environmental appraisal' of the site. That appraisal became the basis for a land-use plan concept and for the subsequent plan of subdivision. It was meant to determine whether the woods should be developed for housing, and to identify the areas of the site that were most appropriate for this land use (Proctor and Redfern (a) 1977).

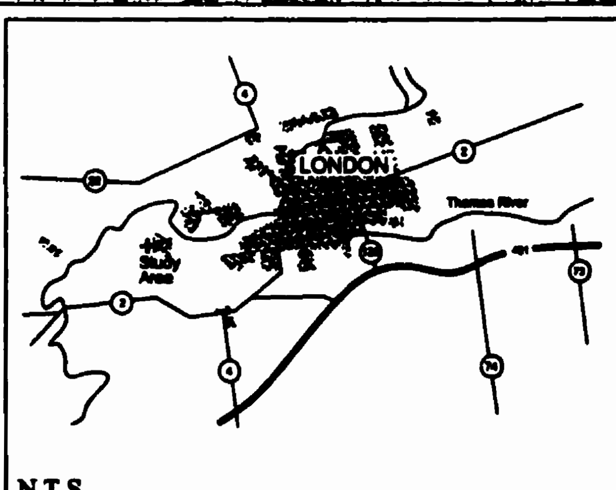


Figure 1: 1983 Study Site Location and Context

Key

Natural Areas

Agricultural or 'Open Space' Areas

Housing Areas

0 100 400
Metres

One of the conclusions of the assessment was that the housing development would not significantly effect the diversity of bird species within the fragment because the most important areas of bird habitat were retained in the design. Two Ontario Municipal Board (OMB) hearings occurred between 1979 and 1983 to determine whether the site should be annexed by the City of London for the purpose of development, and whether the plan of subdivision should proceed. One opponent of the development predicted that the diversity of species would decrease substantially as a result of the reduction in the size of the forested area and the increase in the perimeter-to-area ratio (Bietz, Innes, Nudds and Wypkema 1977). This evidence was discarded at the 1977 OMB hearing, on the grounds that the prediction was based on existing theory and the results of other studies, rather than on an on-site field study. Between 1984 and 1990, the proposed plan of subdivision was put in place and approximately 45 of the original 84 ha of the site were developed into housing, leaving 39 ha as 'open space' (Figure 2).

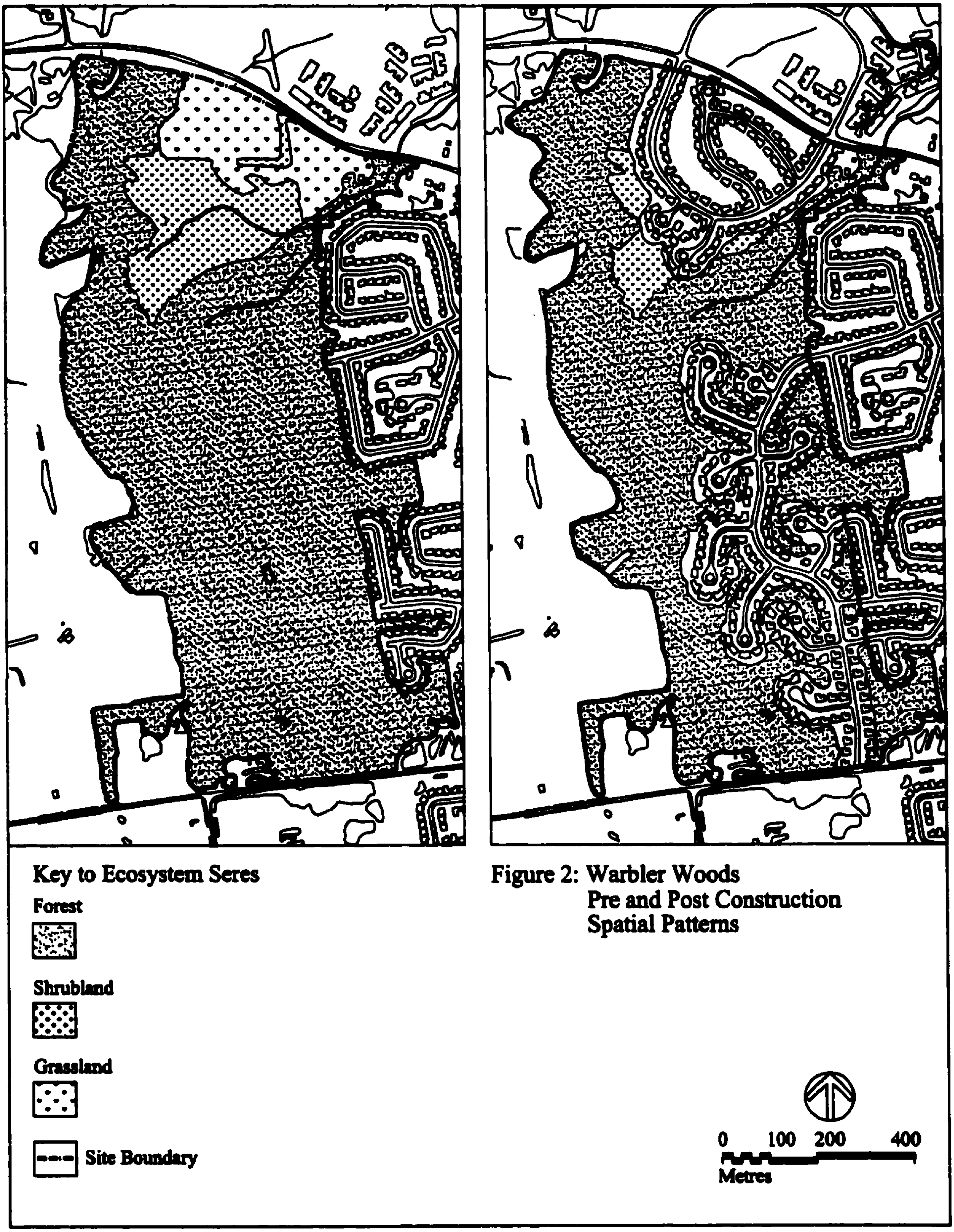


Figure 2: Warbler Woods
Pre and Post Construction
Spatial Patterns

Methods

As part of their appraisal, Proctor and Redfern Ltd., took an inventory of the birds. The number of bird species was recorded within each identified vegetation area. The exact date(s), times and locations in which the birds were recorded are unknown. A list of bird species was compiled sometime between the 13th of June and the 23rd of August. However, correspondence suggests that most of the bird inventory was taken during three dawn and dusk periods between the 13th of June and the 3rd of August, 1977. A few additional species were added to this list between the 4th and the 23rd of August, 1977, during 'normal business hours.' Whereas the dawn and dusk periods were spent strictly noting birds, the latter observations were recorded while they were performing a plant inventory (Proctor and Redfern (a),(b) 1977). With tree canopies in full leaf, it would have been difficult to distinguish the birds by sight. Therefore, it is assumed that the principle means of identifying birds was by their songs.

By today's standards, Proctor and Redfern did not census the birds according to a good methodology (Ralph and Scott 1980). However, if a better methodology were to have been used to census the birds in 1999, the data collected from the different time periods could not be compared. It would be impossible to ascertain whether the data collected was a reflection of the effects of the housing development or the effects of the different methodology.

Therefore, in the 1999 study, the approach taken was to follow a similar, if not identical, methodology. A list of bird species was compiled by identifying the species through song. Since it is not known exactly when, or for how long, Proctor and Redfern Ltd. took their census, it was decided to perform a reasonable amount of inventory within the same range of dates and during the same time of day. Even with this approach, it is suspected that more time was spent identifying birds in the 1999 census.

One dusk and one dawn period on the 20th and 21st of July were spent strictly recording bird species by song. The inventory at dusk took place between 5:00 and 8:00pm and the dawn inventory between 5:45 and 8:00am for a total of 5 hours and 15 minutes. Approximately one hour five minutes was spent recording bird species in each of the remaining vegetation communities.

In addition, on 20th and 21st of July, as on the 5th and 6th of August, birds were identified through song during an inventory of vegetation from 9:00am – 12:00am and 12:30pm – 5:00pm (assumed to be 'normal business hours') for a total of 30 hours. Because the birds were recorded during a plant study, the time spent within each of the remaining vegetation communities was determined by the number of transects Proctor and Redfern Ltd. located within each vegetation community. They located a total of 11 plant transects: four in the upland deciduous area, one in the old shrubby field area, two in the hardwood ridges area, one in the forest regeneration area and three in the lowland deciduous area. The amount of time recording birds in each area was determined by dividing the total inventory time (30 hours) by the total number of transects (11) to arrive at a recording time per transect (2 hours 42 minutes). The time per transect was then multiplied by the number of transects within each area to determine the total amount of time within each area (see Appendix 1 for a map locating the vegetation communities identified by Proctor and Redfern Ltd.).

The inventoried birds were categorized by habitat preference according to Freemark and Collins, 1989, pp. 445-446. Interior birds are defined as species that nest in the interior of a forest and rarely occur near the forest edge. Interior-edge birds are species with territories lying within a forest fragment, and sometimes within more than one forest fragment, that also occur at the forest edge. Edge species typically occur at the edges of forests, within clearings and within the surrounding fields and other appropriate external habitats.

Results

There were 5 more species observed in 1999 (31) than 1977 (26), an increase of 19 percent. Despite this fact, in terms of species composition by habitat preference, the number of interior species observed decreased by 75 percent, from four to one; the interior-edge species increased 54 percent, from 6 to 13; and the edge species increased 6 percent, from 16 to 17 (Table1).

Table 1: Bird Species Found in Warbler Woods 1977 and 1999 by Habitat Strategy

Habitat Strategy	1977	#	1999	#
Interior Species	American Redstart Hairy Woodpecker Pileated Woodpecker Veery	4	White-breasted Nuthatch	1
Interior/Edge Species	Blue Jay Eastern Towhee Grey Catbird Northern Cardinal Northern Flicker Yellow-throated Vireo	6	Black-capped Chickadee Blue Jay Carolina Wren Downey Woodpecker Eastern Towhee E. Wood Peewee Great Crested Flycatcher Great. Horned Owl Grey Catbird Northern Cardinal Northern Flicker Red-eyed Vireo Wood Thrush	13
Edge Species	American Crow American Robin Barn Swallow Cedar Waxwing Chimney Swift Eastern Kingbird European Starling House Wren Indigo Bunting Mourning Dove Red-tailed Hawk Red-winged Blackbird Rock Dove Song Sparrow White-throated Sparrow Prothonotary Warbler	16	American Crow American Goldfinch American Robin Baltimore Oriole Barn Swallow Cedar Waxwing Chipping Sparrow Common Grackle European Starling Field Sparrow House Sparrow House Finch Indigo Bunting Killdeer Mourning Dove Red-tailed Hawk Song Sparrow	17
Total		26		31

Discussion

1. Did the Housing Development Change the Number of Bird Species?

More species were observed in 1999 than in 1977, although the ecological literature strongly predicts that a decrease in habitat area produces a corresponding decrease in the number of species (Ambuel and Temple 1983; Opdam, Rijsdijk and Hustings 1985; Freemark and Merriam 1986; Askins and Philbrick 1987; Blake and Karr 1987; Austen, Francis, Brenner and Bradstreet 1996; Schmiegelow 1990; Henschel 1997).

The observed bird species increase in Warbler Woods may be explained by the fact that Proctor and Redfern Ltd. may have overlooked 5 of the species found in 1999, perhaps because of the incessant noise of motor bikes running through the site (Proctor and Redfern (a) 1977, p.44). With tree canopies in full leaf, bird song is practically the only possible method of bird identification. In addition, the 1999 study may have involved more time spent noting birds, or more time specifically listening for birds, than the original study.

2. Did the Housing Development Change the Bird Species Composition?

The reduction in the number of species predicted in the literature is attributed to a decrease in the number of forest interior species, a prediction that is confirmed by this study (Humphreys and Kitchener 1982; Freemark and Merriam 1986; Blake and Karr 1987; Askins 1995; Freemark and Collins 1992; Austen et al. 1996).

Ultimately, it is the number of interior species that determines bird species diversity, since interior-edge and edge species are relatively common in the landscape. However, an increase in these common birds may lead to higher levels of competition and predation and therefore a decrease in the number of the competitively inferior interior species. There is evidence to suggest that if the forest edge increases in area, the number of edge species may also increase (Morgan and Gates 1982; Ranney, Brunner and Levenson 1981; Schonewald-Cox and Bayless 1986; Yahner 1988). However, the decrease in the number of interior species as a result of a reduction in area far outweighs the increases in the number of interior-edge and edge species (Harris and Kangas 1979; Marcot and Meretsky 1983; Gutzwiller and Anderson 1992).

In Warbler Woods there was no expansion of the forest edge habitat. If all the remaining forest were edge, the area would still have decreased from 47 ha in 1977 to 43 ha in 1999. If the area of the housing development were added, in addition to the shrubland and grassland areas, as other types of edge habitat, the edge area would increase by 15 ha, from 62 to 77 ha. However, an increase in edge species is only predicted to occur in edges that are structurally and floristically diverse (Laudenslayer and Balda 1976; Kroodsma 1982; Helle and Muona 1985). Housing habitat, as it is currently designed, is structurally and floristically simple. In addition, other reductions in the quality of edge habitat occurred with the removal of the original eastern forest edge, a portion of the gradual north eastern edge border, the reduction in the area of the shrubland and the removal of the grassland. In summary, although the overall edge habitat increased by 15ha, the quality of this habitat decreased significantly. Therefore, it is unlikely that this change in spatial pattern led to a doubling in the number of interior-edge species.

3. What Ecological Relationships may be Responsible for the Observed decrease in Interior Species Diversity? What Design Criteria can be generated as a Result of these Relationships?

The ecological relationships which affect bird species diversity within forest fragments are still being explored and debated. However, current theories can be supported and developed as landscape architects and planners establish criteria for the manipulation and testing of spatial patterns that conserve species diversity.

These theories will be outlined below and discussed in terms of their applicability to Warbler Woods. In addition, design criteria will be generated and an alternative spatial pattern for Warbler Woods will be provided illustrating each criterion. The alternative pattern reflects the current importance placed on interior area as the primary determinant of species diversity. However, this alternative should not to be viewed as the 'best' design solution for the site, but rather as an illustration of how the design criteria can be applied.

Currently, interior habitat area is considered the most important determinant of the number of bird species within forest fragments. However, the importance of area is tempered by the degree to which the fragment is connected to other supporting interior habitat areas both locally and within the landscape. As the level of connectivity increases, its role in determining species diversity increases, relative to that played by area. Within an extensive series of studies within the Dutch landscape, these two factors, area and connectivity, were estimated to explain 66 percent of the variation in species richness (van Dorp and Opdam 1987).

Beyond this, the quantity and quality of the interior habitat of a fragment is determined, to a certain degree, by the quantity and quality of the forest edge boundary. Therefore the characteristics of this boundary are significant in determining species diversity. The amount of edge area in relation to the amount of interior area is an additional contributor to species diversity and is thought to be a measure of the 'edge effect' upon interior birds. The 'edge effect' refers to the high population density and diversity of species in the forest boundary (Thomas, Maser and Rodiek 1979; Yahner 1988). The quantity and quality of the habitat within the adjacent seres/ecosystems is also important in determining species diversity, particularly within smaller fragments. However, little is currently known about the influence of surrounding land uses and more research is required to identify the key relationships that influence species diversity.

3.1 Area

All species have been found to decrease in number with a reduction in the area of a fragment. Some interior-edge and edge bird species, begin to disappear from fragments only after very large decreases in area. It is estimated that a fragment can be reduced to two ha in size before many edge and interior-edge species decline (Forman, Galli and Leck 1976; Galli, Leck and Forman 1976). Interior birds have a greater area requirement and begin to diminish after relatively small reductions in area. In Ontario, the threshold at which interior species begin to drop off is between 55ha (Henschel 1997) and 70ha (Schmiegelow 1990) larger than the current size of Warbler Woods.

A decline in species diversity as the result of a reduction in area, has been attributed to a decrease in the pairing success of interior birds (Gibbs and Faaborg 1990; Hinsley, Bellamy, Newton and Sparks 1996) and a decreased probability of survival

(Wilcox 1980; Wilcove *et al.* 1986; McNeely *et al.* 1990; Saunders *et al.* 1991). A smaller fragment can only support smaller population sizes and therefore the probability of local extinction through chance events increases (MacArthur and Wilson 1967; Gilpin and Soule' 1986; Soule' 1987).

Since interior bird species have been found to nest only in the interior of forests and are rarely found near the edge (Freemark *et al.* 1992), the amount and quality of the interior habitat, rather than the area *per se*, is the critical determinant of interior species diversity. The amount of interior habitat is determined by the area of the fragment, the width of the forest edge habitat, the shape of the fragment and the size and diversity of micro-habitats within the interior.

The width of the forest edge depends on the forest and upon the variable being measured. Although the width of the edge is not consistent, the width of the forest edge for interior forest birds is commonly defined as the first 100 metres from the edge boundary. This distance is considered the distance at which there is a lessening of the competition between interior and interior-edge and edge species. At that point also is a reduction in the rates of predation and nest parasitism (Ambuel and Temple 1983; Wilcove 1985; Temple 1986; Robinson 1988; Temple and Cary 1988).

The shape of the fragment determines how much interior habitat remains after the 100 metre edge is removed from the area of the fragment. Different shaped fragments have different potential interior habitats given the same total area. For example, a roughly circular fragment has a greater amount of potential interior habitat than a long narrow fragment of equal area (Dramstad, Olson and Forman 1996). In order to compare the extent of interior habitat between fragments, particularly convoluted fragments, a circle

Fig. 3a) Pre-construction Forest Interior and Edge Habitats
Interior 22 ha/ Forest edge 47 ha
Interior Core Habitat: 7 ha
Forest Edge to Interior Ratio: 2:1

Fig. 3b) Post-construction Forest Interior and Edge Habitats
Interior: 1 ha/Forest Edge: 42 ha
Interior Core Habitat: .4 ha
Forest Edge to Interior Ratio: 42:1
Housing Area: 32 ha

Fig. 3c) Alternative Forest Interior and Edge Habitats
Interior: 20 ha/ Forest Edge: 30 ha
Interior Core Habitat : 7ha
Forest Edge to Interior Ratio: 1.5:1
Housing Area: 32 ha

Key

Interior Habitat
- Forest Interior Habitat
- Interior Core Habitat

Edge Habitats
- Forest Edge Habitat
- Concentrated Housing Habitat

0 100 200 400
Metres

with the largest possible diameter is sometimes inscribed in the interior area of each forest fragment. This circle is referred to as the 'core interior habitat' (Temple 1986; Laurence and Yensen 1991). It is considered the most important area of the interior for species requiring remoteness. It is the area most likely to retain its integrity and reflects the ovoid or elliptic shape of the home ranges of most vertebrates (Jennrich and Turner 1969; Koeppl, Slade and Hoffman 1975; Covich 1976). The forest sere in Warbler Woods changed from a relatively wide rectangle to a narrow strip. As a result the amount of interior habitat was reduced from 22 ha to 1 ha and the core interior habitat decreased from 7 ha to .4 ha. Figure 3 portrays the area and shape of the fragment pre- and post-development and offers an alternative spatial pattern that would have maximized the amount of interior habitat while offering the same area of housing.

The number and quality of micro-habitats available within the forest interior is also an important determinant of bird species diversity, but may be less important than the total area of the interior. In many studies, interior birds have been missing from small fragments, even with the existence of appropriate micro-habitats (Ambuel *et al.* 1983; Askins *et al.* 1987; Blake *et al.* 1987). Within Warbler Woods, the housing development significantly reduced the number and size of vegetation communities. 6 of the 26 pre-development forest communities were effectively removed, while 14 more were reduced in size. The interior bird habitats and their locations were not identified in the 1977 study, so the extent to which these habitats were lost in the development cannot be determined. However, the number of vegetation communities within the interior habitat area decreased from 14 prior to development to 3 after the development (Figure 4). The

Fig. 4a Pre-development Vegetation Communities — 14 Interior Forest Vegetation Communities

Fig. 4b) Post-construction Vegetation Communities — 3 Interior Forest Vegetation Communities

Fig. 4c) Alternative Vegetation Communities — 12 Interior Forest Vegetation Communities

Key

Homogeneous Forest Communities

- Vegetation Communities approx. 90 Years Old (1982)
- Vegetation Communities approx. 40-50 Years Old (1982)

Heterogeneous Forest Communities

Shrubland

Grassland

Interior habitat area

0 100 200 400 Metres

Source of Vegetation Communities: Hough, Stansbury & Michalski Ltd., 1982 alternative spatial pattern, portrayed in Figure 4c, decreases the number of vegetation communities from 14 pre-development to 12 post-development.

For the conservation of bird species diversity, the most important design criterion is the maximization of the amount of forest interior habitat, and particularly the amount of core interior habitat. Maximizing the number and quality of interior micro-habitats is another criterion, but may be of lessor importance.

3.2 Connectivity to other Fragments of Suitable Interior Habitat

Although the bird species extinction rate is held to be largely dependent upon fragment area and habitat quality, the re-colonization rate is believed to increase with the proximity of other appropriate habitat patches and the level of connection between these patches (Forman 1995). Without adequate connection, species that become locally extinct through chance events cannot easily be re-introduced through immigration from another source patch. Effectively, isolated fragments provide the only habitat for forest-dependent species and therefore, area and to a lesser extent, configuration and surrounding context, become the major determinants of species diversity. Conversely, when a fragment exists within a landscape that has a high degree of connectivity, area becomes a less significant indicator of diversity.

The definition of connectivity is species specific and depends upon the scale sensitivity and dispersal capacity of the species (Opdam 1991). However, as a group, interior birds are vulnerable to the effects of isolation. With small population sizes, and correspondingly high rates of local extinction, many of these species rely on immigration from adjacent interior habitat patches to maintain viable populations. There is not yet a consensus as to what constitutes connectivity for interior birds, either locally or within the landscape. Some interior species appear to be sensitive to connectivity at the local scale, while others are sensitive at the regional scale. An extensive study within the Dutch landscape found that about 50 percent of forest bird species were sensitive to connectivity within 10 km, while the other 50 percent were sensitive within 100 km (van Dorp and Opdam 1987). Therefore, providing connectivity at both scales is required if species diversity is to be supported.

At the regional scale, a number of studies have found that fragments situated in regions with a higher forest cover had more interior birds than fragments within regions with a lower forest cover (Austen *et al.* 1996; Freemark *et al.* 1992; Robinson,Thompson, Donovan, Whitehead and Faaborg 1995). Other studies have indicated that the number of interior species begins to increase, beyond that predicted by area, at approximately 30 percent regional forest cover (Freemark *et al.* 1992, Robbins, Dawson and Dowell 1989). In fact, the study by Robbins *et al.*, 1989, found that the number of interior species was unrelated to area within landscapes that had more than 33 percent forest cover within 2 km of the bird survey point. The Ontario Ministry of Natural Resources (OMNR) has established that within regions with less than 30 percent forest cover, the size of the woodland alone is sufficient to determine its significance. If a forest is within a region with greater than 30 percent forest cover, other criteria are used in addition to area (OMNR 1999). Fragments as small as 4 ha are now considered significant in areas of Southern Ontario where the regional forest cover is between 5 and 15 percent, and as small as 2 ha, where the cover is less than 5 percent (OMNR 1999). In 1977, Warbler Wood's regional forest cover was approximately 6 percent.

While there is a consensus that the abundance of forests within and between landscapes is an important determinant of connectivity, the value of corridors in this regard is more controversial. Birds are more mobile than many forest species and may not dependent upon connected corridors for dispersal. In addition, some argue that in certain cases corridors function as 'ecological traps' that funnel competitor edge species, nest predators and parasites into the adjacent fragment (Gates and Gysel 1978; Angelstam 1986; Andren and Angelstam 1988; Ratti and Reese 1988). On the other hand, some argue that fragments already contain most of the edge species in the landscape for their patch type and therefore corridors are unlikely to introduce any new edge species that are not already present (Forman 1995).

A number of studies have found a correlation between interior species diversity and the presence of corridors, particularly within fragments that are connected by corridors to other interior forest areas (MacClintock; Whitcomb and Whitcomb 1977; Schmieglow, Machtans and Hannon 1997). Studies in the Dutch landscape have found that interior species richness is correlated with the density of hedgerows near a fragment, but have not found a correlation with the rate of re-colonization (Verboom, Schotman, Opdam and Metz 1991). The study by Schmieglow *et al.*, 1997, involved corridors that were 100 metres in width. Many studies have found that interior species will only use wide corridors with interior habitat (Anderson, Mann and Shugart 1977; Forman 1983; Dmowski and Kozakiewicz 1990). It is possible that relatively wide corridors, versus corridors *per se*, increase connectivity for forest interior birds.

The shortest distance to the nearest interior habitat 'source' patch appears to be a more supported measure of connectivity for interior birds. Within Dutch landscapes, it was found that the re-colonization rate of interior birds increased when a woods was within 2 km of the fragment, particularly if it were greater than 20 ha in size (Verboom *et al.*, 1991; Opdam 1991; Opdam and Schotman 1987).

Thus, an additional design criterion is the encouragement of interior bird connectivity both locally and regionally. At the local scale it is not clear whether corridors immediately connected to patches are desirable, particularly narrow corridors. However, the presence of interior source patches within a certain distance from the fragment appears to be important for maintaining viable populations of interior birds. Although there is no consensus regarding an appropriate distance, many studies have indicated that 1 – 2 km may be the distance at which there is a relationship between the presence of the patch and species diversity within the adjacent fragment. Other interior species appear to be sensitive to coarser scales of connectivity. Maintaining forest cover, and encouraging the creation of new areas of forest, is particularly important in regions with less than 30 percent forest cover.

3.3 The Edge to Interior Ratio

Although considered less significant than either area or connectivity, the relationship between the forest edge and the interior is a significant determinant of forest species diversity. Although there was a decrease in the area of the forest edge habitat, the area of this habitat relative to the area of the forest interior habitat increased. An increase in this ratio has been linked to an expansion in the numerical dominance of interior-edge and edge species relative to the competitively inferior interior species (Engels and Sexton 1994). As predicted in 1977, the change in the shape of Warbler Woods altered this ratio, dramatically increasing the exposure of the remaining interior habitat to that of the forest edge. The edge to interior ratio increased from roughly 2:1 in 1977 to 42:1 in 1999. Figure 3 illustrates the change in the ratio of edge to interior habitat. The alternative spatial pattern would have increased the ratio from 2:1 in 1977 to 1.5:1 in 1999.

3.4 The Forest Boundary

The amount and quality of the forest edge boundary not only determines the level of competition, predation and parasitism occurring within the edge, but also the amount of exposure of the interior habitat to the physical and biological conditions prevailing in external areas. Increased levels of exposure have been found to lead to increased levels of predation and parasitism (Ambuel *et al.* 1983), and the alteration of interior habitats in response to external microclimatic conditions (Forman 1995).

The amount of exposure to exterior conditions is determined largely by the length of the boundary, in addition to its structural, and to a lessor extent, floristic composition. The forest boundary is made up of the forest edge, the border and the edge of the external habitats (see Figure 8) and in 'naturally-formed' edges these components function together to determine the amount of exposure of the forest to areas outside the external habitat edge.

3.4.1 Length of Forest Boundary

The configuration of the edge boundary determines its length. In Warbler Woods the configuration was altered from a linear to a convoluted form, increasing the length of the boundary by 764 metres. This is illustrated in Figure 5, along with the alternative boundary configuration that would have decreased the length 364 metres post-development relative to the pre-development boundary.

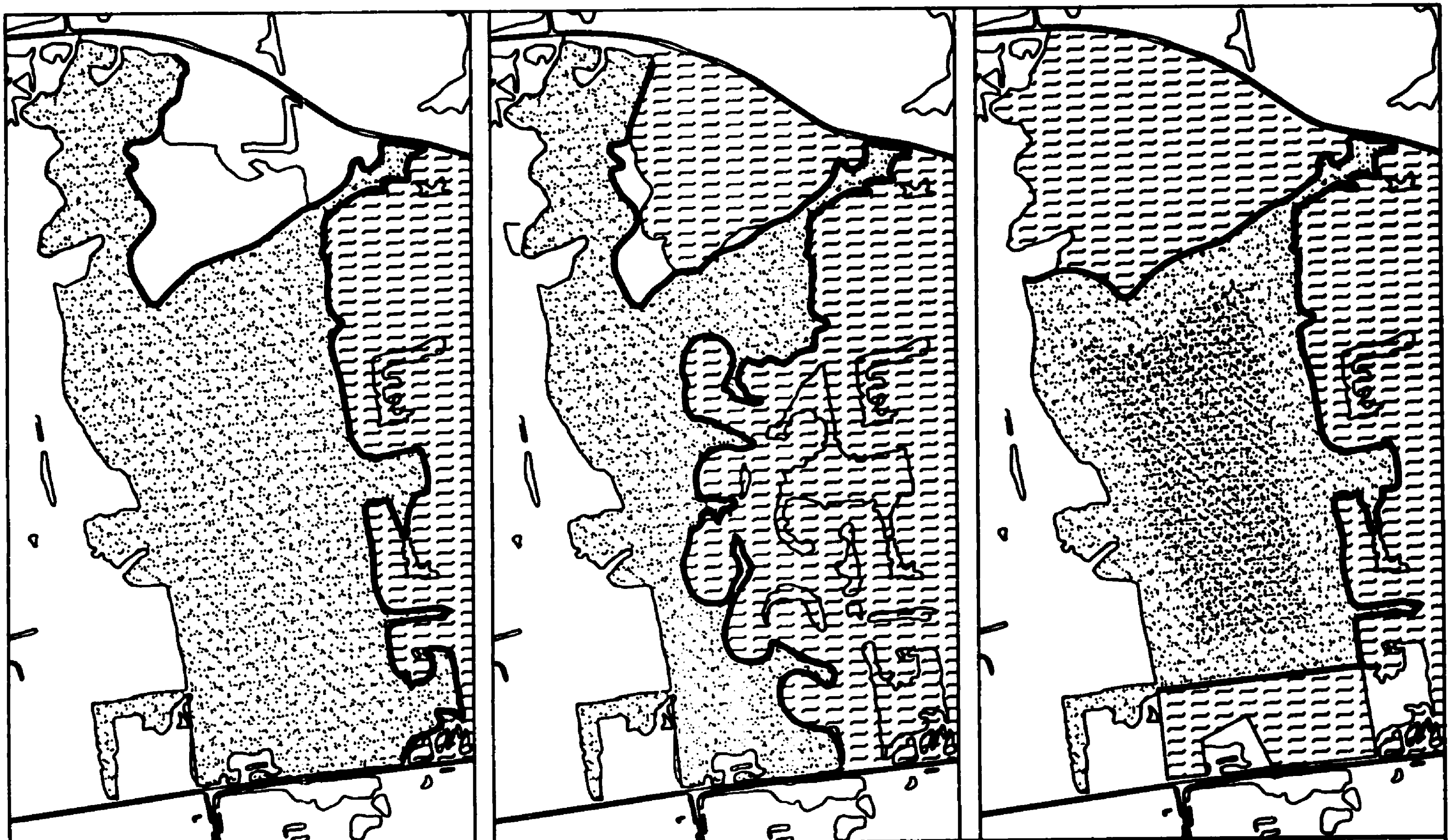


Fig. 5a) Pre-construction Length of Forest Edge Boundary — Length: 3747 m. Housing Area: 0 ha

Fig. 5b) Post-construction Forest Edge Boundary — Length: 4511 m. Housing Area: 32ha

Fig. 5c) Alternative Forest Edge Boundary — Length: 3383 m. Housing Area: 32 ha

Key

- Forest Sere
- Eastern Edge Border
- Concentrated Housing Habitat

0 100 200 400
Metres

3.4.2 Structural and Floristic Composition of the Forest Boundary

The structural density and the floristic composition of the forest boundary determines its capacity to reduce the different microclimatic factors, such as heat, light and wind, prevailing in the external environment. The more efficient a boundary is in reducing these conditions, the narrower the interior edge, and therefore the greater the interior area. Edge vegetation responds to different microclimatic conditions prevailing within the external environment and therefore is not consistent in width. For example, south-facing boundaries are thicker than north-facing boundaries.

If a component of the boundary removed, such as the border or the external edge, then the external microclimatic conditions will extend further into the edge of the forest and thus may reduce the area of the interior habitat. It is estimated that if these two boundary components are removed, the effects of the external microclimate may extend into the forest as far as 1.5 to 3 times the height of the average edge tree (Harris 1984, Franklin and Forman 1987, Chen, Franklin and Spies 1992).

There is no consensus as to an average boundary width necessary to protect the microclimatic conditions within the forest interior. However, a study within the tropics showed that following the creation of a forest fragment, a 10-25 metre strip of vines and secondary growth vegetation developed surrounding the fragment (Lovejoy, Bierregaard, Rylands, Malcolm, Quintela, Harper, Brown, Powell, Powell, Schubart and Hays 1986). Similar natural edges have formed following the creation of temperate forest fragments (Gysel 1951; Trimble and Tryon 1966; Ranney, Bruner and Levenson 1981). This 'naturally-formed' edge width could be used as a guide for the design of protective edges.

In England, dense thorny shrubs and trees, in addition to piles of branches and brush, were used to protect the interior of forest reserves within agricultural areas (Forman 1995). This edge would serve not only to reduce the effects of external microclimatic factors, but also discourage the disturbance of the forest by humans, and large herbivores. It would also reduce encroachment. Following the creation of the new housing edge within Warbler Woods, there were numerous examples of extensive encroachment into the forest by adjacent homeowners, some extending up to 11 metres into the forest (City of London Report on Encroachment, 1998).

The width of edge necessary to support interior conditions for birds is usually wider than that required to reduce the effects of external microclimatic conditions, because of the added effects of competition, predation and parasitism. However, increases in the number of these species have also been correlated with an increase in exposure to the external environment (Ambuel and Temple 1983).

Within Warbler Woods, 140 metres of the gradual eastern edge boundary was removed and the amount of abrupt edge increased by 904 m, or 34%. Figure 6 illustrates the areas of gradual and abrupt edge pre- and post- construction and the alternative spatial pattern that proposes the design of an approximately 10 metre wide protective boundary gradient that includes forest edge, border and adjacent habitat edge. The floristic and structural composition of this edge could be designed to reduce external microclimatic effects, and discourage disturbance of the forest by humans.

Structurally and floristically diverse edges have been linked with an increase in the number of interior-edge and edge bird species, in addition to a higher incidences of nest predation and parasitism (Gates *et al.* 1978; Angelstam 1986; Andren *et al.* 1988).

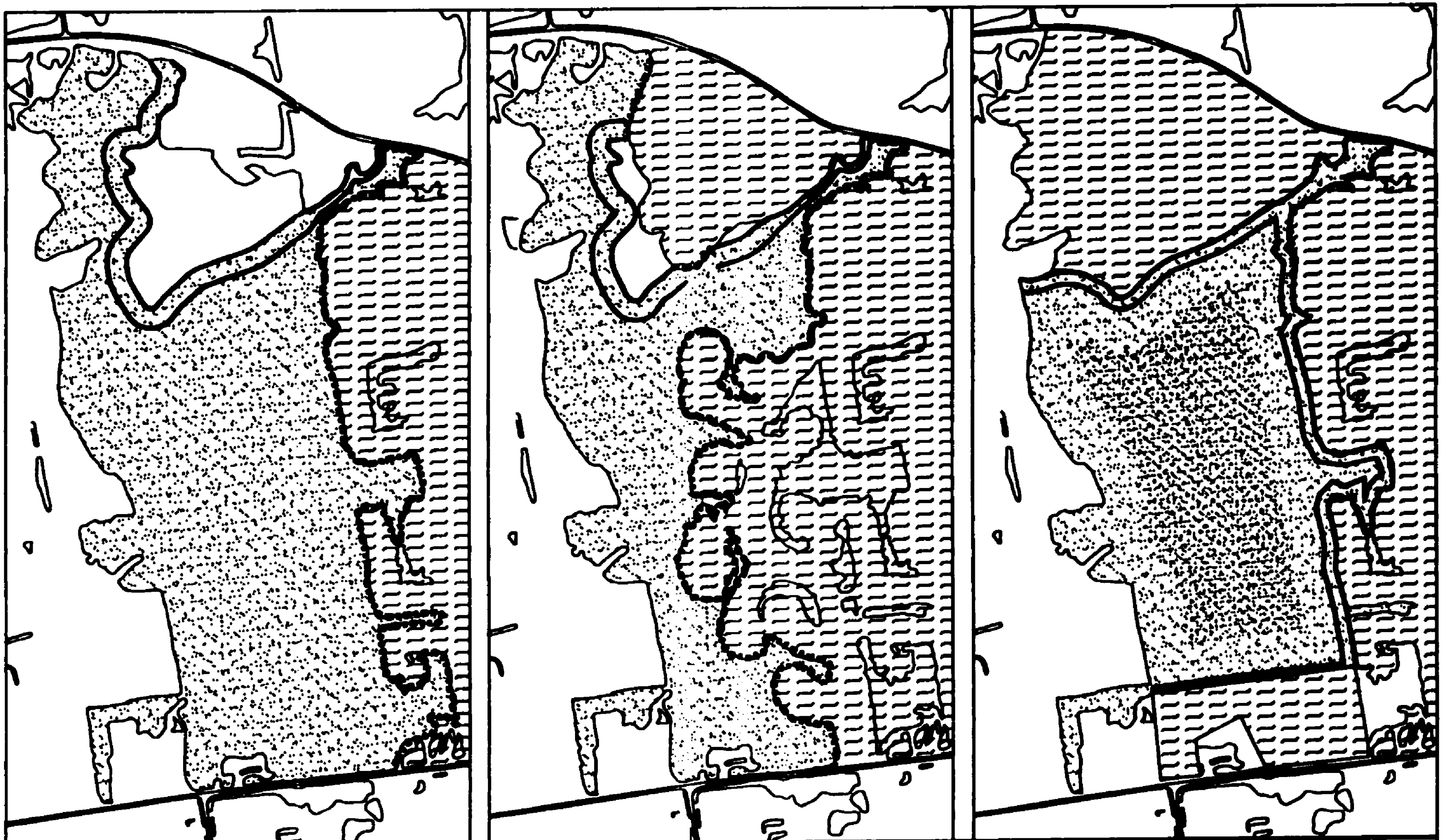


Fig. 6a) Pre-construction
Forest Edge Boundary
Structural Characteristics

Gradual Edge Length: 1087 m.
Abrupt Edge Length: 2660 m
Housing Area: 0 ha

Fig. 6b) Post-construction
Forest Edge Boundary
Structural Characteristics

Gradual Edge Length: 947 m.
Abrupt Edge Length: 3564 m
Housing Area: 32 ha

Fig. 6c) Alternative
Forest Edge Boundary
Structural Characteristics

Gradual Edge Length: 0 m
Abrupt Edge Length: 0 m
Re-created Protective
Edge Length: 3383 m
Housing Area: 32 ha

Key

Forest Sere
Concentrated Housing Habitat
Gradual Edge
Abrupt Edge
Re-created Gradual Edge

0 100 200 400
Metres

Therefore, care must be taken to design protective edges that do not inadvertently increase the number of competitors, predators and parasites within the forest edge. On the other hand, forests contain many species that require conservation, and a balanced approach must be taken that considers the needs of the threatened species as well as those that are relatively common within the landscape.

Therefore, additional design criteria include: the minimization of the length of the forest boundary and the maximization of the boundary's ability to protect the interior of the forest from external physical and biological characteristics that extend the length of the forest edge.

3.5 Adjacent Seres and Ecosystems

Many ecologists argue that the physical and biological characteristics of the areas immediately adjacent to the fragment may have more influence on its ecological function than the characteristics of the forest. The smaller the size of fragment, the more external characteristics are thought to dominate (Noss 1987; Saunders *et al.* 1991; Janzen 1983; 1986). A number of studies have shown that varying land uses adjacent to fragments have different effects on species diversity within the fragment (Forman and Godron 1986; Tilghman 1987; Herkert, Szafoni, Kleen and Schwegmean 1993; Engels and Sexton 1994; Friesen, Eagles and MacKay 1995). A study that was conducted within the Region of Waterloo indicated that the number of houses immediately adjacent to a forest edge was inversely related to the number of forest birds, especially interior forest species (Friesen *et al.* 1995). This relationship was found to exist independent of forest size, providing evidence in support of the hypothesis that external land uses may be more influential in determining bird species diversity than factors internal to the forest.

However, controversy exists over the ecological relationships within the adjacent land uses responsible for influencing species diversity within forest fragments (Churcher & Lawton 1989; Leimgruber, McShea and Rappole 1994; Whitcomb, Robbins, Lynch, Whitcomb, Klimkiewicz and Bystrak 1981; Morton 1992).

There are studies that suggest that even the largest natural areas, such as the provincial or national parks, may not be large enough to conserve species diversity. The ecological effects of surrounding land uses may be undermining efforts to conserve species within these areas (Noss 1983; Noss and Harris 1986; Brussard 1991). Given this finding, it can be argued that it is particularly important to design supportive land uses around the remaining fragments, if species diversity is to be conserved. Some ecologists are promoting the creation of 'buffer' or 'multi-use' zones around the provincial or national parks to help conserve species diversity (Noss and Harris 1986). The primary functions advocated for a buffer zone surrounding a large nature reserve could be revised to apply to land uses adjacent to smaller fragments. These functions include the insulation of the forest interior from surrounding intensive land uses, the provision of connectivity between the fragment and adjacent fragments and the provision of supplemental habitat for populations of native species within the fragment (revised from Noss 1994, p157). More research is required to further define the ecological relationships that constitute a supportive adjacent land use.

The area around a fragment that is significant in determining interior forest species diversity is debatable. For forest species in general, the Nature Conservancy analyzes adjacent land use within a 2 km radius. Within these boundaries, they determine the 'quality' of bordering areas, the extent of linkages to adjacent patches, and the percent

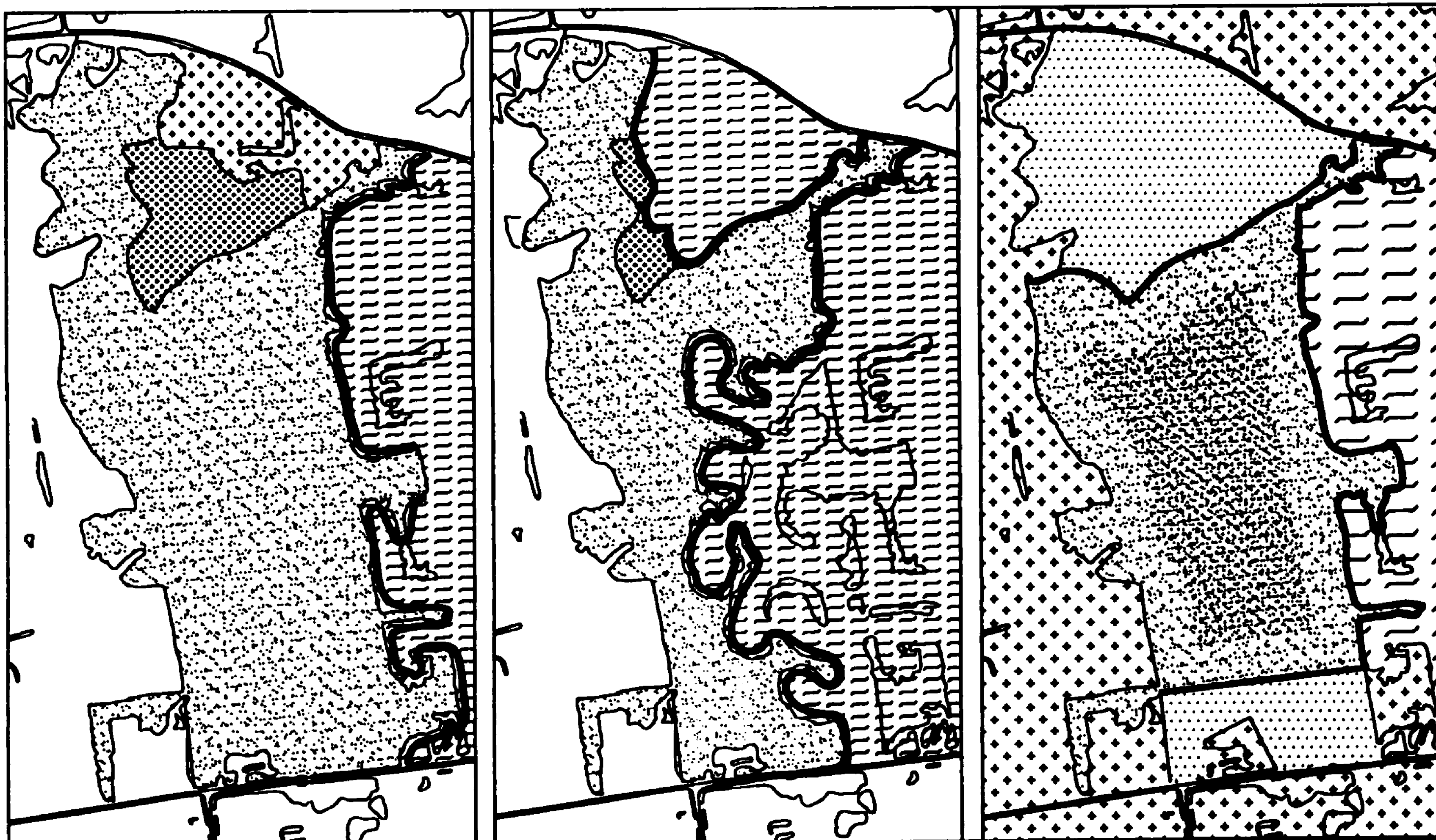


Fig. 7a) Pre-construction Adjacent Seres/Ecosystems
Shrubland Sere Area: 9 ha
Grassland Sere Area: 6 ha
Housing Ecosystem Area: 0
Housing Edge Length: 2172 m

Fig. 8b) Post-construction Adjacent Seres/Ecosystems
Shrubland Sere Area: 2 ha
Grassland Sere Area: 0 ha
Housing Ecosystem Area: 32 ha
Housing Edge Length: 4144 m

Fig. 8c) Alternative Adjacent Seres/ Ecosystems
Shrubland Sere Area: 0 ha
Grassland Sere Area: 0 ha
Sympathetic Housing Area: 32 ha
Housing Edge Length: 3273 m

Key
Forest Sere
Shrubland Sere
Grassland Sere
Non-supportive Housing Habitat
Housing Edge Boundary
More Supportive Original Housing Habitat
Supportive Housing Habitat
Supportive Future development

0 100 200 400
Metres

forest cover (Nature Conservancy 1997). In a study by the Federation of Ontario Naturalists (FON), a 1 km radius was used to evaluate percentage natural area cover, total length of roads in metres per hectare and the number of buildings per hectare (FON 1999).

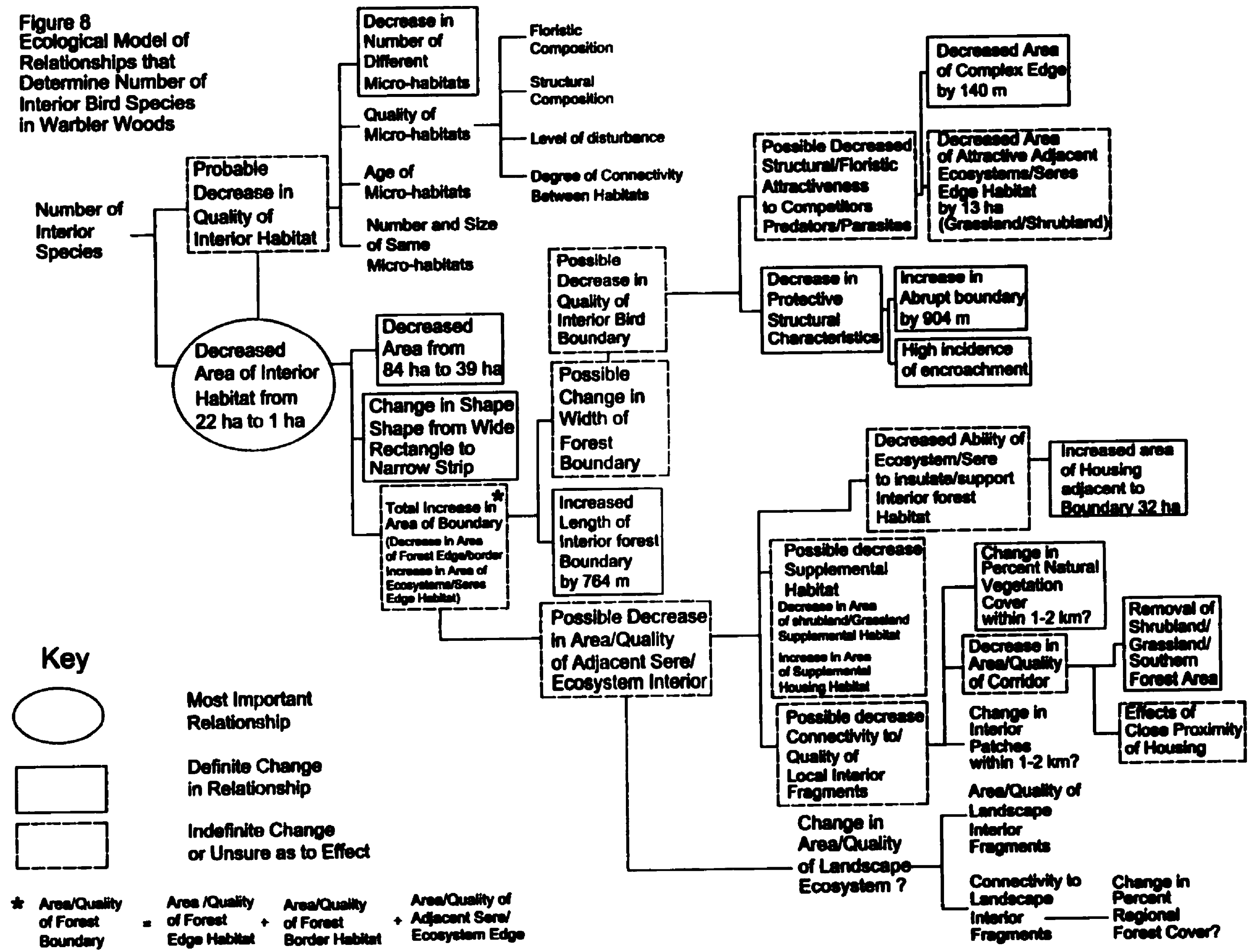
In Warbler Woods, the length of the forest perimeter with adjacent housing increased by 1972 m, or 92 percent. In addition, the grassland was removed and 7 ha, or 80 percent, of the shrubland were removed as adjacent land uses. These areas were seres of the same ecosystem as the forest and thus shared some of their ecological relationships. The housing ecosystem that replaced them is very dissimilar in both form and function. Therefore, there may have been a reduction in the ability of the adjacent land use to support the forest ecosystem. Figure 7 illustrates the changes brought on by the housing development in the bordering land uses, and introduces the idea of designing adjacent land uses that are supportive of interior forest species. The alternative spatial pattern increases the perimeter with adjacent housing by roughly 1100 m, or 50 percent. It also promotes the idea of a more supportive adjacent housing ecosystem, an improvement in the quality of the existing housing development and the establishment of a criteria for the design of more supportive future developments.

A further design criterion is, therefore, the creation around the fragment of transition zone, possibly 1- 2 km in width, in which an effort is made to create patterns that support interior species diversity within adjacent fragments.

4. A Rudimentary Ecological Model

Figure 8 illustrates an ecological model that describes and relates the ecological relationships that may be responsible for the observed decrease in bird species diversity

Figure 8
Ecological Model of Relationships that Determine Number of Interior Bird Species in Warbler Woods



within Warbler Woods. From this model a generalized model has been developed (Figure 9) to express the key relationships and design criteria involved in determining bird species diversity in a fragment large enough to have interior habitat. These ecological relationships are currently viewed as the principal determinants of bird species diversity within forest fragments. Together they can begin to form the structure upon which designs related to forest fragments can be supported, subsequently tested, revised and re-formed.

The generalized model organizes the key ecological relationships within an inter-nested spatial hierarchy that stretches from the scale of the interior forest micro-habitats to the scale of landscapes. The inter-connection between the relationships, where one relationship is determined by others beneath it and composes those above it, reflects the hierarchical operation of the ecosystem and ensures that relationships are not considered in isolation. The designer is encouraged to look beyond the forest and the site when identifying relationships that determine species diversity.

This model, and the ecological relationships upon which it is based, will alter over time as ecological theory changes, and design criterion and spatial relationships are tested post construction for their ability to conserve species diversity.

5. Forest Fragment Design Decision Tree

Ultimately, landscape architects, planners, and any other person involved in land use decisions in and around fragments, (decision-makers), wish to know which ecological relationships are important in a given situation, and what design or management decisions to make that will support species diversity within a fragment. Figure 10 organizes the ecological relationships outlined within Figure 9 in a decision tree format

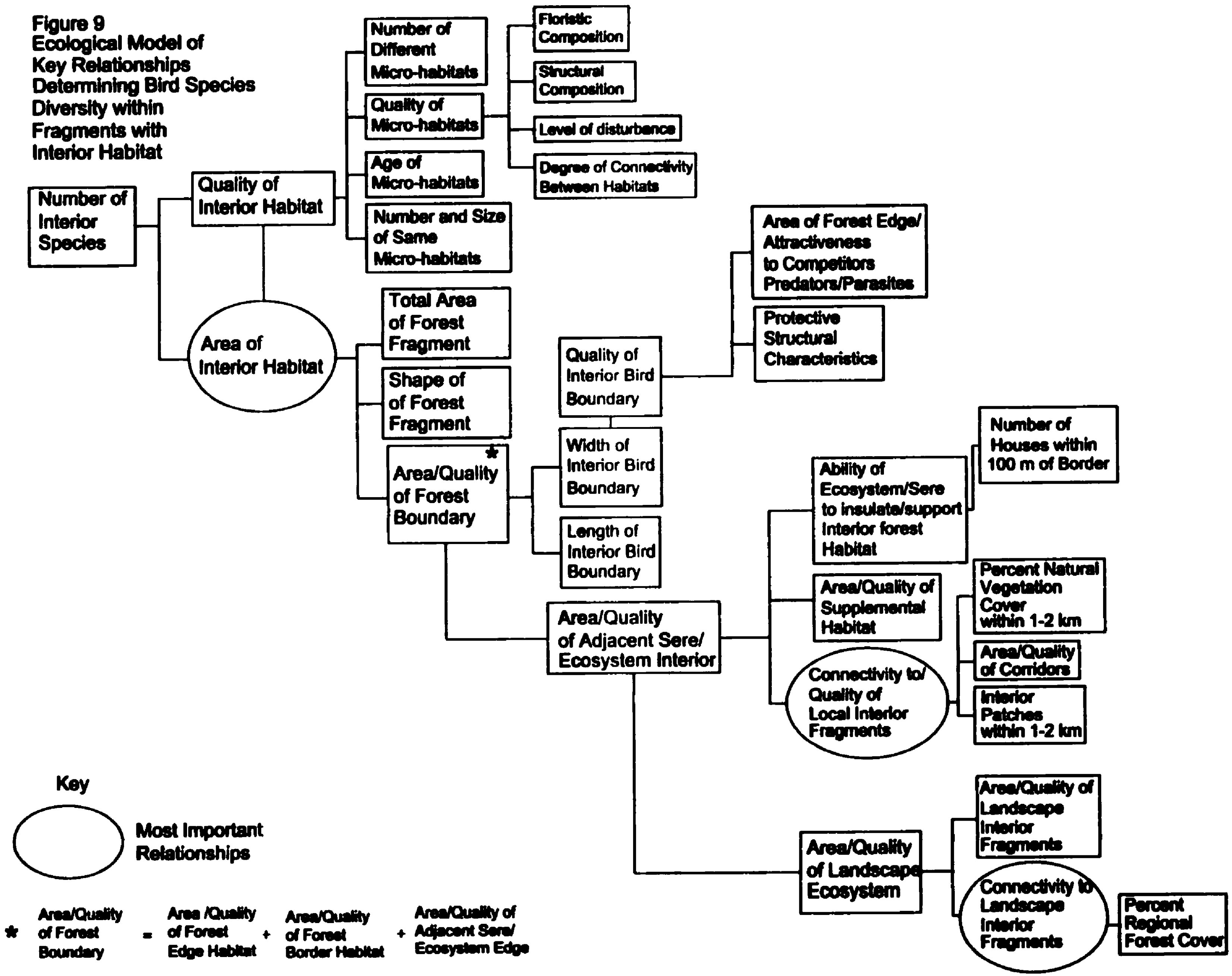


Figure 9
Ecological Model of Key Relationships Determining Bird Species Diversity within Fragments with Interior Habitat

according to the order in which they should be considered, largely according to scale. The decision tree takes the decision-maker through a series of questions to determine the key ecological relationships that are related to the specific conditions within the fragment in question and then suggests a general design or management direction to follow.

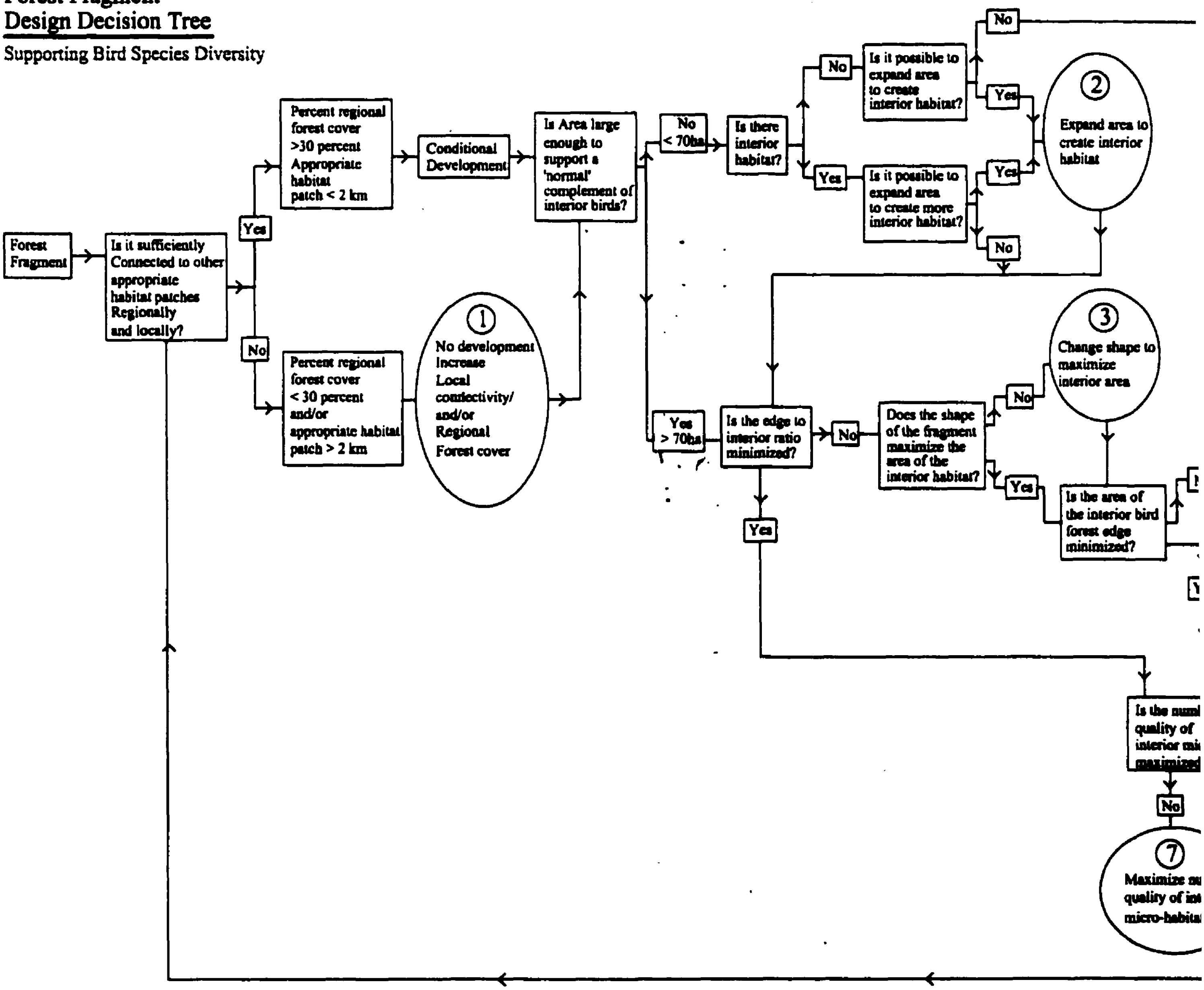
For example, the first question of the tree asks the decision-maker whether the fragment is sufficiently connected to other supporting patches both regionally and locally and offers a currently accepted criterion upon which to answer the question. If the fragment is within a region with less than 30% forest cover and/or is not sufficiently connected to a supporting patch within 2 km, then the first priority that conserves species diversity is to increase local and regional forest cover and connectivity. Secondly, the decision-maker is encouraged to increase the area of the fragment in order to create or increase the interior habitat. A series of questions then follow that help the decision-maker to formulate a finer-scaled design/management strategy for maximizing and/or conserving species diversity within the fragment.

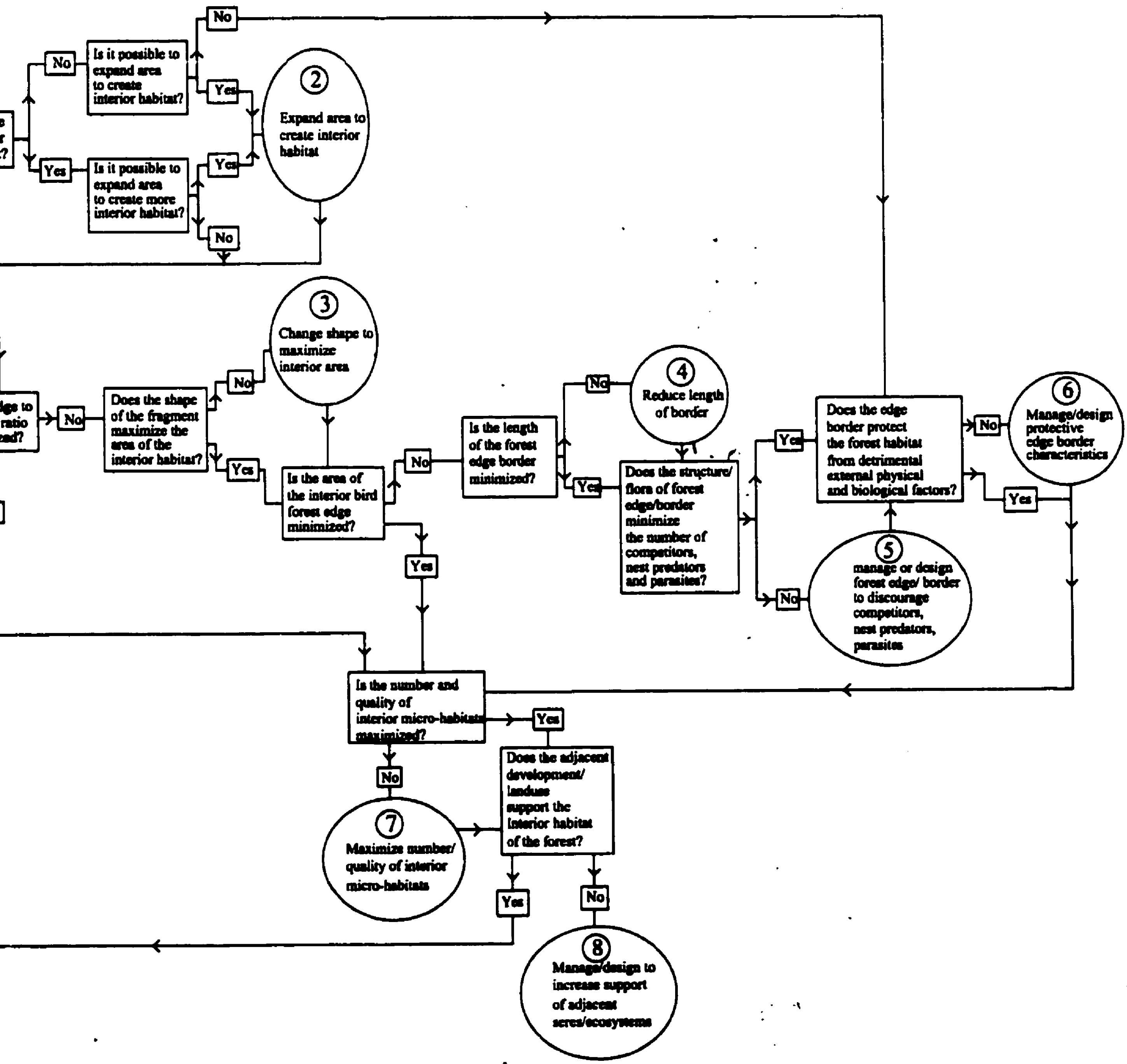
If the fragment is within a landscape that has more than 30 percent regional forest cover and is adequately connected to a supporting interior fragment within 1 –2 km, then the decision-maker is encouraged to focus on area as the number one priority for increasing diversity. Again, a series of questions follow to point the decision-maker to the relationships and design criteria that may help to maximize/conserve species diversity at finer scales.

Decisions regarding fragments and their landscapes are made by many different decision-makers working at different spatial and temporal scales. The tree could function as a common framework by which common objectives could be achieved at different

Figure 10
Forest Fragment
Design Decision Tree

Supporting Bird Species Diversity




No
Is it possible to expand area to create interior habitat?
Yes
2
Expand area to create interior habitat
Yes
Is it possible to expand area to create more interior habitat?
No
3
Change shape to maximize interior area
No
Does the shape of the fragment maximize the area of the interior habitat?
Yes
Is the area of the interior bird forest edge minimized?
No
Is the length of the forest edge border minimized?
No
4
Reduce length of border
Yes
Does the structure/ flora of forest edge/border minimize the number of competitors, nest predators and parasites?
Yes
Does the edge border protect the forest habitat from detrimental external physical and biological factors?
No
6
Manage/design protective edge border characteristics
Yes
No
5
manage or design forest edge/ border to discourage competitors, nest predators, parasites
Yes
Is the number and quality of interior micro-habitats maximized?
Yes
No
7
Maximize number/ quality of interior micro-habitats
Does the adjacent development/ landuse support the interior habitat of the forest?
Yes
No
8
Manage/design to increase support of adjacent seres/ecosystems

temporal and spatial scales. For example, Planners and Policy Makers often make decisions at coarser scales and over longer time periods and may be more able to achieve objectives at larger spatial and temporal scales, such as increasing regional forest cover, increasing the area of a fragment beyond its current boundary, or determining a design criteria to encourage supportive adjacent land uses. Designers and developers, on the other hand, are often limited to site and inner site scale decisions and shorter time frames. They may be more able to implement ecological relationships that are governed at the site scale and can be implemented in a relatively short period of time, such as improving the shape of the fragment, and manipulating the edge in order to decrease the exposure of the interior habitat, etc.

Using this decision tree in the case of Warbler Woods in 1977, may have led to a focus, perhaps by the City of London, on increasing regional forest cover beyond the prevailing 6 percent. It may have encouraged the retention, and perhaps expansion, of Warbler Woods along with other fragments within the landscape, particularly within a 2 km radius of Warbler Woods. Beyond this, in answering the subsequent questions, the City of London may have worked together with designers and planners to expand the interior area of the fragment in a manner that increased the width in relation to the length of the fragment, particularly in the area of the interior core. At finer scales, designers and managers may have used the decision tree to focus on the minimization of the edge relative to the interior area, and to design a protective edge along the eastern housing boundary that may have prevented encroachment, and other forms of human disturbance.

The decision criteria reflect the current values and thresholds applied to the key ecological relationships within the ecological literature. It does not necessarily reflect the value that the design community, or society in general, places on conserving species diversity relative to achieving other land use objectives. In order to decide whether development should occur in a particular fragment or within the landscape as a whole, society must make conscious choices as to the value it places on conserving forest species diversity. This tree has not been developed, and should not be used, to serve as a method for determining whether or not development should occur in a fragment. Its purpose is solely to provide guidance to decision makers in the identification and support of ecological relationships that conserve species diversity within fragments.

At the same time, establishing links between the spatial patterns and their effects on species diversity will allow conscious decisions to be made. Otherwise, the ecological effects remain unknown and designers, in addition to society as a whole, are left to hope that species diversity will somehow be conserved, perhaps by someone else.

Ecological theories change over time as they are tested in the field and revised. Many of the currently supported relationships require further testing and still others have not yet been discovered. Within this tree, for example, some of the ecological criteria are not strongly supported in the literature, but merely reflect the results of one or two studies. In this respect, the tree does not express absolute time-tested truths that should be applied in the design or planning of fragments over long periods of time, but merely current knowledge and experience. Constant revision of the tree is required as theories are tested in particular circumstances. The tree may develop differently according to the different conditions under which it is applied. In addition, many of the design criteria have not yet been tested and may require revision. In particular, different combinations of criterion require testing for their ability to conserve species diversity. Given this, post occupancy assessments of ecological relationships and design criterion are essential to the ongoing development and utility of the tree, and more importantly, to the achievement of design that conserves species diversity.

Conclusions

This study has demonstrated that the housing development had a significant effect upon the species diversity of Warbler woods. Although more species were observed in 1999, possibly due to greater sampling effort, the composition of the bird community changed substantially. The decrease in the number of interior birds observed in this study is exactly as predicted by theory and by other studies within Ontario and throughout Eastern North America.

According to the literature, the observed reduction in the number of interior bird species is predicted to be primarily due to the reduction in the area of the forest, and more specifically, the area of the interior habitat. The level of connectivity of the fragment, both locally and within the landscape is also an important determinant of interior species diversity, but establishing whether there was a change in the level of connectivity between the two time periods was beyond the scope of this study. Other alterations in the configuration of the fragment may have contributed to the observed decrease including: a reduction in the number and quality of interior micro-habitats; an increase in the edge to interior ratio; a decrease in the ability of the forest boundary to protect forest interior conditions; and a decrease in the quantity and quality of supportive adjacent habitats.

The most important design criterion for conserving bird species diversity within forest fragments is to maximize the area of interior habitat. This involves the maximization of the total area of the fragment, the shaping of the fragment so that length and width are roughly equal, and the minimization of the area of the forest edge habitat. In addition, a secondary design criterion is to improve the connection of the fragment to other supplemental interior fragments in the landscape. This criteria includes improving both the regional connection, particularly in regions with less than 30 percent forest cover, and the local connection, to fragments within 1 – 2 km. Other design criteria are also important, particularly for smaller fragments, and include the maximization of the protective function of the forest edge boundary and the supporting function of adjacent ecosystems or seres. The characteristics of a supporting adjacent ecosystem or sere may include providing insulation from adjacent intensive land uses, supplemental habitat and connection to other interior patches within 1-2 km.

Some of these ecological relationships and their design criterion are well supported both in theory and in empirical studies, others are less supported and require more exploration and testing. Ecological study has largely been focused on the testing of single ecological relationships, such as that between fragment area and diversity. Very little testing has occurred around the combined effects of different ecological relationships or criteria. While a comparison of the effects of different spatial patterns on species diversity is difficult, given the complexity of relationships, landscape architects and planners are uniquely positioned to perform these studies in the form of post occupancy assessments.

If species diversity is to be conserved in a fragmented landscape, landscape architects much understand the ecological effects of the spatial patterns they create. Through the identification and post construction testing of key ecological relationships, and their associated design criteria, landscape architects and planners can begin to consciously develop spatial patterns that conserve species diversity in the landscape.

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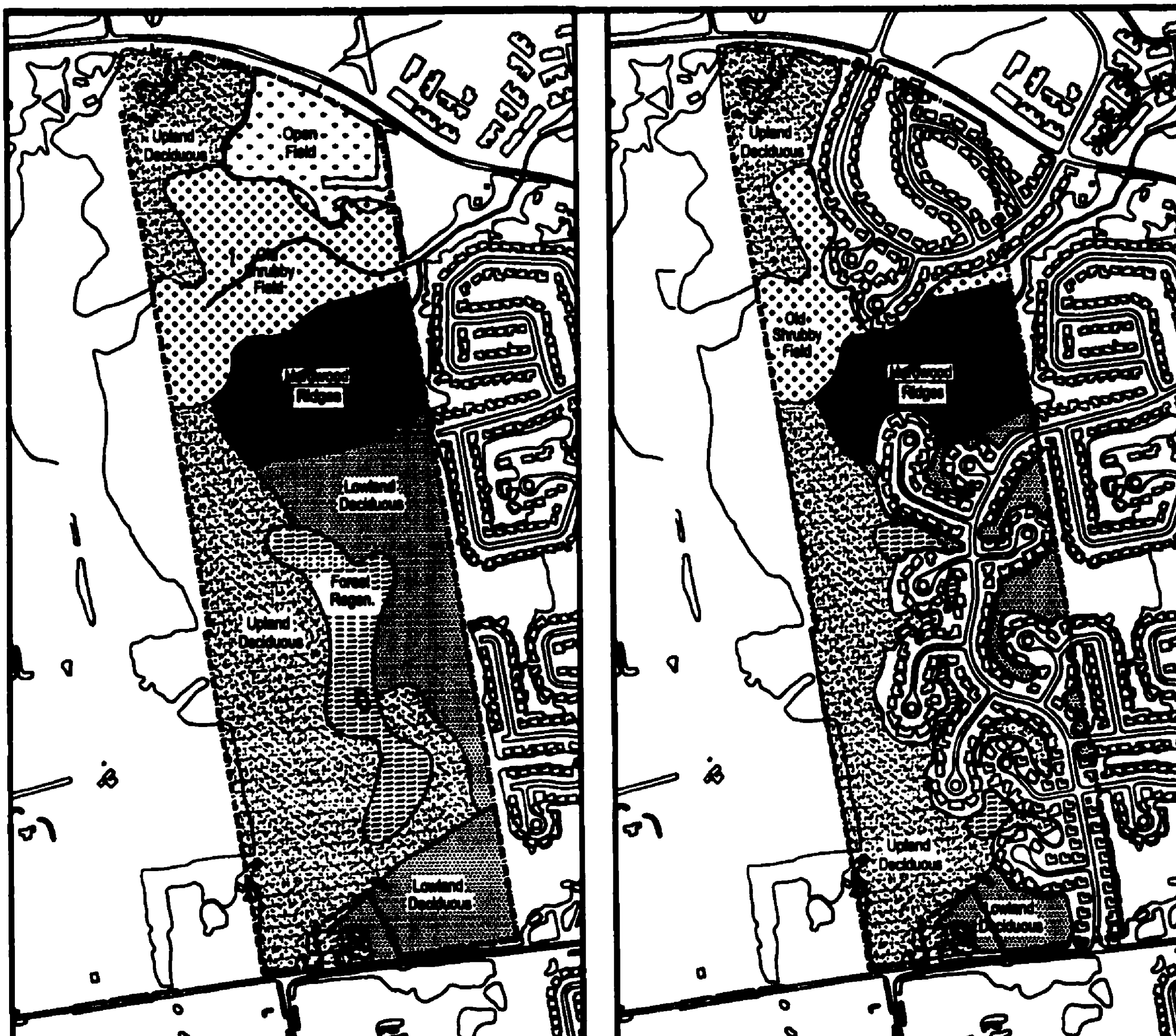
Appendix 1



Appendix 1:
1977 Pre-construction
Proctor and Redfern Ltd.
Vegetation Communities

1999 Post-construction
Proctor and Redfern Ltd.
Vegetation Communities

Key

Proctor and Redfern Site Boundary

Source: Proctor and Redfern Ltd. (a) 1977

0 100 200 400
Metres