# RESEARCH SUB-PROGRAM

# A LITERATURE REVIEW ON WILDLIFE HABITATS IN AGRICULTURAL LANDSCAPES

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# *FORWARD*

This report is one of a series of **COESA** (Canada-Ontario Environmental Sustainability Accord) reports from the Research Sub-Program of the Canada-Ontario Green Plan. The **GREEN PLAN** agreement, signed Sept. 21, 1992, is an equally-shared Canada-Ontario program totalling $64.2 M, to be delivered over a five-year period starting April 1, 1992 and ending March 31, 1997. It is designed to encourage and assist farmers with the implementation of appropriate farm management practices within the framework of environmentally sustainable agriculture. The Federal component will be delivered by Agriculture and Agri-Food Canada and the Ontario component will be delivered by the Ontario Ministry of Agriculture and Food and Rural Assistance.

From the 30 recommendations crafted at the Kempenfelt Stakeholders conference (Barrie, October 1991), the Agreement Management Committee (AMC) identified nine program areas for Green Plan activities of which the three comprising research activities are (with Team Leaders):

1. **Manure/Nutrient Management and Utilization of Biodegradable Organic Wastes** through land application, with emphasis on water quality implications
   - **A**. Animal Manure Management (nutrients and bacteria)
   - **B.** Biodegradable organic urban waste application on agricultural lands (closed loop recycling) (Dr. Bruce T. Bowman, Pest Management Research Centre, London, ONT)
2. **On-Farm Research**: Tillage and crop management in a sustainable agriculture system. (Dr. Al Hamill, Harrow Research Station, Harrow, ONT)
3. **Development of an integrated monitoring capability** to track and diagnose aspects of resource quality and sustainability. (Dr. Bruce MacDonald, Centre for Land and Biological Resource Research, Guelph, ONT)

The original level of funding for the research component was $9,700,000 through Mar. 31, 1997. Projects will be carried out by Agriculture and Agri-Food Canada, universities, colleges or private sector agencies including farm groups. This Research Sub-Program is being managed by the Pest Management Research Centre, Agriculture and Agri-Food Canada, 1391 Sandford St., London, ONT. N5V 4T3.

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# CONTRIBUTING TEAM

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Alan has been studying terrestrial soil ecosystems and the impact of agronomic practices on soil organisms for over 20 years as a research scientist. Currently he leads a team developing a suite of indicator organisms to measure impact of soil management practices on soil ecosystems, and models pollutant and nutrient transport through soil food webs.

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# EXECUTIVE SUMMARY

Agriculture, perhaps more than any other human activity, has an adverse, impact on wildlife. Clearing forested lands for agriculture, agriculture itself, and agriculture's side effects are the major causes of worldwide species loss. Farm effects are damaging because they are so widespread; about half the planet's land surface has been converted to agricultural use. In many regions of southern Ontario, home of Canada's best croplands, this figure may reach 90%. The central resource of farming is soil which itself harbours a large proportion of wildlife diversity and biomass, and about which we know so little.

Responsibility for agriculture's environmental effects should not be shouldered by farmers alone. Modern farm practice responds to the priorities of an urbanized society which demands inexpensive farm products at the expense of the rural resource base. Farmers are under tremendous pressure to maximize production and profits through greater efficiency, and, in order to survive economically, they feel they must strip natural vegetation to expand and compete.

Agriculture affects wildlife by reducing and isolating natural habitat. Often all that remains of natural habitat in heavily farmed areas are scattered remnant patches, wet depressions, and linear strips lost in a sea of cropland. An agroecosystem is a simplified, perturbed environment that replaces richer natural diversity with a relatively impoverished assemblage of cultivated plants and domesticated animals. Fewer native plants and animals adapt to, or can be tolerated in, intensively managed cropping systems. Recent trends in agricultural practices such as increased farm and field size, reduction of uncultivated field boundaries, increased chemical inputs, and lower crop diversity point to more ecosystem simplification, with ominous implications for local wildlife.

This literature review critically examines the situation of wildlife habitats in agricultural landscapes with a particular view to finding ways that can enhance or restore the value of farmland for wildlife. The subject is a timely one, given Canada's stated support for sustainable use of wildlife and biodiversity. It is woefully

inadequate to concentrate conservation efforts only on specially protected areas that cover only about 3% of the world land area, but ignore the vast remainder of the landscape managed for agriculture, forestry, and human settlement. What happens in this wider landscape, far more than conditions in protected landscapes, is now the single greatest limiting factor for the distribution and abundance of wildlife species.

Two separate areas within agroecosystems will be examined — the crop fields themselves and the non-crop habitats with which they interface (field margins, fencerows, roadsides, ditches, woodlots). In each instance the approach will focus on the importance of habitat generally rather than on single-species habitat needs. By preserving appropriate habitat, we may be able to conserve most of our native species including the large array of smaller organisms such as invertebrates, fungi, and bacteria that receive little attention in most conservation efforts, but dominate both the biomass and diversity of organisms. Wildlife throughout this report includes plants, invertebrates, and vertebrates.

The review ends with some suggestions for actions that should assist in enhancing or conserving wildlife within agroecosystems. There are some proposals for researching the managing of agroecosystems to establish whether some management techniques are more benign for wildlife than others. This all presupposes that the public at large can be convinced, and educated in the importance of managing wildlife resources within agroecosystems for common present common good, and benefit of future generations.

## SOMMAIRE

L'agriculture, probablement plus que toute autre activité humaine, a un impact négatif sur la faune. Le déboisement de terres à des fins agricoles, l'agriculture elle-même et ses effets secondaires sont les principales causes de la disparition d'espèces à l'échelle mondiale. Les effets attribuables à l'agriculture sont nuisibles en raison de leur étendue; environ la moitié des terres de la planète servent à l'agriculture. Dans de nombreuses régions du sud de l'Ontario, où se trouvent les meilleures terres du Canada, le pourcentage peut atteindre 90 %. L'agriculture repose principalement sur le sol, qui abrite une faune très diversifiée, ainsi que la biomasse, domaine où nos connaissances sont bien limitées.

La responsabilité des effets de l'agriculture sur l'environnement ne devrait pas incomber uniquement aux agriculteurs. Les pratiques culturales modernes répondent aux priorités d'une société urbanisée qui exige des produits agricoles bon marché aux dépens cependant de la base rurale. Les agriculteurs subissent d'énormes pressions pour maximiser la production et les profits. Par conséquent, ils mettent l'accent sur l'efficacité. De plus, pour survivre sur le plan économique, ils se sentent obligés de détruire la végétation naturelle afin de prendre de l'expansion et être concurrentiels.

L'agriculture affecte la faune du fait qu'elle réduit la surface d'habitat naturel et l'isole. Bien souvent, le seul habitat qui reste dans les régions très agricoles se compose de parcelles éparses, de dépressions mouillées et de bandes linéaires perdues au milieu des champs cultivés. Un agro-écosystème est un milieu simplifié et perturbé qui remplace la riche diversité naturelle par un mélange plutôt pauvre de plantes cultivées et d'animaux domestiqués. Un moins grand nombre de plantes et d'animaux indigènes peuvent s'adapter ou être tolérés dans un système cultural à exploitation intensive. L'écosystème se simplifie de plus en plus en raison des tendances récentes en pratiques culturales, notamment la plus grande superficie des champs et des fermes, la réduction des limites des champs non cultivés, l'utilisation accrue de produits chimiques et la moins grande diversité des cultures. Cette simplification a des conséquences néfastes pour la faune locale.

Dans cet examen de la documentation, on se penche sur la situation des habitats fauniques dans les terres agricoles afin de trouver des façons d'améliorer ou de restaurer la valeur des terres agricoles pour les espèces fauniques. Le sujet vient à point, étant donné l'appui accordé par le Canada à l'utilisation durable des espèces sauvages et à la biodiversité. Il est malheureusement insuffisant de limiter les efforts de conservation aux zones protégées, qui ne couvrent environ que 3 % de la surface des terres du monde, et d'oublier le reste des terres servant à des fins agricoles, forestières et humaines. La situation dans le reste des terres, beaucoup plus que celle dans les aires protégées, est aujourd'hui le plus grand facteur limitant la distribution et l'abondance des espèces sauvages.

L'examen portera sur deux régions distinctes à l'intérieur d'agro-écosystèmes : les terres cultivées elles-mêmes et les habitats non agricoles avec lesquels elles entrent en contact (marges des champs, clôtures vaines, bords de chemin, fossés, terres à bois). Dans chaque cas, on mettra l'accent sur l'importance de l'habitat en général plutôt que sur les besoins d'habitat d'une espèce. En préservant l'habitat, on peut arriver à conserver la plupart de nos espèces indigènes, y compris un grand nombre d'organismes plus petits, comme les invertébrés, les champignons et les bactéries. Ces petits organismes, le plus souvent négligés dans les efforts de conservation, sont prédominants dans la biomasse et contribuent à la biodiversité. La faune traitée dans ce rapport comprend les plantes, les invertébrés et les vertébrés.

L'examen se termine sur une note positive : des suggestions de mesures pour améliorer ou conserver la faune au sein des agro-écosystèmes. Il y a des propositions de recherche sur la gestion des agro-écosystèmes pour établir si des techniques de gestion sont moins nocives que d'autres pour la faune. Cela présuppose que l'on peut convaincre le grand public de l'importance de la gestion des ressources fauniques au sein des agro-écosystèmes et, par le fait même, l'éduquer pour le bien des générations actuelles et futures.

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# 1. INTRODUCTION

Agriculture, perhaps more than any other human activity, has a profound, mostly adverse, impact on wildlife (Rattie and Scott 1991). Ehrenfeld's (1989) assessment was blunt: agriculture and its side effects are now the major cause of the worldwide loss of species. Farm effects are so damaging in large part because they are so widespread. About half of the planet's land surface has been converted to agricultural use (Pimentel et al. 1992), and in many regions of southern Ontario, home of Canada's best croplands, up to 90% (Anon., 1986).

Responsibility for agriculture's environmental effects should not be shouldered by farmers alone. Modern farm practice mirrors the values and priorities of the larger, predominantly urbanized, society. Urban consumers demand inexpensive farm products, even if these come at the expense of the rural resource base (Rowe 1990). Thus, farmers are under tremendous pressure to maximize production and profits through greater efficiency, bigger machines, and more specialization. In order to survive economically, many farmers feel they have little option but to strip much or all of the natural vegetation from their land in order to expand their field size.

Agriculture affects wildlife in several ways. First, it reduces and isolates the amount of natural habitat so that all that remains in heavily farmed areas are scattered remnant patches, wet depressions, and linear strips awash in a sea of cropland (Saunders et al., 1991). Second, the agroecosystem itself is a simplified, constantly perturbed environment that replaces a richer natural diversity (Tomlin & Miller, 1987) with a relatively impoverished assemblage of cultivated plants and domesticated animals (see Wilson 1988). Few native plants and animals adapt to, or can be tolerated in, intensively managed cropping systems. Recent trends in agricultural practices such as increased farm and field size, loss of uncultivated field boundaries, greater chemical use, lower crop diversity (Barrett et al. 1990), point to even greater ecosystem simplification, with ominous implications for local wildlife.

This literature review examines the situation of wildlife habitats in agricultural landscapes with a particular view to finding ways that can enhance or restore the value of farmland for wildlife. The subject is a timely one, given Canada's stated support for sustainable use of wildlife and biodiversity (Anon., 1990). It is woefully inadequate to concentrate conservation efforts only on specially protected areas (that cover ~3% of the world land area) and ignore the vast remainder of the landscape managed for agriculture, forestry, and human settlement (Rattie and Scott 1991; Pimentel et al. 1992). What happens in the wider landscape, far more than conditions in individual protected landscape elements alone, is now the single greatest limiting factor to the distribution and abundance of the great majority of wildlife species (Franklin 1983).

Two separate areas will be examined — the crop fields themselves and the noncrop habitats with which they interface (field margins, fencerows, roadsides, ditches, woodlots). In each instance the approach will focus on the importance of habitat generally rather than on single-species habitat needs. By preserving appropriate habitat, we can conserve most of our native species including the large array of smaller organisms such as invertebrates, fungi, and bacteria that receive little attention in most conservation efforts (Chadwick 1991; Franklin 1993). Wildlife throughout this report will include plants, microbes, invertebrates, herpetofauna, birds, and mammals.

### 1.1 Relevance of Island Biogeography and Landscape Ecology

Island biogeography theory and landscape ecology provide insights that can help to better understand the dynamics of wildlife in human-dominated landscapes. Researchers generally agree that the less fragmented a habitat is, and the nearer it is to other like habitats, the better are the survival prospects for its associated species. Studies of oceanic islands suggest that the number of species is higher on larger, less isolated islands than on smaller, more distant ones. Larger islands contain more resources and thus can support larger populations which are less likely to go extinct from chance environmental events (Wilson 1992). Less isolated islands are nearer to colonizing sources that can replace species that disappear.

The applicability of island biogeography theory to remnant patches fragmented by agriculture and settlement has inspired lively debate and much study (see reviews in Shafer 1990). The application of the theory to habitat islands has yielded equivocal results but the exercise has reinforced the notion that general ecological principles might exist upon which to base sound conservation strategies. Specifically, attention has been drawn to community response to habitat size and isolation (Hansen et al. 1992).

Landscape ecology expanded the scale of investigation from single habitat elements to multiple elements within complex landscapes (Hobbs et al. 1993). Forman and Godron (1986) viewed all landscapes as consisting of three interlinked constituent elements, matrix, patches, and corridors. Energy, species, and materials constantly move within and between them. Of particular relevance to this study is an appreciation of the pervasive, often overwhelming, impacts bombarding patches and corridors from the surrounding agricultural matrix.

External influences vary according to the nature of the matrix. If a patch is surrounded by a matrix that is highly dissimilar in nature, a much larger area is needed to maintain the patch's structure and function. For example, a woodlot surrounded by soybeans must be much larger to retain forest interior conditions than if it were surrounded by a diverse system of meadows, fencerows, wetlands, and small forest patches (Hansson and Angelstram 1991). External influences can be large, in keeping with Margelef"s (1963) suggestion that when considering the flows between adjacent ecosystems or elements, the younger may operate as a source of energy or material, and the more mature as a sink or recipient.

When distilled to their basics, management considerations derived from landscape ecology are similar to those of island biogeography. Generally, regional biodiversity is best served by larger rather than smaller habitats, by areas closer together than further apart, and by compact rather than elongated habitat shape (Noss 1983, 1987b; Wilcove et al. 1986).

# 2 WILDLIFE IN CROPLAND

## 2.1 Invertebrates

Invertebrates account for 90 to 95% of animal species (Pimentel et al. 1992, Table 1) and total faunal biomass on Earth, yet their critical role in maintaining life is customarily ignored or under-appreciated (Crossley et al. 1992; Stevens 1994; Wilson 1988). Creatures such as insects, spiders, worms, snails, and nematodes, by sheer numbers alone, constitute the backbone of any terrestrial ecosystem. In agroecosystems, as in any terrestrial ecosystem, invertebrates mediate absolutely vital processes as decomposers, pollinators, soil conditioners, food sources for higher organisms, and control agents of potentially harmful organisms. Soil fauna are particularly important in the comminution and initial stages of mineralization of organic matter and macronutrients. Crop residues, manure applications, and leaf fall induce large and rapid expansion of the soil biota that mineralizes the macronutrients to make them available for subsequent plant growth. The interactions of organisms, plants, and detritus in agricultural (and all) soils to establish nutrient and energy flows through food webs has become a central concern of soil ecologists in their efforts to define sustainable agro-ecosystems (de Ruiter et al. 1994).

Changes in agronomic practices such as conversion to conservation tillage from conventional tillage leaves protective crop residues on the soil surface (Edwards et al. 1990), which serve as mulch, safeguarding soil from the erosive forces of wind and water, and conserving soil moisture. Crop residues furnish nutrients, shelter, and suitable microclimates for soil biota and other organisms (Tomlin et al. 1993a). Conversions to no-till land management have large effects on wildlife (*sensu lato*) that are only beginning to be understood.

**Table 1. Biomass of various organisms per ha of temperate region pasture.**

| Organism | Biomass (kg fresh wt) |
|---|---|
| Plants | 20,000 |
| Fungi | 4,000 |
| Bacteria | 3,000 |
| Arthropods | 1,000 |
| Annelids | 1,320 |
| Protozoa | 380 |
| Algae | 200 |
| Nematodes | 120 |
| Mammals | 1.2 |
| Birds | 0.3 |

Agricultural soils harbour a biotic community that, while often resilient to cultivation and herbicides, nonetheless is far less diverse and abundant than occurs in similar soil types in adjacent forest or grassland (Crossley et al. 1992; Tomlin et al. 1993a). Evidence suggests that more intensive tillage methods result in progressively more impoverished populations of microfauna and invertebrates (Welch 1990; Tomlin et al. 1993a). However, faunal biodiversity in agroecosystems, mostly represented by arthropods, is higher than might be intuitively expected (Wooley et al. 1985 and Pimentel et al. 1992). One experiment documented 24 genera of soil mites in an old field, 15 genera in a plot of the field that was converted to no-tillage, and 5 genera in a conventionally tilled plot (Crossley et al. 1992). The upheaval associated with cultivation has direct impacts on fauna such as earthworms and soil mites that have a long life span and relatively low fecundity (Sgardelis and Usher 1994) and on spiders that require less disturbed conditions in order to complete life cycles, especially overwinter survival (Kromp and Steinberger 1992).

Investigations in Britain found that the least disturbed soils in a field complex, permanent grass fields used for grazing cattle and sheep, contained soil invertebrate densities an order of magnitude higher than were found in nearby cereal and oil-seed croplands (Tucker 1992). Studies from the American Midwest revealed that abundance of soil and litter arthropods was correlated to the amount of plant residue on the soil surface which in turn was determined largely by tillage practices (House and Stinner 1983; Warburton and Klimstra 1984; additional reviews in Robinson 1991; Orians and Lack 1992; Rodenhouse et al. 1993). Recent studies in Maine and Austria demonstrated more abundant ground beetles in no-tillage experimental plots and organically farmed wheat fields than in conventionally farmed fields (Fan et al. 1993; Kromp and Steinberger 1992).

Studies have noted a correlation between the application of manure and greater arthropod populations. Earthworm densities in cultivated fields in Britain increased substantially when manure was added to the land (Tucker 1992). Experiments in the former USSR, Japan, and Hungary recorded large increases in soil microbes and arthropod species ranging in the order of 16 to 50% and even higher after manure was spread on farm fields (Pimentel et al. 1992). In Ontario, nutrient rich sludge-treated plots contained significantly higher numbers and biomass of earthworms than untreated plots (Tomlin et al. 1993b).

Soil biota in individual fields may be significantly enhanced by the extent and isolation of uncultivated habitat areas in the regional landscape. Corn fields in Sweden contained a much higher diversity of beetles and spiders than similarly cultivated areas in Central Europe, perhaps because of the increased presence of small-sized fields and numerous semi-natural areas that assisted dispersal and over-winter survival (Duelli et al. 1990).

## 2.2 Birds

Fields are utilized by birds during migration and in winter for their food resources. Castrale (1985) noted that fields in Indiana littered with corn residue were used by twice as many birds (both in diversity and abundance) in winter than were soybean residue and tilled fields. He attributed the differences in usage to the larger amounts of debris remaining in corn fields. In Britain, Tucker (1992) observed that fields with higher invertebrate populations (permanent grass fields and manured fields) attracted the highest diversity and number of wintering birds that commonly use open fields for feeding. Further understanding of this subject in needed for Ontario, especially given the use of fields by migrating shorebirds and waterfowl and by northern species such as Snow Bunting, Lapland Longspur, and Common Redpoll (Latin names of species are given in Appendix 1).

Vesper Sparrows display a clear preference in spring/summer for foraging in fields with the most crop residue, probably because of the more elevated song perches, increased cover, and the greater abundance of residue-dwelling arthropods (Rodenhouse and Best 1994). Diversified farms featuring a variety of crops adjacent to each other might benefit bird species by expanding the range of habitat choices important to nesting, food gathering, and escape from predators (Stinner and Blair 1990). Several studies from the American Midwest found higher avian diversity on organically farmed fields than on conventional farms (reviewed by Robinson 1991). Differences in bird activity were attributed to the increased amount of crop litter, seed abundance, and pasture present on the organic farms.

Large, open fields devoid of natural cover typically lack all but a few bird (and mammal) species. In Idaho, for example, a 27 km survey in early spring through a vast expanse of plowed fields turned up just one vertebrate species, a Vesper Sparrow (Rattie and Scott 1991). In part, the paucity of wildlife in large fields results from the low ratio of edge habitat relative to field centers. More bird species, and about five times as many individual birds, have been found on the perimeter of cornfields than in the center, mainly on account of birds' preference for foraging along field margins (Best et al. 1990; Rodenhouse and Best 1994). Consequently, as field size increases, the proportion of field edge decreases and so too does the average abundance of birds per field.

Field monocultures are not entirely avoided during nesting season. Row crop environments are regularly utilized by a small group of species that prefer, or can tolerate, areas with bare ground or sparse vegetation

(Best et al. 1990; Camp and Best 1993). Predominant species include Brown-headed Cowbird, Horned Lark, Vesper Sparrow, Killdeer, and Red-winged Blackbird. Greater field diversity leads to greater avian diversity. Wooley et al. (1985) noted that the highest nest density of nongame birds found in any system of row cropland was 13 per 40 ha; this compared with 142 nests per 40 ha in strip cover, and 174 nests per 40 ha in fencerows.

Bird diversity and abundance along field perimeters is very much influenced by whether the field is bounded by woodland or herbaceous cover. Cornfield/woodland edges may contain over twice as many species (50 versus 23) in more than seven times the abundance as cornfield/herbaceous edges (Best et al. 1990). Moreover, the type of edge affects the composition of the birds species present within cornfields and further illustrates the conservation implications of eliminating woody vegetation from fencerows (Best 1983).

Grassland birds with more specialized habitat requirements — Bobolink, Grasshopper Sparrow, Upland Sandpiper — are found on farmlands, having expanded their ranges eastward as the original forest cover was sheared away. Today, hayfields and old meadows are critical to their distribution. The shift away from diversified farming and the elimination of many hay patches has greatly reduced nesting habitats for these species (Warner 1992).

Bobolink populations in eastern North America have declined not only because of habitat loss but also because the type of hay crops has switched from timothy/clover to alfalfa. Bollinger and Gavin (1992) observed that Bobolinks in New York generally avoid alfalfa fields. Fields with the least alfalfa cover had over 15 times more Bobolinks than fields with the most alfalfa cover. The research indicated that optimum habitat for Bobolinks were 'old' hayfields (about 8 years) that were 10 to 15 ha in size and sparsely sown in grass-dominated vegetation. Creating habitat for Bobolinks also creates living space for Eastern Meadowlark, Henslow's Sparrow, Grasshopper Sparrow, and Upland Sandpiper whose numbers all have been positively correlated with Bobolink abundances (Bollinger and Gavin 1992).

## 2.3 Mammals

Cultivated land offers poor living conditions for most mammals. Small mammal communities in agroecosystems in the American Midwest typically reflect low species diversity and moderate abundance (Warburton and Klimstra (1984), Wooley et al. (1985), and Castrale (1985). Deer Mice are the predominant mammal found in cropland although White-footed Mice, House Mice, voles, and ground squirrels are widespread. These studies found that no-till fields supported higher species diversity and diversity was greater at field margins than in field centers.

Small rodents are of concern to farmers who fear damage to their crops. While these fears may sometimes be justified, Wooley et al. (1985) pointed out that insect damage poses a much greater threat (perhaps two to ten times greater). Moreover, small mammals are omnivorous and may consume large numbers of arthropods; checks on Deer Mice, for instance, showed that arthropods constituted 33 to 85% of their diet (reviewed in Wooley et al. 1985).

Increasing field complexity offers a greater range of microhabitats and sustainable food resources resulting in more diverse and abundant small mammal populations. A comparison of small mammals in three adjacent fields of varying successional age — hayfield (annual cuts), native grasses (uncut for several years), and old field (undergoing secondary succession for over a decade) — demonstrated that the relative abundance and diversity was highest in the old field and lowest in the hayfield (Sietman et al. 1994).

# 3 WILDLIFE IN NON-CROPLAND

Agriculture is not by definition inimical to wildlife. Indeed, many species thrive in association with moderately high levels of cultivation providing that some space is left for them (Ratti and Scott 1991). It is no accident that in southern Ontario, the southern section of the Norfolk sand plain where there is still a significant forest cover (25%), along with varied habitat elements, supports an unusually diverse and abundant biotic community (Gartshore et al. 1987). Farmlands near Ottawa with at least 20% forest cover have retained about 90% of the plants and animals found in large forest ecosystems, illustrating the large degree of compatibility that can occur between natural and agricultural systems (Middleton and Merriam 1983).

Habitat — fencerows, scrubby strips, meadows, shallow vegetated ditches, and woodlands — is central to wildlife. Invariably, when these diverse habitat elements disappear, so too does wildlife. For example, in Illinois the habitat losses associated with modern farming that occurred between 1910 and 1970 (i.e. the removal of "odd' features such as old fields, woody cover, and edge habitat) led to a 50% decline of farmland game harvest and a 80 to 95% reduction of grassland bird species (Vance 1976). Graber and Graber (1963) conservatively estimated a net population loss in southern Illinois during this time of 4,000,000 breeding birds.

Farm practices designed to reduce soil loss bestow some secondary benefits on wild communities. However, no real improvements to wildlife will occur unless at least some natural cover is protected, restored, or created preferably using native plant species (Jordan et al. 1988; Hobbs et al. 1993). Restoration has enormous potential for increasing biodiversity. Soule and Kohm (1989) predicted that "rehabilitation of degraded places may become the dominant activity of conservationists in the twenty-first century." Marginal or retired farm lands may be the best setting for restoration programs, but smaller measures might also be implemented in more intensively farmed landscapes.

### 3.1 Plants

Disturbance and higher light levels such as are found between field and fencerow and field and forest support high plant diversity and productivity. Higher species diversity, however, should not be used as an unqualified index of environmental quality (Yahner 1988; Westmacott 1991). Edge species are common and abundant and rarely in danger of extinction in fragmented landscapes. By comparison, late successional habitats (i.e. deciduous forest) may feature fewer species but these are usually of higher conservation interest since they are dependent entirely on less disturbed conditions and have become increasingly rare or restricted in range since European settlement (Saunders 1993).

If the intent were to preserve forest interior plants, a conservation strategy might favour a large number of relatively small patches (Usher 1987). A maple-beech forest, for instance, need only be 3.8 ha (assuming it is round or square) in order to support self-sustaining forest interior conditions (Levenson 1981; Ranney et al. 1981). This is a size of reserve that could be accommodated in most farmscapes.

Whether species dispersal would occur among small, isolated forests is another matter. Some tree species are more difficult to re-establish after they have been eliminated from a site than others. Species that are bird dispersed (such as cherries) have a considerable advantage over the heavy-seeded mammal-dispersed or wind-dispersed species (such as oaks and maples) (Levenson 1981). Corridor linkages, either the result of regeneration or restoration, could facilitate species dispersal (Maitland Valley Conservation Authority 1993).

Small forest fragments can experience significant internal microclimatic changes resulting from increased exposure to wind and sun (Saunders et al. 1991; Hobbs 1993;). Drier conditions along the edge can lead to the loss of plant species especially rich in nectar (i.e. jewelweeds), their departure soon followed by pollinator fauna and other plants that depend on these pollinators (Hansson and Angelstram 1991). It is tempting as well to speculate whether increased local evapotranspiration rates and decreased soil and litter moisture in forest patches reduces leaf litter fauna on which species such as Redback Salamander and Ovenbird depend (Francis and Campbell 1983; Gibbs and Faaborg 1990).

High plant diversity can occur in farmland mosaics but this usually is due to the large numbers of introduced weeds and exotics that prevail. In one Iowa countryside, 99% of the roadside acreage was covered by introduced species (Drake and Kirchner 1987). Although these species provided erosion control and some wildlife habitat, the small areas covered by native species of prairie grasses and woodland plants had less disturbed soils, more natural fauna, and a deeper water table. It is difficult to say, though, whether the system with introduced flora is any less stable than a natural system. This would require further study using direct comparisons between the two.

What is known, however, is that natural systems with greater species diversity are more robust than species-poor ones. Tilman and Downing (1994) observed that grassland plots with the greatest diversity of plant species lost far less of their vegetative cover as a result of severe drought and recovered much faster than plots with the fewest species. Their study suggested that with each species lost from a study plot, the system's resistance to drought was diminished.

Efforts are underway in some parts of the American Midwest to restore native prairie habitat using seed sources from nearby remnant areas (Camp and Best 1993). The Nature Conservancy, which usually has sought to acquire pristine habitat, has purchased hundreds of acres consisting of pasture, cropland, and alien scrub in Illinois with the intention of restoring them to native prairie (Packard 1989). This might be an appropriate conservation model for southern Ontario. Even though forests predominated in pre-settlement times, large patches of prairie did occur (Brown 1993), and it would be much easier, and now perhaps more appropriate, to reintroduce a prairie ecosystem to portions of the open agricultural landscape.

### 3.2 Invertebrates

Invertebrates are the dominant faunal component of soil. However, it is not widely recognized even by biologists, policy makers or the lay public, that soil is a complex habitat that harbours about half of the living biomass of temperate terrestrial ecosystems (Biodiversity in Canada, 1994). This means that something in the order of about half of our biodiversity heritage in temperate terrestrial ecosystems resides within the soil.

However, because of the small number of scientists working with soil ecosystems, we have no inventory of that biodiversity, mostly represented by invertebrates and microbial organisms.

Areas with permanent vegetation, even if only grasses, increase general arthropod diversity on farmland (Brust and House 1988; Tucker 1992). Field margins are more naturally diverse and structurally complex than the surrounding cropland and offer arthropods a greater range of habitat choice (Hassal et al. 1992). Predatory insects may be particularly dependent on dense vegetation and deep sod layers for their persistence (Kromp and Steinberger 1992; Lagerlof and Wallin 1993). Uncultivated areas serve as a retreat for some invertebrates when conditions in a field are unfavorable, especially during winter or after heavy cultivation (Dennis and Fry 1992; Usher et al. 1993).

One of wildlife's most important roles in above ground (epigaeic) terrestrial ecosystems is as pollinators, primarily carried out by insects. The estimated economic value of insect pollination to agricultural production in Canada is $1.2 billion per annum (Kevan et al. 1990a). Pollination is one of several crucial ecological and evolutionary links in the sustaining of all life (Kevan et al. 1990b). Pollinators such as bees and butterflies have declined following the destruction of fencerows and other neglected strips (Kingsmill 1993). In Britain, unimproved scrubby pastures were seen to support at least 28 species of butterflies (Woiwod and Stewart 1990). This number dropped to zero when the pastures were plowed. Dover (1991) found that virtually all of the butterflies (98%) present in a field system were restricted to the uncultivated field perimeter, attracted there by nectar sources. Herbicide sprays eliminate most pollen- and nectar-producing flowers. In their place appear a few resistant grass and herb species that are of little use to pollinating insects (Lagerlof et al. 1992). Spray-free buffer zones around field margins could enhance these areas for pollinators and other wildlife.

Woodlands support a varied and abundant invertebrate community. Sgardelis and Usher (1994) compared the diversity and abundance of soil mites found in British woodlands and adjacent fields. Woodland soil hosted rich mite populations (at least 29 species). By contrast, only one mite species effectively occupied nearby arable land while perhaps an additional 9 species were restricted to the narrow field/forest ecotone. Agricultural lands in this instance seemed to present a real barrier to the dispersal of most cryptostigmatic mite populations. Mader (1984) found that small woodland islands in agricultural settings held much higher numbers of beetles and spiders than was expected. He speculated this was due to undisturbed conditions and the fact that woodlands offered a retreat for species escaping intensive or chemical disturbance in nearby fields.

Habitat size and isolation have been shown to exert considerable influence on some arthropod populations. Species richness and densities of flies and beetles in nine city parks in Cincinnati, Ohio increased with area (Faeth and Kane 1978). Heathland spiders in Britain were found to be restricted to the largest habitat patches, having disappeared from smaller ones (Hopkins and Webb 1984). Carabid beetles in the Netherlands apparently have vanished from many localities on account of habitat fragmentation (Turin and den Boer 1988).

Area effects have figured less prominently in other studies. Usher et al. (1993) concluded that size (as well as shape and isolation) of forest patches were of limited use in predicting overall species richness of ground beetles and spiders. They found that the considerable movement of species into woodlands from the surrounding fields seriously confounded the area/species relationship. There was some evidence, though, that increased isolation from other woodlots resulted in fewer spider species. Studies from diversified agricultural areas in Switzerland considered that habitat suitability (presence of patchy habitats), rather than the size or distance from other habitat islands, was the most important influence on invertebrate populations (Duelli et al. 1990).

Whatever the exact reason, whether on account of size, proximity to other colonizing sources, or just plain suitability, it is apparent that natural habitat elements support abundant invertebrate populations. This fact is not lost upon birds. Many insectivorous neotropical bird migrants make extensive use of brushy fencerows and small (<3 ha) woodlots (but not cleared fields) during spring and fall migration (Cable 1991; Winker et al. 1992; Gartshore 1993). Peak densities of invertebrates in fencerows and forests may coincide with migration dates, thus making these areas extremely important as stopovers for migrant travellers (Winker et al. 1992). Increased populations of flying insects have been observed on the leeward side of windbreaks, and in windbreak canopies (Yahner 1983a; Cable 1991). These concentrations serve as rich food sources for aerial feeders such as bats, nighthawks, and swallows.

### 3.3 Amphibians

Amphibians and reptiles are believed to be less susceptible to habitat fragmentation than either mammals or birds. Wilcox (1980) argued that herpetofauna are least prone to rapid collapse by virtue of their high population densities, smaller body size, and lower metabolic demands. Hedges (1993) noted that mammal populations in the West Indies had bottomed out long before amphibians in the face of fragmentation; he believed that large-scale amphibian extinctions were unlikely until forest cover reached very low levels (which it now has). While there may be considerable merit to these views, they do not sufficiently explain the recent precipitous decline or disappearance of frogs and toads, many of them from seemingly pristine habitats (Wake 1991).

Amphibian response to habitat fragmentation has received surprisingly little attention in the published literature. In Germany, Mann et al. (1991) reported that ponds situated close to other ponds were more likely to be inhabited by many amphibian species than were single, isolated ponds. No information was provided on the terrestrial habitat between ponds. Similar benefits on the advantages to frogs and toads of clustered pools were cited by Laan and Verboom (1990) and Sjogren (1991).

Francis and Campbell (1983) found the diversity and abundance of most herpetofauna in the Region of Waterloo to be lowest in those areas subjected to intensive agriculture, including extensive drainage and clearing of woodlands. Spring Peepers, Gray Treefrogs, and Redback Salamanders, which all should be common countryside species, were scarce or absent in areas with few woodlots or where the remaining woodlots were intensively drained by deep ditches (causing the rapid loss of ephemeral pools and the desiccation of the forest floor). Laan and Verboom (1990) similarly observed that the likelihood of encountering amphibians in newly created pools was greatly increased by the presence of nearby woodland. In agricultural districts, the presence of marshes, swales, low roadside ditches, brushy fields and thickets, and meadows help to enhance habitat for a diverse number of amphibians and reptiles (Francis and Campbell 1983; Reh and Seitz 1990).

A word about fish. Habitat fragmentation for amphibians may follow not just from the physical destruction of natural areas but from the presence of introduced fish predators. Non-native fish such as bass and trout are stocked in many farm ponds and rural watersheds. Their presence can effectively reduce or eliminate populations of frogs and salamanders or limit their dispersal down waterways (Fellers and Drost 1993).

### 3.4 Birds

Studies of birds provide us with much of what we know about species' response to habitat fragmentation and alteration. As already noted, intensively managed crop lands represent the equivalent of ecological deserts for most bird species. The retention of even small habitat elements such as grassy verges and tangled thickets increases landscape and biological diversity. Progressively more complex vegetative features — herbaceous strips, treed fencerows, small woodlots, large forests — generally result in either a more diverse and abundant avifauna or a more specialized bird community that could not survive in the surrounding agricultural matrix.

In many parts of the USA, and to a lesser but still considerable extent in southern Ontario, pasture, hay, and oat fields have been replaced by monocultures of corn and soybeans (Freemark et al. 1991). In some agricultural lands, grassy roadside strips may offer the only semblance of 'natural' areas and thus constitute the most important local conservation resource (Hobbs et al. 1993). Warner (1992) examined 593 nests along interstate and secondary roads dissecting the corn/soybean belt in central Illinois. About 92% of the discovered nests were of one species, Red-winged Blackbird. At least for birds, narrow linear roadsides cannot compensate for the loss of large grassy tracts (such as hayfields) that can support a much more diverse community.

Camp and Best (1993) studied bird use of roadsides adjacent to rowcrop fields in central Iowa. They reported that bird diversity was marginally higher, and abundances much higher, in roadsides than in fields, with both communities comprised almost entirely of omnivorous or granivorous species well adapted to human-modified landscapes. The three most abundant species by far in roadsides were Red-winged Blackbird, Brown-headed Cowbird, and Vesper Sparrow. Dominant field species were Brown-headed Cowbird, Horned Lark, and Vesper Sparrow.

Field and road margins often are susceptible to agricultural encroachment (i.e., cultivation and herbicide spraying). In Europe and the USA, experiments are underway to study the effects on field borders of not spraying the outer 6 m of crop fields (Dover 1991; Ratti and Scott 1991). A reduction in the use of sprays around field margins results in a more diverse non-crop flora and a generally safer environment for edge species (Wratten and Thomas 1990). Greater richness of vegetation increases nectar sources for flies, bees, and butterflies, increases arthropod diversity including predatory species, and enhances the habitat for birds that require arthropod food (Dennis and Fry 1992; Rodenhouse and Best 1994).

Many studies have documented the benefits to birds of fencerows, field margins, and vegetated stream corridors. The bulk of these studies originate in parts of the U.S. where regional tree cover is scant. Research from these areas might have special relevance for similarly open regions that prevail throughout southern Ontario (in Essex County, less than 4% of the countryside stands as natural habitat [NHRP n.d.]). Increased landscape diversity, especially if this includes woody cover, contributes to a dramatic rise in avian diversity (Johnson and Beck 1988). Trees and shrubs are attractive to birds because they offer additional foraging substrates, and perhaps more importantly, additional nesting sites (Martin 1993).

Grazed riparian corridors that have been fenced off to promote regeneration and succession experience significant increases in avian species richness and abundance (Hafner and Brittingham 1993). Best (1983) reported that over the course of a year Iowa farmscapes with fencerows contained more that six times as many bird species as farmland without any such features (62 species versus <10 respectively). Best (1983) further observed that fencerows with trees supported a much more diverse and abundant breeding avifauna than did herbaceous fencerows (27 species versus 6 respectively).

It is encouraging to note that species can quickly recolonize areas if suitable habitat is provided. In Idaho, a 7 ha plot of farmland set in a sea of intensively cultivated fields was converted to permanent cover and partially reforested. Over a 10-year period, the number of recorded avian species steadily increased from 18 to 73 species, and breeding species increased from 2 to 24 (Ratti and Scott 1991).

Some writers refer to fencerow-type habitats as "woodland edges without the woods" (Forman and Baudry 1984). While treed corridors often are avian oases, no species are restricted exclusively to these habitats. The species that thrive here, not surprisingly, are generally common types well adapted to edge conditions. Insectivorous birds (warblers, vireos) that prefer forest interior conditions are relatively rare in even the widest corridors (Best 1983; Johnson and Beck 1988). However, there are exceptions such as Indigo Bunting, Yellow Warbler, and Common Yellowthroat (Kline 1990).

Yahner (1983a) recorded 87 species of birds in seven shelterbelts in Minnesota, though only 17 were known nesters. Of these, almost all were habitat generalists well adapted to foraging in adjacent farmsteads and agricultural lands. Yahner (1988) held that the diversity of breeding birds depended in part on the nature of the surrounding fields; shelterbelts adjacent to cropland such as corn had greater diversity that if abutted by well-grazed pasture. Presumably, vegetation in cropland provides better foraging and singing sites for birds such as Eastern Kingbird, Vesper Sparrow, and Song Sparrow than the sparse pasture grass. The influence of adjacent habitat elements was similarly observed by Morgan and Gates

(1982) who found higher species richness of breeding birds at interfaces of forests and multiflora rose hedgerows than at interfaces of forests and cultivated fields.

In rural southern Ontario, unique bird communities are usually found in relatively large remnant patches — savannah, wetland, meadow and old field, and forest. Forests are by far the most common and best-studied of these habitat features, in large part because of recent widespread concern over the status of forest-dwelling neotropical migrants (see Terborg 1989; Hagan and Johnston 1992).

Studies of many forest sites within a single region have shown that small forests may contain as many or more avian species than large forests (Whitcomb et al. 1981; Lynch and Whigham 1984; Friesen 1991; Loman and Von Schantz 1991). These findings seemingly contravene island biogeography wisdom (which states that larger areas should have more species). A critical factor here, however, is the impact of external influences. In the Region of Waterloo, the great majority of birds found in small woodlots (<5 ha) are generalist species — European Starling, Northern Cardinal, American Robin, Song Sparrow, Common Grackle — that utilize both forests and the surrounding landscape (Friesen 1991). Their presence more than compensates (if viewed strictly from a diversity perspective) for the loss of species that are sensitive to habitat fragmentation.

The conservation value of larger forests becomes apparent when one examines the distribution patterns of those species — most of which are neotropical migrants — that are restricted mainly to forest habitat. Numerous studies have demonstrated that forest size accounts for most of the variability in the species composition and individual abundance of neotropical forest birds (for reviews see Askins et al. 1990; Wilcove and Robinson 1990; Finch 1991). In a study of 76 woodlots in the Region of Waterloo, Friesen (1994 unpublished data) found that small woodlots (<5 ha) contained on average 5 neotropical migrant species totalling 7 individuals; 10 ha-sized woodlots contained on average 8 neotropical migrant species totalling 14 individuals.

The importance of area has also been demonstrated for grassland and savannah species of birds. Bollinger and Gavine (1992) found that large hayfields (10 to 15 ha) held more breeding Bobolinks than numerous smaller patches of equivalent area. Cheskey (1991) reported that habitat size in Ontario's Grand River Valley was positively correlated with the presence and abundance of savannah species such as Blue-winged Warbler, Golden-winged Warbler, and Rufous-sided Towhee.

The total amount of regional forest cover has been identified as an important factor in determining the distribution of neotropical and other forest bird species (Lynch and Whigham 1984; Askins and Philbrick 1987). Freemark and Collins (1992) found that in comparing four landscapes with different amounts of forest cover, the number of forest-interior species (75% of them neotropical) increased most quickly with forest size in the study area which had the greatest cover. Smaller forests in this landscape were also more likely to harbour forest-interior species than were forests in regions with less cover where the forest birds became more area-sensitive. However, studies from other areas, most notably those in intensively farmed districts, have found high numbers of neotropical migrants in extremely isolated forests, provided they were of sufficient size (Blake and Karr 1987; Robinson 1992).

### 3.5 Mammals

Forest fragmentation clearly has had a major impact on mammal populations in southern Ontario. In Waterloo Region, for example, nine mammal species out of an original pool of 50 have been extirpated since European settlement (Campbell et al. 1972). The species lost were generally the largest or highest on the trophic ladder and included Wapiti, Black Bear, Cougar , and Timber Wolf. Several new species have arrived, most notably dogs, cats, and Opossums.

Land clearance, either for agricultural purposes or timber, poses a grave threat to forest mammals. But owing to the logistical difficulties of censusing these species, few published accounts exist describing their response to fragmentation. The best report to date dealing with mammalian species-area relationships and the effects of the surrounding landscape comes from southeastern Wisconsin (Matthiae and Stearns 1981). Here, a total of 13 mammal species on 22 deciduous forest islands (0.03 to 40 ha in size) were observed or live-trapped. Eastern Chipmunks were the only true forest specialists among the species under study, other specialists either having been extirpated (Moose, Lynx) or having extended their range beyond the forest (White-footed Mouse, Raccoon). The Wisconsin research revealed that while the overall number of species increased with forest size, the abundance of some species such as White-footed Mouse, Eastern Chipmunk, Gray Squirrel, and Raccoon showed no relationship to habitat size.

The distribution of Red Squirrels in the Netherlands and Grey Squirrels in Britain both seem to be affected by woodland size and isolation (Verboom and Van Apeldoorn 1990; Fitzgibbon 1993). Both species are more likely to occur in larger woods and in small woods that are close to a large woodland. In Iowa, larger, less remote forests contained more White-footed Mice and other small mammals than smaller, isolated habitats (Gottfried 1979).

It may be that fragmentation dynamics operate differently in more forested, less isolated landscapes. Yahner (1992) studied the effects of forest clear-cutting on populations of small mammals in heavily forested regions of central Pennsylvania. As forest patches became smaller, the two most common rodents (White-footed Mouse and Southern Red-backed Vole) both increased in abundance. Similar patterns of increase of small mammals following clear-cutting have been noted elsewhere (Kirkland 1977). Yahner (1992) cautioned about extending his findings to other taxa, particularly wide-ranging, area dependent species.

In some districts, narrow linear strips such as shelterbelts and fencerows represent the best, and sometimes the only, treed refuge for mammals. Up to 28 species of mammals (most of them of small body size) have been recorded in U.S. windbreaks. Seven of these species are highly dependent on windbreaks for their survival (Johnson and Beck 1988). The three most common small mammals in Minnesota shelterbelts — White-footed Mouse, Meadow Vole, Short-tailed Shrew — typically inhabit woodlands or grasslands but in the absence of these habitat elements settle in windbreaks (Yahner 1983b). Windbreaks thus provide habitat for wildlife species that otherwise would be much more restricted in their distribution.

## 4 CORRIDORS

The role of corridors (hedgerows, windbreaks, ditches, roadsides, and streambanks) has generated considerable debate among ecologists. Corridors may offer benefits (habitat refuges in intensively managed agroecosystems, linkages facilitating the movement of flora and fauna, food sources for swallows and bats) and disadvantages (barriers to dispersal, conduits for disease and disturbance [Simberloff and Cox 1987]). Given the prominence of corridors in both the agricultural landscape and in the conservation literature, their value to wildlife (particularly as travel lanes for movement) will be reviewed.

The subject of corridors provokes strong, sometimes conflicting, opinions. One corridor proponent recently exclaimed that "these linkages hold more promise for the conservation of the diversity of life than any other management factor except stabilization of the human population" (quoted in Chadwick 1991). Critics, on the other hand, contend that wide advocacy for corridors seems to be based more on intuition and wishful thinking than actual scientific evidence of which there is an impressive shortage (Simberloff et al. 1992).

Corridors offer the potential of linking up isolated remnants patches, thereby increasing immigration and/or decreasing extinction rates of local populations. But do facts fit the theory? In the case of woodland vegetation, the answer appears to be 'No'. Studies from Europe and Ontario have provided no supporting evidence for the spread of interior-adapted plant species along corridors; the prevailing edge conditions are simply too harsh for either their establishment or dispersal (Levenson 1981; Fritz and Merriam 1993). Ranney et al. (1981) felt that wooded corridors in Wisconsin would need to be at least 100 m wide to sustain beech trees and 30 m wide to support sugar maple.

The importance of corridors to dispersing invertebrates remains largely unknown (Dempster 1991). Burel and Baudry (1990) supplied some evidence that hedgerows in France may assist in the movement of ground beetles between established forest habitat and old fields. Dover (1991) found that butterflies were inclined to follow the contours of hedgerows and copse edges when in flight. Many species of forest soil mites appear incapable of surviving in arable fields, prompting speculation that a hedgerow network might facilitate dispersal (Sgardelis and Usher 1994).

The use of corridors by amphibians and reptiles is similarly shrouded in mystery. Reh and Seitz (1990) held that meadows and ditches play an important role as corridors for the dispersal of frogs in Germany though they provided no quantitative data on movement.

Studies of birds yield contradictory evidence on the conservation merits of corridors as avenues for movement. In Brazil, Ant-birds promptly disappeared from a remnant jungle patch when the linkage to a nearby rainforest was severed (Stolzenburg 1991). When this avenue was re-established by new growth, the birds quickly reappeared. Johnson and Adkisson (1985) studied the dispersal of beech nuts by Blue Jays along a 500 m hedgerow between a forest and a bog. Over 90% of the 158 flights observed followed the hedgerow.

MacClintock et al. (1977) studied bird communities in a small 14 ha forest fragment and a larger 162 ha woodland that were connected by a narrow vegetated corridor. They believed that the connecting causeway, which also held territories of forest interior birds, was an important reason why the fragment contained most of the breeding birds found in the larger forest. Simberloff and Cox (1987) contended that this study was uncontrolled and failed to separate corridor effects from the effects of proximity of the habitat island to the extensive forest. Ambuel and Temple (1983) suggested that, at least from the standpoint of neotropical migrants, corridors are just long strips of edge with associated problems. Far from benefitting these species, corridors may actually funnel predators, potential competitors, and brood parasites into a forest.

Studies of mammals are no more conclusive in determining the role of corridors for the movement of individuals. Red and Grey Squirrels are more likely to be found in woods with a higher density of hedges in the countryside, suggesting the importance of connectivity (Fitzgibbon 1993). Bennett (1990) surveyed Long-nosed Potoroos in Australian forest patches and concluded that corridors serve these small marsupials as both habitat and avenues for movement. Simberloff et al. (1992) noted that Bennett's conclusions rested on just two animals trapped in forested corridors while no traps had been placed outside corridors to detect possible movement there. They cautioned that though "an animal uses corridors when these are present, (this) need not mean movement without them is impossible, or even less frequent."

In Ontario, numerous studies have demonstrated the importance of fencerows as movement corridors and also as habitat for small breeding populations of White-footed Mice and Eastern Chipmunks (Henderson et al. 1985; Merriam et al. 1989; Merriam and Wegner 1992). Simberloff et al. (1992) voiced concern that movement might occur just as readily outside of corridors, although Merriam and Lanou (1990) demonstrated that White-footed Mice display a marked preference for moving through agricultural landscapes via fencerows. However, studies also indicate that White-footed Mice routinely voyage through fields (Merriam and Wegner 1992). The evidence gathered so far is equivocal in affirming or denying the notion that corridors function as wildlife travel lanes. Further judgment of their effectiveness in this regard requires more detailed study on the movement of individual species. Noss (1987a) argued that in the face of ignorance about corridor phenomena, prudence should dictate that we preserve or restore corridor networks. Natural landscapes are fundamentally interconnected, he reflected, a situation which contrasts sharply with human-modified landscapes. Noss (1987a), along with Saunders et al. (1991), concluded that the pattern of habitat connectivity observed in nature should inform our own management models.

It should be remembered that corridors have considerable value for wildlife apart from their movement potential. As noted earlier, naturalized field margins are species-rich sanctuaries for invertebrates and are important for the conservation of overall species diversity in the agricultural landscape. Treed corridors dramatically improve conditions for the avian community and in some districts apparently have extended the breeding range of as many as 10 bird species (Johnson and Beck 1988). Migratory songbirds make extensive use of treed corridors for feeding during spring and autumn passage (Cable 1991). During winter, Wild Turkey and Ruffed Grouse regularly feed on the fruit and seeds found in fencerows (personal observation). And as will be discussed later, corridors serve as environmental filters, windbreaks, and streambank stabilizers.

Corridors can also be an important biotic reservoir for the restoration of cleared or retired agricultural land (Zanaboni and Lorenzoni 1989). Local genetic stock is desirable for many reasons, among them that corridors function better when they resemble the blocks they connect (Noss 1987a). In southern Ontario, two separate restoration projects — one in Essex County (NHRP n.d.), the other in Haldiman Norfolk (Gartshore 1993) — have relied exclusively on local plant materials collected from local farm woodlots, fencerows, and meadows.

## 5 POPULATION DYNAMICS IN AGRICULTURAL LANDSCAPES

Fragmented habitats shortchange wildlife populations in a number of ways. Subdivided habitats can support only a limited number of individuals. Many researchers believe that some populations surviving in habitat islands may be too small to sustain themselves without frequent immigration. The loss of connectivity (hedgerows, verges, forests) diminishes the potential for migration and dispersal. External influences from the surroundings undermine the reproductive success and survival of many species.

### 5.1 Genetics

According to population theory, the fewer the individuals, the more at risk they are from the chance forces of nature (Shaffer 1981, 1987). Stochastic (random) events may leave a population with too few females, too many aged, or too little genetic variability. At this stage, natural catastrophes such as storms or fire or a sudden influx of predators that might have little lasting impact on large populations could snuff out the remnant.

Small stable populations, however, have persisted in various places over relatively long periods of time. Numerous endemic species on small islands apparently have thrived for millennia though their numbers have never been more than several hundred (Simberloff et al. 1992). On Soccoro Island located 500 km off the coast of Baja California, a small sedentary population of Red-tailed Hawks has persisted for at least a century with an isolated effective breeding population of only 15 to 20 individuals (Walter 1990). In New Mexico, Acorn Woodpeckers survive in small fragmented populations of as few as 50 individuals without showing any sign of going extinct (Stacey and Taper 1992).

Reh and Seitz (1990) found that less isolated populations of amphibians had more alleles and were more heterozygous than the more isolated ones. But whether a loss of genetic diversity would ultimately doom this or other populations remains an open question (Saunders et al. 1991; Simberloff et al. 1992). It is worth noting that only a tiny amount of gene flow, perhaps in the order of one or two new dispersing individuals per generation, is required to counteract the loss of genetic variation in subpopulations (Lande and Barrowclough 1987).

### 5.2 Fragmentation Effects

Genetic considerations appear to be the least of the problems besetting fragmented populations. Of far greater concern are the adverse impacts that flood in from the surroundings. Saunders et al. (1991) asserted that in small patches and corridors "ecosystem dynamics are probably driven predominantly by external rather than internal forces." Spillover effects are reflected in forest patches that are overbrowsed by deer and rabbits which thrive in nearby farm country, and in wetland habitats that have become poor producers of waterfowl and other aquatic birds because so many eggs and young are taken by skunks and raccoons.

Fragmentation degrades habitat in varied ways. Remnants may be vulnerable to the depradations of rodents that invade forests from croplands. In central Europe, mice consume substantial quantities of seeds and so affect plant regeneration and community structure in forest systems (Hansson and Angelstram 1991). The increase in habitat edge proportional to habitat interior exposes more patch area to a greater intensity of external forces. Greater exposure to solar radiation and increased winds may result in tree blowdowns, increased evapotranspiration, and changes in soil and air temperatures and moisture regimes (Hobbs 1993). Along edges and in small forest fragments, holes excavated by woodpeckers often are appropriated by opportunistic species such as starlings to the detriment of typical forest species (Nilsson and Ericson 1991).

Edges per se are not the problem for many animal species. High abundances of Great-crested Flycatchers, Eastern Wood-pewees, and Carolina Chickadees occur within the initial 25 m of forest edge, perhaps because of the abundant foraging and singing sites here compared to greater distances from the edge (Strelke and Dickson 1980). Kroodsma (1984) studied the pattern of bird territories with respect to forest edges in eastern Tennessee. Of 22 forest-dwelling species, he reported that three preferred to nest near the edge, two nested in higher densities away from the edge, and the remaining 18 showed no preference for either edge or interior. Edge aversion evidently is not the main factor responsible for the low number of neotropical migrants found in many forest fragments.

Edges support high species diversity. Unfortunately, included among these species are a high concentration of predators, parasites, and competitors that greatly amplify pressures on plant and animal populations living in the subdivided habitats (Laurance and Yensen 1991). Adverse edge effects are especially powerful forces when fragments are small or irregularly shaped or when the transition between natural and modified habitats is abrupt (Wilcove et al. 1986). These are precisely the conditions that apply in farmland mosaics.

Ambuel and Temple (1983) speculated that competition from edge species may be especially pronounced in smaller forests. They noted that small woodlots (<5 ha) have a high density of Common Grackles, Red-winged Blackbirds, and European Starlings that may compete with neotropical forest species for food and shelter. Wilcove and Robinson (1990) reported that in some fragmented forests in Illinois, post-breeding flocks of up to 80 Common Grackles combed the forest floor in search of invertebrates, an important food source for litter-foraging birds as Wood Thrush and Ovenbird. Though the hypothesis is suggestive, to date no quantitative data exist to support the hypothesis that competition from generalist species may be limiting neotropical forest songbirds (Askins et al. 1990).

Predation and parasitism pressures become more pronounced as the proportion of agricultural land increases (Andren 1992). A variety of predators — cats, dogs, foxes, raccoons, skunks, mice, squirrels, crows, jays — flourish in farmlands and readily utilize food sources both around farms and other human settlements and in natural habitat patches (Andren 1992).

Raccoons well illustrate the detrimental impact of altered predation patterns common to fragmented landscapes. Since 1930, it is conservatively estimated that raccoon populations in North America have increased 15 to 20 times (Sanderson 1988). Raccoons prey on over 100 species; their nest depradations exert heavy pressures on species ranging in size from tiny songbirds to large alligators (Harris and Silva-Lopez 1992). The absence of large predators that might control raccoons and other small predators may contribute to their high abundance (Wilcove et al. 1986). Where predators such as wolves are found, raccoons themselves become a staple prey item (Phillips and Henry 1992).

Predation appears to be higher in small than in large forests and along the forest edge than in the interior (Wilcove 1985; Andren and Angelstam 1988). Predator activity can be so severe that it limits the distribution of some forest species. The southern range of Snowshoe Hares in Wisconsin is likely set not so much by an absence of habitat as by inflated predator abundance associated with fragmented landscapes (Sievert and Keith 1985).

Birds are vulnerable to both predation and parasitism pressures. Nest predation is the single leading cause of nest failures across a wide range of species, habitats, and geographic locations, accounting for about

80% of all nest losses (Martin 1993). Predation not only wipes out nests but it may also lead to species' desertion of marginal habitats. Wood Thrush and other species that failed to breed successfully in one season tend not to return the following season, perhaps seeking to establish themselves in safer sites (Opdam et al. 1993; Roth and Johnson 1993). In some localities, notably in the American Midwest, nest parasitism by Brown-headed Cowbirds combines with predation to deliver a two-fisted blow to breeding birds that results in virtually no reproductive success (Robinson 1992).

Nest survival seems to be significantly higher in large forests than in small. In an unfragmented northern hardwood forest in New Hampshire, overall nesting success averaged ~63% for Black-throated Blue Warblers, and ~50% for American Redstarts (Holmes et al. 1992; Sherry and Holmes 1992). In both cases, predation was the primary cause of nest failure. Cowbird activity was negligible in New Hampshire, as it generally is in heavily forested regions, especially those furthest removed from the cowbird's historical range (Hoover and Brittingham 1993; Porneluzi 1993, Robinson 1993).

Nesting success is dramatically lower in at least some forest fragments and may be a crucial factor in the decline of neotropical migrant birds. Ovenbirds in Pennsylvania nesting in 11 forest fragments of varying size (9 to 183 ha) were found to have a nest success rate of ~ 6% (this compared with a 60% success rate in nearby large, contiguous forests; Porneluzi et al. 1993). Predation, but not parasitism, appeared to be the prominent factor undermining reproductive performance.

Robinson (1992) and Temple and Cary (1988) reported such high nest predation and parasitism rates (80% of nests overall, 100% in the case of some individual species) that some neotropical species registered a level of breeding success almost too low to measure. By contrast, Roth and Johnson (1993) estimated nesting success of Wood Thrush in a 15 ha Delaware woodlot to be between 60 to 65% over a ten-year period . Much lower rates of parasitism in their study area as opposed to Robinson's (1992) in Illinois may account for the higher nesting success.

How far into a forest do adverse edge effects extend ? Depending on the type of habitat and taxa, the answer seems to vary from 10 m to 7 km. In the northern hemisphere, major vegetational changes caused by the edge extend 10 to 30 m inside a forest, depending on whether the edge has a northern or southern exposure (Ranney et al. 1981; Yahner 1988).

The effects of edge-related predation and parasitism slice much deeper into a woodland. Brittingham and Temple (1983) noted an inverse relation between parasitism and distance to the edge, the highest rates occurring in the initial 100 m of forest. Temple (1986) later used an edge effect penetration distance of 100 m to measure the 'core areas' of fragments in a study of forest interior bird species. He found that core area (area 100 m from a forest edge) was a better predictor of neotropical species presence and abundance than forest area alone. Core area has also proven to be a better predictor of Wood Thrush nesting success than area alone (Faaborg et al. 1993). Wilcove (1985) demonstrated that edge-related increases in predation may extend 300 to 600 m into a forest. Robinson et al. (1993) found no appreciable decreases in parasitism levels even 800 m from the nearest edge; moreover, they noted that cowbirds are capable of regularly commuting at least 7 km between feeding and nest-searching sites.

Fragmentation studies reaffirm the ecological importance of large habitats containing as much core area as possible. Unfortunately, in many farming districts, habitat remnants are often small, long, and thin and offer virtually no core area habitat. The Region of Haldimand-Norfolk is the most heavily forested district in southern Ontario but even here, there is a dwindling supply of core area habitat. Only 3% of the land area contains forests with core areas at least 100 m from the forest edge (Steve Hounsall, unpublished data); this percentage drops to 0.7 % when a 200 m buffer zone is employed, and to 0.2% when a 300 m buffer zone is used.

Reforestation or restoration is unrealistic for most parts of southern Ontario, at least if the goal is to create habitat with substantial core areas. Yet some measures might be taken to protect the remaining interior structure and reduce detrimental edge effects. Plant communities and the forest floor are vulnerable to the effects of livestock grazing, horseback riding, and recreational use by motorized vehicles. These activities, which can create ideal situations for invasive, nonnative species (Saunders et al. 1991) should be prohibited (in the case of grazing) or carefully controlled. Placing roads and paths as close to the edge as possible leaves a larger central area with less disturbance (Harker et al. 1993). Promoting a thick forest edge might lessen predation and parasitism pressures in this vicinity (Yahner 1988; Martin 1993) and would also buffer the forest interior from some of the deleterious effects of wind, sun, and chemical sprays (Gartshore 1993).

Robinson et al. (1993) recommended that data on the distribution and abundance of female cowbirds can provide a useful index of likely parasitism levels. Actual parasitism estimates are needed for individual species. Such information is lacking for southern Ontario. But more challenging by far is how to make the farm landscape a less hospitable environment for cowbirds, given that pastures, feedlots, mowed areas, and fields littered with crop residues are ideally suited to them. Obviously, preventing further fragmentation of forest cover is an important consideration. Logging operations that reduce canopy openings and that do not open up the edge may make a forest less accessible to cowbirds. Research might also be directed at minimizing feeding opportunities for cowbirds and experimenting with pasture rotations that reduce the availability of short grass areas where cowbirds commonly forage (Robinson et al. 1993).

## 6 METAPOPULATIONS

Researchers have become more interested in how small, relatively isolated populations manage to sustain themselves in fragmented landscapes. Metapopulation theory increasingly is being called upon to explain the mechanisms of their persistence. According to the theory, regional populations consist of local, semi-isolated groups that are linked through the dispersal of individuals (Pulliam 1988; Merriam and Wegner 1992). Central to the metapopulation model is the notion of optimal quality 'source' patches which produce a surfeit of offspring. Some of the surplus disperses to marginal patches called 'sinks.' Sink patches are occupied less frequently than sources because they have smaller populations, are less likely to be chosen by dispersing individuals, and may be deserted by species as territories become available in better quality patches (Opdam et al. 1993). The result in the landscape is a dynamic pattern of local extinction and recolonization as sinks lose their populations and are subsequently, if irregularly, regenerated by dispersing individuals.

Actual field evidence providing support for metapopulation theory is slim. Simberloff et al. (1992) voiced concerns about the "tendency to take the metapopulation model as broadly representative of nature, rather than as a new and untested hypothesis." Dunning et al. (1992) concurred in that there are few empirical studies that have reliably differentiated between source and sink habitats or that have specified the range of dispersal rates and reproductive success that qualifies a group of populations as a metapopulation.

Invertebrates offer unique opportunities and challenges for study but their population dynamics have not been well documented (Kremen et al. 1994). Invertebrates are perceived as more difficult to survey than vertebrates, and it often is easier, especially in large patches, to produce information on their presence rather than their absence (Opdam et al. 1993). Sampling problems aside, some researchers still consider that invertebrates are less susceptible to extinction because of their relatively large population size (Opdam 1990). However, this assumes that invertebrates always have large population sizes, but we just don't have enough knowledge about invertebrate population dynamics in any ecosystem to make that statement with confidence. There is some evidence, though, that local extinctions may occur, at least for populations of carabid beetles (den Boer 1985), and phytophagous insects on goldenrod (Cappuccino 1991). One suspects that as more populations of invertebrates are studied, that local extinction will be demonstrated more frequently.

If extinction among invertebrates is more frequent than commonly thought, then dispersal ability becomes a critical factor for recolonization. Species like earthworms have limited mobility, moving no more than 4 to 9 m per year (Welch 1990). Flying forest insects, on the other hand, have been collected in traps set in fields positioned kilometers away from their nearest woodland haunts (Duelli et al. 1990). Sedentary species, then, might be more sensitive to fragmentation effects than their more mobile counterparts. A study of distribution of two forest beetles species — one non-flying, the other flying — showed the former to be present in only 4 out of 22 woodlots whereas the latter occurred at every site (Opdam et al. 1993).

Metapopulation theory assumes that larger patches will be occupied more often and over longer periods than small ones, and that less isolated patches will be recolonized faster than more isolated ones (Freemark et al. 1992). In a study of amphibians in the Netherlands, Laan and Verboom (1990) reported that isolation was indeed an important factor in the colonization of newly constructed pools by toads. Only those pools situated within 500 m of source ponds received dispersers.

Studies of Eurasian Red Squirrels in the Netherlands concluded that this mammal's distribution and population dynamics accorded well with metapopulation theory (Verboom and Apeldoorn 1990; Wauters et al. 1994). The squirrel's probability of occurrence was correlated to the size and structure of woodlots, the density of connecting hedgerows in the surroundings, and distance to the nearest woodlot larger than a critical size (source patches).

Studies of Eastern Chipmunks (Henderson et al. 1985) and White-footed Mice (Merriam et al. 1989) in farmlands near Ottawa revealed that populations can disappear from individual woods but then quickly reappear. For chipmunks at least, the researchers concluded that at least five woods and interconnecting fencerows in an area of ~4 $km^2$ were required to assure continuance of the species in this small region (Henderson et al. 1985).

The presence of empty, but suitable patches suggests not only the existence of metapopulations but also illustrates the effects that fragmentation might have on them (Opdam et al. 1993). A three-year study of European Nuthatches in the Netherlands demonstrated a clear pattern of colonization and extinction in 47 woodlots, almost half of which were unoccupied at any one time (Van Dorp and Opdam 1987). The probability of extinction decreased in larger woodlots and the probability of colonization decreased with isolation from occupied sites.

Villard et al. (1992) measured local extinctions of three neotropical species in 71 wooded patches near Ottawa over three years, and in 16 patches in the U.S. over another two years. They found that while the size of the population affected by metapopulation dynamics was small (one or two singing males per patch), the frequency of patches experiencing either extinction or recolonization was a relatively high 20 to 25%. For two species — Wood Thrush and Ovenbird — populations turnovers were concentrated in smaller patches.

Populations need not go extinct in order to function as sinks. Some populations that outwardly appear to be stable may in fact be sinks that are continually being bolstered by immigrants (Stacey and Taper 1992). This seems to be the case with at least some forest birds. Gibbs and Faaborg (1990) wondered how Ovenbirds in small forest fragments (9 to 183 ha) in Missouri could sustain themselves, given that three-quarters of territorial males were unpaired versus one-quarter on larger sites (>500 ha). Lower levels yet of Ovenbird reproductive success in small forests have been recorded in Pennsylvania (Porneluzi et al. 1993).

Researchers in other fragmented regions have noted that reproductive success of neotropical migrants is generally so low that populations could only be sustained by a steady infusion of immigrants (Ambuel and Temple 1983; Leck et al. 1988; Robinson 1992). And it is not just neotropical migrant populations that require a regular flow of colonists; in sites in New Mexico, research has shown that in some years at least 70% of resident Acorn Woodpeckers consist of newly arrived individuals from other populations (Stacey and Taper 1992).

Suggesting the existence of metapopulations begs knowing just what are the boundaries of regional populations. What is the scope of movement? How far do individuals disperse? That some species disperse widely and in ways beyond our current understanding is clear. Merriam et al. (1989) reported on a genetic study done on White-footed Mice in farmlands south of Ottawa. The mice were trapped in 11 fragments chosen specifically to have no fencerow linkages to other wooded patches and to be geographically isolated from each other by an average of 5 km. Genetic studies performed on a sample of mice from each of the woodlots indicated so little genetic variation that all could be considered a single interbreeding genetic population. The researchers were clearly perplexed by the extensive genetic exchange between apparently isolated populations.

Songbird populations interact over considerable distances, though at present no one has even an approximate clue of the ranges involved (Wilcove and Robinson 1990). A recent study using DNA fingerprinting of Ovenbirds found essentially no genetic differences between isolated populations as much as 150 km apart, suggesting high dispersal rates in Missouri forests (Faaborg et al. 1993). Returns of birds to natal areas are usually low (in the range of 1 to 10%) based on the return rates of individuals banded the previous year as fledglings (Leck et al. 1988; Sherry and Holmes 1992; Holmes et al. 1992; Roth and Johnson 1993). The destination of first-year breeders remains a mystery.

Adult birds may also be inclined to move about. Roth and Johnson (1993) observed that resident Wood Thrush who suffered nest failure one year (sometimes half the population) were much less likely to return to the woodlot the following year. However, they had no idea where they went; checks of 230 Wood Thrush in forests within a 10 km radius of the study sight failed to turn up a single emigrant (an alternative explanation might be that all of the unsuccessful nesters died during the nonbreeding season). Robinson (1992) concluded that the persistence of Wood Thrush in Illinois woodlots (where reproduction is negligible) depended on annual recruitment of birds from somewhere else. Yet there are no large, unfragmented woodlands within at least a 200-km radius of central Illinois that could possibly supply dispersers. Immigrants therefore must be coming in from areas hundreds of km distant.

Metapopulation studies, even at this early stage of understanding, offer some guidelines for habitat management and improvement. Effort is needed to determine the reproductive rates of certain species in order to at least roughly distinguish sources from sinks. This would require detailed autecological studies over a period of years. The uncertainty of differentiating a source from a sink, and the possibility that these roles might change depending on variable local conditions, argues for the preservation of suitable but intermittently unoccupied habitat (Freemark et al. 1993; Stacey and Taper 1992). Sinks may in fact play a crucial role in the long-term stability of regional populations by offering alternative habitat during exceptional times. The findings by Villard et al. (1992) that smaller patches tend to be sinks underscores again the importance of preserving large habitat patches. Care should also be taken that cumulative impacts — lot severances, increased isolation, disturbance due to logging, surrounding development — do not jeopardize the functioning of productive source areas (Freemark et al. 1992).

## 7 ANTICIPATED VALUES OF WILDLIFE AND WILDLIFE HABITAT

Incorporating ecological principles into farm planning practice has many potential benefits, not just for individual landowners but for larger society as well. Healthy and productive soils, tighter nutrient cycles, clean streams and aquifers, pollution abatement, increased land value, scenery, recreation, and a rich array of regional biodiversity are some of the gains that follow from a more diversified natural landscape (Noss 1987; Burel and Baudry 1990). These gains are indicative of sustainable land use patterns and increasingly are being associated with "quality of life" factors (Noss 1987b).

### 7.1 Healthy Soil and Environmental Filters

Natural habitat enriches the farm community in many ways. Perhaps most important, it provides agroecosystems with a readily observed model of sustainability and relative stability. Mature ecosystems tend towards a diversity of life forms and have a natural capacity for soil-building, drought-resistance, insect-resistance, and productivity. These features stand in sharp contrast to farm monocultures that require intensive care and expensive inputs.

Agriculture is intimately dependent upon services rendered by the natural biota. Soil microbes and invertebrates provide a host of essential functions without which the agroecosystem, and in fact the global ecosystem, would collapse (Stevens 1994). Soil biota condition the soil, consume decay and eliminate wastes, and recycle and transport essential nutrients and materials. Many of these organisms are also active in pollination which is essential to reproduction in many crops as well as in natural vegetation. In the U.S., more than 40 crops valued at approximately $30 billion are absolutely dependent on insect pollination for production (Pimentel et al. 1992).

Soil riddled by the tunnelling and decomposing work of microfauna and larger organisms has expanded water-holding capacity (Pimentel et al. 1992). About half the volume of healthy soil consists of spaces created by soil organisms (McAllister 1993). Healthy soil works as a huge sponge, absorbing nutrients, rain, and snowmelt that would otherwise leave as runoff. Reduced runoff lessens the chance of severe flooding since water is stored or slowed before it reaches rivers. Groundwater resources on which many communities depend are replenished as moisture percolates down into the earth.

Less runoff also means that one of the most valuable of farm resources — topsoil — remains on the field instead of out in the streams. Lowered sediment loads result in healthier aquatic systems, which given the vulnerability of freshwater ecosystems has important biological value (Franklin 1993; Wilcove 1993). Clearer streams also mean cleaner water supplies for downstream settlements and prolonged capacity for dams and hydroelectric installations (Hobbs 1993).

Natural features such as fencerows and forests limit soil loss by reducing surface and subsurface waterflow via interception, evapotranspiration, and movement to the groundwater through stem-and-root flow (Hobbs 1993; McAllister 1993). Plant cover impedes water flow and creates barriers to soil movement (Forman and Baudry 1984). The effects can be pronounced, as fields may be a foot higher on the uphill side of a fencerow than on the downhill side (Kline 1990). The closer that fencerows are to each other, the more they act to inhibit soil erosion. Doubling the distance between fencerows may result in a 40% increase in erosion (Forman and Baudry 1984). Corridors that follow topographic features usually are more effective in protecting soils against erosion than imposed linear linkages (Burel and Baudry 1990).

Early successional systems such as agroecosystems are less efficient at holding nutrients such as nitrogen, phosphorus, and calcium than mature systems such as forests (Odum 1969; 1985). Because they "leak" nutrients, farm systems need large inputs of fertilizers each year. A considerable portion of these nutrients is subsequently lost through surface runoff and groundwater flow. Natural vegetation can be an important filter of mineral nutrients, storing them in plant tissue or immobilizing them in soil, thus preventing their discharge into local watersheds (Lowrance et al. 1984).

Small riparian strips located between streams and cornfields have been shown to remove a substantial quantity of nitrate-nitrogen from the groundwater that otherwise would have moved into the stream (Peterjohn and Correll 1984). Similarly, shelterbelts have been demonstrated to effectively limit the water migration of various chemical compounds (Ryszkowski 1992) Ryszkowski (1992) concluded that an "agricultural landscape rich in ecotones loses fewer nutrients than a catchment area consisting only of cultivated fields."

Measures taken to promote and retain healthy soil may also keep natural areas in better repair. Heavy runoff from fields can wash eroded soils into habitat patches, destroying significant vegetation or providing ideal germination plots for invasive species (such as Garlic Mustard and Periwinkle) (Grand River Conservation Authority 1993; Hobbs 1993). Barriers that mitigate wind speeds benefit both cropland and natural habitat. Wind blows away or dries out topsoil, and may also transport nonnative seeds from the surrounding fields far into the interior of natural remnants (Saunders et al. 1991). Winds whipping in across an open landscape can cause high rates of treefalls and tree mortality along forest edges that alter forest structure and composition (Ranney et al. 1981).

### 7.2 Integrated Pest Management

An intriguing aspect of uncultivated field margins and hedgerows is their role in biopest control. Naturally diverse flora harbours rich arthropod populations, including predators that might consume cropland pests (Lagerlof and Wallin 1993). Predators and parasites from natural ecosystems are already performing a significant service in this regard, their contribution estimated as being far beyond that provided by pesticides (Pimentel et al. 1992). Yet they might accomplish even more if additional habitat was allotted to them. A natural, or integrated, system of pest control that relies less on chemical treatments could become an important component of lower input, self-regulatory farming methods (Luna and House 1990).

Integrated pest control usually considers only the work of invertebrate predators. However, the contribution of amphibians and insectivorous birds should not be overlooked. Toads, frogs, and salamanders, all of them voracious consumers of invertebrates (Johnson 1989), can be widespread on farmlands if provided with suitable habitat. Vesper Sparrows forage extensively in fields (Rodenhouse and Best 1994), while migratory songbirds consume enormous numbers of insects in farm woodlots and hedgerows (Cable 1991; Winker et al. 1992). Tillage methods and landscape features that increase population densities of beneficial species should be incorporated into integrated pest control programs.

Integrated pest control rests on a series of assumptions. One is that predatory invertebrates are more diverse and abundant in grassy or scrubby field margins than in cultivated fields. A second is that these predators are not restricted to off-field habitat but will forage in the cropland. A third is that the predatory activities can have a significant, measurable effect on crop pests and crop yield, enough to at least offset the loss of production on land occupied by margins.

Investigations have demonstrated that arthropods, including predators, are more abundant in uncropped areas with perennial vegetation, provided these areas are unaffected by chemical sprays and fertilizers (Kemp and Barrett 1989; Thomas et al. 1991; Rodenhouse et al. 1992; Kiss et al. 1993). Some predator species do foray out into adjacent fields while others remain almost exclusively within the naturalized field margins (Kromp and Steinberger 1992; Kiss et al. 1993). Evidently the disturbance and chemical treatment associated with cultivated fields is unacceptable to many predators although less intensive farming methods (no-till and organic) can result in a greater abundance of ground-dwelling predator species (Fan et al. 1993).

What evidence is there that predators migrate from field margins into fields? Rodenhouse et al. (1992) found that predators were more abundant in test plots of soybeans bounded by successional and grassy corridors than in plots without corridors, suggesting that migration was occurring. Studies of non-flying beetle populations showed them to be considerably reduced in adjacent fields when overwintering populations had been experimentally removed by application of insecticides in field margins (Wratten and Thomas 1990; Hassal et al. 1992). The inference again was that beetles had moved into the fields from the field edge. The presence of grassy field boundaries has been deemed essential for the presence of 60% of the spider fauna found in adjacent wheat fields (Duelli et al. 1990). Other studies suggest that predators invade croplands but that their numbers decrease sharply as they fan out to the field centers (Kromp and Steinberger 1992; Kiss et al. 1993).

No one knows for certain how far predatory arthropods disperse into a field (Kogan and Lattin 1993). Species assemblages of carabid beetles are substantially different in field centers than those located 250 m away on the field border, suggesting there are limits to dispersal (Kiss et al. 1993). Price (1976) reported that grassy field borders can significantly increase colonization by predacious arthropods extending approximately 30 m into a field. Investigations elsewhere have found that high predator densities extend no further than 10 m into cropland (Dennis and Fry 1992). Other studies contend that predatory species such as spiders rarely venture into fields (Kromp and Steinberger 1992).

The trend to larger field sizes, together with the observation that many predators are aggregated near the field border, raise doubts as to whether predators from the edge could ever effectively saturate a field. Experiments have been designed to facilitate the dispersal of arthropod predators over large holdings. One project created within-field artificial habitat islands that would allow predators with lower dispersal abilities to reach the field center earlier than they would have if coming in from the field margins (Thomas et al. 1991). The grassy habitat banks provided overwintering sites for many predaceous species during the first year of establishment, in densities comparable to those found along the field boundaries. At least two predator species were uniformly dispersed through the crop, suggesting the possibilities of manipulating arable environments in order to build up predator numbers and evenness of distribution.

Whether predatory activities actually lead to higher crop yields remains an open question. Kemp and Barrett (1989) noted that in an experimental field plot, uncultivated corridors contained high arthropod abundance and this was associated with reduced pest abundances and increased soybean yields. Higher yields in this instance were sufficient to compensate for the loss of land required for grassy corridors.

Results from other studies are less conclusive. Rodenhouse et al. (1992) examined the relationship between predator abundance and crop yields in a complex of experimental soybean plots, some of which were fringed by grassy and successional corridors, others of which had no corridors. They found that although predators were more numerous in plots with corridors, crop yields could not compensate for crop rows displaced by the corridors. The researchers noted, however, that when other economic and ecological benefits of corridors are factored in — decreased soil erosion, nutrient filtering, wind reduction — significant yield increases could occur.

## 8 PROVEN VALUES OF WILDLIFE TO AGROECOSYSTEMS

Crop residues such as stover that are left on the land for erosion control, in combination with no-till planting, can reduce soil erosion by 80% compared to fall moldboard plowing (Grand River Conservation Authority 1993). Crop residues increase the organic matter at soil surfaces and result in more abundant soil fauna and microflora (Tomlin et al. 1995). Increased invertebrate activities — burrowing through soil, breaking down wastes, transporting and recycling nutrients — serve to enhance soil structure and fertility on which plant growth and thus all other life depends (Ditchfield 1993).

Many other benefits are derived from wildlife and wildlife habitat. Windbreaks are employed in virtually every region in the world where trees can be grown Windbreaks can be highly effective in this regard, their mitigating effects extending to 28 times the windbreak height (Forman and Godron 1986). Wind speeds in an open landscape can be 15% higher than in a fencerow landscape and can cause greater crop and soil desiccation (Forman and Baudry 1984). Fencerows favorably modify soil and air temperature on their leeward sides but whether these effects, from the standpoint of crop yields, offset the resultant increased shading is debatable (Forman and Godron 1986). Fencerows are "living snow fences" that keep snow on the land and out of ditches (Grand River Conservation Authority 1993). Gradual melting of accumulated snow later prevents soil from drying out as quickly. Fencerows may also shelter buildings and thus decrease energy needs (10 to 30% energy savings are possible; Agriculture and Agri-Food Canada 1993). They offer livestock shade in summer and shelter from storms and cold winds (Forman and Godron 1986). Fencerows contribute to soil humus in the form of decaying leaves (Gartshore 1993), and supply resources such as blackberries, raspberries, and elderberries (Forman and Baudry 1984). Fencerows and woodlots can provide firewood as well as wood for furniture making, fenceposts, and building (Kline 1990). Maple trees can be tapped for maple sugar production while walnut trees can provide income from nuts (Ecological Farmers Association of Ontario 1993).

Woodlots help to protect ground- and stream-water quality, reduce erosion by wind and water, and filter nutrients from runoff (Lowrance et al. 1984). Woodlots and other wildlife habitat may offer the best use of easily damaged land, and the removal of poor yielding land from production can reduce production costs (Agriculture and Agri-Food Canada 1993; Ducks Unlimited Canada 1993). Even more pertinent from an economic perspective, woodlots increase property value (Agriculture and Agri-Food Canada 1993).

Natural features can also provide opportunities for recreational activities such as hunting. In some U.S. districts, windbreaks support high populations of quail, pheasant, and deer which in turn attract the considerable attention of hunters. Cable (1991) estimated that hunters in Kansas annually spend upwards of $35 million, a significant portion of which is used to pay farmers for the right to hunt in their windbreaks. In southern Ontario, farmers can be similarly remunerated by hunters wishing to pursue valued game species such as Ruffed Grouse, Wild Turkey, and Whitetail Deer.

## 9 RECOMMENDATIONS TO IMPROVE HABITAT CONDITIONS FOR WILDLIFE

For many farmers, ecological awareness has not extended much beyond soil conservation (Maitland Valley Conservation Authority 1993). Fortunately, a broader appreciation of the value of natural elements in farmlands appears to be growing. Within the past year, farm management programs that integrate conservation objectives have been prepared by a number of organizations including Agriculture and Agri-Food Canada (1993), Conservation Authorities (Grand River Conservation Authority 1993, Maitland Valley Conservation Authority 1993), and nongovernment organizations (Ducks Unlimited 1993, Ecological Farmers Association of Ontario 1993). This is an important development since farmers often have been unaware of the value of natural areas or have lacked the relevant information or advice on how to manage them (Hobbs et al. 1993).

A summary of ways in which farm management might incorporate conservation objectives is given below. The strategies draw on the advice of the organizations just listed, as well as that of other agencies, consultants, and the conservation literature.

### 9.1 Croplands and Pasture

(1) Use no-till cultivation (and crop residues) to reduce soil erosion and promote greater biological diversity (Edwards et al. 1990; Grand River Conservation Authority 1993).

(2) Incorporate manure into the soil within a day of its application to reduce nutrient runoff (Agriculture & Agri-Food Canada 1993).

(3) Plow across slopes to reduce rill and gully erosion that can wash sediments into natural areas (Grand River Conservation Authority 1993).

(4) Establish natural cover crops on highly erodible or fragile lands (Ducks Unlimited 1993; Gartshore 1993).

(5) Experiment with intercropping methods that permit the growing of field/forage crops and tree crops at the same time on the same land (Stinner and Blair 1990). Tree crops decrease the total amount of acreage in herbaceous crops but compensate with increased environmental stability and long-term economic value of trees.

(6) Introduce silvipastures that allow for the production of trees and livestock on the same land at the same time (not to be confused with pasturing livestock in natural areas) (Agriculture and Agri-Food Canada 1993).

### 9.2 Field Margins and Hayfields

(1) Native grasses and forbes should be planted or retained along roadsides and field margins (Warner 1992).

(2) Field margins width should be maximized to increase habitat area (Warner 1992).

(3) Spray-free buffer zones 6 m wide should be established along field perimeters to protect field margins (Kogan and Lattin 1993).

(4) Fences should be retained along roads and uncultivated strips that birds can use for singing and perching (Camp and Best 1993).

(5) Woody (native) vegetation should be introduced in some grassy margins to increase structural complexity and biodiversity (Best 1983a).

(6) Field- and road-side mowing (and burning) should be avoided. If necessary, mowing should be staged in blocks to ensure that some portions of the roadside or margin remain undisturbed at all times (Camp and Best 1993).

(7) Hayfields should be sown with timothy/clover rather than alfalfa to provide habitat for grassland birds (Bollinger and Gavin 1992).

(8) Hayfield mowing should be delayed to provide for safer nesting. Flushing bars can be attached to haying equipment to scare birds off nests (Ducks Unlimited Canada 1993).

## 9.3 Corridors

(1) Diversified native plantings should be used. Plants that are indigenous to an area maximize local biodiversity, provide important food sources for birds and animals (especially during summer and fall when the great majority of migrant birds need them), support pollinators, and are well-adapted to local environmental conditions (Gartshore 1993; Harker et al. 1993) Exotic or inappropriate plantings may have little wildlife or economic value. For instance, introduced coniferous plantations or corridors in a deciduous landscape contain few bird species (even though they may support a diverse community of birds in their native sites; Harker et al. 1993). Exotic shrubs (such as Autumn Olive) may contribute to the displacement of native species, either indirectly by subsidizing populations of aggressive non-native bird species such as European Starling, or directly by invading forest patches and fencerows to the detriment of native plants (Gartshore 1993).

A good listing of plants native to southern Ontario, along with suppliers of plant materials, is available from the Guelph Arboretum (Kock 1993).

(2) Corridors of similar vegetation structure should be used to connect woodlots isolated by fragmentation ( Noss 1987a).

(3) Corridors should be as long and wide as possible (including several rows of trees in open country). Long, narrow corridors tend to support more bird species than short, block-like ones (Yahner 1983a).

(4) Snags should be retained. Standing dead trees are home to fungi and invertebrates and provide food and shelter for numerous birds and mammals (Deckert 1993).

(5) Corridors should be permitted to mature since older strips contain greater plant and animal diversity (Johnson and Beck 1988).

(6) Grazing should be prohibited. Cattle trample or devour the understory and ground cover, thereby eliminating cover, nesting sites, and food sources.

(7) Livestock access to riparian corridors should be eliminated or carefully regulated, as this contributes to loss of vegetation, bank erosion, sedimentation in the stream, and bacterial and phosphorus problems (Grand River Conservation Authority 1993). Vegetated buffer strips along waterways should be restored.

(8) Mowing should be avoided as it destroys nests and reduces cover, thus increasing predation on ground nesting birds (Cable 1991).

## 9.4 Wetlands and Ponds

(1) Wet areas should not be drained or have water tables lowered (Johnson 1989).

(2) Low roadside ditches, brushy fields and thickets (especially adjacent to breeding ponds), and meadows help to enhance habitat for a diverse number of amphibians and reptiles (Francis and Campbell 1983).

(3) Created ponds should have irregularly shaped borders (not straight and square) and gradually sloping bottoms, and should be surrounded by shrubbery and trees (Agriculture and Agri-Food Canada 1993).

### 9.5 Forests

(1) Preserving large forests is the optimum strategy for maximizing native diversity (Wilcove et al. 1986). Forest habitats should not be subdivided, but expanded wherever possible. Marginal or fragile areas around woodlots should be retired and reforested with species appropriate to the woodlot. Reforestation should aim at creating a square or round forest rather than one that is long and thin.

(2) Forest edges should be as densely vegetated as possible. Thick edges provide greater protection to the forest interior and may contribute to higher nesting success along the edge (Martin 1993). Forest edges can be enhanced by not logging too near the edge and by establishing a 6 m no-spray buffer zone along field perimeters.

(3) Logging operations should be conducted only in winter. Care should be taken to avoid leaving large gaps in the forest canopy, to designate 5-10% of older trees as permanently uncut, and to leave 5-10 snags per ha (James 1984).

(4) Forests should be fenced off from livestock (Agriculture and Agri-Food Canada 1993).

(5) Avoid "tidying" up a woodland by removing underbrush and fallen logs. Many species are dependent on these features (Maitland Valley Conservation Authority 1993).

## QUESTIONS AND RECOMMENDATIONS FOR FURTHER RESEARCH

M What are the effects of low intensity cultivation methods on invertebrate populations? Further research is needed on the response of individual species, particularly predators, to different cultivation systems (some predatory species apparently spend the entire life cycle in arable fields and spread out into adjacent margins habitats rather than vice versa).

- **M** What are the effects of low intensity cultivation methods on bird and small mammal populations?

- **M** Very little is know of the status of pollinating insects in farmscapes. There is a need for wide-ranging quantitative studies involving both crops and natural habitats. Some questions to consider are 1) How important are field margins to supporting populations of pollinating insects such as butterflies, bees, and flies? 2) Which field margin plants optimize pollinator abundance? 3) What is the necessary insect density for appropriate plant pollination?

- **M** Much research remains to be done on changes to soil fauna associated with conversion from forest to pasture to crop systems.

- **M** More research is needed to determine the effects of spray-free buffer zones around the field perimeter on non-crop flora in adjacent fencerows and forest edge. What is the impact on invertebrates, particularly predators and pollinators, and on nesting birds? What is the optimum width of such a zone?

- **M** Additional work is needed on the influence of uncultivated field margins on croplands. Which invertebrate predators are found here? How far into the field do they move? What is the optimal margin width and how far apart should they be to facilitate optimum predator dispersal?

- **M** Do habitat islands established inside a field lead to higher numbers of invertebrate predators in the field? What is the optimum distance between habitat islands? What is the effect of linking them with a corridor?

**M** There is a need to quantify the proportion of predatory arthropods which migrate regularly between margins and fields and those which are restricted to either field or margins.

**M** Are crop yields in the vicinity of field margins reduced? the same? increased? Do the effects of predatory invertebrates compensate for the loss of productive land?

**M** What is the effect on crop yields of breaking up a large field into several smaller plots separated by uncultivated margins or fencerows? Do changes in wind, water, and temperature regimes, in combination with biopest control, make up for the loss of productive land?

**M** Establish an experimental intercropping plot in which field crops and tree crops are grown at the same time. Which tree species and field crops are most compatible? Profitable? Of greatest benefit to the soil? To wildlife?

**M** Do field margins comprised of native herbaceous vegetation such as asters, goldenrod, and vervain support a different faunal community than a margin dominated by exotic species such as burdock and thistle? Is native herbaceous vegetation as invasive of cropland as exotic species? Which native plants maximize faunal diversity yet pose the least invasive threat to cropland?

**M** Contrast grassland bird populations in timothy/clover/ hayfields with those in alfalfa fields. What is the optimum field size for a robust grassland bird community?

**M** Identify fragile or marginal lands that could be retired from agricultural use and be planted into prairie, shrubs, or trees. Begin a long-term monitoring study (this type of research is urgently needed). Comparatively little information is available on species changes following revegetation. Linear habitats such as field margins and fencerows are an obvious starting point for restoration. What are the conservation benefits of these elements? Features such as windbreaks help to control soil loss and movement of agricultural chemicals. At the same time, they also provide wildlife habitat or link up isolated remnant areas. What species are found here (or could be expected) and in what abundance? Over what time frame do changes occur?

**M** Compare soil composition and faunal communities (invertebrates, birds, and mammals) on retired agricultural land in which the cover crop is comprised of native, locally occurring plants with land on which exotic species (Bird's-foot Trefoil, Tall Fescue) currently recommended by government planting programs are used.

**M** Do birds that nest in field margins, fencerows, and forest edges also forage in cropland? Do they consume insects? crop materials? In what amount? Documented evidence is needed of the role of birds and other vertebrates in biopest control.

**M** What is the reproductive success of birds nesting in fields and along edges? There are very few studies of the annual breeding productivity and survival of songbirds in these habitats. Do they represent sources or sinks?

**M** What is the comparative value to birds in winter and during migration of fields containing manure or crop residues and fields that have no manure and are conventionally tilled? Manured fields may be preferred by northern migrants such as redpolls and Snow Buntings while residues may provide both cover and food.

**M** Species such as cowbirds may also make greater use of fields containing manure and crop residues. Are parasitism rates higher in the vicinity of these fields than around conventionally tilled fields?

M What are the rates of cowbird parasitism across a range of habitat types in southern Ontario? Hayfields, hedgerows, field margins, and woodlots all should be examined. No such studies have been conducted.

M What are the effects of agricultural practices on the abundance of nest predators (cats, raccoons, skunks, squirrels, mice, crows, grackles, jays) in farmland?

M Begin a long-term monitoring project (at least 5 years) on a grazed riparian corridor that is fenced off from livestock. Regeneration could be either natural or intentional (using locally occurring native species). What changes occur to the floral and faunal communities over time?

M Compare faunal activity in corridors containing locally occurring native tree and shrub species with corridors comprised of nonnative species. What are their respective values to invertebrates? nesting birds? migrating birds? amphibians and reptiles? small mammals?

M Expand studies from single fields to a landscape level. The overall pattern of field margins in a region may contribute to the difference in population densities and species richness as opposed to local habitat availability alone. A mosaic landscape may enhance the possibilities for region survival of many species.

Does a diversified farm (treed laneways, orchards, fencerows, woodlots, varied crops, hayfields) support a different wildlife community than nearby monoculture-style farms? Compare floral and faunal diversity on mixed farms (such as occur, for example, among the Old Order Mennonite and Amish communities) with that found on conventional farms.

M Consider the comparative effects to regional biodiversity of intense farming on a small acreage versus less intense farming on larger acreages.

M Design a habitat enhancement/restoration model specific to a single farm or several adjoining farms. A conservation network plan featuring revegetation and including field margin and fencerow development, woodlot and wetland enhancement, and farm stead design should be prepared. The scheme could follow either:

1) the existing rectangular grid (linear roadsides, field boundaries, property lines);

or

2) the natural landscape features (soil types, drainage lines, topography).

M Is dense, thick forest edge less permeable to chemical sprays, wind, solar radiation and other external forces than edge that is thin and open? Does the floral composition inside the forest change depending on whether the edge is enhanced or fortified? Is nesting success greater in one type of edge than the other?

M Areas that are under cultivation around woodlots could be retired and planted to trees appropriate to the site. What is the effect of woodlot enlargement on avian diversity? Is it possible that woodlot enlargement could transform a sink into a source? Results from elsewhere suggest that increasing forest cover may enhance both local and regional avian diversity.

M What are the effects on breeding birds in farm woodlots of high-grade logging (removal of all trees over a minimum size) as compared to selective logging that harvests dominant tress on average at 1% per year?

M Assess the impacts of introduced fish species in farm ponds on local amphibian populations.

M Study small mammals commonly found in cropland (Deer Mice, White-footed Mice). What percentage of their summer diet is comprised of invertebrates? Crop materials?

**APPENDIX 1**

English and scientific names of species cited in the text.

| | Common Name | Scientific Name |
|---|---|---|
| AMPHIBIANS | | |
| | Redback Salamander | *Plethodon cinereus* |
| | Spring Peeper | *Hyla crucifer* |
| | Gray Treefrog | *Hyla versicolor* |
| BIRDS | | |
| | Upland Sandpiper | *Bartramia longicauda* |
| | Eastern Wood-Pewee | *Contopus virens* |
| | Great-crested Flycatcher | *Myiarchus crinitus* |
| | Eastern Kingbird | *Tyrannus tyrannus* |
| | Wood Thrush | *Hylocichla mustelina* |
| | Black-throated Blue Warbler | *Dendroica caerulescens* |
| | Blue-winged Warbler | *Vermivora pinus* |
| | Golden-winged Warbler | *Vermivora chrysoptera* |
| | American Redstart | *Setophaga ruticilla* |
| | Common Yellowthroat | *Geothlypis trichas* |
| | Yellow Warbler | *Dendroica petechia* |
| | Ovenbird | *Seiurus aurocapillus*I |
| | Indigo Bunting | *Passerina cyanea* |
| | Bobolink | *Dolichonyx oryzivorus* |
| | Killdeer | *Charadrius vociferus* |
| | Red-tailed Hawk | *Buteo jamaicensis* |
| | American Robin | *Turdus migratorius* |
| | Horned Lark | *Eremophila alperstris* |
| | Rufous-sided Towhee | *Pipilo erythrophthalmus* |
| | Vesper Sparrow | *Pooecetes gramineus* |
| | Song Sparrow | *Melospiza melodia* |
| | *Henslow's Sparrow* | *Ammodramus henslowii* |
| | Grasshopper Sparrow | *Ammodramus savannarum* |
| | Common Grackle | *Quiscalus quiscula* |
| | Brown-headed Cowbird | *Molothrus ater* |

| | |
|---|---|
| Eastern Meadowlark | *Sturnella magna* |
| Red-winged Blackbird | *Agelaius phoeniceus* |
| Wild Turkey | *Meleagris gallopavo* |
| Ruffed Grouse | *Bonasa umbellus* |
| Acorn Woodpecker | *Melanerpes formicivorus* |
| Blue Jay | *Cyanocitta cristata* |
| Carolina Chickadee | *Parus carolinensis* |
| European Nuthatch | *Sitta europaea* |
| European Starling | *Sturnus vulgaris* |
| Northern Cardinal | *Cardinalis cardinalis* |
| Lapland Longspur | *Calcarius lapponicus* |
| Snow Bunting | *Plectrophenax nivalis* |
| Common Redpoll | *Caruelis flammea* |

MAMMALS

| | |
|---|---|
| Short-tailed Shrew | *Blarina brevicauda* |
| House Mouse | *Mus musculus* |
| Meadow Vole | *Microtus pennsylvanicus* |
| Red-backed Vole | *Clethrionomys gapperi* |
| Deer Mouse | *Peromyscus maniculatus* |
| White-footed Mouse | *Peromyscus leucopus* |
| Eastern Chipmunk | *Tamias striatus* |
| Red Squirrel | *Sciurus vulgaris* |
| Gray Squirrel | *Sciurus carolinensis* |
| Snowshoe Hare | *Lepus americanus* |
| Raccoon | *Procyon lotor* |
| Opposum | *Didelphis marsupialis* |
| White-tailed Deer | *Odocoileus virginianus* |
| Moose | *Alces alces* |
| Lynx | *Lynx canadensis* |
| Cougar | *Felis concolor* |
| Black Bear | *Ursus americanus* |
| Timber Wolf | *Canis lupus* |
| Wapiti | *Cervus canadensis* |
| Long-nosed Potoroo | *Potorous tridactylus* |

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