Living on the edge: Field boundary habitats, biodiversity and agriculture

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In many agricultural regions of Canada, the most common remnant natural areas are field boundaries, these habitats being linear features or narrow areas located beside cropland. Boundaries are often perceived to harbour noxious weeds, insects and birds that could potentially damage crops or interfere with crop production. Therefore, boundary habitat may be degraded by pesticides, fertilizers, tillage, wind and water exposure, excessive burning, haying and grazing. One conservation objective is to work with land owners to retain and protect existing boundaries, a goal that could be achieved more readily with evidence of benefits and practical ways of managing field margins. Direct services provided by boundary habitats include control of soil and water erosion, protection (e.g., from agro-chemicals) of surface water used by livestock and people, and provision of forage for livestock through grazing or haying. Boundaries serve as refugia for plants, insects or other animals that are either neutral or beneficial to agriculture. Native plants often are more common farther from field edges and in habitats abutting pastures and

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hayfields, whereas weeds are more abundant in boundaries adjacent to intensively managed agricultural fields, possibly as a result of competitive advantages or outright loss of native species created by disturbance and agrochemical use. Wildlife has been studied in several countries and under different agricultural settings, but survival and reproductive rates of animals occurring in boundaries are not well known. Relationships between boundary width, height and composition and wildlife value, carbon storage, and protection of surface waters are poorly quantified. Answers to these questions will help land owners, conservation agencies and policy-makers make better decisions about sustainable farm practices.

Additional Keywords: biodiversity, conservation, farming systems, natural habitats, wetland margins

Introduction

Over the past 100 years, natural habitat in southern Canada has been lost and degraded through drainage of wetlands (Zedler 1996), cultivation (Weaver 1954; Burke et al. 1995) and use of agrochemicals (Drinkwater et al. 1995; McLaughlin and Mineau 1995). Native herbivores and plants have been replaced with domestic livestock, crops, and alien species (Knopf 1988; McNicholl 1988; Campbell et al. 1994). Because most land is now largely devoted to agriculture, retention and restoration of residual native habitat and adoption of conservation-oriented farming practices could have enormous positive impacts on the environment and wildlife (Jackson and Piper 1989; Paul and Robertson 1989; Freemark and Boutin 1995). In recent years, agricultural policies in the U.S.A. have been designed and promoted to conserve soil and water quality and to indirectly benefit the environment, including wildlife (Schnepf 2003). Canada has not embraced these types of large-scale policy initiatives, but environmental sustainability is gradually becoming a central pillar of sustainable Canadian agricultural systems and the public is increasingly interested in purchasing “green” agricultural products, as suggested by the recent launching of Canada’s Agricultural Policy Framework.

Because it is impossible for wildlife conservation agencies to manage directly or otherwise affect land use on large areas of Canada, it is timely and opportune that agriculture is moving to policies that potentially benefit producers and wildlife habitat. Retention and restoration of field boundary habitats often are explicitly incorporated into landscape planning in Europe where these habitats are well recognised for cultural-aesthetic and environmental values (Marshall 2003; Marshall et al. 2002; Ryszkowski 2002). On the Canadian prairies, shelterbelt plantings have been encouraged for decades to reduce wind erosion of cropland but the area covered by hedgerows remains relatively small and clearing of remnant natural habitat continues at an alarming rate in parkland-southern boreal areas

(Hobson et al. 2002). In southern Québec, hundreds of kilometers of hedgerows have been planted in the last 20 years but hedgerow loss is still ongoing in intensive agricultural regions of the province (Boutin et al. 2001a; 2001b). Thus, there is a large conceptual and cultural gap in perceptions of hedgerow values between Canada and elsewhere.

The most obvious benefit of hedgerows and shelterbelts is reduction of wind and water erosion, this being a principal rationale for implementing planting programs on the Canadian prairies following droughts of the 1930s. Initially, non-native caragana (Caragana arborescens Lam.) was the dominant woody species planted but native tree and shrub species are becoming increasingly popular (see Mah, undated).

Boundaries can prevent pesticides, animal waste and fertilizers from moving on to adjacent non-target crops, or into water sources used by livestock and people. Interception is affected by width, height and species composition of the boundary, application procedures and equipment, wind velocity and water erosion events (Cessna et al. 2003; Wolf et al. 2003). Heightened concerns for water quality and availability in most areas of southern Canada demand innovative solutions involving management of natural habitat buffers. Recent work on field margins in different areas of Canada provides insights into values and limitations of these habitats for meeting biodiversity goals.

Here, we focus primarily on the role of field boundaries, and other semi-natural habitats that are part of the agricultural landscape mosaic, in conserving biodiversity in Canada. We define field boundaries as the structural components (hedgerows, riparian strips, grass banks, ditches) of field margins which also include the crop edge and the margin strip between crop and boundary (Marshall et al. 2002). Also important in the mosaic are patches of habitat such as wetlands and woodlands with varying mixes of natural or introduced vegetation, which may be located mid-field or integrated into field margins (Fry 1994; Marshall et al. 2002; Ryszkowski et al. 2002). Several reviews have examined effects of agricultural practices on biodiversity in field margins in Canada (Freemark and Boutin 1995; McLaughlin and Mineau 1995; Boutin et al. 2001a; 2001b). Objectives of this paper were to: (1) briefly review beneficial aspects of boundaries for agriculture; (2) provide new information about boundary effects on diversity of selected groups of plants and animals, and; (3) identify areas requiring further work in acquiring a better understanding of costs and benefits of protecting and restoring these habitats. We draw on recent studies conducted in different regions of Canada.

Case-studies of Field Boundary Effects on Biodiversity

Wildlife Diversity in Saskatchewan in Relation to Shelterbelt Planting and Retention of Aspen Groves

Godwin et al. (1998) studied abundance and diversity of selected wildlife groups on two pairs of neighbouring farms in Saskatchewan, one pair to assess effects of shelterbelts (composed of caragana and Siberian elm [*Ulmus pumila* L.]) and the second pair to evaluate impacts of retaining aspen poplar (*Populus tremuloides* Michx.) groves. Although lack of replication limited strong inferences, several general patterns were noteworthy.

Butterfly use of the single farm with a network of mature shelterbelts and an understory dominated by exotic plants (few native plants had established) was similar to that observed on the matched open farm lacking these habitats. However, the shelterbelt farm harboured more species of ground beetles and spiders and 10 times more terrestrial bird species (20 versus 2) than the treeless farm. A small patch of grassland on the shelterbelt farm had 17 times more native plant species than did the shelterbelt (51 versus 3), perhaps suggesting high conservation value of remnant native grassland habitat. Exotic perennial plant species in 16 grassland remnant areas comprised approximately 55% by weight of plant biomass near the crop edge and this diminished to 25-30% at 10-30 m from the edge.

Overall, Godwin et al's (1998) study supported several general patterns reported from central Canada and Europe. Specifically, remnant natural patches support higher diversity of native wildlife species than do restored boundary habitats generally composed of exotic species (Freemark et al. 2002; Marshall et al. 2002). However, regardless of composition, restored habitats contribute to improvements in species diversity of many taxa and therefore have some conservation values, albeit more limited than those of natural habitats (Boutin et al. 2002).

Correlates of Biodiversity on Saskatchewan Farmland

Thomas et al. (1999) conducted studies of selected wildlife groups on 12 clusters of Saskatchewan sites during 1996-1998, each cluster consisting of a conventional farm, a minimum tillage farm, an organic farm and a natural (wild) area located within 25 km of an organic farm. On conventional farms, tillage operations occurred three or more times annually, whereas minimum tillage usually involved one to two passes over fields. Organic farms had been certified as chemical-free operations for more than 4 years and these producers relied heavily on tillage and diverse cropping practices for weed control. Natural or wild areas were designated as wildlife habitat with planted or idle cover. Most study sites were 65 ha (1/4 section) with at least one wetland. Sampling methods and an overview of the data were presented in Thomas et al. (1999), and detailed analyses have been published elsewhere (Donald et al. 2001; Shutler et al. 2000). Here, we present new analyses focused on field boundary effects.

Native plants in wetland margins. Number of native plant species did not differ significantly among the four types of field (Table 1). There was a tendency towards higher species richness of herbaceous plants (but not of trees and shrubs) in natural areas and lower richness in organic fields. More herbaceous species were unique to natural areas, followed by minimum tillage, organic and conventional sites (Table 1). The majority of the unique species were found on only one or two sites in a category. These data indicate that wetland margins on cultivated land supported assemblages of plant species that were similar among farm regimes, although greater numbers of species were generally found in wetland margins of natural areas. The diversity of vegetative structure represented by shrubs, trees and herbaceous plants provides a variety of essential habitat features for wildlife living in these islands surrounded by cropland: cover for nesting and escape from predators, modification of temperatures in summer and winter, and food for herbivores and carnivores.

Table 1. Mean ± SE and median species richness (number of species) of native plants growing in wetland margins in fields of three types of farm (conventional, minimum tillage and organic) and in uncultivated natural areas designated for wildlife in Saskatchewan. Species unique to each type of field are also shown. Sample sizes were 10 or 11 fields in each of the four categories. Plants include those surveyed in 15, 1.0 m^2 quadrats located on five randomly selected transects per site plus those found by searching for every species growing on the site during 1996 and 1997.

	Type of Field			
Vegetation	Conventional	Minimum tillage	Organic	Natural area
Herbaceous plants				
Mean ± SE	24.3 ± 2.7	27.2 ± 2.5	21.6 ± 2.4	32.6 ± 4.6
Median	21.5	25.0	21.0	26.5
Range	12 – 38	17 – 45	13 - 37	13 – 57
Unique species	7	21	13	39
Trees and shrubs				
Mean ± SE	5.3 ± 1.2	4.8 ± 0.7	5.6 ± 1.1	6.7 ± 1.1
Median	5.0	4.0	6.5	7.5
Range	0 – 11	1 – 8	0 - 12	0 – 10
Unique species	0	0	4	0

Weeds in the ecotone between crop and wetland. In all farmed systems, weeds were a major component of plant diversity in wetland margins and adjacent crops (Figure 1). Plant diversity along transects from field to wetland margins was not significantly different between conventional and minimum tillage systems. In wetland margin habitats, species richness was lowest on organic farms. This tendency towards low plant diversity, in particular low number of non-weedy species, was unexpected and may have been related to management practices of some organic producers. As a weed control measure, organic producers occasionally tilled the field margin between the crop and wetland, while this area was usually undisturbed in conventional and minimum tillage systems. For all systems, diversity was highest in the edge between field margin and wetland due to the presence of species associated with both habitats. In the field margin, diversity tended to be higher on organic than on non-organic farms, particularly at 19 and 39 m from the edge. In all systems, most of the species found in the field margin were weeds ranked within the top 50 most abundant weeds in a 1995 Saskatchewan survey (Thomas et al. 1996).

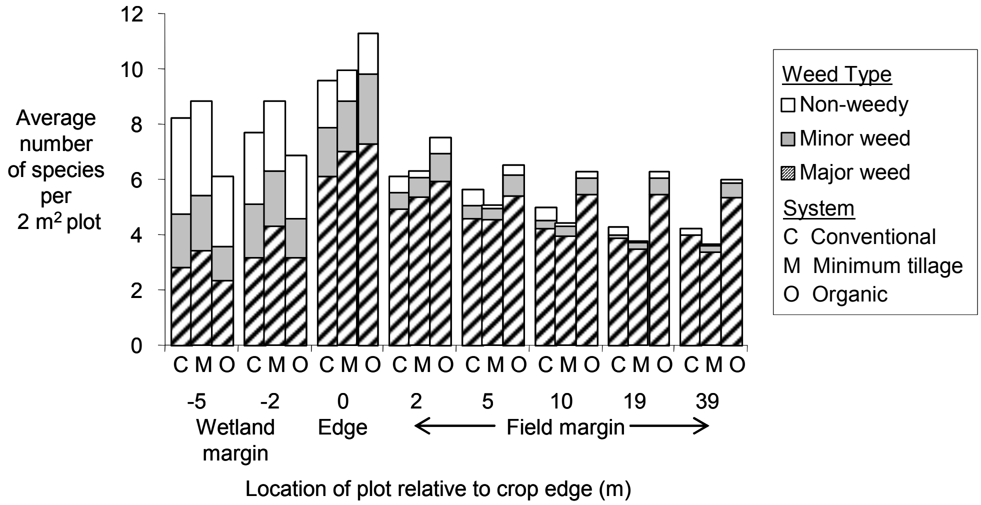

Figure 1. Average number of plant species per plot placed along four transects extending into the crop from each wetland. The edge plot was placed to include 0.5 m either side of the crop edge. Weed types are defined based on abundance in 1995 Saskatchewan provincial weed survey of cereal, oilseed and pulse crops (Thomas et al. 1996). Major weeds rank amongst the 50 most abundant weed species in the provincial survey, minor weeds were less abundant and non-weedy species were those not found in the survey.

A higher number of non-weedy species was associated with wetland margins than reported in grassy roadside ditches (Leeson et al. 2003; Welch's approximate t-test, $P < 0.01$). This difference may be attributable to the wetlands being remnant natural patches. However, wetland margins also tended to have higher numbers of major weed species than ditches (t-test, $P < 0.005$). Tillage of wetland margins in organic fields would be expected to create microsites ideal for the establishment of weeds. Also, wetland margins may be disturbed occasionally in conventional systems as these boundaries are seldom as well defined as ditches and may change depending on water levels. Conventional systems also had higher numbers of major weed species in plots placed 2, 5 and 10 m into the crop from the wetland margin than in plots placed at equivalent distances into the crop from ditches (t-test, $P < 0.05$). This may reflect compliance with herbicide labelling directing no application within 15 m of wildlife habitat.

A total of 191 plant species were identified along transects during the study of wetland margins. Conventional and minimum tillage systems had 139 species each (72 and 80 transects, respectively), while the organic system had 128 species (72 transects). The majority of species found only in wetland margins were non-weedy; however, a few species were classified as minor weeds (Figure 2). A large proportion of species identified in each system was found in both wetland margins and crops, including most major and minor weed species. These results contrast with those reported for field boundaries adjacent to roadside ditches in which fewer species were found in the crop and ditch associated with organic than with conventional fields (Leeson et al. 2003). This difference could be attributed to the disturbance of wetland margins by tillage. With the exception of a few invasive

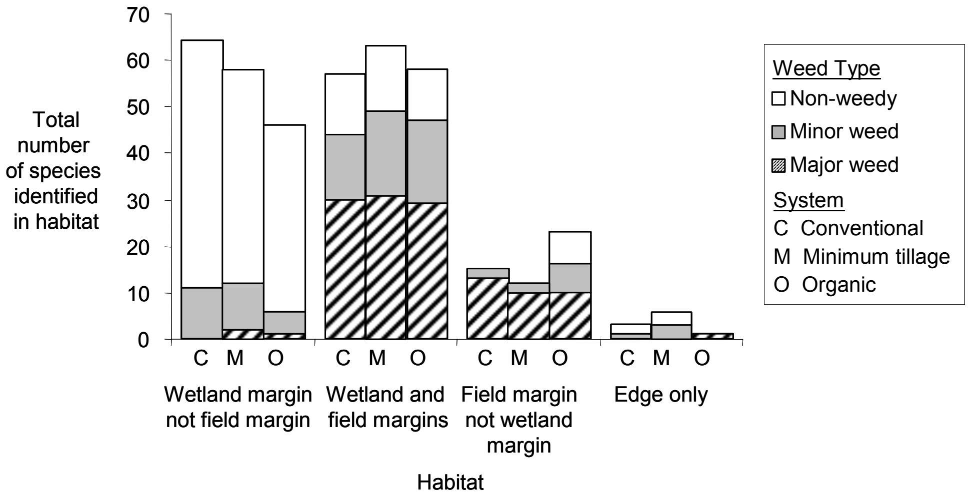

Figure 2. Total number of plant species identified in each habitat in each system. Data were collected on 72 transects in conventional and organic systems and 80 transects in minimum tillage systems. Weed types were based on abundance in 1995 Saskatchewan provincial weed survey of cereal, oilseed and pulse crops (Thomas et al 1996). Major weeds rank among the 50 most abundant weeds in the provincial survey; minor weeds were less abundant and non-weedy species were those not found in the survey.

species (e.g., Canada thistle, *Cirsium arvense* (L.) Scop.; perennial sow-thistle *Sonchus arvensis* L.), most major weed species were introduced annual grasses and herbs not generally expected in undisturbed habitats. Most non-weedy species found in field margins would not be expected to persist past the outer edges of the crop (see declining species richness in Figure 1). Relatively few species were found only within the field margin in all systems (Figure 2). Organic systems had more minor and non-weedy species than the other systems, possibly attributable to the low representation of this system within the provincial weed survey. Few species were found only at the edge of the crop and wetland margin.

Invertebrates in wetland and roadside margins. Ground- and foliage-dwelling invertebrates were sampled with pitfall traps and sweep nets, respectively, in wetland margins; foliage-dwelling species were sampled with sweep nets in roadside field boundary habitats. Sampling was conducted between mid-July and early August, 1996 and 1997. Pitfall traps made of 1-litre plastic buckets fitted with funnels and filled to a depth of 2-3 cm with dilute propylene glycol (50% v:v water) were set for a total of 3 days over two summers. Arthropods sampling with pitfall traps is affected by a variety of factors including density and activity; thus, "… the catch of any one species is only an approximate analogue of its population density" (Luff 2002, see page 42). Of the data for invertebrates sampled in wetland margins, those for carabid beetles, a group of considerable conservation interest, are presented. Carabid abundance derived from pitfall trap catches constitutes an index of relative activity (Cárcamo et al. 1995). Invertebrates from roadside habitats were sorted to the family level; those from wetland margins were sorted to species.

Table 2. Insect families collected in 1996 and 1997 that were unique to a given farm system or natural area, Saskatchewan, 1996-1997.

System/Habitat	Insect order	Unique families	Family name
Organic System	Coleoptera	1	Anthicidae
	Hymenoptera	2	Halictidae, Sphecidae
Natural areas	Coleoptera	2	Byrrhidae, Phalacridae
	Hemiptera	2	Pentatomidae, Scutelleridae
	Homoptera	3	Aetalionidae, Cercopidae, Membracidae
	Hymenoptera	12	Anthophoridae, Aphelinidae, Apidae, Bethylidae, Charipidae, Chrysididae, Eupelmidae, Eurytomidae, Figitidae, Formicidae, Megaspilidae, Nyssonidae

In roadside habitats, there were no significant differences in richness of insect families among farming systems. However, a closer examination of the species complex revealed that only the organic production system (n = 3) and natural areas (n = 19) contained unique insect families (Table 2). Within organic systems, these unique species represented families that are primarily beneficial, Halictidae (pollinators) and Sphecidae (predators), or those that are related to plant diversity, Anthicidae (attracted to flowers). Within natural areas, the unique species represented mainly beneficial families. Hymenoptera were well represented by unique species (n = 12 different families) that comprised primarily parasites, pollinators and predators. Remaining families consisted primarily of plant-feeding species, but none considered as pests. Such uniqueness is important in characterizing the diversity of ecosystems. Agricultural systems tend to fragment natural habitats, a process of habitat isolation that has contributed to a loss in species diversity (Diamond and May 1981). The conventional and minimum tillage systems shared all their insect families with one or more of the other ecosystems.

There is growing interest in the beneficial arthropods that are involved in biological control because they suppress pest species at little cost and cause minimal harm to humans and the environment (Pimentel 1995). In the context of extensive agriculture, field-boundary habitats provide stable refugia for these species relative to cropland. Species that can adapt to life in crop and field boundaries will tend to play a larger role than species associated primarily with natural areas.

Species richness and abundance of carabids were lowest in natural areas, higher in conventional and minimum tillage fields and highest in organic fields (Table 3). Wetland margins, in comparison to the adjacent cultivated or uncultivated land, did not contain higher richness or abundance; in the case of organic fields, the cultivated cropland contained more species and individuals than did the margin. Cárcamo et al (1995), in comparing species richness of carabids among organic, conventional, minimum tillage and uncultivated fields in Alberta, reported that richness was lowest in uncultivated meadow.

Higher carabid richness and abundance in margins on all types of farm fields compared to wildlife areas (Table 3) suggest that presence of crops was beneficial to carabids. In addition, greater richness in organic fields indicates that organic farm practices benefited carabids more than conventional or minimum tillage. Mean weed densities in crops of the organic farms averaged approximately 200 plants m^{-2}, about four times greater than densities recorded on conventional and minimum tillage fields (Thomas et al. 1999). Higher weed densities in organic crops have been positively correlated with carabid species richness and abundance in other studies (e.g., Cárcamo et al. 1995; Andersen and Eltun 2000). Weeds provide seeds for granivorous species and habitat for a greater diversity of prey for predatory species.

The importance of field boundaries in providing overwintering refuges for carabid beetles and other invertebrate predators in agricultural cropland has been demonstrated (Wallin 1985), and planted strips of grassy refuges (beetle banks) within fields have been introduced and their effectiveness studied in England

(Thomas et al. 1991; Collins et al. 2002). The ranges in richness and abundance within each type of farm (Table 3) indicate that conditions were more beneficial to carabids in some fields than others within the same management regime. Qualitative differences among wetland margins might have contributed to differences in beetle populations; however, we lack data for autumn or spring when carabids might have been found more commonly in margins than in fields. Quality of margin habitat that could produce differences among fields includes structural diversity (height of woody plants), presence of tussock-forming grasses, weediness and landscape complexity (reviewed by Thomas et al. 2002).

Table 3. Mean ± SE and median species richness and abundance of beetles of the family Carabidae in wetland margins in fields of three types of farm (conventional, minimum tillage and organic) and in uncultivated natural areas designated for wildlife. Sample sizes were 10 or 11 fields in each of the four categories. Data are derived from the total numbers of species (richness) or individuals (abundance) per field site captured in pitfall traps set 1 and 10 m into wetland margins and 25 and 75 m into the adjacent cultivated or uncultivated land, during 1996 and 1997 combined. Index of abundance is based on activity and density (see text).

	Wetland margin		Adjacent land	
Type of field	10 m	1 m	25 m	75 m
Natural area				
Mean richness ± SE	1.5 ± 0.4	1.8 ± 0.8	1.5 ± 0.4	3.0 ± 0.8
Median richness (range)	2.0 (0 - 4)	1.0 (0 - 9)	2.0 (0 - 4)	3.0 (0 - 7)
Mean abundance ± SE	2.5 ± 0.8	2.1 ± 0.9	1.7 ± 0.5	4.0 ± 1.2
Median abundance (range)	2.0 (0 - 9)	1.0 (0 -11)	2.0 (0 -5)	3.0 (0 - 12)
Conventional tillage				
Mean richness ± SE	2.7 ± 0.6	5.4 ± 1.1	4.3 ± 1.0	5.0 ± 1.2
Median richness (range)	3.5 (0 - 5)	4.5 (2 - 14)	4.0 (0 - 10)	4.0 (1 - 13)
Mean abundance ± SE	3.5 ± 0.9	11.4 ± 2.7	10.5 ± 3.7	11.7 ± 3.3
Median abundance (range)	4.0 (0 - 7)	8.5 (4 - 27)	7.0 (0 - 34)	8.5 (1 - 34)
Minimum tillage				
Mean richness ± SE	3.9 ±1.1	4.4 ± 1.5	4.9 ± 1.3	4.2 ± 1.3
Median richness (range)	2.0 (1 - 13)	2.0 (0 - 17)	3.0 (1 - 14)	4.0 (1 - 17)
Mean abundance ± SE	6.1 ± 1.8	9.9 ± 4.7	8.8 ± 3.7	5.9 ± 1.8
Median abundance (range)	3.0 (1 - 19)	7.0 (0 - 56)	4.0 (2 - 44)	8.5 (1 - 21)
Organic				
Mean richness ± SE	3.1 ± 0.5	5.2 ± 1.2	8.5 ± 1.3	8.2 ± 1.3
Median richness (range)	3.0 (0 - 6)	5.0 (1 - 14)	9.0 (2 - 17)	7.0 (2 - 16)
Mean abundance ± SE	4.5 ± 0.9	9.3 ± 2.9	19.2 ± 5.9	16.5 ± 2.9
Median abundance (range)	4.0 (0 - 10)	6.0 (1 - 33)	15.0 (2 - 74)	13.0 (4 - 35)

Natural areas tended to have greater numbers and diversity of foliage-dwelling arthropods than farm sites, and there was an effect of farming system on the carabid community in fields but not in wetland margins. Since mechanical tools, side effects of pesticides, and ploughing can all be detrimental to ground dwelling animals (Krooss and Schaefer 1998), we might expect differences between farmed and unfarmed land. It is more difficult to discern separate effects of tillage and agrochemical use. There was more insect diversity on both wild and organic sites, suggesting that agrochemicals had some negative impact on some species. Other research has found that minimum tillage farming increases arthropod community diversity (Gregory and Musick 1976; House and Stinner 1983; Edwards and Lofty 1982; Blumberg and Crossley 1983; but see Basore et al. 1987).

Terrestrial bird surveys. Birds detected in non-crop wetland margins were counted within semi-circular plots (radius = 100 m; Hutto et al. 1986) but plots contained the entire non-crop margins of small wetlands (see Shutler et al. 2000). Species richness of common birds (i.e., detected in >3% of surveys) averaged 4-5 times greater on wetlands than in adjacent cropland, underscoring the critical role of wetlands to bird diversity (Shutler et al. 2000). Wetlands with greater complexity were more likely to have a larger variety of terrestrial bird species (Figure 3), after accounting for possible effects of wetland area, because complex basins contained greater vegetation diversity including shrubs and trees. Even small wetland basins with grassy margins attracted as many bird species (approximately 7-8, see Figure 3) as did either cropland (mean = 2.5-3.2) or fields of planted cover (mean = 4.1; Shutler et al. 2000).

Field Boundary Studies in Québec and Ontario

In Québec, agriculture is mostly concentrated along the St. Lawrence Valley and is dominated by corn, wheat, soybean, and vegetable monocultures in the southwestern part of the St. Lawrence Lowland; whereas, dairy farming dominates in northeastern regions. Multifaceted studies have been conducted on field boundary habitats during the past decade, as summarised below.

Plant diversity. Vegetation composition was studied in hedgerows, riparian, and woodlot-edge habitats adjacent to cultivated fields under different human-related disturbances (i.e., chemical pesticide and fertilizer drift, tree planting, mowing) to evaluate the integrity of their herbaceous strata. Three independent studies were conducted: 1) hedgerows and woodlot edges adjacent to fields under different farming intensities in the Richelieu River basin (for details, see Boutin and Jobin 1998); 2) planted and natural hedgerows (windbreaks) and grassy field margins near Saint-Hyacinthe (Boutin et al. 2001a; 2001b; Boutin et al. 2002); and 3) herbaceous, shrub-dominated and woody riparian habitats in the Boyer River basin (Boutin et al. 2003). Vegetation was inventoried in quadrats and herbaceous species were identified and characterized according to lifespan (annuals including biennials, perennials), status (introduced, native), and weediness.

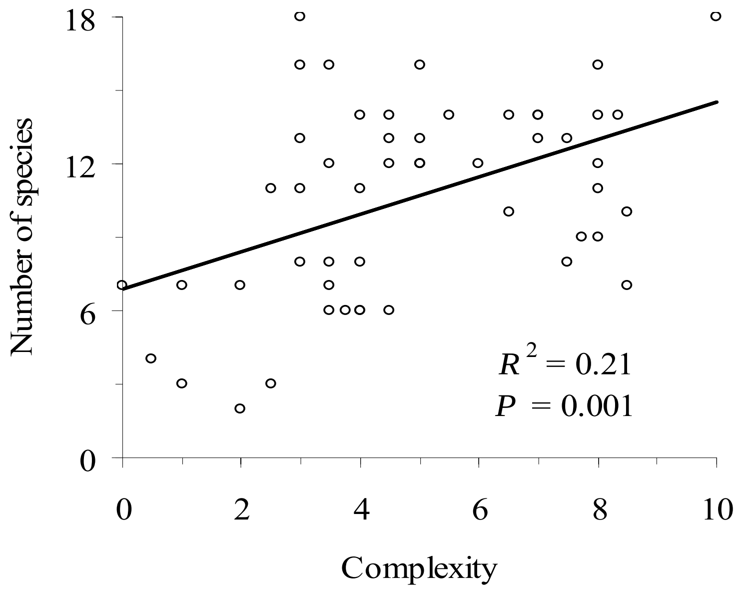

Figure 3. Relationship (r = +0.46, n = 48 wetlands) between number of terrestrial bird species detected in wetland boundary habitats and wetland complexity index on 36 farm sites and 12 natural wildlife habitat areas located in south-central Saskatchewan, Canada, 1996 and 1997. [Wetland complexity ranged from simple basins with a value of 0 (1 undivided basin, round, small; upland is a thin strip of grass and/or crops only), to moderately complex basins with an index of 5 (1 undivided basin, elongate or round, medium size; emergent aquatic vegetation, willows, and trees present) and highly complex at 10 (subdivided basins joined by natural vegetation and a short distance apart, having irregular shoreline; total of basins large, with emergent vegetation, willows, and trees all present in roughly equal amounts.)]

In general, although species richness and cover of the herbaceous strata were similar among sites within a given study, weeds, annuals, and introduced species were better represented in disturbed sites compared to "natural" sites where non-weed, perennial, and native species predominated (see also Jobin et al. 2001b). This species composition pattern was observed in all three studies (Table 4). This emphasizes the need to deepen the analysis of biodiversity data to the level of species composition and not to rely solely on species richness as an indicator of habitat integrity and biodiversity conservation when evaluating the impact of human activities on wildlife.

Table 4. Comparisons of the richness, structure and composition of the herbaceous strata in habitats adjacent to cultivated fields among sites under different human-related disturbances (L: Low, M: Moderate, H: High) in southern Québec. Intensity of human-related disturbance as follows: *Richelieu Low* - forage crop and pasture adjacent to study habitats, no pesticides used in adjacent fields; *Richelieu Moderate* - forage crop and pasture adjacent to study habitats, moderate use of pesticides in adjacent fields in past 5 years; *Richelieu High* - cash crop adjacent to study habitats with regular use of agrochemicals; *Saint-Hyacinthe Low* - natural hedgerows; *Saint-Hyacinthe Moderate* - herbaceous field margins; *Saint-Hyacinthe High* - planted hedgerows; *Boyer Low* - woody riparian habitats with trees; *Boyer Moderate* - woody riparian habitats with shrubs; *Boyer High* - herbaceous riparian habitats.

Variable	Richelieu Woodlot edges n=39	Richelieu Hedgerows n=39	Saint-Hyacinthe Hedgerows n=61	Boyer Riparian habitats n=29
Number of species	H = M = L	L > M = H	H = M > L	H = M = L
Cover	H = M = L	H = M = L	H = M > L	H = M > L
% weeds	H > M = L	H > M > L	H > M = L	H > M-L
% annuals	H > M = L	H > M = L	H = M > L	H > M (H = L; M = L)
% introduced	H = M > L	H = M = L	H = M = L	H = M = L

Invertebrates in boundaries versus fields. Invertebrates were sampled for 1 week in June 1996 at multiple sites in southern Québec, using 168 pitfall traps set in hedgerows (centre and sides) and in fields at 3 m and 25 m from the edge of hedgerows. Invertebrates were identified to family and classified as beneficial and neutral species, or pests.

A total of 12,601 invertebrates were captured. The most important groups were either beneficial or neutral: Araneidae, Phalangidae, Entomobryidae, Sminthuridae, Carabidae, Formicidae and several Diptera species. It is noteworthy that insects from two pest families, Gryllidae and Cicadellidae, were only found in large numbers within herbaceous field margins. This explains partly the reason why pest species were more abundant in herbaceous field margins than in the other three types of hedgerows (Figure 4). More generally, invertebrate abundance was higher in herbaceous margins than in shrubby or woody hedgerows. In addition, invertebrate abundance was higher in the immediate field margin (edge), followed by crop field and lowest in the centre of hedgerows, regardless of hedgerow type. Nonetheless, in fields, >95% of all invertebrates collected were non-pest species. In hedgerows, beneficial or neutral species accounted for 77-92% of individuals. Thus, most invertebrates encountered in fields and, to a lesser extent, in hedgerows were either beneficial to crops (pollinators, predators) or neutral.

Vertebrate diversity. Bird use of field margins was studied in Saint-Hyacinthe hedgerows and Boyer River riparian strips during the breeding season (Jobin et al. 2001a, b; Deschênes et al. 2003). Bird diversity and abundance were higher in well-structured and diversified field boundaries (i.e., natural hedgerows, woody riparian strips) than in homogeneous grassy field margins and riparian strips. Additional species only observed in woody field boundaries were mainly insectivorous species that can act as biological control agents of pest insects in adjacent crop fields whereas use of crop fields by birds potentially detrimental to crops (blackbirds, fruit-eating birds) was minimal (Jobin et al. 2001a, b). Small mammal and herpetofaunal communities were also surveyed in riparian habitats (Maisonneuve and Rioux, 2001). Amphibian and reptile abundance increased with vegetation complexity but more species were observed in shrubby strips. Small mammal abundance and to a lesser extent species richness increased with complexity of vegetation structure.

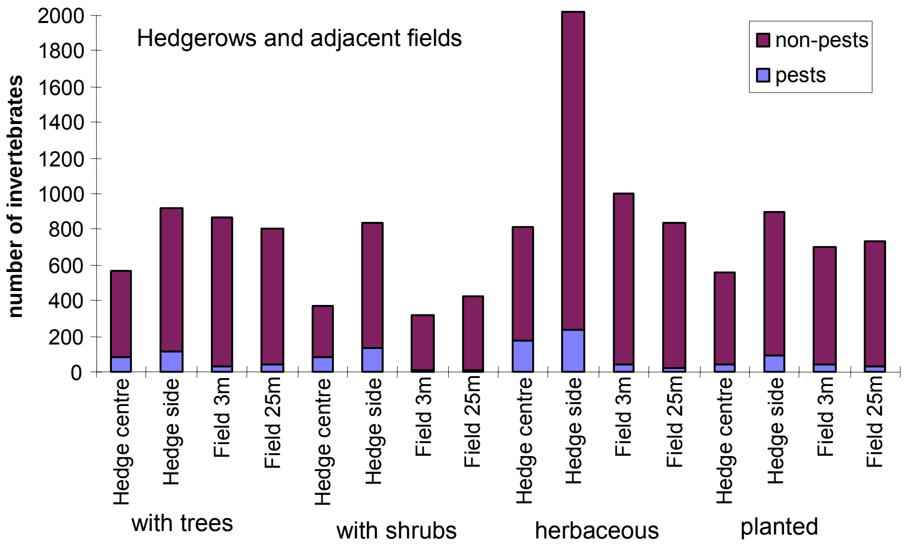

Figure 4. Total number of invertebrates found in hedgerows (centre and sides) and at 3 m and 25 m into adjacent fields in the different types of hedgerows studied near Saint-Hyacinthe, Québec, June 1996: natural with trees, with shrubs, herbaceous and planted with trees. Invertebrates considered pests in agriculture are shown separately from non-pest species.

Bird activities in boundaries versus fields. In two separate studies, bird occurrence in boundaries and adjacent fields was recorded. The first was completed in 1987 (July to September) and 1988 (May to September) in southern Ontario (Boutin et al. 1996). Birds were surveyed several times in 18 corn fields of Essex and Haldimand-Norfolk counties and locations of birds were assigned to field edge or interior. At the landscape level, <4% natural area can be found in Essex county whereas ~25% of Haldimand-Norfolk county is still forested but fragmented

(Friesen 1994). At least half of the corn fields surveyed in Haldimand-Norfolk abutted woodlots, plantations or regenerating woody vegetation (but usually on one side). In Essex, wooded habitats did not occur next to corn fields. Herbaceous or sparsely vegetated hedgerows were more prevalent in Essex.

Consistently more species and individuals were enumerated in Haldimand-Norfolk than in Essex. In Essex corn fields, 59 bird species were recorded in 1987 and 72 in 1988; in Haldimand-Norfolk corn fields, 83 and 93 species were observed in 1987 and 88, respectively. More species were reported in 1988 than in 1987 because the former counts included breeding and migration periods. Most bird species were observed in edges rather than in the field centre except barn swallow (*Hirundo rustica* L.), purple martin (*Progne subis* L.), horned lark (*Eremophila alpestris* L.) and killdeer (*Charadrius vociferous* L.); none causes damage to crops. Red-winged blackbirds (*Agelaius phoeniceus* L.) visited field centres more frequently by September, in some cases to feed on unharvested grains.

The second study was performed in 1996 in southern Québec. Nine hedgerows of similar total length were selected for surveys of bird occurrence and behaviour: two natural hedgerows with trees (1400 m), three natural hedgerows with shrubs (1600 m), two planted windbreaks (1400 m) and two herbaceous field margins (1400 m). All were situated between neighbouring fields of corn (*Zea mays* L.), peas (*Pisum arvense* L.), or soybeans (*Glycine max* (L.) Merr.). Each site was visited twice for a total of 14 to 16 hours for each hedge type. Activities of birds were noted in the hedgerow and within 5 m of adjacent fields. A subset of results is presented here.

In total, 582 individuals from 27 species were observed; all species were most frequently associated with woody hedges, except savannah sparrow (*Passerculus sandwichensis* Gmelin), which preferred herbaceous field margins. Cedar waxwing (*Bombycilla cedrorum* Vieillot, n = 15), common yellowthroat (*Geothlypis trichas* L., n = 6), Baltimore oriole (*Icterus galbula* L., n = 3), alder flycatcher (*Empidonax alnorum* Brewster, n = 2), eastern phoebe (*Sayornis phoebe* Latham, n = 2), eastern kingbird (*Tyrannus tyrannus* L., n = 2) and great crested flycatcher (*Myiarchus crinitus* L., n = 1) were only seen in hedgerows with trees or shrubs, never in fields or in herbaceous boundaries. Horned lark (n = 46), killdeer (n = 10), rock dove (*Columba livia* Gmelin, n = 9), spotted sandpiper (*Actitis macularia* L., n = 7), mallard (*Anas platyrhynchos* L., n = 2) and barn swallow (n = 1) were only observed in fields regardless of hedgerow type. The most abundant species encountered were red-winged blackbird (n = 111), song sparrow (*Melospiza melodia* Wilson, n = 73), savannah sparrow (n = 71), American goldfinch (*Carduelis tristis* L., n = 55), American robin (*Turdus migratorius* L., n = 39), brown-headed cowbird (*Molothrus ater* Boddaert, n = 30), vesper sparrow (*Pooecetes gramineus* Gmelin, n = 27) and yellow warbler (*Dendroica petechia* L., n = 25).

Relevance to Setting Field Boundary Regulations in Canada

Published reviews and field studies summarised here support the general conclusion that field boundary habitats, especially natural boundaries, can serve as important reservoirs for native plants, invertebrates and birds. Given that these areas do not support complete communities, maintenance and restoration of native habitats placed in larger contiguous parcels will remain an important component of conservation planning and action (also see Freemark and Kirk 2001). Diversity should be based on assessment of species richness and composition rather than richness alone because the latter measure may not account for important community changes resulting from habitat alteration.

Several areas require further attention if we hope to enhance our understanding of the effects of farm-management practices on wildlife habitat and species, and assist conservation decisions. Natural areas adjacent to crops harbour beneficial invertebrates, pollinators and predators or parasites of noxious plants and invertebrates (Table 2, Figure 4); however, to our knowledge, these potential benefits have not been adequately weighed against costs of pests residing in these areas. Our findings reported here suggest that interactions among agrochemical use and tillage frequency are complex (Table 3), so predicting impacts on invertebrates is difficult. Direct benefits to producers may also be obtained by haying or grazing of wetland margins but relationships between habitat quality or impacts on wildlife and management timing, frequency or severity is unclear.

The importance of water quality protection has been growing, heightening the need for guidelines that create a positive reaction by producers while effectively protecting surface waters used by humans and livestock. Larger interconnected natural habitats generally are most valuable for conservation goals, so further work is needed to determine the optimal trade-off between natural (restored) area retention and producer acceptance. Furthermore, identifying incentives (e.g., tax credits, easements) that would encourage landowners to protect natural habitats, including boundaries, would be extremely beneficial for conservation and farm policy agencies.

Boundaries can create corridors for dispersal (Wegner and Merriam 1979; Fahrig and Merriam 1985; Inglis and Underwood 1992; Haas 1995) and provide habitat for species not normally found there (Freemark et al. 2002), including invasive species. However, relationships between boundary habitats, their management, and wildlife movements and productivity (not just numbers; Figure 3) should be better quantified (Lokemoen and Beiser 1997).

Disturbance of natural habitats adjacent to cultivated fields should be minimised to maintain the integrity of herbaceous vegetation (Figures 1 and 2). This should help reduce the spread of weeds in those habitats as well as in adjacent cultivated fields. A reduction in pesticide use should lower diffuse pollution. Natural hedgerows should take priority over planted hedgerows in areas where windbreaks are needed. Both farmers and wildlife could benefit from this practice via cost reduction and maintenance of natural habitats. Woody riparian habitats should take precedence over grassy strips because of their role in protecting and enhancing terrestrial and aquatic wildlife species (Figure 3), reducing bank erosion, enhancing chemical filtering, and aesthetic improvement of rural landscapes.

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Literature Cited

Andersen, A. and R. Eltun. 2000. Long-term developments in the carabid and staphylinid (Col., Carabidae and Staphylinidae) fauna during conversion from conventional to biological farming. J. Appl. Entomol. 124:51-56.

Basore, N. S., L. B. Best, and J. B. Wooley, Jr. 1987. Arthropod availability to pheasant broods in no-tillage fields. Wildl. Soc. Bull. 15:229-233.

Blumberg, A. Y. and D. A. Crossley Jr. 1983. Comparison of soil surface arthropod populations in conventional tillage, no-tillage and old field systems. Agro-Ecosystems 8:247-253.

Boutin, C. and B. Jobin. 1998. Intensity of agricultural practices and effects on adjacent habitats. Ecol. Appl. 8:544-557.

Boutin C., K. E. Freemark, D. V. Weseloh, G. M. Donaldson, M. Csizy, P. A. Martin, A. Wormington, J. McCracken, and D. Shepherd. 1996. Bird use of crops in southern Ontario: Implications for assessment of pesticide risk, CWS Technical Report No. 264. Hull, Québec: Environment Canada.

Boutin, C., B. Jobin, L. Bélanger, and L. Choinière. 2001a. Comparing weed composition in natural and planted hedgerows and in herbaceous field margins adjacent to crop fields. Can. J. of Plant Sci. 81:313-324.

Boutin, C., B. Jobin, L. Bélanger, A. Baril, and K. E. Freemark. 2001b. Hedgerows in the farming landscapes of Canada. Pages 35-42 *in* C. Barr and S. Petit, eds. Hedgerows of the World: Their Ecological Functions in Different Landscapes. University of Birmingham, UK: International Association of Landscape Ecology.

Boutin, C., B. Jobin, L. Bélanger, and L. Choinière. 2002. Plant diversity in three types of hedgerows adjacent to cropfields. Biodiversity Conserv. 11:1-25.

Boutin, C., B. Jobin, and L. Bélanger. 2003. Importance of riparian habitats to flora conservation in farming landscape of southern Québec, Canada. Agric. Ecosyst. Environ. 94:73-87.

Burke, I. C., W. K. Lauenroth, and D. P. Coffin. 1995. Soil organic matter recovery in semiarid grasslands: implications for the Conservation Reserve Program. Ecol. Appl. 5:793-801.

Campbell C., I. D. Campbell, C. B. Blyth, and J. H. McAndrews. 1994. Bison extirpation may have caused aspen expansion in western Canada. Ecography 17:360-362.

Cárcamo, H. A., J. K. Niemalä and J. R. Spence. 1995. Farming and ground beetles: Effects of agronomic practice on populations and community structure. Can. Entomol. 127:123-140.

Cessna, A. J., T. M. Wolf, G. R. Stephenson, and R. B. Brown. 2005. Pesticide movement to field margins: Routes, impacts and mitigation. Pages 69-112 *in* A. G. Thomas, ed. Field Boundary Habitats: Implications for Weed, Insect and Disease Management. Topics in Canadian Weed Science, Volume 1. Sainte-Anne-de-Bellevue, Québec: Canadian Weed Science Society – Société canadienne de malherbologie.

Collins, K. L., N. D. Boatman, A. Wilcox, J. M. Holland, and K. Chaney. 2002. Influence of beetle banks on cereal aphid predation in winter wheat. Agric. Ecosyst. Environ. 93:337-350.

Deschênes, M., L. Bélanger, and J.-F. Giroux. 2003. Use of farmland riparian strips by declining and crop damaging birds. Agric. Ecosyst. Environ. 95:567-577.

Diamond, J. M. and R. M. May. 1981. Island biogeography and the design of natural reserves. Pages 228-252 *in* R. M. May, ed. Theoretical Ecology: Principles and Applications. 2nd edition. Oxford, UK: Blackwell Scientific.

Donald, D. B., N. P. Gurprasad, L. Quinnett-Abbott, and K. Cash. 2001. Diffuse geographic distribution of herbicides in northern prairie wetlands. Environ. Toxicol. Chem. 20:273-279.

Drinkwater, L. E., D. K. Letourneau, F. Workneh, A. H. C. van Bruggen, and C. Shennan. 1995. Fundamental differences between conventional and organic tomato agroecosystems in California. Ecol. Appl. 5:1098-1112.

Edwards, C. A. and J. R. Lofty. 1982. The effect of direct drilling and minimal cultivation on earthworm populations. J. Appl. Ecol. 19:723-734.

Fahrig, L. and G. Merriam. 1985. Habitat patch connectivity and population survival. Ecology 66:1762-1768.

Freemark, K. E. and C. Boutin. 1995. Impacts of agricultural herbicide use on terrestrial wildlife in temperate landscapes: A review with special reference in North America. Agric. Ecosyst. Environ. 52:67-91.

Freemark, K. E., C. Boutin, and C. J. Keddy. 2002. Importance of farmland habitats for conservation of plant species. Conserv. Biol. 16:399-412.

Freemark, K. E. and D. A. Kirk. 2001. Birds on organic and conventional farms in Ontario: Partitioning effects of habitat and practices on species composition and abundance. Biol. Conserv. 101:337-350.

Fry, G. L. A. 1994. The role of field margins in the landscape. Pages 31-40 in N. Boatman, ed. Field Margins: Integrating Agriculture and Conservation. Monograph No. 58. Farnham, UK: British Crop Protection Council.

Friesen, L. 1994. A literature review on wildlife habitats in agricultural landscapes. Canada-Ontario Agriculture Green Plan. COESA Report No. RES/MAN-009/94. [Online] Available: http://res2.agr.ca/initiatives/manurenet/env_prog/gp/gpres/download/rep1_9.pdf [6 October 2003]

Godwin, B., J. Thorpe, K. Pivnik, and J. Bantle. 1998. Conservation and enhancement of on-farm wildlife habitat and biodiversity. Publication No. R-1540-5E-98 (March 1998). Saskatoon, Saskatchewan: Saskatchewan Research Council. 138 pp.

Gregory, W. W. and G. J. Musick. 1976. Insect management in reduced tillage systems. Bull. Entomol. Soc. Am. 22:302-304.

Haas, C. A. 1995. Dispersal and use of corridors by birds in wooded patches on an agricultural landscape. Conserv. Biol. 9:845-854.

Hobson, K. A., E. M. Bayne, and S. L. van Wilgenburg. 2002. Large-scale conversion of forest to agriculture in the boreal plains of Saskatchewan. Conserv. Biol. 16:1530-1541.

House, G. J. and B. R. Stinner. 1983. Arthropods in no-tillage soybean agroecosystems: Community composition and ecosystem interactions. Environ. Manage. 7:23-28.

Hutto, R. L., S. M. Pletschet, and P. Hendricks. 1986. A fixed-radius point count method for nonbreeding and breeding season use. Auk 103:593-602.

Inglis, G. and A. J. Underwood. 1992. Comments on some designs proposed for experiments on the biological importance of corridors. Conserv. Biol. 6:581-586.

Jackson, W. and J. Piper. 1989. The necessary marriage between ecology and agriculture. Ecology 70:1591-1593.

Jobin, B., L. Choinière, and L. Bélanger. 2001a. Bird use of three types of field margins in relation to intensive agriculture in Québec, Canada. Agric. Ecosyst. Environ. 84:131-143.

Jobin, B., C. Boutin, and L. Bélanger. 2001b. Hedgerows as refuges for pest birds and plants: Could Québec's farmers be wrong? Pages 207-212 *in* C. Barr and S. Petit, eds. Hedgerows of the World: Their Ecological Functions in Different Landscapes. Birmingham, UK: International Association for Landscape Ecology.

Knopf, F. L. 1988. Conservation of steppe birds in North America. Pages 27-41 *in* P. D. Goriup, ed. Ecology and Conservation of Grassland Birds. Technical Publication 7. Cambridge, UK: International Council for Bird Preservation.

Krooss, S. and M. Schaefer. 1998. The effect of different farming systems on epigeic arthropods: A five-year study on the rove beetle fauna (Coleoptera: Staphylinidae) of winter wheat. Agric. Ecosyst. Environ. 69:121-133.

Leeson, J. Y., A. G. Thomas, and J. W. Sheard. 2005. Weed distribution across field boundaries adjacent to roadsides. Pages 185-199 *in* A. G. Thomas, ed. Field Boundary Habitats: Implications for Weed, Insect and Disease Management. Topics in Canadian Weed Science, Volume 1. Sainte-Anne-de-Bellevue, Québec: Canadian Weed Science Society – Société canadienne de malherbologie.

Lokemoen, J. T. and J. A. Beiser. 1997. Bird use and nesting in conventional, minimum-tillage, and organic cropland. J. Wildl. Manage. 61:644-655.

Luff, M. L. 2002. Carabid assemblage organization and species composition. Pages 41-80 *in* J.M. Holland, ed. The Agroecology of Carabid Beetles. Andover: Intercept Ltd.

Mah, R. F. Undated. Designing and managing shelterbelts for wildlife: The relationship between farmyard shelterbelt characteristics and breeding birds in the prairie region of Saskatchewan. Unpublished Report, PFRA Shelterbelt Centre. Indian Head, Saskatchewan: Agriculture and Agri-Food Canada. 20 p.

Maisonneuve, C. and S. Rioux. 2001. Importance of riparian habitats for small mammal and herpetofaunal communities in agricultural landscapes of southern Québec. Agric. Ecosyst. Environ. 83:165-175.

Marshall, E. J. P. 2005. Field margins in northern Europe: Integrating agricultural, environmental and biodiversity functions. Pages 39-67 *in* A. G. Thomas, ed. Field Boundary Habitats: Implications for Weed, Insect and Disease Management. Topics in Canadian Weed Science, Volume 1. Sainte-Anne-de-Bellevue, Québec: Canadian Weed Science Society – Société canadienne de malherbologie.

Marshall, J., J. Baudry, F. Burel, W. Joenje, B. Gerowitt, M. Paoletti, G. Thomas, D. Kleijn, D. Le Coeur, and C. Moonen. 2002. Field boundary habitats for wildlife, crop, and environmental protection. Pages 219-247 *in* L. Ryszkowski, ed. Landscape Ecology in Agroecosystems Management. New York: CRC Press.

McLaughlin, A. and P. Mineau. 1995. The impact of agricultural practices on biodiversity. Agric. Ecosyst. Environ. 55:201-212.

McNicholl, M. K. 1988. Ecological and human influences on Canadian populations of grassland birds. Pages 1-26 *in* P. D. Goriup, ed. Ecology and conservation of grassland birds. Technical Publication 7. Cambridge, UK: International Council for Bird Preservation.

Paul, E. A., and G. P. Robertson. 1989. Ecology and the agricultural sciences: A false dichotomy? Ecology 70:1594-1597.

Pimentel, D. 1995. Ecological theory, pest problems and biologically based solutions. Pages 69-82, *in* D. M. Glen, M. P. Greaves, and H. M. Andersen, eds. Ecology and Integrated Farming Systems. Chichester, UK: John Wiley.

Ryszkowski, L. 2002. Landscape Ecology in Agroecosystems Management. Boca Raton, FL: CRC Press. 366 p.

Schnepf, M. 2005. Realizing the promise of conservation buffer technology. Pages 15-24 *in* A. G. Thomas, ed. Field Boundary Habitats: Implications for Weed, Insect and Disease Management. Topics in Canadian Weed Science, Volume 1. Sainte-Anne-de-Bellevue, Québec: Canadian Weed Science Society – Société canadienne de malherbologie.

Shutler, D., A. Mullie, and R. G. Clark. 2000. Bird communities of prairie uplands and wetlands in relation to farming practices in Saskatchewan. Conserv. Biol. 14:1441-1451.

Thomas, A. G., O. Olfert, J. Leeson, N. Melnychuk, B. Frick, B. Youngs, A. Mullie, D. Shutler, D. J. Forsyth, D. Donald, and R. G. Clark. 1999. Correlates of biodiversity on Saskatchewan farmland. Project Report No. 8.48.2R. Ottawa, Ontario: Wildlife Habitat Canada. 58 p.

Thomas, A. G., R. F. Wise, B. L. Frick, and L. T. Juras. 1996. Saskatchewan weed survey of cereal, oilseed and pulse crops in 1995. Weed Survey Series Publication 96-1. Saskatoon, Saskatchewan: Agriculture and Agri-Food Canada.

Thomas, C. F., J. M. Holland, and N. J. Brown. 2002. The spatial distribution of carabid beetles in agricultural landscapes. Pages 305-344, *in* J. M. Holland, ed. The Agroecology of Carabid Beetles. Andover, UK: Intercept Ltd.

Thomas, M. B., S. D. Wratten, and N. W. Sotherton. 1991. Creation of "island" habitats in farmland to manipulate populations of beneficial arthropods: Predator densities and emigration. J. Appl. Ecol. 28:906-917.

Wallin, H. 1985. Spatial and temporal distribution of some abundant carabid beetles (Coleoptera: Carabidae) in cereal fields and adjacent habitats. Pedobiologia 28:19-34.

Weaver, J. E. 1954. North American Prairie. Lincoln, Nebraska: Johnsen Publishing.

Wegner, J. F. and G. Merriam. 1979. Movements by birds and small mammals between a wood and adjoining farmland habitats. J. Appl. Ecol. 16:349-357.

Wolf, T. M., A. J. Cessna, B. C. Caldwell, and J. L. Pederson. 2005. Riparian vegetation reduces spray drift deposition into water bodies. Pages 201-212 *in* A. G. Thomas, ed. Field Boundary Habitats: Implications for Weed, Insect and Disease Management. Topics in Canadian Weed Science, Volume 1. Sainte-Anne-de-Bellevue, Québec: Canadian Weed Science Society – Société canadienne de malherbologie.

Zedler, J. B. 1996. Ecological issues in wetland mitigation: An introduction to the forum. Ecol. Appl. 6:33-37.