Topics in Canadian Weed Science Volume 1

Field Boundary Habitats:

Implications for Weed, Insect and Disease Management

Edited by A. Gordon Thomas

Canadian Weed Science Society
Société canadienne de malherbologie

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Foreword

Problems with farm weeds led to the formation of first formal Canadian weed committee in 1929 - the Associate Committee on Weed Control. At this inaugural meeting, eighteen committee members met in Edmonton to find answers for weed problems plaguing farmers. Similar committees under various banners such as the Canada Weed Committee, the National Weed Committee and the Expert Committee on Weeds, have met regularly since that time to focus on weed management challenges in Canada. The introduction of 2,4-D in the 1940s and the numerous synthetic herbicides that followed, heralded a new era for weed control and many joined the weed science discipline. Herbicides dominated weed control discussions for the next forty years. After a difficult transition period in the late 1980s and early 1990s, where herbicide recipe discussions broadened to include topics such as integrated weed management, weed biology and ecology, biological weed control, application technology, and environmental issues, a vibrant, new weed science society emerged in 2002.

Today, the Canadian Weed Science Society - Société canadienne de malherbologie, includes a rich mixture of members involving federal, provincial and municipal government employees, multinational herbicide industry researchers and managers, university professors and graduate students, contract researchers, and consultants and industry agronomists. Our goals are (1) to establish and maintain a process for sharing and disseminating weed science knowledge in Canada; (2) to provide a forum for discussion of weed management issues in Canada; and (3) to take a proactive stand on behalf of all stakeholders on issues related to weed management at provincial and federal levels.

This year I am pleased to introduce the first volume in a new series - "Topics in Canadian Weed Science". It is our intention to utilize this publication format to more consistently publish and distribute the relevant proceedings of our annual workshops and symposia. I encourage you to visit our website for further information regarding our society (www.cwss-scm.ca).

K. Neil Harker
President, 2002-2003
CWSS-SCM

Preface

"Topics in Canadian Weed Science" is a series of volumes published periodically by the Canadian Weed Science Society - Société canadienne de malherbologie (CWSS-SCM). The series provides current information, reviews, research results and viewpoints on weed-related topics and issues. It is intended to advance the knowledge of weed science and increase awareness of the consequences of weeds in agroecosystems, forestry, and natural habitats. The topics addressed are diverse and exemplify the challenges facing the various stakeholder groups that make up CWSS-SCM.

Symposia and workshops are major components of the program at the CWSS-SCM Annual Meeting. The Local Arrangements Committee for the Annual Meeting identifies the theme of the workshops or symposia and invites national or international speakers to address the subject. Participants review results of current weed research and provide insight into the issues, thereby assisting the Society in formulating and implementing action plans, when appropriate. The volumes in the series are a compilation of peer-reviewed papers based on oral and poster presentations made at these symposia or workshops.

The CWSS-SCM Board of Directors expresses their gratitude to the contributing authors, reviewers, and the editor who have made this publication possible. We also solicit the readers' assistance in publicizing this series to a more global audience.

Eric Johnson
Publications Director
CWSS-SCM

Acknowledgements

Cover

Top Photograph: Newly-established shelterbelt adjacent to a canola field in northeastern Saskatchewan, near Tisdale. Shelterbelts on the prairies are an integral part of conservation farming systems but they can provide a haven for weeds of field crops. Drift of herbicides applied to crops can damage shelterbelts and reduce their effectiveness. This image provided by Rick Holm, Crop Development Centre, University of Saskatchewan, Saskatoon, SK.

Bottom Photograph: A herbaceous field margin and a woody hedgerow adjacent to a conventional corn field in southern Québec. Several broad-leaved plant species and grasses can be identified including goldenrods (*Solidago* spp.), asters (*Aster* spp.), wild carrot (*Daucus carota* L.), and chicory (*Cichorium intybus* L.). This image provided by Céline Boutin, Canadian Wildlife Service, National Wildlife Research Centre, Environment Canada, Ottawa, ON.

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SYMPOSIUM

Field boundary habitats: Implications for weed, insect, and disease management in Canada

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Introduction

The papers in this first volume of *Topics in Canadian Weed Science* were presented at a symposium held during the inaugural meeting of the Canadian Weed Science Society – Société canadienne de malherbologie (CWSS-SCM) in Saskatoon, Saskatchewan in November 2002. The goals of the symposium were to review our current knowledge, to hear the viewpoints of various sectors, to present current research results, and to encourage discussion of the issues relevant to the management of weeds, insects and diseases in the field boundary habitats that are part of the Canadian agricultural landscape. This symposium provided a forum for researchers, extension specialists, educators, consultants, and managers involved in weed science to explore this multidisciplinary topic for the first time in Canada.

Field boundary habitats are ubiquitous features of the agricultural landscape that have received very little research attention in most of Canada, with the exception of Québec (e.g. Boutin et al. 2001). In contrast, field margins in Europe have been the focus of many research papers and several multidisciplinary compilations based on meetings and symposia (e.g. Boatman 1994; Boatman et al. 1999; Way and Greig-Smith 1987) and a recent issue of the journal *Agriculture, Ecosystems and Environment* was entirely devoted to field margin ecology in Europe (Marshall 2002).

The Pest Management Regulatory Agency (PMRA) of Health Canada had established a Buffer Zone Working Group in 2001. The objective for the formation of this group was to provide a forum to discuss various options for the development of flexible rather than fixed buffer zones. This symposium provided an opportunity for members of Canadian weed science community to learn of PMRA's approach for determining pesticide-specific and site-specific buffer zones that protect sensitive areas but are flexible enough to meet the needs of farmers and applicators. The implementation of flexible buffer zones has implications for the management of not only weeds but also insect pests and plant diseases. Recognition of the complex interactions among the three pest groups provided an opportunity for the organizing committee to broaden the scope of the topic and invite members of the Canadian Expert Committee on Integrated Pest Management (insects and diseases) to participate in the symposium since their meeting was held in Saskatoon the day prior to the symposium.

The symposium highlighted the need to clarify the terms used to describe field boundary habitats in Canada. A buffer zone is the unsprayed area between an intensively managed crop and an environmentally sensitive area such as an upland or wetland habitat that needs protection. This definition implies that a buffer zone is a transient area of the agricultural landscape that is established for operational requirements of pesticide applications. In contrast, a field boundary is usually, but not always, viewed as a semi-natural and permanent component of the landscape but the structure and complexity of this habitat varies depending on the agro-ecoregion, farming system and management practices. In some cases, the field boundary is an unsprayed edge or headland area of the crop that might be very weedy because herbicides have not been used. In other cases, the boundary is a cultivated strip on the margin of the field. The field boundary may be an area of seeded and managed annual or perennial grass cover or an area of permanent semi-natural vegetation that serves to trap water runoff, nutrients and soil from the field and reduce the off-target movement of pesticides. Frequently, the field boundary is a well-defined linear structure such as a fencerow, woody shelterbelt or roadside drainage ditch. Contributors to the symposium have discussed these various boundary types in the absence of a structural framework for defining Canadian field boundary habitats or field margins. Arable field margins in Europe have been formally defined (Greaves and Marshall 1987) with several structural elements that encompass the type of field boundaries that are common in the Canadian agricultural landscape and the buffer zones envisioned by PMRA but the contributors have not used the European definition of field margins. The titles and content of the chapters in this volume reflect the current diversity of views in Canada.

Researchers, regulators, managers, consultants, and farmers presented their viewpoints on particular aspects of the topic. The first chapter in this volume deals with the use of buffer zones to protect sensitive areas (Kuchnicki et al.). The following three chapters consider the implications of buffer zones for conservation of soil and water resources (Schnepf), farm management (Cudmore), and herbicide manufacturers and distributors (Belyk). The next two chapters are in-depth reviews of the current literature on the structure and functions of field margins in Europe (Marshall) and the movement of pesticides from treated agricultural land to field margins in Canada (Cessna et al.). These reviews are followed by three chapters that focus on the interaction of field boundary habitats in Canada with specific groups of organisms, namely wildlife (Clark et al.), insects (Olfert et al.), and plant diseases (Bailey and Gossen). The final three chapters are based on poster presentations that report the results of empirical investigations in Canada on weed fecundity (Weaver and Downs), weed distribution (Leeson et al.), and spray drift (Wolf et al.) in diverse field boundary habitats.

The chapters in this symposium reflect the structural diversity of field boundary habitats in the agricultural landscape in Canada and emphasize the complexity of pest management in relation to these habitats. The symposium illustrated that understanding the role of field margins in maintaining species and habitat diversity, protecting sensitive areas, preserving air and water quality, and reducing soil erosion, while managing weed, insect and disease pests, will continue to be a challenge in Canada.

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The use of buffer zones for habitat protection: A proposed strategy

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The toxicity of a pesticide to non-target organisms is an inherent property of the pesticide's active ingredient and is used by the Pest Management Regulatory Agency (PMRA) to establish pesticide-specific buffer zones. However, the characteristics that define the differences between sensitive habitats or the operational configurations (i.e., meteorological conditions and sprayer configurations) at the time of application are currently not considered when calculating these buffer zones. As agricultural pesticides are applied across Canada under a wide range of conditions, there is a need to refine the way in which buffer zones are determined to reflect the variability between sensitive habitats, differing application practices, and advances in application technology. This document outlines a proposed strategy for a new flexible approach to modify pesticide-specific buffer zones for agricultural applications of pesticides. The new approach will allow applicators to consider defined parameters and thereby reduce buffer zone widths from that currently advised on the label. It is believed that the proposed approach is 'risk neutral'; that is, it will provide the PMRA and the applicator with considerably more flexibility than is presently allowed without increasing risk to the environment.

Additional Keywords: pesticide application, risk assessment, risk mitigation, pesticide regulation

Introduction

One manner in which a pesticide can move to sensitive habitats during its application is by particle spray drift. Particle spray drift arising from the application of pesticides to agricultural fields is a potential risk to non-target sensitive habitats

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that are adjacent to or within the application area. The Pest Management Regulatory Agency (PMRA) believes the risks to these sensitive habitats, and the organisms within them, can be mitigated by using appropriate no-spray areas or buffer zones. A buffer zone, also commonly known as a setback, is defined by the PMRA as the distance between the downwind point of direct pesticide application and the nearest boundary of a sensitive habitat. The key factors governing the magnitude of this buffer zone are: (a) the toxicity of the pesticide's active ingredient to non-target organisms, (b) the characteristics of the sensitive habitat adjacent to or within the site of application, (c) the local meteorological conditions at the time of application, and (d) the pesticide application method and sprayer configuration.

During the review process, the PMRA evaluates the risks to non-target organisms posed by the use of a pesticide. In risk assessment, the environmental toxicity of the pesticide's active ingredient is assessed, and aquatic or terrestrial organisms that are sensitive to the compound are identified. If required, the PMRA establishes pesticide-specific buffer zones that reflect the inherent toxicity of a pesticide and its estimated environmental concentration. No consideration is given to conditions that may differ with habitat sensitivity or the operational configurations (i.e., meteorological conditions and sprayer configurations) at the time of application. The PMRA believes, however, that as agricultural pesticides are applied across Canada under a wide range of conditions, there is a need to refine the way in which buffer zones are determined to reflect variability among sensitive habitats and differing application practices, and to encourage advances in application technology.

In order to address the inadequacies of the current approach, the PMRA has been examining ways:

(1) to develop an approach for determining site-specific buffer zones for agricultural applications of pesticides that protect sensitive habitats, but which is also flexible enough to meet the needs of growers and applicators;
(2) to encourage applicators to use new technology and sprayer configurations to reduce spray drift;
(3) to increase awareness of the effects of meteorological conditions on spray drift and to encourage applicators to spray only under favourable conditions; and
(4) to increase awareness of the appropriate buffer zones to use when preparing a spray program.

The PMRA is developing an approach that is considered 'risk neutral'; that is, it will provide the PMRA and the applicator with considerably more flexibility than is presently allowed without increasing risk to the environment. The proposed approach allows for the reduction of buffer zones, determined by the inherent toxicity of a pesticide, through consideration of the characteristics of the sensitive habitat and the operational configurations. In this manner, the observed buffer zone will be pesticide-, site-, and operationally-specific, thereby more accurately reflecting ‘real-life’ conditions rather than relying on a ‘one size-fit-all’ conservative solution.

Current PMRA Methods for Buffer Zone Determination

The environmental risk posed by a pesticide is a function of the pesticide’s toxicity to non-target organisms and the predicted level of exposure of these organisms to the pesticide. The integration of these two factors (toxicity and exposure) provides an indication of the level of concern for non-target organisms in the environment and the need for risk mitigation (e.g. a buffer zone).

The toxicity of a pesticide to non-target organisms is primarily due to the active ingredient(s) (a.i.). This toxicity is expressed as a dose-response relationship between the active ingredient and the adverse effects upon the organism, such that increased exposure to the compound results in increased adverse effects. Adverse effects may be lethal or sub-lethal (e.g., changes in behaviour, changes in reproductive success). Currently, the PMRA uses the no observable effect concentration (NOEC) for aquatic organisms and the EC_{25} (a 25% inhibitory effect on seedling emergence or vegetative vigour) for terrestrial plants as the endpoints of concern in its risk assessments. In either of these cases (terrestrial or aquatic), the appropriate endpoint of the most sensitive non-target organism is used to calculate a buffer zone.

The exposure of non-target organisms to a pesticide is estimated through the calculation of an Expected Environmental Concentration (EEC) of the pesticide following application. For terrestrial plants, the EEC is expressed as the active ingredient’s application rate (g a.i. ha^{-1}). For aquatic organisms, the EEC is expressed as the concentration of the active ingredient in water (g a.i. L^{-1}). The EEC in water is determined by assuming a direct over spray of a standard water body with the maximum labelled application rate of the pesticide. The standard water body, used by the PMRA to calculate the water volume, is a field-side pond with a surface area of 1 ha (100 m x 100 m) and a depth of 30 cm.

Off-site spray drift is largely independent of the physical/chemical characteristics of an active ingredient, but may be dependent on the physical/chemical characteristics of a formulation. Some formulation ingredients are known to influence the size of spray droplets and hence their potential to drift. However, the dominating determinants of the amount of spray drift that occurs are the meteorological conditions at the time of spraying and the sprayer configuration used to deliver the pesticide.

By combining information on the amount of drift and exposure with appropriate data on toxicity, it is possible to determine if drift is likely to cause adverse effects on non-target organisms. If a risk is identified, i.e., if the EEC is greater than the NOEC or EC_{25} of the most sensitive non-target organism, it is then possible to determine what reduction in drift would be required to reduce the risk to an acceptable level, i.e., the EEC equal to or less than the NOEC or EC_{25} of the most sensitive organism. Assuming that the applied dose remains unchanged, a reduction in drift to sensitive habitats can be achieved by: (a) implementing a buffer zone; (b) spraying under more favourable meteorological conditions; (c) changing the sprayer configuration; or (d) a combination of the above. Currently, however, only the implementation of a buffer zone can be used by the applicator to reduce the volume of drifting pesticide reaching sensitive habitats.

Buffer zones for aquatic habitats are calculated by using the aquatic EEC and the NOEC for the most sensitive aquatic organism as input values to a function that describes the deposition of the pesticide over distance. This function is used to determine the appropriate distance: width of the buffer zone that the spray equipment should be from the sensitive aquatic habitat when the pesticide is applied. It should be noted that buffer zones are used when a sensitive aquatic habitat is downwind of the spray swath. Terrestrial buffer zones are calculated in a similar manner except the EC_{25} for the most sensitive terrestrial plant is used rather than a NOEC.

For field sprayer applications, the function used by the PMRA in their buffer zone calculations is based on the empirical data of Nordby and Skuterud (1975). It should be noted that the assumptions of Nordby and Skuterud (1975) are currently under review and an improved model may be chosen in the future. For airblast applications, data from Ganzelmeier et al. (1995) are used in the PMRA's risk assessment. For chemigation, basic application is assumed to use a high pressure, impact sprinkler, not equipped with an end gun, with a height of 3.5 m. Due to the lack of suitable drift data for chemigation, the Nordby and Skuterud (1975) function for field spraying is used to calculate buffer zones. The rationale for this is that, even though the droplets are much larger for chemigation, the higher boom height increases the drift potential and these factors roughly compensate for one another. The use of this model is also under review and a more representative model may be used in the future. The AgDrift model (see http://www.agdrift.com/index.htm) is used to calculate the buffer zones for aerial applications. It should be noted that the assumptions used in the AgDrift model represent a reasonable but conservative application scenario.

The PMRA considers that the use of conservative drift scenarios and the NOEC or EC_{25} of the most sensitive species results in buffer zones that are upper bound estimates of those required for protection of non-target organisms.

Proposed Approach for Site-Specific Buffer Zones

A new approach to determine the width of buffer zones for mitigating the toxic effects of pesticides due to spray drift is being developed by the PMRA. The proposed approach is more flexible than the current method and allows for buffer zone reductions by the applicator depending on the type of sensitive habitat being protected, the application equipment used, and the meteorological conditions at the time of spraying.

The PMRA currently calculates buffer zones using the methods outlined in the previous section and for most products, this process results in one or two buffer zones (aquatic and/or terrestrial) on product labels. The new approach proposes that the use of drift-reducing application equipment and spraying under favourable meteorological conditions be rewarded with narrower buffer zones. The characteristics of the sensitive habitats adjacent to or within the treated field are also considered, with the recognition that buffer zones can be reduced for those areas with lower risks of adverse effects from spray drift. As indicated earlier, this approach was designed to be ‘risk neutral’; thus, there would be no additional risk to natural environments from this strategy.

The most important variables affecting spray drift are droplet size or spray quality, and wind speed. Other factors (which can be specific to a particular application method) include atmospheric stability, carrier volume, discharge height and direction, temperature and relative humidity, travel speed, shrouds, adjuvants, and crop canopy conditions. As the inclusion of all possible factors would result in an overwhelmingly complex scheme, only the most important variables were chosen as determined from the published literature or sensitivity analysis with the AgDrift model. The major factors affecting drift for specific application methods that will be used by the PMRA for reducing labelled buffer zones are summarised in Table 1.

Table 1. Major factors affecting spray drift for different application methods

Application method	Major factors
Field sprayers	Droplet size, wind speed, boom height
Airblast	Wind speed and sprayer type
Chemigation	Wind speed and sprinkler type
Aerial	Droplet size, wind speed, temperature and relative humidity

For field sprayers, shrouds and cones have been shown to be an effective tool for reducing spray drift, consequently, some provision will be made to reduce buffer zones if the applicator chooses to use these drift-reducing strategies. As other new technologies become proven drift-reducing strategies, the PMRA will endeavour to recognize them. Regulatory recognition has been a key requisite to the introduction of comparable schemes within Europe.

For ground-based applications, (i.e. field sprayers, airblast, and chemigation), the modified buffer zones will be determined by the PMRA using several sets of multipliers. Briefly, the buffer zones calculated using the PMRA’s current methods for ground-based applications would be modified by appropriate application equipment multipliers and meteorological multipliers. These multipliers are generated from the best available information that is cited by recognized scientific literature or publicly available spray drift models.

For example, wind is an important factor affecting spray drift. All other things being constant, spray drift has been found to increase linearly with increasing wind speed for field sprayers (Goering and Butler 1975, Bode et al. 1976, Maybank et al. 1978, Wolf et al. 1993, Grover et al. 1997). Consequently, for a fixed set of application conditions, wind speeds can be categorized and a multiplier can be generated for each category which considers the effect of wind speed; a proposal already used with success in Sweden.

Buffer zone multipliers of 1.0 are assigned to those sprayer configurations and conditions for which the initial risk assessments are conducted. These multipliers were then revised according to the expected drift risk for other application conditions. For field, orchard, and chemigation application, documented or estimated changes in drift amounts resulted in a proportional change in buffer zone (i.e., 50% drift reduction = 50% buffer zone reduction).

For aerial applications, rather than modifying a single buffer zone value using multipliers, the PMRA will input a combination of various equipment and meteorological scenarios into the aerial model, AgDrift, to generate numerous buffer zone values. The aerial operation configurations chosen were those shown to produce the most variation in buffer zones but which were operationally achievable.

The modified buffer zone values resulting from these calculations will be provided to applicators in tables printed on product labels. Spray qualities (a term used to indicate the mean size of spray atomized by the nozzle) were introduced by the British Crop Protection Council (BCPC) onto product labels in the United Kingdom to help ensure product efficacy. Now, spray quality is also considered a important variable in drift reduction. The PMRA has adopted the spray quality classification of American Society of Agricultural Engineers (ASAE). Table 2 is an example of a buffer zone table that would be placed on the label.

Table 2. Example of buffer zone table

	Spray quality			
Wind speed	Fine	Medium	Coarse	Very Coarse
Low	10	3	1	0
Medium	14	7	2	1
High	27	15	5	1

In addition, product labels will include site-specific multipliers for the protection of sensitive aquatic habitats. A sensitive aquatic habitat is defined as any area adjacent to a spray area that consists of any form of water, such as, but not limited to, a lake, pond, stream, river, creek, slough, canal, coulee, prairie pothole, or reservoir. Although these habitats are ecologically different, they can be grouped based on broad temporal and spatial similarities.

Aquatic areas may vary over time. Some, such as lakes, are present throughout the season, whereas others, such as sloughs, may be temporary. Consequently, aquatic areas have been divided into two categories based on their temporal nature, permanent and non-permanent, where a permanent aquatic area is an area holding water all year round.

Assuming a closed system and complete mixing of the water body, the risk to permanent water bodies is determined by the concentration of the pesticide in the water, which itself is a function of the amount of spray drift, the surface area of the water body, and the depth of water. A sensitivity analysis of water depth and surface area, performed using the AgDrift model, indicated that calculated buffer zones are more sensitive to the depth of the water body than its surface area. Decreased pesticide concentrations due to an increased width of the water body are counter-balanced by the increased amount of spray drift deposited to it. Thus, the average depth of the water body was determined to be the most important characteristic of water bodies for calculating buffer zones. In practice, the average depth of the water body will be visually estimated by the applicator and recorded on the application record.

An example of depth-dependent multipliers for permanent water bodies are shown in Table 3. These multipliers would be included on the label. A buffer zone multiplier of 1 is assigned to the basic water depth used in determination of the labelled buffer zone. To determine the appropriate multipliers, buffer zones for different water depths (1 - 3 m and > 3 m) for a variety of registered products (insecticides, fungicides, and herbicides), spray qualities (Fine, Medium, and Coarse), and toxicological endpoints were calculated using AgDrift. The respective buffer zone multipliers were calculated by comparing buffer zone distances. Changes in calculated buffer zone distance resulted in a proportional change in buffer zone multiplier.

Table 3. Site-specific multipliers for permanent aquatic areas

Estimated average depth	Multiplier
< 1 m	1
1 - 3 m	0.5
> 3 m	0.1

For temporary and seasonal water bodies, regional differences in water body type and ecological importance prevented a single multiplier from being determined. The PMRA anticipates that Provincial authorities will provide guidance for applicators for these water bodies.

Terrestrial areas vary widely in their characteristics and there are insufficient data available at this time to group these areas according to their ecological sensitivity to pesticides. Therefore, no additional multipliers are provided to the applicator and the labelled buffer zone distances will apply to all terrestrial areas. The PMRA is, however, consulting with the provinces and territories to determine if a list of excluded terrestrial areas could be included on the label.

Summary

This document has outlined a strategy for a new approach for agricultural buffer zones. In developing this approach, the PMRA considered flexibility, convenience, and ease of application as necessary attributes for fostering the use of buffer zones by applicators and, therefore, good environmental stewardship.

Although, the mechanics of buffer zone modification are complex, the proposed approach should allow the applicator to understand the process quickly, to gather the required site-specific information before the spray application, to select an appropriate buffer zone from tables on product labels, and, in some cases, to reduce the labelled buffer zone using a multiplier. The emphasis has been to develop a relatively simple process for a quick and effective determination of a buffer zone, but one based on sound science to ensure the protection of sensitive habitats. In this manner, the observed buffer zone will be pesticide, site, and operationally specific.

It is recognized that increased flexibility means increased responsibility for the applicator to gather the required information and, if necessary, to perform the proper calculations. Consequently, an important component of this initiative is the involvement of provincial authorities and other stakeholders to educate applicators about this new approach. Revised product label statements will be developed to draw attention to the new buffer zone requirements.

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Realizing the promise of conservation buffer technology

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Conservation buffers are a promising way to increase the effectiveness and lower the cost of programs to protect soil and water quality. This was among the important conclusions in an exhaustive 1993 report by the National Research Council's Board on Agriculture. Particularly when combined with supporting practices that enhance buffer performance, such as conservation tillage, nutrient management, and integrated pest management, conservation buffers offer great potential to achieve multiple environmental management objectives. Those objectives include soil erosion and sediment control, air and water quality improvement, fish and wildlife habitat enhancement, flood control, carbon sequestration, and more scenic and diverse landscapes. The potential for using conservation buffers to address a range of environmental issues was a primary reason why the U.S. Department of Agriculture (USDA), in 1997, created the National Conservation Buffer Initiative. This initiative is intended to help producers better understand the value of buffers and become acquainted with those USDA conservation programs available to help producers use buffers for a variety of conservation purposes. The goal of the initiative is to encourage producers to install up to 3.2 million kilometres of buffers. Nearly 100 of the leading agricultural and conservation organizations in the nation are members of USDA's National Conservation Buffer Team. A number of USDA conservation programs are available to help producers install and maintain buffer practices. Particularly important is the continuous Conservation Reserve Program sign-up, which offers attractive financial incentives to help producers install specific buffer practices. Those incentives make buffers work financially for producers, and an increasing body of research indicates that buffers work environmentally as well.

Additional Keywords: agricultural land management, soil erosion, water quality, conservation program incentives, social and economic barriers, riparian restoration and protection

Introduction

Managing the landscape by creating or restoring buffer zones is a promising way to increase the effectiveness and lower the cost of programs to protect soil and water resources.

This was among the more important conclusions in a voluminous 1993 report by the National Research Council's Board on Agriculture (National Research Council 1993). Particularly when combined with supporting practices that enhance buffer performance, such as conservation tillage, nutrient management, and integrated pest management, conservation buffers offer great potential to achieve multiple conservation objectives. Those objectives include the control of soil erosion and sedimentation, improvement of air and water quality, enhancement of fish and wildlife habitat, control of storm water runoff and flooding, recharge of groundwater resources, sequestration of carbon, and conservation of biodiversity.

Over the past six years, the U.S. Department of Agriculture (USDA) has sought to encourage the use of conservation buffers by farmers and ranchers with an outreach program, the National Conservation Buffer Initiative, and by using its conservation program authorities to increase the financial incentives available to those farmers and ranchers willing to adopt buffer technology.

Why Buffers?

Agriculture is often singled out as a major contributor to water quality problems in the United States. Sediment, nutrients, pesticides, and pathogens are among the potential pollutants leaving crop fields, livestock feedlots, grazing land, and woodlots. Air quality is likewise threatened in certain regions of the country by blowing soil particles and attached contaminants. For decades as well, fish and wildlife interests have considered agricultural activities to be among the greatest threat to important fish and wildlife habitats.

When one considers that three-fourths of the land in the United States, exclusive of Alaska, is privately owned; that more than 90 percent of this land is cropland, grazing land, or forestland; and that an estimated 88 percent of all precipitation that falls on the contiguous 48 states falls on this "working" land, one fact becomes perfectly clear: How the nation's farmers and ranchers use and manage the preponderance of this privately owned land has everything to do with the environmental quality enjoyed by nearly all citizens (U.S. Department of Agriculture 1997).

This circumstance puts agriculture in the public crosshairs and conservation buffers are among the time-tested ways for the agricultural industry generally, and farmers and ranchers individually, to confront this environmental management challenge. That certainly was the upshot of the Board on Agriculture report, and it was among the primary reasons that national policymakers incorporated language into recent farm bills that has allowed USDA to pursue the enrolment of buffers in the Conservation Reserve Program (CRP).

Buffers also have received more attention of late because of the growing body of research that confirms their effectiveness for a variety of conservation purposes, including water quality improvement. At the outset of USDA's buffer initiative, for example, an unpublished literature review was conducted to determine the effectiveness of buffers for water quality improvement purposes. While that review discovered great variation in the performance of buffers from one location to another, USDA officials concluded that buffers, if properly designed, located, installed, and maintained, could remove 75 percent or more of sediment, 50 percent or more of nutrients and pesticides, and 60 percent or more of pathogens in storm water runoff.

A mathematical modeling study completed at the request of NRCS officials in 1998 by Texas A&M University scientists (Arnold et al. 1998) simulated the effectiveness of conservation buffers for reducing soil erosion and sediment delivery from cropland. That work concluded that sediment delivery from crop fields could be reduced up to 60 percent with the installation, nationwide, of in-field and edge-of-field buffers, as appropriate.

Recent research by Iowa State University scientists (Lee et al. 2003) on the Bear Creek demonstration watershed in central Iowa showed removal rates by a 7-meter-wide switchgrass filter strip of 95 percent for sediment, 80 percent for total-nitrogen, 62 percent for nitrate-nitrogen, 78 percent for total-phosphorus, and 58 percent for phosphate-phosphorus. A 16.3-meter-wide riparian buffer containing a combination of switchgrass and woody vegetation showed removal rates of 97 percent for sediment, 94 percent for total-nitrogen, 85 percent for nitrate-nitrogen, 91 percent for total-phosphorus, and 80 percent for phosphate-phosphorus.

David Correll, before retiring at the Smithsonian Institute in the late 1990s, constructed a wide-ranging bibliography of the research literature on use of buffers for water quality improvement purposes (Correll 1999). Many other researchers over the past decade have initiated research on the use of buffers for such purposes as enhancement of upland bird and mammal habitats, protection of aquatic habitats, management of snow deposition, and protection of floodplains in urbanizing landscapes. A National Conservation Buffer Workshop was organized in 2001 and attempted to identify the remaining and most pressing buffer-related research needs. A report based on the workshop has been published (Soil and Water Conservation Society 2001).

The potential for using conservation buffers far more extensively to address a range of conservation issues was a primary reason why USDA in 1997 created the National Conservation Buffer Initiative. This initiative, under the leadership of the Natural Resources Conservation Service (NRCS), is intended to help farmers and ranchers better understand the value and importance of buffers for multiple conservation purposes. It also is intended to make farmers and ranchers more aware of the USDA conservation programs that are available to help them install buffers. The initiative counts among its supporters nearly 100 of the nation's leading agricultural and conservation organizations and several prominent agribusiness firms.

The initiative, which has as its theme "Buffers: Common-sense Conservation," had an initial goal of helping farmers and ranchers install up to 3.2 million kilometres of conservation buffers. While that goal has not yet been met, farmers and ranchers had installed 2.2 million kilometres of buffers by the end of calendar year 2002. The prospect for continued installations also remains good, given the substantial increase in funding for a variety of USDA conservation programs in the new U.S. farm bill, the Farm Security and Rural Investment Act of 2002.

Table 1. Kilometres of buffers installed during the first six years of the National Conservation Buffer Initiative, January 1997 – January 2003

Program category	Kilometres of buffers installed
Technical assistance only	307,140
Cost-share programs	298,895
Wetlands Reserve Program[a]	44,224
Conservation Reserve Program[b]	538,360
Continuous Conservation Reserve Program Sign-up	1,041,669
Total	2,230,288
National Conservation Buffer Initiative target	3,200,000

[a] Prior to fiscal year 2001, a 20 percent credit was taken for WRP acres under easement in the courthouse. Thereafter, actual buffer installations were to be reported through the NRCS Performance and Results Measurement System.
[b] Prior to fiscal year 2001, a 4 percent credit was taken for CRP acres enrolled adjacent to water and producing significant environmental benefits. Thereafter, actual buffer installations were to be reported through the NRCS Performance and Results Measurement System.

At the outset of the buffer initiative, NRCS set forth three guiding principles for field staff working with farmers and ranchers:

- Be flexible in working with farmers and ranchers to make certain buffers are operational.
- Use of buffers should be coupled with supporting practices that enhance buffer performance.
- Buffer installations should seek to achieve multiple conservation purposes whenever possible.

What are Buffers?

In general, buffers are linear strips of land in a permanent vegetative cover of grass, forbs, shrubs, and/or trees. Buffers are strategically located within, at the edge, or outside of crop fields and grazing land where they can protect important environmental elements on the landscape from the consequences of agricultural production. Those environmental elements can be natural amenities, such as streams or lakes, or manmade structures, such as buildings and roads.

USDA's Natural Resources Conservation Service (NRCS) recognizes the following buffer types in its list of conservation practices:

- Filter strips
- Riparian forest buffers
- Grassed waterways
- Field borders
- Alley cropping
- Contour grass strips
- Vegetative barriers
- Cross-wind trap strips
- Herbaceous wind barriers
- Windbreaks/shelterbelts/living snow fences

There are many variations on these buffer types and different names attached to each in different parts of the country. Other common conservation practices are sometimes considered buffers as well, depending on their placement and purpose. This is particularly the case for such practices as streambank restoration, herbaceous riparian cover, and wetlands, whether restored or constructed.

Programs that Support Buffer Use

As a result of recent U.S. farm bills, there are several USDA conservation programs available to help farmers and ranchers use conservation buffers. The financial incentives in some cases are extremely attractive, given current commodity prices. Most of these programs include technical assistance for planning buffer systems as well as cost-sharing dollars for installation of buffers. Among the important programs are the following:

- Environmental Quality Incentives Program (EQIP) – This program is USDA's primary conservation cost-share program. Administered by NRCS, it makes technical, financial, and educational assistance available to farmers and ranchers throughout the country.
- Wildlife Habitat Incentives Program (WHIP) – This NRCS-administered program provides technical assistance and cost-share funds to farmers, ranchers, and others wanting to enhance fish and wildlife habitat.
- Wetlands Reserve Program (WRP) – This voluntary program offers financial assistance, mainly through the purchase of conservation

easements, to farmers and ranchers willing to restore wetlands. WRP also is administered by NRCS.
- Continuous CRP sign-up (CCRP) – This component of the well-known CRP targets buffer practices specifically and, like the CRP, allows farmers and ranchers to retire land from agricultural production under 10- to 15-year contracts in return for annual rental payments and other financial incentives. The CRP and CCRP are both administered by USDA's Farm Service Agency (FSA).

While all of these programs offer reasonable financial incentives and varying sets of "rules to live by" for farmers and ranchers, the CCRP clearly is the most important from the standpoint of conservation buffers. That program targets 10 specific buffer practices:
- Riparian forest buffers
- Filter strips
- Grassed waterways
- Contour grass strips
- Cross-wind trap strips
- Field windbreaks and shelterbelts
- Living snow fences
- Shallow water areas for wildlife
- Salt-tolerant vegetation to reduce salinity
- Designated wellhead protection areas

The CCRP operates under most of the same rules as its parent program, but there are some marked differences. For example, unlike the CRP, which uses periodic sign-ups to enrol land, the CCRP allows farmers and ranchers to offer land for enrolment throughout the year. Moreover, farmers and ranchers need not compete with one another to enter land into the CCRP, which is the case with the CRP. If a farmer or rancher meets the eligibility requirements and the land he or she offers for enrolment is suitable for the buffer practice to be installed, the offer is automatically accepted.

Acceptance of an offer and completion of a contract triggers payment of several financial incentives. These incentives are in addition to the maximum CRP rental payment that is made for comparable land in a particular location. The incentives include the following:
- An up-front signing incentive payment of $10 per acre per year for each year of the CRP contract for certain high-priority buffer practices: riparian forest buffers, filter strips, grassed waterways, shelterbelts, field windbreaks, and living snow fences.
- Up to 50 percent cost sharing for practice installation.
- A practice incentive payment equal to 40 percent of the eligible practice installation cost.

- A 20 percent incentive on the annual CRP rental payment per acre for installation of riparian forest buffers, filter strips, grassed waterways, and field windbreaks.
- A 10 percent incentive on the annual CRP rental payment per acre for installation of a buffer in a designated wellhead protection area.
- Higher maintenance payments, up to $10 per acre per year, for certain practices, such as tree planting, fencing, and water development.

Participation in the CCRP normally requires that any land enrolled must have been cropped in at least two of the prior five years and remain physically and legally capable of being cropped. A provision of the law also has allowed the enrolment of marginal pastureland along streams and around other permanent water bodies if the farmer or rancher is willing to install a riparian forest buffer on that land. Marginal pastureland was redefined early on to include grazing land that had never been seeded, a back-door way of making rangeland eligible for the program.

The cropping history test and a number of other provisions of the CCRP were altered somewhat in the 2002 farm bill. FSA is now working on new program rules and policies for the CRP that reflect the changes, many of which should encourage use of conservation buffers even more. The financial incentives available through the program are not expected to change in any significant way.

Interestingly, a number of state and local governments, as well as private organizations, also make financial incentives available to farmers and ranchers who install buffers under the CCRP. Illinois, for example, provides a property tax discount on land devoted to streamside buffers. Kansas and Nebraska supplement the federal CCRP rental payments per acre. Pheasants Forever, Quail Unlimited, and other wildlife groups make free seed and other financial incentives available in numerous locations. A watershed association in Iowa paid a signing bonus for CCRP enrolments prior to initiation of the federal signing incentive payment, and that same association supplements the federal cost-share payment for buffer installations.

The Potential for Buffers

In spite of the success with buffer installations to date, there remains substantial potential for far greater acreages of buffers. At the outset of USDA's buffer initiative, estimates were made on a state-by-state basis of potential buffer needs on cropland meeting the CRP cropping history test and on marginal pastureland. That unpublished survey showed a need for at least 3.5 million hectares of buffers on cropland and 1.3 million hectares of buffers on grazing land. Those estimates were admittedly conservative, however.

Any back-of-the-envelope estimate of the need for filter strips or riparian forest buffers along the 5.6 million kilometres of permanent and seasonal streams in the United States suggests far greater potential. If one assumes that 25 percent of those stream kilometres are in need of treatment with buffers, an assumption some scientists contend is too conservative, and one assumes the installation of a 30.5-meter-wide buffer on each side of those approximately 1.5 million stream kilometres, the potential buffer need approaches 8.5 million hectares. And this estimate does not include buffer needs around or along other permanent water bodies, such as lakes, wetlands, and drainage ditches. Neither does it consider any upland buffer needs.

A recent National Research Council report, *Riparian Areas: Functions and Strategies for Management* (National Research Council 2002), calls attention to the critical environmental importance of riparian areas. The report refers to riparian areas as the nation's "forgotten wetlands" and suggests the need for a national policy to ensure their restoration and protection. Up to 95 percent of the riparian areas in certain parts of the country have been degraded or destroyed, according to the report.

Barriers to Buffer Use

There are impediments to buffer use in agricultural landscapes. A series of focus groups with farmers and ranchers, conducted in 1996, 1999, and 2002, sought to document these impediments and ways to overcome them.

The most recent set of focus groups in particular focused on barriers to use of buffers and to participation in the CCRP. The report grouped the identified barriers into six different categories: (1) monetary barriers, (2) practical problems, (3) program restrictions and requirements, (4) competition with other programs, (5) landowner and tenant relations, and (6) knowledge of program details. Among the more important barriers were the following:

- CCRP rental rates are not high enough to attract the high-quality land along some streams.
- Land in buffers is often minimal, so the CCRP payment is too small to make program participation worth the time and effort.
- Buffers harbour weeds and harmful insects.
- Trees invade buffers unless the buffers are mowed.
- Buffers are difficult to farm around and across.
- Buffers in the CCRP can't be hayed or grazed.
- Fencing buffers is a major problem in some areas.
- Commodity program payments are more lucrative than CCRP payments.
- Tenants or landlords dislike buffers.
- Some farmers and ranchers distrust government or are too independent to participate in government programs.
- Some farmers and ranchers question the effectiveness of buffers to achieve water quality improvement or other conservation purposes.

Some of these barriers should be overcome by changes in the CRP contained in the 2002 farm bill.

The Bottom Line

Conservation buffers represent a time-tested technology that works both environmentally and economically, in most cases, given the financial incentives available through USDA conservation programs and other public- and private-sector programs. Moreover, buffer designs are being adapted constantly to address particular conservation needs and the management requirements of farmers and ranchers. The vegetative barrier or grass hedge, for example, a relatively new buffer type, has been adapted for use in lieu of terraces on some soils. This buffer is much less expensive to install than a terrace, and already has proved effective for soil erosion control purposes. Vegetative barriers also can be used to enhance the performance of grassed waterways.

Buffers are not the only answer to the many environmental management challenges confronting farmers and ranchers, but they are among the important components of the more comprehensive conservation systems that farmers and ranchers almost certainly will need to use if they are to meet whatever land stewardship obligations they feel or society might require.

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Linking agriculture and the environment: A branded approach to the market place

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Agricultural practices have to be economically viable, socially responsible and environmentally sound. In recognition of the intimacy of the agricultural landscape with the people of Prince Edward Island (PEI) and increasing pressure on the landscape from intensive potato production, the government of PEI established the Round Table on Resource Land Use and Stewardship in 1996. The purpose of this paper is primarily to present information on the development and implementation of improved practices for a sustainable system of production of quality food products on PEI and secondly to give insight into a marketing and branding initiative that such a system of food production gives to PEI. Protection of stream buffer zones was legislated under the Environmental Protection Act. Under the terms of the Act, 10 to 20 m buffer zones are required on agricultural land adjacent to water courses and wetlands. Producers have a number of options for management of these buffer zones. In addition, the Agricultural Crop Rotation Act was passed that prohibits producers from planting potatoes more than once in three years on land where the average slope is equal or greater than 9%. In addition, approximately two-thirds of the PEI producers have completed Environmental Farm Plans. The provincial government directed funding through the Sustainable Resource Conservation Program to correct issues identified in the action plans of the Environmental Farm Plans. To take advantage of these initiatives, a not-for-profit marketing and branding company, FoodTrust of Prince Edward Island Ltd. was created to market high quality branded products from sustainable systems.

Additional Keywords: environmental farm plans, buffer zones, branded food products, crop rotations

Introduction

The purpose of this paper is primarily to present information on the development and implementation of improved practices for a sustainable system of production of quality food products on Prince Edward Island (PEI) and secondly to give insight into a marketing and branding initiative that such a system of food production gives to PEI.

Creating the Environment

The Government and the agricultural industry have long recognized that given the small size of PEI, and the intimacy of the working landscape with the population, agricultural practices have to be socially responsible and environmentally sound. The large increase in potato acreage in the early 1990's to feed the expanding french fry market placed additional burden on PEI's landbase. The key result of this burden was a significant increase in soil erosion. In recognition of this, and the impact that agricultural and forestry practices were having on the social fiber of PEI, the government of PEI established the Round Table on Resource Land Use and Stewardship in 1996. This group of citizens, who represented all stakeholders in Resource Land Use, reported back to government in 1997 with 87 recommendations (Anonymous 1997).

The Round Table report created a foundation whereby sustainable development could be discussed. The mandate of the Round Table was four-fold:

- to increase the contribution of resource lands and their use to wealth creation in the province;
- to maintain and improve the capacity of the lands to generate wealth for future generations;
- to minimize the conflicts between the use of resource lands and other land uses, and minimize the impacts on human health and the environment; and
- to increase public satisfaction with resource land use.

The report addressed the issues of soil quality, water quality, pesticide use, forest resources, regulating the use of resource lands, managing landscape and bio-diversity, and management of provincial lands. The report was submitted to government in 1997 and most of the 87 recommendations have been addressed reflecting the changes our citizens wanted. Government policy now reflects ten of those recommendations and government's response has been to initiate legislation, in particular, for buffer zones and crop rotation.

Protection of stream buffer zones was legislated in 1999 under the Environmental Protection Act. In May, 2001 and 2003 this legislation was further amended (Anonymous 2003). Buffer zones are required to be established and maintained on all non-forested land adjacent to (a) watercourses, including intermittent streams and springs that have a defined sediment bed and flow-defining banks that connect with a larger watercourse, or exhibit continuous flow during any 72-hour period from July 1 to October 31 of any year and (b) wetlands identified as open water, deep marsh, shallow marsh or salt marsh as defined in the 1990 Prince Edward Island Wetland Inventory. These buffers must be 10 m in width where non-forested land is in non-agricultural use, including but not limited to residential, commercial, industrial, institutional and recreational use. For agricultural land, buffer zones must be 10 m in width. Where land in agricultural use is within 50 m of the upland boundary of a buffer zone and has a slope of 5% or greater, fall tillage is prohibited and a winter cover is required. Alternatively, instead of these measures, a 20 m buffer zone may be established. As well, agricultural crops cannot be planted within a 10 or 20 m buffer zone except forage crops under certain conditions. Buffer zones are also required for intensive livestock operations. Eliminating access to streams for livestock has been targeted for the fall of 2003.

Producers have a number of options for the management of these buffer zones. While row cropping is prohibited, forage crops can be produced in these areas, with spring tillage and under-seeded cereal production allowed once every five years. A second option is to reforest the buffer zones; however, this can cause future problems regarding the use of agricultural equipment next to the treed area. There is also work underway to investigate the potential of other valuable agri-forestry crops which could be grown in these zones, such as nut crops, or cultivating ground hemlock. While the legislation has not been in effect very long, a large number of producers are actively managing these areas so that the buffer remains a productive area of the their operation and not a "weed wasteland."

In May 2001, the Government of PEI passed the Agricultural Crop Rotation Act (Anonymous 2001a). The purpose of the Act, through crop rotation and responsible land management, is to maintain and improve surface water quality by reducing runoff and soil erosion; to maintain and improve groundwater quality; to maintain and improve soil quality; and to preserve soil productivity. The Act prohibits any grower from planting or any landowner from permitting regulated crops (potatoes) to be planted on any area of land greater than 1 hectare at any time for more than one calendar year in any three consecutive calendar years. Regulated crops are also prohibited from being planted on a land area greater than 1 hectare where the average slope of the land area is equal or greater than 9%.

Prince Edward Island has the highest percentage of farmers who have completed Environmental Farm Plans (EFP's). Approximately 2/3 of the agricultural acreage has been covered off by the landowners attending and completing workshops. Participation has been high in all commodities, especially the potato, beef and pork sectors. The success of the program can be attributed to strong farmer led initiatives from the beginning. The Atlantic Canada EFP Workbook was developed with the cooperation of the four Federations of Agriculture, with valuable technical input from the departments of Agriculture and Environment of the four Atlantic Provinces (Anonymous 2001b). The Eastern Canada Soil and Conservation Center in Grand Falls, NB, which has a Pan-Atlantic mandate, was the driving force in the workbook development. A significant amount of encouragement and support came from the Ontario Environmental Farm Plan Coalition in helping the committee adapt the workbook to reflect the distinctiveness of Atlantic Canada Agriculture. Currently the workbook is being reviewed to reflect changing times - nutrient management plans and climate change issues will be acknowledged in the updated workbook. The high uptake rate is also strongly attributed to:

- linkage as an eligibility criteria to provincial assistance programs such as the Sustainable Resource Conservation Program;
- review of actions plans with producers by the EFP coordinator as opposed to

a peer review process;
- confidentiality of the document;
- acceptance of the document as an educational resource; and
- completing an EFP and active implementation of the resulting action plan is a requirement for all producers participating in the FOODTRUST Brand.

The provincial government has directed over $10 million through the Sustainable Resource Conservation Program to correct issues identified in the action plan of Environmental Farm Plans. Table 1 summarizes the investment in the first three years. This funding is also matched with significant investment by the producer. Prince Edward Island is also active in the area of Integrated Pest Management. The majority of the potato crop is covered by crop scouting plans, and a new Bio Intensive IPM Protocol has been developed and is being field tested.

Table 1. Issues funded through the Sustainable Resource Conservation Program

		Manure storage	Soil conservation	Hedgerows	Fencing & watering	Storages/ structures	TOTAL
Year I 1999-2000	Completed projects	36	29	6	12	1	84
	Spent	$824,000	$145,000	$4,000	$46,000	$1,000	$1,020,000
Year II 2000-1	Completed projects	64	56	7	19	17	163
	Spent	$1,647,000	$291,000	$8,000	$65,000	$81,000	$2,092,000
Year III 2001-2	Approved projects	84	54	12	148	57	355
	Committed	$2,160,000	$359,000	$7,000	$666,000	$475,000	$3,667,000
TOTAL	Projects	184	139	25	179	75	602
	Funding	$4,631,000	$796,000	$19,500	$776,500	$557,000	$6,779,000

The Round Table was also challenged to identify economic strategies based on this credible foundation for sustainability; however, dealing with the key areas of their mandate identified earlier was the main focus of the report. This is where branding entered the picture. In searching for recognition of good practices in the marketplace, it soon became evident that a brand was required. This brand would provide a vehicle for producers to reconnect their story with consumers.

A Branded Approach to Marketing Sustainable Products

Prince Edward Island is small, 139,000 inhabitants, with the majority living in and around the cities of Charlottetown and Summerside. Approximately 1,200 farmers work 500,000 acres of agricultural land. PEI produces 30% of Canada’s potatoes, but only 0.41% of world production. We are truly small potatoes in the big picture.

While the commodity model of production and marketing is successful, it relies upon volume and the cheapest competitive price. PEI is unable to produce volume, yet we are quite capable of producing high quality products. Because of our size, and to a lesser extent our location, we cannot successfully participate in the commodity-driven game. Much has been said about level playing fields. Our input costs handicap us and consequently our selling price does not reflect the real cost of producing food on PEI. We are not competitive. The playing field is not level.

At the same time, we have experienced in Canada a tremendous consolidation at the retail level to the extent that two national chains now control over 50% of the market. The current industrial model of vertical integration reflects the competitiveness of the industry and depends upon large volumes to produce pennies of profit per unit. While this has been happening, producers and consumers have become increasingly disconnected. In order for PEI to stay in the game, we must do things differently, in other words - tilt the playing field to our advantage.

When products are treated as commodities, producers cannot be recognized by consumers for doing the right thing. Without a brand, the producer can quite often be portrayed as the villain and can never be the hero. Before a brand espousing sustainability as its cornerstone can be successful, it first must have a strong foundation built on credibility.

A brand tells a story. The FoodTrust of Prince Edward Island Ltd. (FoodTrust) brand reflects the values of Prince Edward Islanders (Islanders) - people the consumer can trust to produce high quality products from sustainable systems. The first mandate of FoodTrust was to develop a brand based upon sustainable practices and the values of Islanders. FoodTrust is a not-for-profit company whose directors represent the sectors of agriculture, fisheries, food service, and tourism. Although FoodTrust is deemed a not-for-profit company, it is most interested in securing better and more profitable opportunities for its partners. FoodTrust interprets systems to be sustainable if they are economically viable, socially responsible, and environmentally sound. A system lacking in any one of these three areas is not sustainable. FoodTrust is a marketing and branding company that facilitates relationships with like-minded groups and individuals. The goals are to:

- market high quality branded products from sustainable systems;
- re-connect producers with consumers; and
- pursue equity in the food system so that all - from the consumer receiving high quality products for their money, to the producer receiving fair value for producing high quality products in a sustainable manner - are rewarded.

The creation of a brand requires the developing and testing of a brand proposition. The FoodTrust brand proposition was tested in Halifax, Toronto, Montreal, Baltimore and Boston, and the conclusion was that there was significant potential to brand PEI food products for both purchase preference and price premium.

People turn to food for reassurance; it is one of the most intimate consumer products. What one eats and how they consume food reflects their individual values. What do consumers want? They want more environmentally responsible products, safe healthy food, to know how food is produced and where it comes from, and simplicity in cooking convenient meals. FoodTrust works here.

Participation with FoodTrust in co-branding initiatives is voluntary. At this time 36 co-branding partners have expressed interest in working with FoodTrust in developing a brand marketing approach. The successful launch of our first product, Summerside Farms Pork, occurred in December 2002. In keeping with its commitment to foster relationships FoodTrust worked with PEI pork producers, PEI grain producers, The Atlantic Veterinary College, Co-op Atlantic, Garden Province Meats, and the Culinary Institute of Canada in launching this first product. In developing this new product, FoodTrust worked with its partners to identify a unique feeding regime that makes this pork product healthier for the consumer. As an added benefit it also tastes great and is naturally moist and tender.

FoodTrust will continue to work with its partners to market new and distinctive products for consumers to the benefit of all.

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Field boundary habitats: A pesticide industry perspective

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Large-scale farming practices have contributed to the recent decline in the abundance or structure of adjacent field boundary habitats. These habitats are becoming increasingly important as areas for biological diversity and must be protected from off-target pesticide movement and the spread of invasive weeds. In Canada, the number of farmers is in decline. Farmers are managing larger farms with a trend towards spending less on pesticides. The business of grain production requires an informed end user that can utilize best management practices that minimize environmental impacts without compromising pest control. The pesticide industry has an important role in developing pesticides with reduced risk characteristics that provide the desired levels of efficacy and crop tolerance. Before a pesticide is accepted for registration in Canada, product specific ecotoxicity data relevant to field boundary habitats must be submitted by the registrant for review by the Pest Management Regulatory Agency (PMRA). Regulatory authorities assess risk on a variety of non-target plants and organisms using experimental data and computer simulation models to predict environmental exposure. Risk assessments and model results together with additional safety factors are used by companies and regulators to protect sensitive habitats in close proximity to agricultural fields.

Additional Keywords: pesticide use, invasive pests, farmland management

Introduction

The pesticide industry plays an important role ensuring both the domestic and global food demands are satisfied with high quality products while maintaining consumer and environmental safety. Today, Canadians enjoy a large variety of nutritious foods at a reasonable cost, without much thought on as to where it came from or what was required to produce it. A disparity exists between the businesses of modern crop production that utilize pesticides and the environmental concerns that oppose their use. Public acceptance for the continued use of pesticides is a prerequisite for increasing world food production in the foreseeable future (Major 1992). However, it has been claimed that herbicide use in conjunction with other farming practices has contributed to an overall reduction in habitat heterogeneity within agricultural landscapes, an increasing uniformity in the spatial arrangement of remaining habitats, and greater isolation of natural or semi-natural habitats (Freemark and Boutin 1995). This claim is not supported by the pesticide industry.

Field Boundary Habitats

Field boundary habitats are considered as "off-field" areas of high ecological or societal value. They include nature preserves, wildlife refuges, provincial/federal parks, grasslands, forested areas, woodlots, shelterbelts, and shrublands. These habitats represent the outer limits of our agricultural fields as defined by natural limitations (e.g. slope, texture, wetland) or anthropogenic limitations (e.g. land ownership, road infrastructure, right of ways). Field boundary habitats are becoming increasingly important in providing a variety of habitats capable of supporting many species of flora and fauna.

An urgent need exists to halt the loss of wildlife habitats and to maintain plant diversity in the remaining areas. Risk to these areas can be mitigated through the use of no-spray areas down wind of application or green belts that intercept pesticide movement via air/water transport, low-drift nozzles and spray shields, integrated pest management, and other best management practices. However, the effort needed to maintain field boundary habitats are often not aligned with the farmer's preference for adopting these best management practices. In Europe, field boundary habitats are an important and necessary feature in intensive farm management systems because of their importance for biological diversity in farming landscapes. However, they are also viewed as sources of weeds, pests and diseases (Marshall 2002).

There is a lack of information on preventing the spread of noxious weeds within field boundary habitats. These areas can act as sources and recipients of noxious weeds. White and Schwarz (1998) reported several strategies to manage this: prevention, preclearance, exclusion, detection, containment, eradication and biological control. Some noxious weed species (e.g. leafy spurge, *Euphorbia esula*; Canada thistle, *Cirsium arvense*; scentless chamomile, *Matricaria perforata*) common to agricultural fields have invaded and thrived in adjacent, undisturbed field margins. Left unchecked, these pests will continue to spread across the northern Great Plains where they will reduce the diversity and quality of desirable native grasses and forbs.

Field boundary habitats should also be monitored for and protected from detrimental pest infestations arriving from surrounding agricultural fields. Many naturalists are surprised to learn that weed invasion is a problem on many nature reserves and are alarmed when it is suggested that herbicides may have a role to play in weed control (Marrs 1985). However, the pesticide industry does not participate actively in the pest management of field boundary habitats. Research is, therefore, left largely to the public domain (e.g. universities, provincial/federal extension). Once established in any ecosystem invasive pests often have cascading effects that change ecosystem function, alter the composition of native species, or simply eliminate them (White and Schwarz 1998).

Foliage diseases, such as anthracnose (Stepanek et al. 1997) and septoria (Jacobi 1999), that are known to harm commercial crops also infect native and shelterbelt trees species. Early detection and control of a disease in the field will limit its spread into adjacent field boundary habitats established for shade or as a windbreak. A portion of the life cycle of several insect pests (e.g. Colorado potato beetle, *Leptinotarsa decemlineata* (Say); flea beetle spp.; and grasshopper spp.) is spent in habitats surrounding agricultural fields (Philip and Mengersen 1989). Conventional methods to control insects in these habitats may not be possible or practical.

Impact of Farming on Field Boundary Habitats

The business of farming has changed in recent years, mainly in order to accommodate modern, large-scale management practices. Unfortunately, farming appears to be losing its special status as the bastion of traditional values since the public recognizes that the small-scale family farm no longer dominates agriculture (Zinn and Blodgett, 1989). With limited time throughout the growing season to seed and fertilize, apply pesticides, and harvest a crop, the use of larger field equipment has become a necessity. There is also a need for greater efficiency of each field operation in order to achieve higher net profit per hectare and lower unit production costs.

In the past, demands for greater grain production were met by bringing new land into cultivation by clearing forested areas, or by irrigating or draining existing fields. Since arable farmland is a finite resource, any substantial improvement in agricultural production must come from increased yields on land already in cultivation. It has been suggested that field margins and other non-crop habitats have been eliminated to increase the amount of land under cultivation, facilitate the application of pesticides and synthetic fertilizers, accommodate larger field machinery and remove potential pest reservoirs (Freemark and Boutin 1995). However, the removal of field boundary habitats also occurs as the result of urban expansion, roads, and recreational areas.

While the target pests are considered undesirable, pesticides can also have an impact on sensitive, non-target species. Habitats adjoining heavily managed croplands are most likely to be exposed to pesticides due to direct overspray (especially during aerial application), spray drift and/or volatilization after application, and movement through runoff or wind-eroded soil (Freemark and Boutin 1995).

Pesticide Use

Pesticide use in agricultural fields has been implicated in the recent decline in the abundance or structure of adjacent field boundary habitats. With respect to ecological effects, the diversity of weeds in field margins was greatest when fewer herbicides were used (Marshall 1985). The use of broad spectrum pesticides tends to have a greater impact on non-target species than does the use of narrow spectrum pesticides. However, data on the use of pesticides in Canadian agriculture are difficult to compile, as information is not always reported in a consistent manner. Statistics Canada asks farmers to report total expenditures and the area treated with pesticides. Year-to-year use of fungicides and insecticides is less predictable than the use of herbicides because of inherent fluctuations in insect and disease outbreaks.

The Prairie Provinces (Manitoba, Saskatchewan and Alberta) account for nearly 80% of cropped land in Canada and represent a primary market for the pesticide industry. Between 1981 and 2001, the total amount of land cropped across the three Prairie Provinces increased from 24.6 to 29.8 million hectares (Table 1). However, Statistics Canada reports the area of unimproved land was under-reported in 1981. Evidence suggests a trend towards fewer but larger and more specialized farms in Canada. Over the last two decades, the number of farms reported in Manitoba, Saskatchewan and Alberta dropped while the average farm size increased. The job of running the larger farms is falling increasingly on fewer and older farmers (Statistics Canada 2002).

Census data on agricultural pesticide use (herbicide, insecticide, fungicide) for the Prairie Provinces show that an additional 2.2 million ha of cropland was treated in 2000 compared to 1995 (Table 2). As in previous censuses, the area of land receiving a pesticide was under-reported. However, these data are comparable with previous censuses.

Western Canadian sales figures between 1997 and 2001 indicate an overall decline in pesticide use primarily in the cereal herbicides and insecticide markets (Table 3). During the same period fungicide use increased. In general, horticulture crops (fruits and vegetables) use pesticides more intensively than field crops. Wheat and other grain crops receive lower rates but these are applied over a larger area.

Table 1. Historical data (1981-2001) on the total number of farms, crop area of farms, farms reporting and average area of farmland reporting in Canada and the Prairie Provinces.

Area	1981	1986	1991	1996	2001
	Total number of farms				
Canada[a]	318,361	293,089	280,043	276,548	246,923
Manitoba[b]	29,442	27,336	25,706	24,383	21,071
Saskatchewan[c]	67,318	63,431	60,840	56,995	50,598
Alberta[d]	58,056	57,777	57,245	59,007	50,598
	Cropped area (ha)				
Canada	30,965,812	33,181,235	33,507,780	34,918,733	36,395,151
Manitoba	4,420,369	4,519,335	4,761,005	4,699,146	4,714,830
Saskatchewan	11,740,864	13,325,811	13,458,915	14,398,651	15,375,929
Alberta	8,441,242	9,162,524	9,292,044	9,546,547	9,728,181
	Farms reporting				
Canada	291,879	264,141	248,147	237,760	215,581
Manitoba	27,242	24,683	23,563	21,527	18,836
Saskatchewan	65,113	61,217	61,217	54,226	48,055
Alberta	53,323	52,347	50,732	50,268	46,028
	Average farm area (ha)				
Canada	106	126	135	147	169
Manitoba	162	183	202	218	250
Saskatchewan	180	218	229	266	320
Alberta	158	175	183	190	211

Sources (accessed January 14, 2003)
[a] Adapted from Statistics Canada's Internet Site http://www.statcan.ca/english/Pgdb/agrc25a.htm
[b] Adapted from Statistics Canada's Internet Site http://www.statcan.ca/english/Pgdb/agrc25h.htm
[c] Adapted from Statistics Canada's Internet Site http://www.statcan.ca/english/Pgdb/agrc25i.htm
[d] Adapted from Statistics Canada's Internet Site http://www.statcan.ca/english/Pgdb/agrc25j.htm

Table 2. Amount of land treated with pesticides in 1995 and 2000.

Area	Herbicides		Insecticides		Fungicides	
	1995	2000	1995	2000	1995	2000
	1000 ha					
Canada[a]	23,265	25,901	2,935	2,226	1,818	2,572
Manitoba[b]	3,422	3,566	614	382	390	741
Saskatchewan[c]	10,852	12,327	1,453	930	532	913
Alberta[d]	6,050	6,624	300	343	543	541

Sources (accessed January 14, 2003)

[a] Adapted from Statistics Canada's Internet Site http://www.statcan.ca/english/Pgdb/agrc05a.htm
[b] Adapted from Statistics Canada's Internet Site http://www.statcan.ca/english/Pgdb/agrc05h.htm
[c] Adapted from Statistics Canada's Internet Site http://www.statcan.ca/english/Pgdb/agrc05i.htm
[d] Adapted from Statistics Canada's Internet Site http://www.statcan.ca/english/Pgdb/agrc05jj.htm

Table 3. Western Canada sales figures for pest control products for the year ending December 31[a].

Pesticide	1997	1998	1999	2000	2001
	$1 million				
Herbicide	90.7	98.2	89.6	81.9	81.8
Insecticide	3.8	3.1	3.2	2.1	1.9
Fungicide	4.8	5.0	5.4	6.2	7.2

[a] CropLife Canada, May 24, 2002.

Challenges to the Pesticide Industry

In recent years, the number of pesticide registrants has declined through mergers and acquisitions. As a result, farmers are offered more choices by fewer registrants but the consolidated homogenous product lines result in greater competition (Juras 2001). The pesticide industry is challenged by farmers to distinguish each from the other. The pesticide business is highly influenced by farmers who are managing larger farms with a trend towards spending less on pesticides.

Another important challenge to the pesticide industry is ensuring sufficient funds to invest in the research and development of new pesticides. In the future, newer pesticides will require safer use profiles (i.e. reduced risk status) and unique modes of action that affect only the targeted weed, insect or disease. Some registrants are not strategically inclined to invest in newer pesticides due to a low return on investment.

By their very nature, pesticides are not exactly alike based on their strengths and weaknesses related to individual biological and environmental characteristics. Pesticides must be thoroughly tested as a condition for registration in Canada to ensure minimal exposure in treated and surrounding areas. With respect to field boundary habitats, ecotoxicity studies are conducted on seven major indicator groups: fish, aquatic invertebrates, plants, amphibians (and reptiles), mammals, birds and terrestrial invertebrates. The ecological effects on these groups are an essential part of the environmental evaluation of these compounds and represent an important criterion in the future development of new products in Canada. Since it is impractical to measure pesticide effects on every plant and organism, computer simulation models have been developed to quantify the theoretical effects of a pesticide. Regulatory authorities utilize these models to predict the impact of a pesticide on non-target habitats but also use this information to develop guidelines to mitigate non-target exposure (e.g. buffer zone distances).

Joint reviews of ecological data between the US Environmental Protection Agency and the Canadian Pest Management Regulatory Agency are becoming increasingly common. Pesticides with reduced risk status are highly desired by both regulatory agencies and pesticide manufacturers. "Safer" products represent a marketable improvement where additional value can be realized. Broad spectrum, persistent and highly mobile pesticides are of particular concern.

Pesticide registrants must follow approved guidelines in order to satisfy the data requirements for registration or re-registration of a pesticide. The current PMRA guidelines facilitate evaluation of pesticides on the basis of value and risk to human health, safety and the environment. These guidelines are based on the current scientific literature as well as expertise offered by the technical community. Prior to common test guidelines, the databases used to evaluate a given pesticide could vary dramatically from one compound to another.

Future Considerations

Field boundary habitats will continue to represent important landscape features for biological diversity and must be protected from off-target pesticide movement and the spread of invasive pests. Protection and maintenance of these sensitive areas must meet the needs and rights of the landowner as part of an overall sustainable management strategy. Current farming decisions that require the removal of field boundary habitats must consider societal, environmental, and economic needs, and whether the parcel of land is used for agricultural, commercial, or recreational purposes.

Pesticide applicators must continue to practice proper application in accordance with label instructions to minimize risk to all non-target areas. Advanced application technologies are proving to be useful tools for maintaining buffer zones near field boundary habitats. On-target placement of pesticides has improved with the introduction of low-drift nozzles, global positioning systems (GPS) and geographic information systems (GIS). Digital mapping of cultivation boundaries (fields, ditches, ponds, roads, etc.) provides precise detail for planning and conducting field activities. However, these technologies are an additional expense for the producer and the cost must be justified for widespread adoption.

Future efforts to educate the public and the media must take into account their lack of knowledge about science and even greater lack of knowledge about the intricacies of pesticide risk management. This being said, the pesticide industry is facing three main concerns: 1) diminished credibility due to the lack of or incomplete disclosure of information to the public, 2) politicians lacking scientific training who act as arbiters between industry and an increasingly skeptical public, and 3) public and media, who are predominantly untrained in science, deal with information that must be assessed and analyzed carefully prior to accepting it as fact (Juras 2001).

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Field margins in northern Europe: Integrating agricultural, environmental and biodiversity functions

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In northwestern Europe, most agricultural landscapes are a mosaic of farmers' fields, semi-natural habitats, human infrastructures (e.g. roads) and occasional natural habitats. Within such landscapes, linear semi-natural habitats often define the edges of agricultural fields. In temperate, intensive agriculture, such field margin habitats, which historically had true agricultural functions, now are important refugia for biodiversity. In contrast to North America, northern Europe has few true wilderness areas and nature conservation increasingly has to be integrated into the managed farmed landscape. Thus margins have agricultural, environmental and conservation roles, though the relative importance of these is changing. As man-made habitats, field margins also have a cultural role as part of landscape heritage and some recreational roles. Nevertheless, field margins are not specific or characteristic habitat types; they can contain a variety of plant communities in a variety of structures. These may range from aquatic elements, to ruderal and woodland communities, with combinations of them over small spatial scales. Studies demonstrate a variety of interactions between fields and their margins. Some margin flora may spread into crops, becoming field weeds. Margins also have a range of associated fauna, some of which may be pest species, while many are beneficial, either as crop pollinators or as pest predators. Agricultural operations, such as fertilizer and pesticide application, can have adverse effects on the margins via drift and disturbance. The biodiversity of the margin may be of particular importance for the maintenance of species at higher trophic levels, notably farmland birds, at the landscape scale. Margins may also contribute to the sustainability of production, by enhancing beneficial species within crops and reducing pesticide use, though further research on the predictability of these effects is needed. Research over recent years has examined a number of management methods of enhancing conservation, environmental and agronomic benefits by manipulating field margins. Some of these involve manipulating crop management, while others involve habitat creation at the field edge. A variety of methods to enhance diversity at field edges have been introduced, including sown grass and flower buffer strips. While minor conflicts exist, notably for the conservation of rare arable weed species and the spread of some pests and weeds, the impacts of well-managed field margins on weed flora and arthropods indicate mostly beneficial effects. Thus field margin strips offer a practical means of providing on-farm biodiversity and enhancing more environmental and sustainable production. In the European Union, financial incentives are included in a range of agri-environment support schemes to encourage active management of field edges by farmers.

Additional Keywords: boundary, hedge, insects, weeds, wildlife

Introduction

Within the European Union, more than 50% of the land surface is in agriculture and within Britain over 75% of the land is farmed. Within these farmed landscapes semi-natural habitats are increasingly fragmented, reflecting agricultural improvement and intensification, drainage and development. There have been significant changes in production methods over the past 50 years (Stoate et al. 2002), with major impacts on farmland wildlife in the UK, notably bird species (Fuller et al. 1995; Chamberlain and Fuller 2000). Nevertheless, most individual fields are bordered by boundary structures (Marshall 2002) of semi-natural vegetation and other linear elements, such as hedges, road verges, streams and rivers. Thus the agricultural landscape is a mosaic of fields, woodlands, linear features and occasional natural habitats.

The juxtaposition of land uses, particularly farmed areas and natural habitat, form mosaics in the landscape (Forman 1995; Burel and Baudry 1999). Landscape mosaics are typically characterized by the matrix, patch and network model. Under this view, the matrix is formed of the agricultural fields and the network and patches are natural or semi-natural habitats. The linear elements of the landscape include watercourses, road verges, hedges and field margins. These may be particularly important for the survival of species and communities typical of the habitats present before the expansion of agricultural production. Clearly the mosaic view is most applicable to enclosed landscapes, such as those found in northern Europe and eastern Canada. It may be less applicable to prairie landscapes, though even here, linear elements occur and rivers, lakes, potholes and forest provide semi-natural habitats within and alongside the matrix of fields.

Extensive surveys across Britain as part of Countryside Survey, an inventory of land use and its impact (Barr et al. 1993; Haines-Young et al. 2000), identify linear semi-natural features in lowland agricultural landscapes as containing the most diversity of plant species. Thus field margins, streamsides and verges are refugia for plant species in intensively managed land in the UK and a key to the conservation of plant diversity in the wider landscape (Bunce et al. 1994). This pattern is repeated across Europe (Van Strien 1991; Melman and Van Strien 1993; Burel and Baudry 1995; Burel et al. 1998) and North America (Forman and Baudry 1984; Freemark and Boutin 1995; Jobin et al. 1997; Boutin and Jobin 1998; Boutin et al. 2001; Boutin, Jobin and Belanger 2002; Boutin et al. 2002). This paper seeks to review the structure and function of field margins in northern Europe, particularly the United Kingdom, and to evaluate our knowledge of the interactions between margins and fields. The potential for field margins to satisfy agricultural and environmental functions are explored, including the promotion of biodiversity, as part of more ecologically sustainable production methods.

Agriculture and Nature Conservation

The classic approach to nature conservation has been the designation of special areas, such as national parks and reserves, based on the identification and protection of areas of high interest, rarity of species or fragility of ecosystems. This has been implemented throughout the world, but is particularly suitable for large countries where human population densities are low. However, in highly developed European landscapes there are few wilderness areas, and designated areas tend to be small and fragmented. Under such conditions, there is a real threat of stochastic events that result in population extinctions. With other threats, such as global climate change, nature conservation authorities are now taking a broader view and increasingly are seeking to integrate their responsibilities with the major land uses, particularly agriculture. Under the Convention on the Conservation of Biodiversity 1992, the so-called Rio Summit agreement, governments are also required to put in place mechanisms to conserve biodiversity. Increasingly, it is argued that biological diversity within ecosystems, including agroecosystems, supports a range of biological functions, such as nutrient recycling and pest control (Altieri 1999). Thus biodiversity has a functional component. For example, there are some indications that more diverse agricultural systems may enhance natural control of crop pests (Estevez et al. 2000).

With policy attention on sustainability, farming is also being asked to match production requirements more closely with biological conservation and renewable resources. In practice, this requires more sustainable production methods and attention to the semi-natural, uncropped elements of the landscape. An emerging paradigm is the conservation of species and communities within the farmed landscape as a whole (Mineau and McLaughlin 1996). Field margins may offer a means of achieving the conservation of biodiversity alongside efficient production.

Field Boundaries in Northern Europe – Structure and Function

Field margins in both arable and grassland farming are typified by having some form of boundary structure, usually with associated herbaceous vegetation, adjacent to the crop (Marshall and Moonen 2002). In arable land, there may not be any physical border between blocks of different crops. However, there is almost invariably some form of margin between land holdings and along roads, tracks and watercourses. The boundary may be a fence, a shelterbelt of trees, a hedge, a wall, a terrace, a ditch or drainage channel, a grass strip or a combination of these structures. In some situations the boundary is simply another habitat type, such as woodland.

Increasingly, there are structures introduced at arable field edges that either enhance access, weed control or conservation of farmland wildlife. In the UK, 13,500 km of field boundary have been modified under agri-environment support schemes. These may be simple farm tracks, or vegetation-free strips. In Europe, there may also be set-aside strips, borders of sown perennial vegetation or so-called conservation headlands, where the cereal crop edge receives reduced pesticide and herbicide inputs (Rands 1985; Rands and Sotherton 1987). Greaves and Marshall (1987) defined the field margin as the field boundary, the boundary strip (not always present) and the crop edge (where crop management may differ from the main field area) (Figure 1). The boundary is usually a structure or barrier, while the boundary strip provides an opportunity to modify field edge management for a variety of objectives.

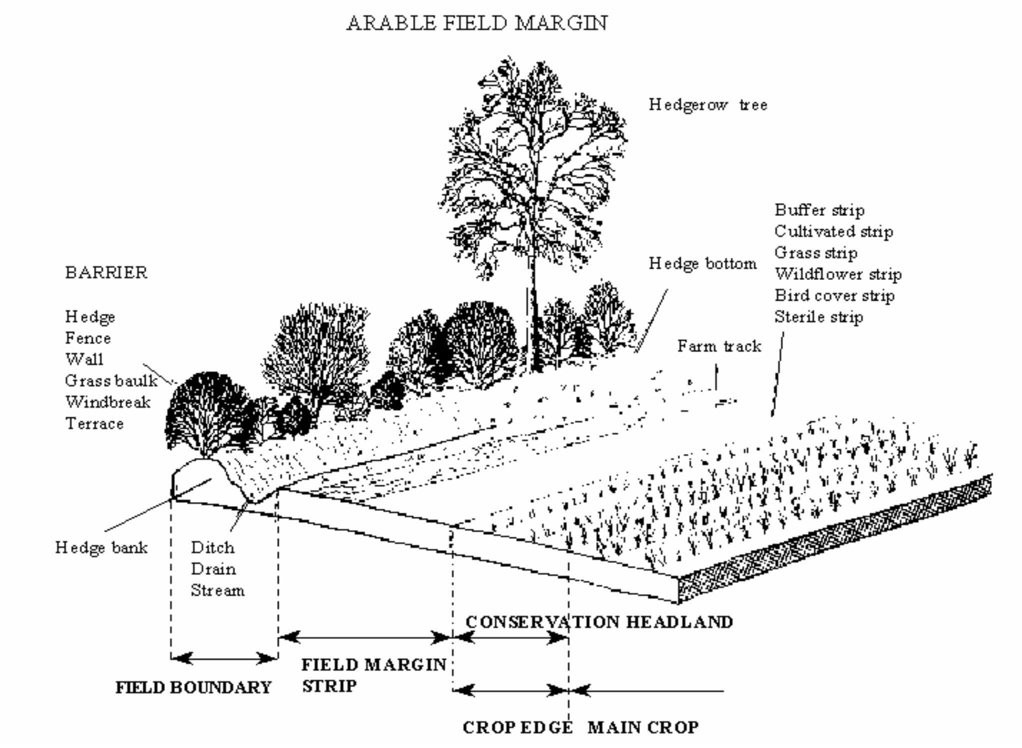

Figure 1. Components of an arable field margin, comprising a boundary structure, sometimes a field margin strip and the crop edge (after Greaves and Marshall 1987).

The term "headland" is widely used to mean the crop edge, typically the area outside the outermost tractor wheeling or tramline through the crop. Strictly speaking, the headland is the area where machinery turns at the ends of the field, but the term is commonly used to mean the crop edge.

As field margins often comprise a variety of structures, including watercourses, banks, woodland edges etc., a variety of plant communities can occur within them, including ruderal plants, typical of arable land or disturbed ground. In addition, grassland communities, tall herb, shrub, woodland and aquatic communities may be present. In Britain only one shrub species, *Pyrus cordata* (Plymouth pear) is found only in field margins, in certain hedges in southwest England (Hooper 1970). Phytosociological surveys of British field margins indicate they represent sub-optimal communities of a variety of other habitat structures. Thus the flora is not characteristic, but rather made up of a wide variety of communities, depending on the structure and location of the field margin.

The role of field margins was entirely functional in the past, reflecting their part in stock impoundment, protection and delineation of land ownership. Subsidiary functions were to provide shelter, wood, browse for stock and fruits. With the development of multifunctional land use, field margins maintain some of their original roles, but a number of other functions have been identified, reflecting the interactions between crop and non-crop habitats (Marshall 1993) (Table 1).

Table 1. Functions of semi-natural field margins in good agricultural practice (after Marshall 1993).

Interest	**Function**
Agronomic	Defining the field edge
	To be stock- or trespasser-proof, to keep animals in or out
	Providing shelter for stock
	Providing shelter for crops, particularly as windbreaks
	Promotion of ecological stability in crops
	Reducing pesticide use: exploiting pest predators and parasitoids
	Enhancing crop pollinator populations
	Providing a source of fruits, forage and wood
Environmental	Reducing soil erosion by wind or water
	Buffering agrochemical drift
	Reducing fertilizer and other pollutant movement, especially in surface runoff
Biodiversity	To act as a refuge or corridor for wildlife
	Promotion of biodiversity and farm wildlife conservation
Social and recreational	Maintaining landscape diversity
	Promotion of game species
	Encouragement of non-farming enterprises
	Maintaining historical features, heritage and "sense of place"

There are a number of direct and indirect interactions between cropped land and adjacent habitats. Agricultural operations, such as pesticide and fertilizer application, can affect the fauna and flora of non-target field margins. Chemicals may also move via leaching and drift to other habitats. In turn, the adjacent semi-natural habitats may affect in-field production following ingress of weeds, pests and diseases. However, margins can also have positive roles, such as natural control of pests (Wratten 1988), as buffer strips to reduce off-field movement of agrochemicals and subsequent pollution (de Snoo and de Wit 1998), as reservoirs of biodiversity (Holland and Fahrig 2000) and as contributors to other forms of farm income, such as hunting (Rands 1985).

Arable Weeds and Field Margins

A commonly held perception amongst UK farmers in the 1980's was that field margins are reservoirs of weed species (Marshall and Smith 1987). Examination of the patterns of seed and seedling occurrence at arable field edges has indicated that in the UK there are relatively few plant species that originate in field boundaries and colonize arable crops as serious weeds (Marshall 2004). Of the 23 most common weeds recorded in cereals in the UK in the late 1980's (Whitehead and Wright 1989), only four species, *Galium aparine*, *Elytrigia repens*, *Bromus sterilis* and *Poa trivialis*, originate in field boundaries. Studies also indicate that the arable weed flora has very little relationship to the adjacent relatively undisturbed boundary flora (Marshall and Arnold 1995), with the majority of species in hedgerows not found in cultivated areas. Several patterns of seedling density have been recorded at field edges, ranging from species that do not establish in adjacent arable land, to those that colonize from the boundary, to species that are almost exclusively found in cultivated soil and are absent from undisturbed margins (Marshall 1989). Data from a farm in Cambridgeshire illustrate the distributions of three common weed species at increasing distance from the field edge (Figure 2). *Galium aparine*, a hedgerow species, is abundant in the margin, but absent beyond 10 m, while the typical annual weeds, *Stellaria media* and *Veronica persica*, are most abundant within the field. A typical pattern for a spreading grass weed is shown in Figure 3, with high densities in the hedge and decreasing density with distance into the field. Whilst few arable weeds originate in field margins, some of those that do are competitive and, in the past, have had few efficient herbicides to control them in certain crops. However, of the four species mentioned above, *P. trivialis* is not particularly competitive. Herbicides are now available to control all four species. Three of the species, *G. aparine*, *B. sterilis* and *P. trivialis*, are annuals or act as annuals in crops and are dependent on seed return and good germination opportunities. Disturbance of the field boundary is implicated in increased populations of such annual species (Moonen and Marshall 2001). If bare ground is not present within the boundary, germination opportunities are limited and populations of such annuals decline.

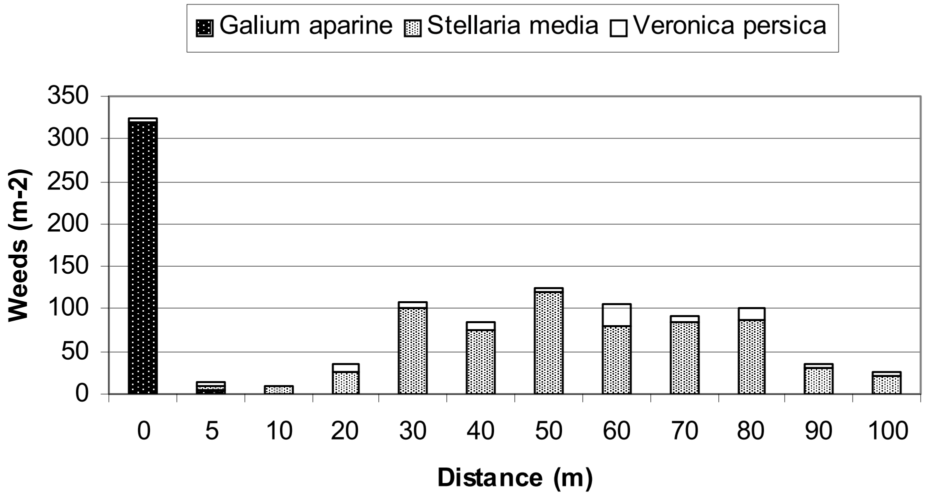

Figure 2. Plant densities (m^{-2}) for three weed species from within a field boundary (0 m) to 100 m into the wheat crop, Cambridgeshire, UK.

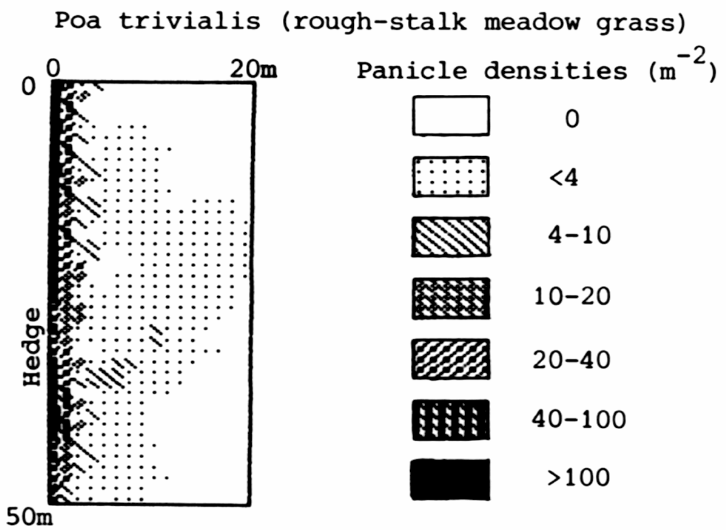

Figure 3. Panicle densities of *Poa trivialis* (rough-stalk meadow grass) in a 50 m by 20 m area of cereal crop edge from a farm in Hampshire, UK (Marshall 1985).

The patterns of weed occurrence and seedbank diversity have indicated that the rare cornfield weeds, for example *Melampyrum arvense* (field cow-wheat) and *Papaver hybridum* (rough poppy), are more likely to be found at field edges than in field centers (Marshall 1989; Wilson 1993; Wilson and Aebischer 1995). This probably reflects more efficient weed control operations in field centers. Thus, schemes aimed at conserving such species in Germany and the UK have concentrated on the field edge. Nevertheless, under extensive arable production, as found occasionally in southern France, these patterns are less clear with arable weed distributions that are unrelated to the field edge (Dutoit et al. 1999).

Fauna and Field Margins

A review of the role of uncultivated land in the biology of crop pests by van Emden (1965) identified many records of pest species using uncultivated areas. The occurrence of pest species in the surroundings of agricultural fields has often been cited as the source of crop losses. In a number of cases this is justified, for example with mollusk pests, e.g. Frank (1998). Certain pest species have alternative hosts for different parts of their life cycle, which involves movement from uncultivated to cultivated areas at particular times of year. For example, the winter host for the black bean aphid, *Aphis fabae*, includes *Euonymus europaeus*, the spindle shrub, a common component of hedgerows. Certain insects are vectors of plant diseases. For example, cereal aphids can transmit barley yellow dwarf virus (Henry et al. 1993; Masterman et al. 1994). Typically, in Britain, aphids move from grasses to winter cereals during the autumn. Virus can be present in grasses in field margins and can be transmitted via the aphids to adjacent or distant crop fields. Uncultivated land can also influence the distribution of insects through the physical presence of hedges and windbreaks. Numbers of aphids can be higher in the crop edge adjacent to hedges, caused by wind vortices and settling (Lewis 1969).

In addition to reviewing the role of uncultivated land for pests, van Emden (1965) also reviewed the available literature on beneficial insects. These can be defined as those that are either of direct benefit to the crop, typically as pollinators, of indirectly by controlling populations of crop pests or vectors of crop disease. These are often referred to as natural enemies. Van Emden (1965) suggested that uncultivated land may have an overall beneficial effect, and that there was scope for managing field margins to enhance beneficial effects for pest control. Since then, there have been increasing amounts of research on the importance of beneficial insects and on the means to enhance them.

Sotherton (1984) noted that a number of important predators of crop pests were found in field margins, particularly during the winter. Spiders (Araneae) and ground beetles (Carabidae, Coleoptera) have been shown to consume significant numbers of cereal aphids (Sunderland et al. 1987). Ground beetles are a diverse group; some of which are seed feeders, while others are polyphagous predators that may be important natural enemies of pests (Kromp 1999). Several species overwinter in uncultivated areas and colonize adjacent crops in spring (Wratten 1988). As well as feeding on aphids, a number of the larger ground beetle species can feed on slugs (Mair and Port 2001). A number of spiders, notably the Linyphiidae, are also predators of aphids and other crop pests (Toft 1995). These species can disperse over wide areas and contribute to pest predation (Halley et al. 1996; Thomas and Jepson 1997). There are also a number of specialist predators of aphids, such as members of the Neuroptera and the Coccinellidae (Zhou et al. 1994). There is good evidence that specialist parasitoids can control aphid populations (Wratten and Powell 1991). Nevertheless, the complex of polyphagous predators may be more effective in reducing pest populations than specialist predators, if they are present in the field. Another group of generalist predators that are associated with field margins are the Syrphidae (hover flies). These can be important aphid predators (Ten Humberg and Poehling 1995), but they require pollen and nectar resources that can be provided in field margins (Cowgill et al. 1993; Hickman and Wratten 1996; MacLeod 1999). As such, they can be important plant and weed pollinators.

Recent work on the spatial behavior of ground beetles has employed dry pitfall traps and mark-recapture techniques over extensive sampling periods. Markedly different spatial behavior was apparent (Thomas and Marshall 1999; Thomas et al. 2001) (Figure 4). Certain species were associated with the hedge, notably *Harpalus rufipes*. Others, such as *Pterostichus cupreus*, are found within the fields, rather than the margins. *Nebria brevicollis* has an aestivation period, when it is limited to the field margin and hedgerow. In September in the UK, the adults of this species move out into the adjacent fields, where they may be involved in predation of aphids and other crop pests active at this time of year (Thomas et al. 2001). This species requires different habitats at different times of year.

Field margins are also important for other taxa, including mammals and birds. For example, bat species hunt along hedgerows (Verboom and Huitema 1997). Bird species also utilize field margins extensively in lowland agricultural landscapes (Chamberlain et al. 2001). In Britain, common birds of farmland have shown huge population declines and some have also shown range contraction (Fuller et al. 1995; Chamberlain and Fuller 2000). Changes in the management of field boundaries may thus have an impact on bird populations.

Field margins have been shown to increase the diversity and abundance of insects, especially if the margins are both botanically and structurally diverse (Thomas et al. 1998; Thomas and Marshall 1999). Thus field margins and uncultivated land can support a diverse fauna, some of which can contribute to the agricultural control of pest species. This contribution to biological diversity may enhance the sustainability of production systems (Altieri 1991, 1999).

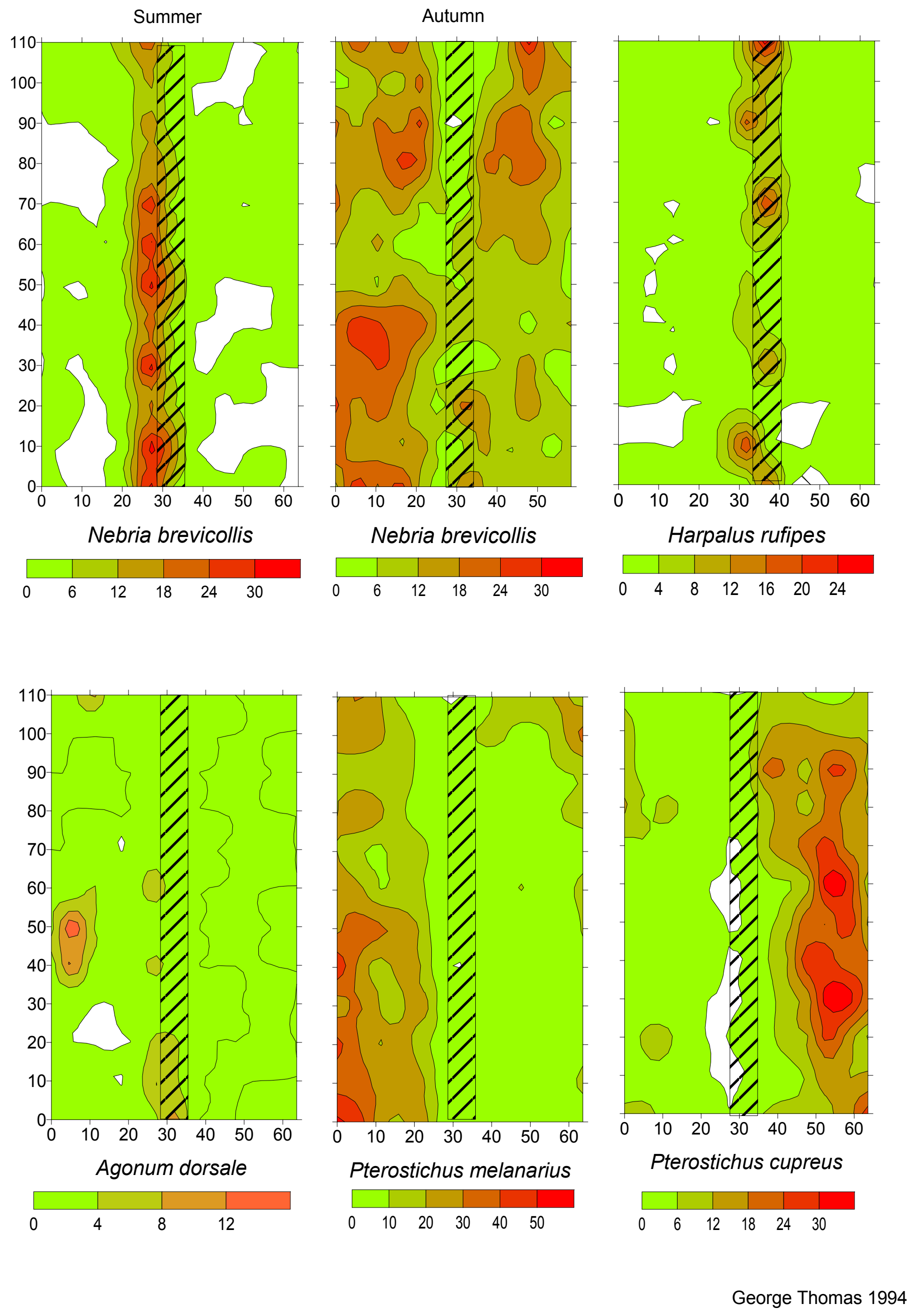

Figure 4. Cumulative trapping densities of different species of Carabidae (ground beetles) in a hedge (central shaded band) and in two adjacent fields of winter wheat over summer and autumn, in Somerset, UK (after Thomas et al. 2001).

Crop Protection and Fertilizer Use

One of the important environmental impacts of production agriculture is eutrophication of soils and water (Addiscott et al. 1991). Nutrient additions are a major factor in plant biodiversity loss and a challenge to conservation (Marrs 1993). Addition of nitrogen fertilizer to natural ecosystems can often result in reduced species richness, e.g. Willis (1963). At high productivity, tall-growing, competitive species out-compete shorter subordinate species (Marrs 1993). It is the case that more fertilizer has been used within arable systems over the past century, though recent economic pressures have encouraged more targeted use. It is likely that increased fertility within crops has encouraged more nitrophilous species. A good example is *Galium aparine* (cleavers), a weed that has increased markedly in frequency from 21% in the 1960s to 88% occurrence in fields in 1997 in central England (Sutcliffe and Kay 2000) and is particularly responsive to nitrogen (Froud-Williams 1985). Nevertheless, herbicide selectivity might also be a factor in changing the prevalence of this species. Repeated Countryside Surveys over the past 25 years indicate that there is a general decline in botanical diversity in lowland landscapes in the UK (Barr et al. 1993; Haines-Young et al. 2000). Both eutrophication and disturbance are implicated in this continuing decline in plant diversity in the wider countryside.

There is good evidence that fertilizer misplacement from field applications into field margins commonly occurs (Rew et al. 1992). Studies by Tsiouris and Marshall (1998) demonstrated that pneumatic fertilizer applicators were accurate and did not contaminate adjacent habitat. However, simple spinning disk applicators could spread fertilizer considerable distances from the target area. A hedge at the field edge can act as a buffer, preventing fertilizer reaching adjacent habitat, but at the same time can concentrate fertilizer drift at the field edge at doses similar to the field. The impacts of fertilizer additions to field margins have been studied in several locations in the UK (Boatman et al. 1994; Rew et al. 1995; Theaker et al. 1995). Whilst clear adverse impacts in terms of increased weed productivity and species declines were not always observed, that tendency is evident (Tsiouris and Marshall 1998).

Nutrient movement by overland flow and leaching through the soil profile are other sources of off-field eutrophication (Addiscott et al. 1991). Overland movement of soil and water can be influenced by field margins and the creation of buffer strips (Pinay et al. 1993; Cooper et al. 1995; Tim et al. 1995; Lowrance et al. 1997; Mander et al. 1997). Vegetated filter strips in North Carolina greatly reduced runoff of chemical loads into the watercourses, with up to 50% of P and NH_4 filtered out (Daniels and Gilliam 1996). A multi-species riparian buffer strip system with four tree species, shrubs and a switchgrass strip placed along a stream in Iowa helped to control soil erosion, trapped and transformed N and P pollution, stabilized the streambank, provided wildlife habitat and enhanced the aesthetics of the landscape (Schultz et al. 1995).

Pesticide drift, as droplet drift or vapor drift, can occur from field applications (Breeze et al. 1992, 1999) and measures to limit non-target effects are in place (Hewitt 2000). Field measurements of drift provide the basis for statutory risk assessment in Europe (Ganzelmeier et al. 1995). Following increased interest in the impacts of pesticide use on non-target habitats, (e.g. Falconer 1998), a number of studies have been made. Significant amounts of pesticide can reach field margins adjacent to sprayed fields (Davis et al. 1994; Longley et al. 1997; Longley and Sotherton 1997a), though many factors affect drift. Studies of the impact of insecticide drift indicate the potential for adverse effects on fauna in field boundaries (Davis et al. 1991; Longley and Sotherton 1997b).

Whilst there are few clear reports of adverse effects of pesticides within field edges, recent work indicates significant impacts of agricultural operations on margin flora (Freemark and Boutin 1995; Jobin et al. 1997; Boutin and Jobin 1998). Kleijn and Snoeijing (1997) made detailed studies of the effects of low levels of herbicide and fertilizer on field margin communities. Field experiments on a natural and a sown community were treated with a range of doses of fluroxypyr (0-50% of field rate) and fertilizer. Fertilizer contamination was more important and a more predictable factor in reducing botanical diversity in adjacent non-target areas, than herbicide drift. However, drift also resulted in reduced species richness, enhancing grass biomass and reducing biomass of flowers, notably the subordinate, lower-growing species (Kleijn and Snoeijing 1997). One might speculate that more broad-spectrum herbicides, such as glyphosate, may have greater impact on non-target flora (e.g. Marrs et al. 1989), but there is little field evidence for this.

Integrating Agriculture and Biodiversity – The Role of Agri-Environment Support Schemes

Whilst there are some conflicts between cultivated and uncultivated land within farms, the challenge of managing the landscape mosaic for the benefit of different land uses is being taken up. At the field, farm and landscape scales, uncultivated areas may provide diversity that can have positive impacts on agriculture, while providing habitat for fauna and flora (Dennis and Fry 1992). For example, weed seed predation may be more effective in situations with small fields and hedgerows (Marino et al. 1997).

As part of the UK response to the Rio Summit, the UK government developed an action plan for biodiversity (Anonymous 1994). A commitment to maintaining biological diversity was made and has been further developed by the UK Biodiversity Steering Group (Anonymous 1995a, 1995b). Specific Biodiversity Action Plans (BAPs) have been developed for individual species under threat and for selected habitats, including two agricultural field margin habitats, Cereal Field Margins and Species-Rich Hedgerows. As a means of retaining biodiversity on farms, environmentally sensitive management is encouraged under Codes of Good

Agricultural Practice (e.g. MAFF 1991) and within support schemes known as agri-environment schemes.

A number of agri-environmental schemes have been implemented across Europe, many with financial support under the European Union Regulation 92/2078. Within the England Rural Development Programme, Environmentally Sensitive Areas (ESA) and the Countryside Stewardship Scheme (CSS) (DEFRA 2001) and several earlier initiatives have addressed a variety of biodiversity targets (DEFRA 2004). The CSS and ESA prescriptions seek to create more diverse agricultural and field margin habitats, in order to arrest the decline in wildlife populations. Specific options related to field margins include conservation headlands, field margin strips, uncropped strips, beetle banks and wildlife seed mixes (Table 2). Options are available to farmers and landowners for modified management of whole arable fields. Farmers may also propose their own habitat creation and management schemes, aimed at specific conservation objectives. These may include birdseed and insect nectar source crops as blocks within fields or field margin strips. Whilst the CSS scheme is competitive and therefore discretionary, farmers who are successful in entering can receive significant financial support, up to £520/ha for certain prescriptions. Up to 1999, there were almost 10,000 agreements with farmers, covering 195,000 ha in the UK. Whilst assessments of the impact of such schemes in the The Netherlands indicated that there were some difficulties in the successful implementation of initial prescriptions (Kleijn et al. 2001), the approach has been replicated widely across Europe (Kleijn and Sutherland 2003).

New Management Initiatives for Field Margins

A number of field margin initiatives have been developed in the UK and Europe, designed to conserve aspects of the farmland biota and provide agricultural benefits (Marshall and Moonen 2002). These initiatives, some of which feature in agri-environment schemes, are listed and briefly described in Table 2. These initiatives can be divided into a) those where the crop edge is managed in a different way to the main crop, such as conservation headlands, b) the creation of new habitat features as a boundary strip (Figure 1), such as grass and wild flower strips and c) new features across fields.

Table 2. Types of modified field edge management aimed at enhancing both wildlife and agricultural production (after Marshall and Moonen 2002; Marshall 2004).

Type	Description	Benefits	References
		Crop edge modification	
Conservation headland	Reduced pesticide inputs to the outside 6 to 12 m of cereal fields	Increased partridge survival; rare weed conservation	Rands 1985; Sotherton et al. 1985; Rands and Sotherton 1987; Chiverton 1993
Uncropped wildlife strip	Cultivation, but no crop sown	Rare weed conservation	Critchley 1994
		New boundary strip	
Grass strip	Sown perennial grass strip	Prevention of weed ingress; habitat for natural enemies; riparian buffer strips; nesting cover	Marshall and Smith 1987; Huusela-Veistola 1998
Grass and wild flower strip	Sown perennial grassland vegetation strip	Prevention of weed ingress; habitat for wide range of natural enemies; wildlife conservation; riparian buffer strips; nesting cover	Marshall and Nowakowski 1991; Smith et al. 1993; Lys et al. 1994; West and Marshall 1996; Kleijn et al. 1998
Flower strips	Sown flower mixtures	Enhancement of pollinators and some crop pest predators	Lys and Nentwig 1992
Sterile strip	Elimination of all herbaceous vegetation by herbicide or cultivation	Weed and harvesting break;	Bond 1987
Set-aside margin	Natural regeneration of perennial vegetation	(Benefits depend on the vegetation structure and composition)	MAFF 1988
Sown wildlife mixtures (strips or blocks)	Sown mixtures for birds or bees	Resources for a range of wildlife, including gamebirds	Game Conservancy 1994
		New habitat across fields	
Beetle banks	Sown tussocky grasses on ridge across large fields	Overwintering habitat for ground beetles, encouraging field colonisation in spring	Thomas et al. 1991; Thomas et al. 1992
Weed/flower strips	Sown strips of flowers	Enhancement of pollinators and some crop pest predators	

Conservation Headlands

In Germany and other European countries, many annual plant species adapted to arable cropping have become extinct or are threatened with extinction. The loss of some of these annual cornfield weed species in Germany has been countered by measures to prevent the use of pesticides in the outside few metres of cereal fields. These "ackerrandstriefen" or weed strips were designed by Schumacher (1987) and have been supported by regional governments in a number of the German states (Jörg 1995). The technique is known in the UK as conservation headlands, in which herbicide and insecticide use in the first 6 to 12 m of the crop is restricted. Conservation headlands were developed in the UK by the Game Conservancy Trust as a practical means of encouraging populations of grey partridge (*Perdix perdix*) (Rands 1985; Rands and Sotherton 1987). These gamebirds require suitable grassy nesting habitat and a supply of insects for chick feeding. Adult birds forage in cereal crops, where many chick food items are associated with dicotyledonous weeds. Improved weed control and losses of these items are important factors in the decline of the partridge (Potts and Aebischer 1995). Whilst initially designed for gamebirds, the technique has been shown to provide many other conservation benefits (Sotherton et al. 1985; Chiverton 1993; Dover 1996; de Snoo et al. 1998). Whilst management results in a weedier field edge that may require separate harvesting, the most pernicious weeds are controlled with selective herbicides.

Uncropped Wildlife Strips

Following observations that rare weed species can continue to survive in field edges, support is available to farmers who cultivate a field edge strip annually, but do not plant a crop or manage the area further (Critchley 1994).

Sown Grass Margins

This proposal was first made by Marshall and Smith (1987) as a means of preventing weed ingress and as a response to the common practice of removing all perennial vegetation in field boundaries with broad-spectrum herbicides. Disturbance from agricultural operations tends to reduce plant species diversity in the field margin, favoring competitive ruderal species, typically annual species that are encouraged by the removal of perennials. Recreation of a perennial grass flora provides a barrier to weed ingress for those species that are not adapted to long distance dispersal, a buffer against agrochemical drift and habitat for some overwintering natural enemies (Barker and Reynolds 1999).

Beetle Banks

A variation on the grass margin strip is known as the "beetle bank". This technique was developed by the Game Conservancy Trust as a means of encouraging the colonisation of very large fields by ground beetle species that overwinter in tussocky grasses in field edges (Thomas et al. 1991, 1992). Simple grass mixtures are sown across the centre of large fields on a slightly raised ridge created by ploughing. The beetle bank can be isolated from existing field boundaries to facilitate machinery movement, or can be connected to become a new margin dividing a field. The tussocky grasses provide suitable overwintering habitat for some beetle species, as well as cover for ground-nesting birds.

Sown Grass and Wild Flower Margins

Sown grass and flower margins at the edges of arable fields have been investigated and developed over a number of years in the UK (Smith and McDonald 1989; Marshall and Nowakowski 1991; 1992; Smith et al. 1993; Marshall et al. 1994; Marshall and Nowakowski 1995). The creation of diverse vegetation should support a diverse fauna (Thomas and Marshall 1999). The use of seed mixtures containing perennial native grasses and flowers can be established successfully, if attention is paid to initial establishment conditions and weed control (Marshall and Nowakowski 1991; West and Marshall 1996). The retention of meadow strips at arable field edges is not new as William Cobbett reported such features in England during the nineteenth century (Cobbett 1853). Perennial seed mixes can reduce weed problems at the field edge (West et al. 1997; Smith et al. 1999) by space pre-emption and competition. As regards arthropod natural enemies, these sown strips can provide overwintering habitat (Pfiffner and Luka 2000) that can be colonized within 12 to 14 months of establishment (Thomas et al. 1994). During the summer, flower margins support a range of invertebrates (Thomas and Marshall 1999). Floral resources provided by sown flowers are important for Syrphidae, effective aphid predators (Frank 1999; Harwood et al. 1992; MacLeod 1999; Sutherland et al. 2001).

Flower Margins and Strips across Fields

The potential of floral resources to encourage beneficial insects has led to work on the creation of flower strips, both at field edges and across fields. For example, the prolifically flowering *Phacelia tanacetifolia* can be sown in strips at field edges to encourage pollinators and pest predators (Gathmann et al. 1994; Hickman and Wratten 1996). Seed mixtures have also been used to promote bees (Carreck and Williams 1997) and ground beetles (Lys and Nentwig 1992). These weed strips may encourage certain pest species (Lethmayer et al. 1997), including mollusks (Frank 1998), though crop damage is usually of little significance and limited to the first meter of field.

Set-aside Margins

The creation of new features may not always require sowing; on some soils and under some conditions natural regeneration of the local flora can be successful. This is usually where soil nutrients are low and there are other limitations to plant growth, such as high or low soil pH (West et al. 1999). Nevertheless, where weed species are already present, natural regeneration tends to encourage these species (Marshall and Moonen 1997; West et al. 1997).

Wildlife Mixtures

The creation of blocks or strips of sown vegetation for the enhancement of particular fauna on farms has been practiced for many years. Initially, these have been established as cover for gamebirds (Game Conservancy 1994). More recently, there has been interest in creating features for wild birds, invertebrates, including bees, and other groups (Marshall 1998).

Sterile Strips

The creation of a "cordon sanitaire" at arable field edges offers some opportunity to limit the movement of weeds from field boundaries into the crop (Bond 1987). Elimination of a strip of herbaceous vegetation at the field edge, usually with a herbicide, may also facilitate harvesting by providing clean crop edges and preventing the combine harvester catching climbing weeds from the margin. This technique has been used by a number of farmers in the UK. However, the variability of location of the strip, caused by the use of hand-held herbicide applicators, may exacerbate annual weed populations, such as *Bromus sterilis* (Marshall and Nowakowski, unpubl.) at the field edge.

Discussion and Conclusions

The use of field margin strips has clear benefits for conservation and environmental concerns. Conservation headlands can enhance invertebrates and gamebirds (Sotherton et al. 1985; Rands and Sotherton 1987; Dover 1996; de Snoo et al. 1998). Sown margin strips can also enhance a range of farmland biota (Barker and Reynolds 1999; de Snoo and de Wit 1998; Huusela-Veistola 1998; Moonen and Marshall 2001; Thomas and Marshall 1999). The creation of new features on farmland may also protect existing features from drift and eutrophication (de Snoo and de Wit 1998; Patty et al. 1997).

The evidence for agricultural benefits of modified field edge management is less clear-cut. There is good evidence that populations of pest predators and pollinating insects can be enhanced by field edge management, (e.g. Lagerlöf et al. 1992; Thomas and Marshall 1999; Sutherland et al. 2001). However, demonstrations of concomitant reductions in pest populations in the crop are limited to aphid reductions up to 10 m into a cereal crop from the edge (Marshall 1997). Modifying habitats to enhance beneficial insects is under investigation in orchards (Wyss 1995; Rieux 1999) and open glasshouses (Alomar et al. 2002). There is, however, good evidence that the creation of grass margins can reduce weed populations within the boundary (Moonen and Marshall 2001). In a comparison of adjacent farms with similar crop rotations, but different margin management, Moonen and Marshall (2001) found differences in plant diversity and abundance of weed species. Where cropping was right up to hedges and sterile strips were used, the abundances of some weeds were significantly greater than where grass margins

4 m to 20 m wide were present. These data indicate that reduced weed pressure can result from modifying the management of the field edge.

The interactions between cultivated and uncultivated land are complex. Both beneficial and disadvantageous effects occur in both directions. Nevertheless, the emerging evidence indicates that the provision of diversity by field margins, at a range of spatial scales, has benefits both to monoculture cropping and to wildlife and the environment.

Where they exist, the diversity of structure that boundaries may have, including walls, hedges and ditches, can promote the diversity of plant communities that may occur there. The addition of conservation management in the form of permanent field margin strips or conservation headlands can further add to this diversity and protect existing habitat from some adverse effects of adjacent farm operations. Boundaries may have a diversity of communities, including woodland, shrub, tall herb, grassland, wetland and arable plant species. However, often the diversity of the margin community is low, reflecting reduced structural diversity and disturbance from fertilizer, herbicide drift and cultivation. The approaches to management supported by agri-environmental schemes in several countries can promote diversity, partly by reducing disturbance and by encouraging an increase in the size of semi-natural habitat on farms. An integration of agricultural, environmental and biodiversity functions based on field margins is thus feasible. Nevertheless, not all the answers regarding possible effects are available and, as the interactions are complex, simple management prescriptions are unlikely to satisfy all the requirements. For example, permanent field margin strips and prescriptions for rare arable weeds are incompatible, as the disturbance regimes for one preclude the other. However, the potential exists to satisfy the requirements of current and future crop production, with wildlife conservation and environmental protection by incorporating non-crop habitats into local land management.

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Pesticide movement to field margins: Routes, impacts and mitigation

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Pesticide use has become integral to forestry and to most crop and animal production systems in Canada. Pesticides are known to move from treated agricultural areas into field margins, and subsequently into the broader environment, through transport in air and water. As a consequence, pesticides have been detected in air and rainfall, surface waters (farm dugouts and ponds, wetlands, rivers and streams) and groundwaters (private and municipal wells) across Canada. Air in field margins may be contaminated with pesticides because of application drift, post-application vapour loss and wind erosion of treated soil. Soil, vegetation and water bodies within field margins may become contaminated through wet (precipitation) and dry (particulate) atmospheric deposition of pesticides and through surface (snow melt and rainfall) runoff from pesticide-treated agricultural land. The impact of this diffusion of pesticides from treated agricultural land is most likely greatest in field margins which, in intensively farmed areas of Canada, can be the primary source of habitat for wildlife. Sensitive plants and animals as well as the water quality of water bodies in field margins can be affected either directly or indirectly. For example, birds can be acutely affected by ingestion of granular insecticide formulations whereas decreased plant diversity due to herbicide exposure can decrease bird food supplies (arthropods, seeds) and nesting cover. Impacts due to agricultural use of pesticides can be mitigated by use of appropriately equipped and operated delivery systems (e.g., low-drift nozzles), appropriate product choice (e.g., low vapour pressure, low water solubility),

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appropriate tillage practices, maintaining adequate soil cover and through the use of buffer zones.

Additional Keywords: pesticide drift, pesticide leaching, pesticide runoff, groundwater contamination, biological impact

Introduction

In Canada, agricultural production occurs in all ten provinces but the extent to which the landscape has been permanently modified by agricultural activities in the various ecozones varies greatly. Depending upon the ecozone, agriculture may occupy from < 1 (Pacific Maritime ecozone) to 90% (Prairie ecozone) of the landscape (McRae et al. 2000). As the percentage of the landscape in agricultural production increases, field margins become more valuable as wildlife habitat.

Field margins refer to areas adjacent to agricultural fields or to cropped or grazed areas. In the Prairie ecozone, which has only 10% of the landscape available for wildlife habitat, field margins frequently consist of narrow strips of vegetation adjacent to fields such as fence lines or edges of road rights-of-way. In other situations, field margins may be treed areas unsuitable for cultivation or riparian areas along rivers or streams. Natural wetlands and constructed reservoirs may also be present in field margins. The vegetation growing within these areas may consist of native plant species, which can include low growing grasses, woody plants such as wild rose (*Rosa woodsii* Lindl.), shrubs such as willow (*Salix* spp.) and tall trees such as aspen poplar (*Populus tremuloides* Michx.). However, planted vegetation, such as trees in shelterbelts and grasses in waterways, may be present. Thus, field margins can vary greatly, not only in vegetation type, area and shape, but also in their ability to provide adequate habitat for wildlife. The presence of plants, insects and animals in field margins determines how farmers manage them to prevent their possible movement into adjacent crops.

Pesticides are known to move from treated agricultural and forested areas into the broader environment. Since many field margins are immediately adjacent to cropland treated with pesticides, greater interception of pesticides, due to off-target transport, and greater adverse effects on vegetation and wildlife within these areas would be expected relative to the broader environment. It is generally accepted that transport of pesticides into field margins, and subsequently into the broader environment, is associated with atmospheric transport and transport in water. Pesticide presence in air occurs by three main routes of entry. These include application drift, post-application vapour loss and wind erosion of treated soil (Figure 1). Once in the atmosphere either as spray droplets, vapour or sorbed to wind-eroded sediment, pesticides, or their photodegradation products, may be transported relatively short (field margins) or long (broader environment) distances before the removal processes of atmospheric wet (precipitation) and dry (particulate) deposition return them to the earth's surface. Through atmospheric deposition, pesticides can deposit in field margins directly onto plant surfaces, wildlife, surface waters and the first few millimetres of soil. Deposition into surface waters must first pass through a surface film of organic material (Maguire and Tkacz 1988; Southwood et al. 1999) that is present in varying thickness depending on the water body and the season. Pesticides may then partition into the water column and, from there, into suspended or bottom sediments. The atmospheric dispersion and deposition of pesticides has been reviewed recently by Van Duk and Guicherit (1999).

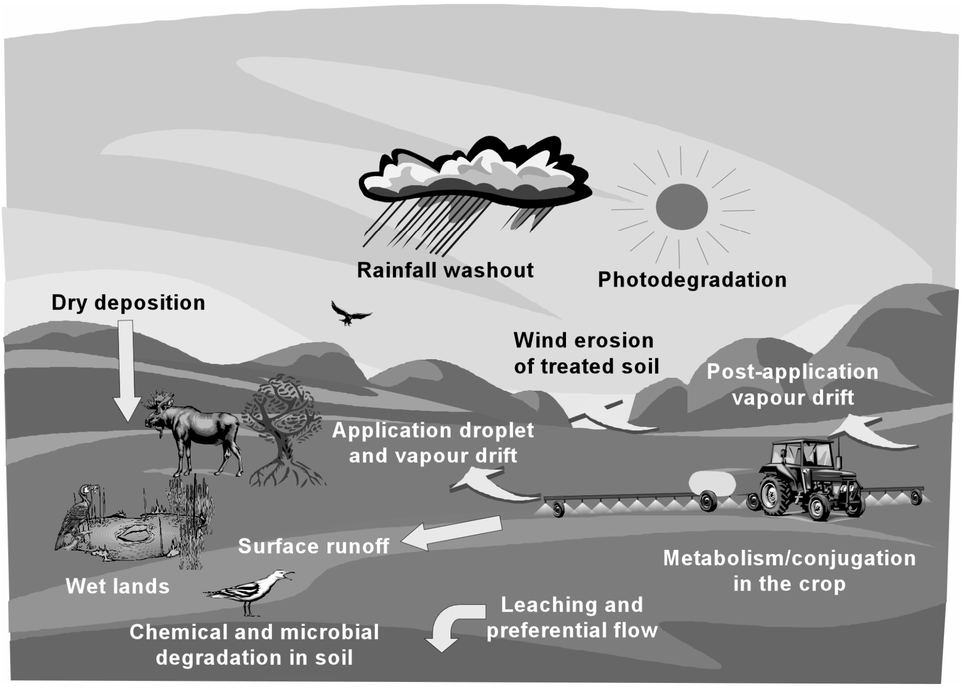

Figure 1. Routes of entry of pesticides into the atmosphere and into surface and groundwaters and mechanisms of pesticide transformation in air, soil and plants.

Pesticides may also enter field margins in surface (irrigation, rainfall or snow melt) runoff and contaminate soil (by infiltration), plants (by plant uptake) and surface (receiving) waters (Figure 1). Pesticides entering a lake, wetland or constructed reservoir are those applied, or atmospherically deposited, within its watershed. Further transport is generally restricted to dispersion within the water body and partitioning into sediment. Surface runoff may traverse riparian areas and enter flowing water (river or stream). Then, not only is it possible for pesticides to be transported long distances, but a diversity of pesticides may be present due to multiple watersheds that can occur along the reach of a river or stream. Surface water bodies in field margins may also contain pesticides because of recharge with groundwater contaminated through the leaching processes of matrix flow and/or preferential flow. Preferential flow occurs via preferential pathways such as cracks or fissures in the soil or continuous macropores consisting of insect burrows or cavities left by decayed plant roots.

The Canadian public is increasingly aware of the diffusion of pesticides into the environment and their potential to impact human health and environmental quality. Public interest in human health issues with respect to pesticide use is high and Canadians remain concerned with air quality and the safety of their drinking water and food supply. Effects of pesticides on wildlife habitat and biodiversity are also important to Canadians as evidenced by the popularity of wildlife- and fish-related activities, and strong commitment to the protection and conservation of abundant and diverse wildlife (Filion et al. 1993).

In this review, pesticide entry into the atmosphere, surface runoff and water infiltrating soil will be discussed as essential background information for understanding the movement of pesticides into field margins. Evidence for the impact of pesticide transport on air, surface water and groundwater quality in Canada will be provided to illustrate that air and water in field margins, which are frequently immediately adjacent to farmland treated with pesticides, may be similarly affected. Impacts of pesticide transport on vegetation and wildlife within field margins will then be discussed together with strategies to mitigate or minimize those impacts. Only pesticides with currently registered uses in Canada will be emphasized in this review.

Entry of Pesticides into Air

Application Drift

Application of liquid sprays is done through nozzles that provide metering, atomization, and uniform distribution of the pesticide mixture. The majority of atomizers use hydraulic pressure as the energy source for breaking the liquid into smaller particles, or droplets. Hydraulic atomizers such as flat fan nozzles produce a heterogeneous spray containing a spectrum of droplet sizes (Chapple and Hall 1993). A typical flat fan nozzle, for example, produces droplet sizes between 5 and 700 µm, but some low-drift sprays can contain droplets larger than 1000 µm. The implications of droplet size on herbicide efficacy have been discussed elsewhere (e.g., Knoche 1994; Wolf 2000).

The proportion of the total spray volume contained in droplet sizes below 150 µm in diameter can be used as an indicator of drift potential, because it is these small droplets that are most prone to movement under windy conditions (Southcombe et al. 1997) and that could potentially deposit on soil, plant or water surfaces and be present in the air within field margins. For conventional flat fan nozzles, the drift-prone size fraction typically varies between 10 and 30% of the total volume (depending on nozzle parameters and measurement methodology);

whereas, for low-drift nozzles, the value can be as low as 1% (Etheridge et al. 1999) and generally ranges between 1 and 5%. Although formulation differences may not significantly affect drift (Kirk 2000), the driftable droplet fraction can vary with formulation types (e.g., suspension concentrate or water-dispersible granule versus emulsifiable concentrate) (Hewitt et al. 1993). Low-drift adjuvants have also been shown to reduce the fine drop component provided that shear stresses are taken into account (Downer et al. 1995).

The amount of spray drift leaving the treated swath depends primarily on the droplet size spectrum of the spray (Cross et al. 2001; Maybank et al. 1974), the height of droplet release (Nordby and Skuterud 1975), and weather conditions such as wind speed and atmospheric turbulence (Threadgill and Smith 1975). Under typical daytime conditions with winds between 10 and 25 km h^{-1}, Wolf et al. (1993) showed that about 95% (±4%) of fine to medium sprays deposited on the treated swath whereas the remaining 5% (±4%) moved off-swath in the direction of the wind.

Off-swath, the spray has been shown to be subject to several processes. First, the largest droplets deposited under the force of gravity with their size and evaporation rate, together with atmospheric turbulence, determining the distance they travelled prior to deposition (Bache and Johnstone 1992). The deposition profile has typically followed a linear pattern on a log-log scale (Wolf and Caldwell 2001). At 0 to 5 m downwind, fallout deposit amounts accounted for < 1% of the applied amount, whereas from 10 to 50 m, deposit amounts were typically < 0.1%. Some studies have shown that these amounts are dependent on atmospheric and topographic conditions. For example, deposition was suppressed in a turbulent atmosphere (Maybank and Yoshida 1969), channelled along low-lying areas (Allwine et al. 2002), or intercepted (filtered) by roughness elements along the soil surface (Miller et al. 2000).

Smaller droplets tend to remain air-borne, moving upward and downward with turbulent eddies, and become vertically mixed and diluted in the process (Bache and Johnstone 1992). The atmospheric loading that results from this latter process accounts for the majority of the pesticide loss from droplet drift (Majewsky 1991) that may then be engaged in long-distance transport prior to being removed from the atmosphere through the processes of precipitation washout (Hill et al. 2002a) and dry deposition (Waite et al. 1999). Vertical structures, such as shrubs and trees, may intercept drifting droplets; with larger amounts being intercepted the nearer such structures are to the application swath (Raupach et al. 2001). Though some authors have suggested the use of shelterbelts or hedgerows as collectors to reduce airborne drift concentrations (Ucar and Hall 2001), others have proposed to use buffer zones or conservation headlands to protect these same hedgerows from exposure to drift (Longley et al. 1997).

Research clearly indicates that the amount of pesticide present in air and depositing on soil, plant and water surfaces within field margins depends, in large measure, on emitted droplet size spectrum and other operational parameters, distance from the field margin, and local weather conditions. However, amounts deposited are difficult to predict due to the heterogeneous nature of natural areas and associated changes in turbulence, interception, and dispersion (Marrs et al. 1991b). As a result, conventional drift models may not accurately predict movement into field margins and biological effects may therefore need to be studied directly rather than inferred.

Post-Application Vapour Losses

In crop production, which accounts for the majority of agricultural use of pesticides in Canada, there are two broad types of pesticide applications. Preemergence applications, applied to the soil surface prior to the emergence of the crop, may be left undisturbed on the soil surface or incorporated by some form of soil disturbance into the upper layer of soil. Postemergence applications are applied directly to the crop/weed canopy, a portion of which may penetrate the crop/weed canopy and deposit on the soil surface.

Soil-incorporated pesticides, and those used as seed treatments, may move as vapours to the soil surface where they sorb to the upper few millimetres of dry surface soil. Greater vapour movement to the soil surface occurs with pesticides with larger Henry's Law constants [ratio of concentration in air to concentration in (soil) water]. Vapour loss to the atmosphere of pesticides sorbed to the soil surface may occur when the surface soil becomes moist by rain or heavy dew. The emission of pesticides from both soil and plant surfaces has been recently reviewed (Van den Berg et al. 1999).

Vapour losses of pesticides from soil and plant surfaces determine post-application concentrations of pesticides in air within field margins. The magnitude of post-application vapour losses from soil and plant surfaces is dependent upon several factors. Losses of pesticides from plant surfaces depend primarily on the vapour pressure of the pesticide, as well as the rate of uptake by the plant, the rate of photodegradation on plant surfaces, and atmospheric turbulence to move vapours away from plant surfaces. Vapour losses following postemergence application to wheat (*Triticum aestivum* L.) were of the order 2,4-D *iso*-octyl ester (Grover et al. 1985) > bromoxynil *n*-butyrate plus octanoate (1:1) (Grover et al. 1994) > diclofop (Smith et al. 1986) (Table 1).

Table 1. Post-application vapour losses of herbicides following postemergence application to wheat.

Herbicide	Percent Loss	Time Period	Reference
Diclofop	< 1	5 days	Smith et al. 1986
Bromoxynil butyrate	16	5 days	Grover et al. 1994
Bromoxynil octanoate	7	5 days	
2,4-D *iso*-octyl ester	21	7 days	Grover et al. 1985

Post-application vapour losses from the soil surface are determined by the physical-chemical properties of the pesticide (e.g., vapour pressure), the degree of incorporation or penetration of the pesticide into the soil, the extent of binding of the pesticide to soil components, the half-life of the pesticide in soil (i.e., its susceptibility to microbial degradation), the tillage system, and the environmental conditions, such as soil moisture and atmospheric turbulence above the soil surface, following application. For example, much greater vapour loss occurred when trifluralin was applied to moist soil with no incorporation compared to the same treatment on dry soil (Glotfelty et al. 1984) or when the herbicide was incorporated shortly after application (White et al. 1977; Grover et al. 1988a) (Table 2).

Table 2. Post-application vapour losses of herbicides following preemergence surface-applied, soil-incorporated and herbigation applications.

Herbicide	Percent Loss	Time Period	Reference
Preemergence, moist surface soil, not incorporated			
Trifluralin	50%	3 to 7 hours	Glotfelty et al. 1984
	90%	2 to 7 days	
Preemergence, dry surface soil, not incorporated			
Trifluralin	2 to 25%	50 hours	Glotfelty et al. 1984
Preemergence, granular, not incorporated			
Trifluralin	15%	14 days	Smith et al. 1997
Ethalfluralin	12%	14 days	
Triallate	19%	14 days	
Preemergence, no till, not incorporated			
Atrazine	4%	35 days	Wienhold and Gish 1994
Alachlor	9%	35 days	
Preemergence, conventional tillage, not incorporated			
Atrazine	9%	35 days	Wienhold and Gish 1994
Alachlor	14%	35 days	
Preemergence, incorporated			
Trifluralin	22%	120 days	White et al. 1977
Trifluralin	24%	67 days	Grover et al. 1988a
Triallate	18%	67 days	
Surface-applied to freshly tilled soil			
α-Endosulfan	29%	21 days	Rice et al. 2002
Trifluralin	14%	21 days	
Chlorpyrifos	10%	21 days	
Metolachlor	6.5%	21 days	
Atrazine	3.6%	21 days	
β-Endosulfan	2.5%	21 days	
Flood irrigation, herbigation			
EPTC	74%	52 hours	Cliath et al. 1980

Using micro-climatological data, Harper et al. (1976) showed that when the soil surface was dry, trifluralin fluxes were controlled by the availability of soil surface water content and its effect on the adsorption of the herbicide to soil components. Cumulative seasonal losses of triallate were also dependent on soil surface moisture conditions (Grover et al. 1988a) as were losses of unincorporated granular formulations of ethalfluralin, trifluralin and triallate over a 2-wk period (Smith et al. 1997). Losses of surface-applied atrazine and alachlor after 35 d were greater from conventionally tilled corn (*Zea mays* L.) fields than from no-till fields (Wienhold and Gish 1994). Losses were further reduced when a starch-encapsulated formulation was used. Recently, Rice et al. (2002) reported pesticide vapour loss from freshly tilled soil for several surface-applied pesticides to be as follows: α–endosulfan (29%), trifluralin (14%), chlorpyrifos (10%), metolachlor (6.5%), atrazine (3.6%) and β-endosulfan (2.5%). When applied by herbigation under flood-irrigation conditions, cumulative vapour loss of EPTC from irrigation water and wet soil was 74% after 52 h (Cliath et al. 1980).

Wind erosion of Pesticide-Treated Soil

Pesticide use is integral to many crop and animal production systems used in Canada, therefore pesticides are frequently present on the surface of agricultural soils. As described above, this occurs with both preemergence and post-emergence pesticide applications to crops. Pesticides on the soil surface may be susceptible to transport through wind erosion of soil in which three processes are considered operative. Large soil particles can roll on the soil surface under the influence of wind and this movement is called surface creep. Smaller particles can become suspended in the air for short periods of time as they move downwind. This process is known as saltation. Even smaller particles can remain suspended in the air as they move laterally, and this process is termed suspension. Since all three processes may involve soil particles with adsorbed pesticide, significant amounts of pesticide may be transported from the soil surface with the wind-eroded sediment into field margins.

Hawthorne et al. (1996) suggested that wind-eroded soil may be a significant source for introducing pesticides into surface and groundwater in North Dakota. The magnitude of this type of pesticide transport would be related to the susceptibility of the soil to wind erosion which, in turn, is related to tillage practices. Wall et al. (1995) have noted that, in the absence of conservation tillage practices, wind erosion remains one of the major processes of soil degradation in the prairie region of Canada.

With the development of efficient dust collectors (Fryear 1986) and models (Hagen 1991) to estimate the mass of soil lost from eroding targets, estimates of the masses of pesticides lost with wind-eroded sediment have been made. Glotfelty et al. (1989) reported that <1% of soil surface applications of simazine and atrazine were transported by wind erosion. They also reported that wettable powder formulations of the herbicides were more prone to wind erosion transport than emulsifiable concentrate formulations because the fine clay particles, which carry the active ingredients in wettable powder formulations, remain exposed on the soil surface. More recently, Larney et al. (1999) reported on the transport of six herbicides by wind erosion of a clay loam soil in southern Alberta. Overall losses for three winter erosion events for two soil-incorporated herbicides, trifluralin and triallate, were approximately 1.5% of the amounts applied. Losses of four postemergence herbicides (2,4-D, mecoprop, bromoxynil, diclofop) applied to the soil surface averaged 4.5%. These studies demonstrate the potential for environmental transport of pesticides on wind-eroded sediment and its associated implications for off-site air and surface water quality within field margins. Granular applications are also prone to erosion by wind and under unusual or extreme conditions, their losses to field margins could be significant. For example, using small plots of sandy soil in southwestern Ontario, Gaynor and MacTavish (1981) reported that wind erosion deposited approximately 43% of a surface-applied granular application of simazine within 2.5 m of the downwind edge of the plots. In Australia, Leys et al. (1998) reported that the insecticide endosulfan was transported on dust emanating from cotton farms.

Entry of Pesticides into Surface Runoff

Pesticides susceptible to surface runoff are those within the runoff-soil interaction zone or the top 0.5 to 1 cm of soil (Ahuja et al. 1981; Leonard et al. 1979; Spencer and Cliath 1991; Wauchope 1978). Several factors may affect the amount of pesticide present within this zone and, consequently, the amount of pesticide that may enter field margins in surface runoff. These include the type of pesticide application (soil surface-applied, soil-incorporated, or postemergence), the physical-chemical properties of the pesticide (vapour pressure, water solubility, Henry's Law constant, soil sorption characteristics), the environmental stability or field half-life of the pesticide (resistance to hydrolysis, photodegradation and microbial degradation), and the formulation type of the pesticide. Other factors affecting the amount of pesticides transported in surface runoff include the slope of the treated area and the interval between pesticide application and the occurrence of the runoff event. Generally, the greater the slope and the shorter the interval between application and runoff, the greater are the contaminant losses in surface runoff (Wauchope 1978).

Reports in the literature indicate the proportion of pesticide applications that may enter field margins in surface runoff. Wauchope (1978) reviewed rainfall runoff losses of pesticides from agricultural land and concluded that, for the majority of pesticides, total losses were generally 0.5% or less of the amounts applied. However, losses up to 5% of soil surface-applied, wettable-powder formulations of herbicides could occur because of ease of washoff of the powder. Losses of pesticides in flood-irrigation runoff have been reported to be 2% or less. In a 5-yr study, Spencer and Cliath (1991) determined transport of 20 pesticides, including six soil-applied herbicides, from several flood-irrigated fields in the

Imperial Valley in California. Seasonal losses, as percentages of amounts applied, were less than 1% for postemergence insecticides and ranged from 1 to 2% for the preemergence herbicides. More recently, the transport of several postemergence-applied herbicides in runoff from corrugation irrigation of wheat in Saskatchewan has been reported (Cessna et al. 1994, 1996). Even with a minimal 7-h interval between application and the first irrigation, seasonal herbicide losses after three irrigations were only 1% of amounts applied (Cessna et al. 1996) (Table 3). These flood-irrigation runoff studies (Cessna et al. 1994, 1996; Spencer and Cliath 1991) verified that the factors which determined transport of pesticides in rainfall runoff (Wauchope 1978) similarly affected losses in irrigation runoff.

Table 3. Herbicide transport in runoff from flood-irrigation of wheat.

Herbicide	Loss in drainage water (time between herbicide application and flood irrigation)		
	----------------------------- % -----------------------------		
Bromoxynil	0.83%	0.12	0.02%
	(7 hours)	(13 days)	(26 days)
Diclofop	0.79%	0.12%	0.03%
	(7 hours)	(13 days)	(26 days)

Entry of Pesticides into Groundwater

Although pesticides dissolved in water infiltrating soil may affect microbial communities and sensitive plant species because of root uptake, the presence of pesticides in groundwater due to the leaching process is generally not considered to impact field margins directly. However, it is possible that water bodies within field margins may derive some of their water through recharge from shallow aquifers. In such situations, recharge from an aquifer contaminated with pesticides may impact aquatic plant and animal life within the water body.

Leaching of water and dissolved pesticides to depth in soil occurs by matrix flow and/or preferential flow. Matrix flow is the slower transport process in which the simultaneous movement of pesticides with water is determined largely by the physical-chemical properties of the pesticides. Such movement of a pesticide is dependent on its water solubility, vapour pressure, Henry's Law constant, and soil sorption coefficient. This dependency of movement to depth on the mobility characteristics of a pesticide has been demonstrated in soil column leaching (e.g., Futch and Singh 1999; Grover 1977; Hogue et al. 1981) and soil thin layer chromatography studies (Majka and Lavy 1977).

Preferential flow consists of more rapid movement of water to depth via preferential pathways such as insect burrows, soil fractures and cavities left by decaying plant roots. In preferential flow, the rate of simultaneous pesticide transport is largely independent of the physical-chemical properties of the pesticide. Such flow is considered to occur when pesticides with differing mobility characteristics are leached to the same depth (Flury et al. 1995) or appear simultaneously in tile-drain effluent (Elliott et al. 2000; Kladivko et al. 1991; Traub-Ebarhard et al. 1995). However, unlike the rate of pesticide transport, the amount of pesticide transported does depend on its mobility characteristics (Elliott et al. 2000; Flury et al. 1995; Kladivko et al. 1991).

There are several reports in the literature regarding pesticide transport through soils at the field scale and these have been reviewed by Flury (1996). He concluded that, when there is no heavy rainfall shortly after pesticide application, the mass of pesticide annually leached below the root zone is in the range of < 0.1 to 1% of the amount applied. Elliott et al. (2000) reported similar amounts being leached under sprinkler irrigation. Although researchers such as Isensee and Sadeghi (1996) and Elliott et al. (2000) reported that greater leaching of pesticides occurred under zero versus conventional tillage, Flury (1996), in his review, concluded that tillage practice or soil surface management may influence pesticide leaching in some cases but not in others and that the factors causing these differences are not well understood. In laboratory studies, Sánchez-Camazano et al. (1995) and Foy (1992) have reported that surfactants can also affect the mobility of pesticides in soil and Gerstl et al. (1998) have reported that controlled-release formulations can reduce leaching of pesticides.

Impacts of Pesticide Use on Air and Water Quality in Canada

Agricultural pesticide use has become an integral component of most crop and animal production systems in Canada. As a consequence, greater than 45 million kilograms of pesticide active ingredient are sold annually in Canada with annual sales exceeding one billion Canadian dollars (Table 4).

Table 4. Pesticide Sales in Canada (2001).

Pesticide	Sales[a]	Percent sales
Herbicides	$1.016 B	80
Insecticides	$0.064 B	5
Fungicides	$0.114 B	9
Other	$0.076 B	6
Total	$1.270 B	100

[a] CropLife Canada 2002

Herbicides account for about 80% of all pesticides sold (Table 4) with approximately 70% of pesticide sales occurring within the three prairie provinces of Alberta, Saskatchewan and Manitoba. With the understanding that some portion of the pesticides used may enter the air or be transported in water, one can ask the question whether or not pesticides have moved beyond field margins and impacted air and water quality in Canada through dispersion into the broader environment.

Impacts on Air Quality

Once pesticides have entered the air through application drift, post-application vapour loss and wind-eroded soil, they are subject to atmospheric transport. The extent to which they move in the atmosphere before depositing to the earth's surface through the processes of atmospheric deposition can vary greatly. Distances moved can be local (less than one to tens of kilometres), regional (hundreds of kilometres) or long-range (thousands of kilometres) in nature. This movement of pesticides in the atmosphere has been reviewed recently by Van Duk and Guicherit (1999).

Ambient air concentrations. Studies have indicated that pesticide inputs into the atmosphere have resulted in detectable ambient air concentrations of pesticides in Canada. As early as the late 1960s, the herbicide 2,4-D, as its *iso*-propyl, mixed butyl and *iso*-octyl esters, was detected in ambient air samples collected at several sites in Saskatchewan when concentrations as high as 23,140 ng m^{-3} were measured (Grover et al. 1976). Triallate concentrations were monitored in 1978/79 (Grover et al. 1981) and triallate and trifluralin concentrations in 1981/82 (Grover et al. 1988b). Maximum concentrations of triallate and trifluralin detected in these studies were 198 and 63 ng m^{-3}. In 1988/89, Hoff et al. (1992a, 1992b) measured concentrations of pesticides in air in southern Ontario, including trifluralin and endosulfan. The maximum ambient air concentrations observed were 3.4 and 3.7 ng m^{-3} for trifluralin and endosulfan, respectively.

More recently, Waite et al. (2002a, 2002b, 2003) and Rawn et al. (1999a) measured ambient air concentrations of several herbicides in southern Saskatchewan and in the South Tobacco Creek watershed of southern Manitoba, respectively. Results from these studies indicated that the herbicides (triallate, trifluralin, 2,4-D, MCPA, dichlorprop, dicamba, bromoxynil and diclofop) were present in the atmosphere mainly in the vapour phase with the remainder associated with atmospheric particles. Maximum ambient air concentrations (vapour plus particles) of these herbicides were detected during the period of regional spring application and varied from 0.39 to 60 ng m^{-3} (Table 5). The marked decrease in 2,4-D concentrations in the more recent studies reflects, in large measure, the deregistration of the more volatile *iso*-propyl and mixed butyl esters. Rawn and Muir (1999) also measured air concentrations of chlorpyrifos and chlorthal-dimethyl in the same southern Manitoba watershed. The maximum concentration of chlorpyrifos, which was used locally, was 103 ng m^{-3}, whereas that for chlorthal-dimethyl, which was not used in the watershed nor in the surrounding region but was present due to long-range transport, was only 0.08 ng m^{-3}. Pentachlorophenol

(Cessna et al. 1997; Waite et al. 1998) and pentachloronitrobenzene (Thompson et al. 1997) concentrations have been measured in ambient air in Saskatchewan and the Northwest Territories.

Table 5. Ambient air concentrations of herbicides detected in southern Saskatchewan and in the South Tobacco Creek watershed in southern Manitoba.

Herbicide	Concentration range	
	Saskatchewan	Manitoba
	ng m^{-3}	
Triallate	< 0.04 to 60[a]	-[b]
2,4-D	< 0.04 to 3.9[a]	< 0.003 to 3.5[c]
Bromoxynil	< 0.04 to 3.8[d]	< 0.003 to 2.0[c]
Trifluralin	< 0.04 to 3.1[d]	-
Dicamba	< 0.04 to 3.1[d]	-
Diclofop	< 0.04 to 2.0[d]	-
MCPA	< 0.04 to 0.39[d]	< 0.002 to 13[c]
Dichlorprop	-	< 0.002 to 1.0[c]

[a] Data from Waite et al. 2002a; [b] Not monitored; [c] Data from Rawn et al. 1999a; [d] Data from Waite et al. 2003.

Concentrations in rainfall. Once pesticides enter the atmosphere, they are subject to the removal processes of wet (precipitation) deposition. In wet deposition, pesticides may be trapped in snow and hail or dissolved in rain. As evident from the study of Rawn and Muir (1999), pesticide deposits may have originated from the region of application or they may have been transported long distances prior to their removal.

The atmospheric transport of anthropogenic organic chemicals and their removal from the atmosphere by deposition processes have been widely reported in the literature. In the prairie region of Canada, bulk (dry plus wet) atmospheric deposition of pesticides has been measured in Alberta (Hill et al. 2001a, 2001b, 2002a), Saskatchewan (Waite et al. 1995, 2002a, 2003) and Manitoba (Rawn et al. 1999a; Rawn and Muir 1999). In each province, herbicides detected in bulk deposition samples reflected regional use patterns and highest deposition rates were measured during the regional spraying period. In the Alberta study (Hill et al. 2001a, 2001b), samples were collected at 18 sites in southern Alberta. Of the 16 pesticides detected, the most frequently detected in both years (1999 and 2000) of the study were the herbicides 2,4-D, dicamba and bromoxynil (Table 6). Herbicide concentrations were highest in samples which included rainfalls of 0.1 to 0.2 mm, indicating that washout of ambient air concentrations occurred early in rainfall events. In terms of spatial distribution, concentrations were lowest in samples from remote areas, intermediate in urban centres, and highest in rural farm areas. Generally, more than one pesticide was detected in the bulk samples.

Table 6. Concentration ranges of the five herbicides detected in greatest amounts in bulk atmospheric deposition samples collected in Alberta (1999 - 2000).

Herbicide	Concentration Range
	-------- µg L^{-1} --------
2,4-D	< 0.025 to 53
MCPA	< 0.025 to 26
Bromoxynil	< 0.025 to 26
Dicamba	< 0.025 to 9.1
Mecoprop	< 0.025 to 2.5

Strachan and Huneault (1979) measured pesticide concentrations in rain samples collected from seven sites in the Great Lakes region of southern Ontario in 1975/76. Several pesticides were detected in the rain samples including α–and β-endosulfan with maximum concentrations being 15 and 45 ng L^{-1}, respectively. Maximum concentrations were detected in the July/August period. These pesticides were also detected in rain from sites in Prince Edward Island and Nova Scotia during the period 1980 to 1989 (Brun et al. 1991).

Concentrations in snow. Unlike rainfall samples, which are collected while the rain is falling, snow samples are usually collected by sampling the snowpack, rather than sampling the falling snow. Few currently used pesticides have been monitored in snow.

In studies carried out in the Canadian Arctic, trifluralin and endosulfan have been detected in snow (Geger and Gummer 1989; Welch et al. 1991). Maximum endosulfan concentrations ranged from 1.3 to 22 ng L^{-1} whereas the maximum concentration of trifluralin was 660 ng L^{-1}. Endosulfan has also been detected in snow collected in the Rocky Mountains of British Columbia and Alberta in which maximum concentrations ranged from 41 to 49 ng L^{-1} (Blais et al. 1998; Donald et al. 1999b). Blais et al. (1998) reported that endosulfan concentrations in snow increased with altitude indicating that volatilization from the snowpack may be lower at higher elevation. Brun et al. (1991), in their Atlantic Canada study, reported that concentrations of endosulfan were greatly reduced in the snow samples compared to rain samples.

Concentrations associated with particles. Pesticides in the atmosphere are also subject to the removal process of dry (particulate) deposition. In dry deposition, pesticides, sorbed to particles of wind-eroded soil or consisting of desiccated application drift droplets or present in aerosols, settle to the earth's surface by gravitational influence. Dry deposition also includes the sorption of pesticides present as vapours in the atmosphere onto surfaces near the earth's surface. As with wet deposition, the pesticides deposited may have originated from the region of application or they may have been transported long distances prior to their removal.

Using a new sampler which permits separate collection of wet and dry atmospheric deposition (Waite et al. 1999), Waite et al. (2002b) reported the dry deposition of 2,4-D and dicamba at two sites in Saskatchewan. During the May/August period, average dry deposition rates for 2,4-D ranged from 42 to 262 ng m^{-2} d^{-1}, whereas those for dicamba ranged from deposition of trace amounts to 67 ng m^{-2} d^{-1}.

Impacts on Surface Water Quality

Surface waters receive inputs of pesticides through the atmospheric processes of wet and dry deposition and downwind deposition of application drift, and through surface runoff. As a consequence of these inputs, detectable concentrations of pesticides have been reported in a variety of surface waters across Canada.

Wetlands. In a recent study in Saskatchewan, in which wetlands situated in wildlife habitat and on farms of high (zero tillage), moderate (conventional tillage) and no (organic farming) pesticide inputs were monitored for herbicide content, Donald et al. (2001) found that frequency of detection and concentrations of individual herbicides were similar regardless of land-use type. The authors suggested that atmospheric processes could account for both the concentrations and relatively uniform distribution of herbicides in the wetlands on all landscape types even though the intensity of pesticide use varied within their immediate vicinities. Herbicide concentrations in the wetlands were generally less than 1 μg L^{-1}.

In another study, Donald et al. (1999a) monitored ten herbicides (2,4-D, MCPA, bromoxynil, triallate, dicamba, dichlorprop, trifluralin, MCPB, diclofop and 2,4-DB) in southern Saskatchewan wetlands to investigate the relationship between pesticide occurrence in wetlands and extent of precipitation. Only 2,4-D, MCPA and triallate were detected frequently and detection frequency reflected their relative use in Saskatchewan. The mean number of herbicide detections in wetlands increased with precipitation, with the maximum number detected in any wetland being six. The number of wetlands with herbicide concentrations exceeding water quality guidelines for aquatic life also increased with increasing rainfall, with triallate exceeding the guideline most frequently. The authors estimated that, of the approximately 1.8 million wetlands in southern Saskatchewan, 9 to 24% would have pesticide concentrations exceeding the aquatic life guideline.

Farm Dugouts and Ponds. Since surface runoff is the principal source of water for the majority of farm dugouts or ponds, the presence of pesticides in their waters would not be unexpected. However, in spite of their frequency of occurrence across the Canadian agricultural landscape and the multifunctional purpose for which these water bodies are used, few studies have reported on pesticide content in these water bodies.

In Ontario, 212 farm ponds were monitored for pesticide content in 1986 and 1989 (Frank et al. 1990). Pesticides were detected in 63% of the ponds and, of the 29 (22 herbicides, 6 insecticides and 1 fungicide) pesticides detected in the water samples, the most frequently detected was atrazine followed by 2,4-D, simazine, PCP, dichlorprop and endosulfan. Highest concentrations were associated with accidental spills. Mean concentrations attributed to application drift and surface runoff were lowest and were generally less than 10 μg L^{-1}. In a 3-year study, Waite et al. (1992) detected 2,4-D, dicamba, triallate and diclofop in two farm ponds in southern Saskatchewan. Herbicide concentrations in the Saskatchewan ponds did not exceed 1 μg L^{-1}. In a later study involving two farm dugouts (Waite et al. 2000), the same four herbicides along with MCPA were detected.

In Alberta in 1994, 112 farm dugouts were monitored for herbicide content as part of the Farmstead Water Quality Survey (Canada-Alberta Environmentally Sustainable Agriculture 1998). Based on a single water sampling during August, herbicide residues were detected in 47% of on-farm surface (dugouts and other sources) water supplies. Herbicides most commonly detected included 2,4-D, MCPA, bromoxynil and dicamba.

In a 2-year (1987/88) study in Saskatchewan, Grover et al. (1997a) monitored 21 farm dugouts by collecting water samples three times during the growing season. The dugouts, situated within four major soil zones, were sampled following snow melt, after spring herbicide application, and in the fall prior to freeze up. Herbicides were detected in all dugouts with frequent detections of more than one herbicide in a dugout. Maximum concentrations tended to be seasonal and, in general, tended to be less than 5 μg L^{-1}. The decreasing frequency of detection in these dugouts was 2,4-D > diclofop > bromoxynil > MCPA > triallate > dicamba > trifluralin. Thompson and Treble (1996) reported the detection of chlorpyrifos in a farm dugout at concentrations exceeding 20 μg L^{-1} following aerial application of the insecticide in the vicinity of the dugout.

The pesticides detected in the prairie dugouts and the Ontario farm ponds generally reflected both use patterns within the vicinities of the water bodies and the environmental stability (field half-lives) of the pesticides. Entry of these pesticides into the dugouts and ponds in the abovementioned studies may have been on-going for several decades via surface runoff and/or atmospheric deposition because of long-term use. For example, of the herbicides detected in the Saskatchewan dugouts by Grover et al. (1997a), 2,4-D and MCPA have been in use in the prairie region for more than 50 years, dicamba, mecoprop, triallate and trifluralin for about 40 years, bromoxynil for approximately 30 years, diclofop for 20 years (Tomlin 1997), and clopyralid and ethalfluralin for about 10 years. Such long-term use may, in part, account for the presence of pesticides in these water bodies. If, due to long-term use, pesticides are present in the bottom sediments of these water bodies, then under appropriate environmental conditions, the sediments may act as a source of the pesticides to the water column. Thus, as suggested by Grover et al. (1997a), the median concentrations of pesticides detected in these water bodies may be an indicator of the general level of contamination of farm dugouts and ponds due to agricultural use within their vicinities.

Lakes. Only three studies have investigated pesticide concentrations in Canadian lakes. In 1989, Donald and Syrgiannis (1995) monitored herbicide (2,4-D, MCPA, atrazine, dicamba, trifluralin, triallate and picloram) concentrations in 10 permanent and 9 semi-permanent lakes in southern Saskatchewan. Herbicides detected in lake water included 2,4-D, MCPA, atrazine, and dicamba, whereas triallate, atrazine, bromoxynil, MCPA and 2,4-D were detected in the sediments. Detection frequencies tended to decrease as the lakes became more saline. In 1995/1996, 25 Alberta lakes were monitored for 13 pesticides (Canada-Alberta Environmentally Sustainable Agriculture 1998). Pesticide detections in the lake waters reflected agricultural pesticide use. 2,4-D and MCPA were most frequently detected followed by imazamethabenz, triallate and dicamba. Those least frequently detected included bromoxynil, trifluralin, picloram and diclofop. Five of the pesticides were also detected in lake sediments.

Rivers and streams. As early as the mid-1970s, rivers in Ontario and Québec were contaminated with agricultural pesticides. Muir et al. (1978) monitored five rivers in the Yamaska river basin of Québec in 1974/1975 and detected atrazine and its metabolite desethylatrazine in all five rivers. Concentrations ranged from 0.01 to 26.9 µg L^{-1} and < 0.01 to 1.34 µg L^{-1} for the herbicide and its metabolite, respectively. The highest levels of atrazine coincided with the regional spraying period and losses of atrazine to the rivers ranged from 0.1 to 2.9% of amounts estimated to have been applied in each watershed. In 1986/1987, atrazine, in concentrations similar to those reported by Muir et al. (1978), and metolachlor were most frequently detected in the Yamaska River (Maguire and Tkacz 1993). Several other pesticides, including chlorpyrifos, cyanazine, diazinon, dichlorvos, naled, prometryn, propazine and simazine, were also detected.

Between May 1975 and April 1977, Frank et al. (1982) monitored streams draining 11 agricultural watersheds in southern Ontario. Eighteen pesticides and three metabolites were detected in the streams. These included 11 herbicides and seven insecticides with atrazine, endosulfan and simazine being detected throughout each year. Pesticide detections in the streams generally coincided with the regional spraying season and reflected pesticides used within the watersheds. In a later 5-year study, Frank and Logan (1988) monitored the Grand, Saugeen and Thames rivers in Ontario in 1981 to 1985 for 48 pesticides. The order of loading in the rivers by pesticide class was triazine herbicides > chloroacetanilide herbicides > chlorophenoxy plus chlorobenzoic acid herbicides > organochlorine insecticides. Of the 13 herbicides detected, atrazine was the most frequently detected, followed by 2,4-D. No fungicides were detected in the rivers and pesticide concentrations were generally less than 1 µg L^{-1}. Bishop et al. (1999) monitored pesticide content in the Holland River in southern Ontario from 1990 to 1992. In addition to atrazine and metolachlor, several organophosphorus pesticides (terbufos, malathion, guthion, chlorpyrifos, ethion, dimethoate, phorate and disulfoton in concentrations < 2.2 µg L^{-1}) were detected in the river water. Chlorpyrifos, ethion and fonofos were also detected in the sediments. In 1991 and 1992, Fischer et al. (1995) determined loadings of atrazine, along with its metabolite desethylatrazine, and metolachlor in the Payne river. In 1990 and 1991, Ng and Clegg (1997) monitored atrazine and metolachlor concentrations in the Nissouri Creek agricultural watershed in southern Ontario and reported that they represented 0.015 and 0.01%, respectively, of amounts applied in the watershed.

The presence of 2,4-D in the Red River in southern Manitoba from 1972 to 1977 was reported by Chacko and Gummer (1980) who also showed that maximum concentrations in the river water occurred during the period of spring (May/June) application. Gummer (1979) reported on pesticide concentrations in several prairie rivers (South Saskatchewan River, Red Deer River, North Saskatchewan River, Missouri River, Qu'Appelle River, Wascana Creek, Souris River, Red River and Assiniboine River) in which 2,4-D, 2,4,5-T and dichlorprop were the most frequently detected. Other pesticides detected included endosulfan, propoxur and carbofuran. Tornes and Brigham (1994) summarized pesticides detected in the Red River basin from 1970 to 1990. Pesticides detected at two Canadian sites in southern Manitoba on the Red and Roseau Rivers included atrazine, 2,4-D, 2,4-DB, dicamba, dichlorprop, MCPA, picloram, 2,4,5-T, triallate and trifluralin. 2,4-D was most frequently detected in both rivers and concentrations of each herbicide did not exceed 1 µg L^{-1}.

In 1984, Muir and Grift (1987) monitored concentrations of triallate, trifluralin, 2,4-D, MCPA, diclofop, dicamba and bromoxynil in the Ochre and Turtle Rivers in northern Manitoba. The herbicides were detected in the river water mainly during the spring spraying period (May to mid-July) and herbicide discharges in the two rivers were less than 0.1% of amounts estimated to have been applied in the respective watersheds. Rawn et al. (1999b) monitored the Red River and seven of its tributaries in southern Manitoba for pesticides in 1993 to 1995. Sixteen pesticides were detected in the river waters. Pesticides were not found at elevated levels in the river waters during the period of spring snow melt runoff but were present at maximum concentrations during the regional spraying period. Pesticides detected most frequently in the tributaries were those used most extensively in the respective watersheds. Alachlor, which is not registered for use in Canada, was detected in the Red River, most likely reflecting usage of this herbicide in the United States. Atrazine, which was widely used in neighbouring U.S. states, was also detected in the Red River even though it was used only to a minor extent in Manitoba. In addition, urban usage of chlorpyrifos, MCPA and 2,4-D in the city of Winnipeg contributed to pesticide loadings in the Red River.

Dichlorprop, 2,4-D, MCPA and bromoxynil in 1993 to 1996 (Rawn et al. 1999c) together with chlorpyrifos and chlorthal in 1994 to 1996 (Rawn and Muir 1999) were detected in South Tobacco Creek which drains a small agricultural watershed in southern Manitoba. Highest concentrations of dichlorprop, 2,4-D, MCPA, bromoxynil and chlorpyrifos were detected in the creek water during the spring application period and coincided with elevated concentrations of these herbicides in air and precipitation suggesting that the most likely source of these pesticides was atmospheric processes. Less than 0.01% of the amounts of these herbicides applied within the watershed were discharged in the water flow of the creek. Concentrations of chlorthal, which was not applied to the watershed in any year, must have been derived from long-range atmospheric transport and deposition processes.

Under the Water Quality Study of the Canada-Alberta Environmentally Sustainable Agriculture (CAESA) agreement, 27 streams in Alberta were monitored from March 1995 to October 1996 for 13 pesticides (Canada-Alberta Environmentally Sustainable Agriculture 1998). The streams drained land that ranged from high to low intensity agriculture. Ten of the streams were intermittent and flowed mainly during spring snow melt. Nine pesticides were detected in the stream waters with 2,4-D, MCPA and triallate the most frequently detected in high intensity agriculture areas. In streams that drained land with high runoff and high erosion potential, significant differences in pesticide detection were observed between areas of high, medium and low pesticide use. Detection frequency reflected pesticide use patterns, with most detections being made in April, the time of year when most surface runoff occurs.

Impacts on Groundwater Quality

During the 1980s to the mid-1990s, it became evident that some groundwater supplies in Canada were contaminated with agricultural pesticides and that the contamination reflected regional pesticide use. In Ontario, Frank et al. (1987a) reported that 38% of 359 farm wells were contaminated with pesticides. Some of the pesticides detected, in order of decreasing frequency, included atrazine, 2,4-D, dichlorprop, simazine, alachlor, metolachlor, dicamba and mecoprop. In this and other studies (Frank et al.1987b, 1990), it was postulated that many of the incidents of well water contamination with pesticides were the result of poor pesticide handling practices in the vicinity of the wellhead (non-use of devises to prevent back-siphoning of spray solution, spills from overfilling or rinsing spray delivery systems), poor siting of wells making them susceptible to surface runoff, or poor well construction which allowed the contaminants to enter the well directly. However, in a later groundwater monitoring study (1985 to 1988) in southwestern Ontario (Lampman 1995), wells were selected to ensure that they were properly constructed and maintained, were not susceptible to surface runoff, and had no history of pesticide spills at or near the wellhead. Of the total number (315) of wells monitored during this 4-year study, 37% contained detectable concentrations of pesticides (atrazine, metolachlor, simazine, metribuzin, cyanazine, prometryn and alachlor) suggesting that much of the contamination was from non-point sources and occurred via the transport mechanism of leaching/preferential flow (Elliott et al. 2000; Hill et al. 1997) to groundwater. More recently, of more than 1200 domestic farm wells monitored in Ontario during the summer of 1992, the majority (900) of which were located in areas of intense agriculture, 12% had detectable concentrations of pesticides (atrazine, desethylatrazine, alachlor, metolachlor, metribuzin and cyanazine) with atrazine and desethylatrazine most frequently detected (Rudolph and Goss 1993).

Surveys of farm wells on Prince Edward Island in 1983/1984 indicated that the insecticide aldicarb was present in 18% of high risk wells near potato (*Solanum tuberosum* L.) fields (Matheson et al. 1987). Priddle and co-workers (Jackson et al. 1990; Priddle et al. 1987), in studies over 1985 to 1988, detected aldicarb and its sulfoxide and sulfone degradation products in a shallow sandstone aquifer more than two years after the last application of the pesticide. The pesticide has also been detected in groundwater in New Brunswick (Gillis and Walker 1986).

In British Columbia, several pesticides (dimethoate, diazinon, atrazine, simazine, carbofuran, dinoseb, endosulfan and alachlor) were detected in groundwater collected from the Abbotsford aquifer during the period 1984 to 1990 (Liebscher et al. 1992). In a more recent groundwater monitoring program (1992 to 1993) in the Fraser Valley, which involved 75 private and 192 community wells, pesticides (oxamyl, bromacil and 1,2-dichloropropane) were detected in 2% of the wells (Carmichael et al. 1995).

In Nova Scotia, 102 farm wells, also situated in an area of intensive agriculture, were monitored for pesticides (Briggins and Moerman 1995). Forty-one percent of the wells had detectable concentrations of pesticides and 19% contained more than one pesticide. The frequency of detection, in decreasing order, was atrazine, simazine, metribuzin, alachlor, metolachlor, captan, chlorothalonil, dimethoate and permethrin.

Pesticide levels in groundwater have also been monitored in the prairie region of Canada. Krawchuk and Webster (1987) detected chlorothalonil and carbofuran in groundwater in southern Manitoba in 1982 and 1983. In Saskatchewan in 1987 and 1988, 2,4-D, diclofop, dicamba, MCPA, triallate and bromoxynil were detected in shallow groundwater under irrigated fields in the Outlook Irrigation District (McNaughton and Crowe 1995). Wood and Anthony (1997) sampled several natural springs in Saskatchewan for herbicide content from 1991 to 1994. All of the springs drained shallow aquifers and no wells were present in the aquifers. Herbicides, at concentrations $< 1\ \mu g\ L^{-1}$, were detected in 23% of the samples with atrazine, picloram and 2,4-D most frequently detected. Other herbicides included triallate, simazine, metolachlor, dichlorprop, MCPB, 2,4-DB and bromoxynil. In 1996, 184 farm wells, situated into unconfined shallow aquifers that were highly vulnerable to contamination from surface sources, were analysed for pesticide content (Saskatchewan Environment and Resource Management 1997). All wells had depths of 15 m or less. One or more pesticides was detected in 26% (48) of the wells with the following frequency of detection: 2,4-D > MCPA > bromoxynil > dicamba > triallate > pentachlorophenol > picloram > atrazine > diclofop). In 1995 and 1996, 824 Alberta farm wells, of which 84% (692) were used for drinking purposes and 54% (445) were considered to be deep wells (>30 m in depth), were monitored for herbicide content (Canada-Alberta Environmentally

Sustainable Agriculture 1998). Herbicides (dicamba, MCPA, bromoxynil, 2,4-D, fenoxaprop, triallate and trifluralin) were detected in only 3% (27; 9 deep and 18 shallow) of the wells. The lower frequency of herbicide detection, relative to that in Saskatchewan wells, probably reflects their much deeper depths and, consequently, decreased susceptibility to contamination.

The widespread presence of pesticides in groundwater in Canada supports the general premise that the shallower the aquifer the greater the probability of contamination with pesticides. Flora and fauna within field margins associated with shallow aquifers contaminated by pesticides could be indirectly exposed to pesticides. Springs draining contaminated aquifers (Wood and Anthony 1997) may act as watering places for animals. Aquatic plants and animals may also become exposed if water bodies within field margins derive some of their water through recharge from aquifers contaminated with pesticides.

Biological Impacts within Field Margins

The impact of pesticides on organisms in boundary habitats is subject to considerable debate. It is clear from the previous discussion that pesticides are frequently found in non-target areas. However, there is a significant lack of information on the biological consequences of their presence in these areas. Biological effects of pesticides on selected indicator non-target organisms are documented, and mitigation steps recommended, as part of risk assessments conducted during modern registration processes. Legislated mitigative measures may include limits on time, rate and frequency of application, buffer zone distances from sensitive areas, and prescribed weather and application methods. However, data from laboratory, microcosm or mesocosm studies on which mitigation steps are based may not be suitable for predicting longer-term biological impacts under field conditions. Many of these studies are more concerned with documenting a threshold acute dose of pesticide such as a No Observable Effects Concentration (NOEC) rather than focusing on low-level chronic, multi-species population, or indirect effects. Data on effects of mixtures of active ingredients or of active ingredients plus fertilizers, which may be synergistic, are also rare. As a result, emphasis must be placed on documenting long-term and interactive effects of pesticides with agronomic practices on field margins.

Plants

In a growth chamber study, Hill et al. (2002b) investigated the potential for sublethal effects on five sensitive crops by simulated rain containing a mixture of four herbicides (2,4-D, MCPA, bromoxynil, dicamba) frequently detected in Alberta rain (Hill et al. 2002a). The amount of each herbicide in the simulated rain approximated the maximum concentration detected in Alberta rain and resulted in a combined total rate of 2.25 g ha^{-1} which adversely affected dry bean (*Phaseolus vulgaris* L.) and tomato (*Lycopersicon esculentum* Mill). Only 2 to 3% of Alberta rain samples collected in agricultural areas during the main growing season contained a combined total concentration of the four herbicides which was similar in magnitude to the bioassay concentration used by Hill et al. (2002b). Simulated herbicide drift studies using sensitive crop species (Eberlein and Guttieri 1994; Fletcher et al. 1996; Wall 1996; Al-Khatib and Peterson 1999) and wetland (Boutin et al. 2000; Roshon et al. 1999) and terrestrial plants (Boutin et al. 2000) indicate that direct deposition of application drift may damage sensitive plants in field margins.

By affecting plant species composition (Boutin and Jobin 1998), decreasing plant species abundance and diversity or altering plant function, herbicides eliminate plants whose seeds are important for several bird species and they reduce or eliminate plant food sources for insects and small mammals (Freemark and Boutin 1994, 1995; McLaughlin and Mineau 1995). Many studies on off-target effects of herbicides involve crop plants, understandably because of their economic value. Fletcher et al. (1996) studied the effect of chlorsulfuron on crop species, and found the herbicide to have the most detrimental effects on canola (*Brassica napus* L.) and soybean (*Glycine max* L.), with effects on seed yield and biomass apparent at 0.004 of the recommended field rate. Wall (1994) reported injury to canola (*B. napus* L.), field pea (*Pisum sativum* L.), and lentil (*Lens culinaris* Medik.) from thifensulfuron:tribenuron (2:1) to be apparent at 0.015 of the recommended field rate. Al-Khatib and Peterson (1999) found growing season and herbicide applied (of eight tested) affected injury to soybean, with injury occurring at herbicide doses of 0.01 to 0.33 of field rate. Visible injury was a poor predictor of soybean yield, and plants usually recovered from initial injury.

Despite the information from the preceding studies, it is difficult to predict the effects of herbicide drift or herbicides in rainfall on natural plant communities in field margins because of high variability caused by diverse natural populations, herbicide selectivity, and weather conditions. Marrs et al. (1989, 1991a) used a series of bioassay experiments with native plant species to assess spray drift in relation to plant damage and yield. At 4 m downwind of the sprayer, all species showed significant changes in growth in response to at least one of five herbicides investigated. Effects varied from growth promotion and reduction to change in flowering performance. The authors suggested that although herbicides may not kill native plants, they can alter species balance and the aesthetic value of plant communities. Breeze et al. (1992) documented a wide range of sensitivities of 14 wild plant species, to four herbicides. They concluded that individual plant effects were minimal (<10% growth reduction) if buffer zones of 10 m were observed, except for glyphosate, where distances of up to 40 m were necessary for the most sensitive species. De Snoo and van der Poll (1999) found that herbicide drift (from a range of products used in commercial practice) did not affect boundary vegetation adjacent to sugarbeet (*Beta vulgaris* L.) and potato fields, but did reduce abundance and floristic value of plants adjacent to a winter wheat field. Perry et al. (1996) found that sublethal rates of glyphosate, as might be expected from spray drift, reduced the cover abundance of grassy species but not broadleaf species. However, Marrs et al. (1991b) found few lasting effects on five native plant species placed 4 m downwind from the application of glyphosate, mecoprop, or MCPA. Canopy structure of the surrounding vegetation influenced response, suggesting that simple drift deposit models may not adequately describe risk. Kleijn et al. (1997) found inconsistent effects of fluroxypyr application to native grasses and forbs, but documented some reduction in species richness and shifts in biomass production from forbs to grasses. Nitrogen fertilizer had a larger effect on these parameters than herbicide.

Herbicide effects are not as widely studied on aquatic plants as on terrestrial plants. Davies et al. (2003) studied exposure of *Glyceria maxima*, *Lagarosiphon major*, *Myriophyllum spicatum*, and *Lemna* sp. to sulfosulfuron. No effects were noted on plants exposed to 3.33 µg L^{-1} for 21 days, but some effects occurred at 3.33 and 10 µg L^{-1} after 70 days. The study concluded that such high concentrations are unlikely to persist for a long time, therefore aquatic plant effects were improbable. Conversely, Nystrom et al. (1999) found a wide range of sensitivities of 40 species of micro-algae to the sulfonylurea herbicides metsulfuron-methyl, chlorsulfuron, and tribenuron-methyl, with sensitivities ranging from the nM to µM range. Faber et al. (1998) documented severe negative effects of glufosinate-ammonium and bialaphos on zooplankton at concentrations simulating spray drift (250 µg L^{-1}). Effects included reductions in taxa abundance and total zooplankton numbers, and effects persisted for several months to a year following exposure.

Amphibians

The decline of amphibians has been of concern in recent years, and probable causes are being investigated. The causes of amphibian decline appear to be complex, and so far, few studies have directly linked pesticides. Fort et al. (1999) evaluated the effect of Minnesota pond water fractions on South African clawed frog (*Xenopus laevis*) development. They found that a complex mixture of both naturally occurring and synthetic compounds were primarily responsible for the observed deformities. The potency of several compounds was also enhanced by the pond water. Direct effects of chlorpyrifos on *X. laevis* development were found by Richards and Kendall (2003). Body length and mass were significantly lower after a 96-h exposure of embryos at concentrations of 1 and 100 µg L^{-1}, respectively. Based on actual concentrations of chlorpyrifos in U.S. waters, the authors ranked the probability of effects due to the insecticide to be moderate to low. Kiesecker (2002) suggested that while theories on amphibian decline fall into two broad categories (trematode infection or chemical contamination), these two may in fact be synergistically related. The study showed that although trematode infection was necessary for deformation, infection occurred more frequently in agricultural sites. In a study of anuran development in relation to agricultural activity, Bishop et al. (1999) reported higher abnormality rates in green frogs (*Rana clamitans melanota*), northern leopard frogs (*R. pipiens*), and American toads (*Bufo americanus americanus*) exposed to water within an agricultural watershed compared to adjacent protected wetland areas. Anuran density and species diversity were also lowest in the agricultural area. The authors could not identify a single cause for these effects, but pointed to evidence of wetlands drainage, channelization of rivers, roadway construction and nutrient and particulate loading in addition to pesticide inputs within the agricultural area. There were, at the time of publication, no reports in the literature showing lethal or sublethal effects of organophosphate insecticides on amphibians at the levels detected in this study. Therefore, the factors governing amphibian welfare in field margins are likely more complicated than simple exposure to specific agricultural chemicals.

Aquatic Invertebrates

Aquatic invertebrates are commonly studied as indicator species for pesticide effects on the food chain and overall ecosystem health. Acute toxic effects are frequently documented in laboratory, microcosm, and field studies (Douglas et al. 1993; Gälli et al. 1994; Schulz et al. 2002). On a field scale, effects can be pronounced. For example, Liess and Schulz (1999) reported that rainfall-induced runoff of insecticides from arable land to a stream resulted in the disappearance of eight of the eleven abundant macroinvertebrates, and reductions in abundance of the remaining three. However, nine species recovered within 11 months, some earlier. Similar results were found by Fairchild and Eidt (1993). In their study, fenitrothion applied by air resulted in a sharp (70 to 90%) decrease in insect emergence from ponds, with recovery between 6 and 12 weeks after spraying. Arthropods were more affected than annelids or nematodes, resulting in a shift in biotic assemblage that appeared characteristic of pesticide or nutrient influx into an aquatic environment as judged by other published studies. The authors suggested that these results may affect food supply for brooding ducks and ducklings in the area as well as nutrient accumulation in the ponds. Matthiessen et al. (1995) also documented severe acute effects of carbofuran runoff to a stream from an oilseed rape field treated with 3 kg ha^{-1}. Caged *Gammarus pulex*, an amphipod crustacean, were killed when about 0.5% of the applied amount mobilized after a 72 mm-rainfall. One way to decrease water-mediated pesticide movement is to use products that are less water soluble and more soil-bound, such as pyrethroids. However, particle-associated residues of the synthetic pyrethroid fenvalerate were also shown to have highly toxic affects on eight aquatic macroinvertebrates (Schulz and Liess 2001). These authors suggested that this type of movement can result in a longer duration of exposure and requires more attention in the regulatory process. Farmer et al. (1995) also reported high macroinvertebrate toxicity of pyrethroids, resulting in an increase in algal growth due to reduced feeding. Toxic effects of chlorpyrifos to aquatic invertebrates in microcosms occurred at 1 μg L^{-1}, but delivery of that dose from spray drift deposition depended on water-body size and drift potential of the application (Biever et al. 1994).

Terrestrial Invertebrates

Of the terrestrial arthropods, butterflies and honeybees have received the greatest attention because these species are generally attracted to field margins but have also suffered serious declines. In a recent review, Longley and Sotherton (1997a) identified a variety of factors that contribute to butterfly population size. These included inherent susceptibility to insecticides, removal of nectar sources and larval host plants, and species-dependent ecological factors determining their within-boundary behaviour and dispersal. De Snoo et al. (1998) documented a 2- to 3-fold decrease in the number of butterfly species in commercially sprayed versus unsprayed edges and ditch banks of winter wheat and potato fields. Differences in species diversity and abundance were also a factor of crop type and adjacent habitat – significantly fewer butterflies were found in the potato field margin compared to the winter wheat, and ditch banks were also favoured habitat compared to seed grass. Similar effects of crop type, pesticide, and adjacent habitat type were reported by Redderson (1994) for lauxaniid flies in field margins. Feber et al. (1996) showed that butterflies were most closely associated with the abundance of flowers of key nectar source species. Herbicides which affected flower abundance therefore reduced butterfly populations. Dover et al. (1990) showed that fields sprayed under a "Conservation Headlands" regime had higher butterfly abundance. Direct butterfly mortality due to the application of insecticides near field margins has been documented. Davis et al. (1991) found that *Pieris* spp. mortality (24 - 73%) occurred due to direct exposure to diflubenzuron drift as well as contact with *Alliaria petiolata* plants (10 - 90%) exposed to drift. Deltamethrin posed high levels of short term risk to *Pieris* spp. larvae exposed to spray drift into hedges at field margins (Cilgi and Jepson 1995). Davis and Williams (1990) suggested a buffer zone of up to 5 m for ground sprayers, and 40 m for aerial sprayers, for protection of non-target insects from selected insecticides.

Vertebrates

In an Ontario study involving 25 species of birds within an agricultural landscape, Boutin et al. (1999) reported that species generally were more significantly associated with field margins than with field interiors. It is therefore of concern that field margins may be contaminated with pesticides that originate from spray drift, runoff, leaching, or eroded soil. With the exception of the exposure of birds to granular formulations of insecticides (McLaughlin and Mineau 1995), such exposure seldom results in acute toxicity to birds and mammals. There may be sublethal effects from spray drift, as birds have low levels of esterases that hydrolyze carbamate and organochlorine insecticides. Therefore, effects of spray drift of such products on birds nesting in field margins should be documented. For example, Cordi et al. (1997) showed that primicarb and dimethoate spray drift reduced overall growth rate of nestling passerine birds in field margin hedges.

Studies on fish focus on larger bodies of water that may not necessarily comprise field margins. Nonetheless, important effects can be expected from the toxicological data. Many studies document reductions in cholinesterase activity in fish such as common carp (*Cyprinus carpio*) (Gruber and Munn 1998), and largemouth bass (*Micropterus salmoides*), bluegill sunfish (*Lepomis macrochirus*) and mosquitofish (*Gambusia affinis*) (Carr et al. 1997) in response to carbamate and organophosphate contaminated runoff from treated sites. However, chlorpyrifos has also been documented to disappear rapidly from aquatic systems, with an initial half-life of 1 to 6 days (Giddings et al. 1997). Toxicological effects of these products in flowing streams are poorly documented.

In summary, it is clear that pesticides can affect organisms that live in or near field margins, in some cases dramatically. Future challenges for research are to quantify longer-term effects such as species shifts and ecosystem stability, and develop a better understanding of pesticide breakdown and cycling within the ecosystem. Further, studies must be designed to better separate pesticide impacts from those related to agricultural practice as a whole. There are currently insufficient data to assess long- or short term ecological impacts for the Canadian situation.

Mitigation Strategies

Atmospheric Transport

Reduction of particle spray drift has been the subject of much study. In summary, drift can be reduced by managing droplet size spectra of nozzles with spray pressure (Nordby and Skuterud 1975), low-drift nozzles (Grover et al. 1997b; Wolf and Caldwell 2001), and adjuvants (Downer et al. 1995) as well as protecting spray from wind with lower boom heights (Nordby and Skuterud 1975), shrouds (Wolf et al. 1993) and air assistance (Cooke et al. 1990). Individually, these measures have been documented to reduce drift by 50 to 75%; therefore, a comprehensive approach can have significant effect on the magnitude of droplet transport. Drift can also be reduced by spraying under appropriate environmental (e.g., wind speed) conditions.

Wind erosion of soil contaminated with pesticides can be minimized by the use of conservation tillage, maintaining adequate trash cover on the soil surface and the use of cover crops. Post-application vapour losses can be mitigated by selecting pesticides with low vapour pressures; however, a pesticide vapour pressure index for pesticides is currently not available to farmers and commercial applicators in Canada.

Transport in Water

Transport in surface runoff can be minimized by use of pesticides with low water solubility; however, a water solubility index is also not readily available to farmers and commercial applicators. It can also be mitigated by appropriate tillage practices; for example, tillage can be used to minimize down slope movement of surface runoff. Use of zero tillage reduces surface runoff through increased water infiltration into soil, but may simultaneously increase the risk of pesticide contamination of groundwaters and decrease water volumes in surface waters such as wetlands.

Leaching of pesticides to groundwater can be decreased by use of pesticides that are less mobile in soil. Various indices of the relative leaching potential of pesticides have been developed (Cohen et al. 1984; Gustafson 1989; Hill et al. 2000; Laskowski et al. 1982; Wilkerson and Kim 1986), with some (Hornsby et al. 1993) being made available to pesticide users to assist them to select pesticides on the basis of water quality impact. Such indices have not yet been made available to farmers and commercial applicators in Canada. Improvements in pesticide leaching and runoff may also be achievable with formulation approaches (Evans et al. 1998; Narayanan et al. 1995).

Buffer Zones

Buffer zones are generally employed to mitigate impacts of pesticides on sensitive ecosystems as a consequence of application drift. Within this context, buffer zones are no-spray areas defined by the distance between the downwind point of direct pesticide application and the nearest boundary of a sensitive habitat. Factors governing the depth of the buffer zone are the toxicity of the pesticide (active ingredient) to non-target organisms, the characteristics of the adjacent sensitive habitat, meteorological conditions at the time of application and the type and operating conditions of the delivery system. Although these variables are complex and some are impossible to control, a large number of researchers have suggested or defined buffer zones for the protection of field margins. For example, Davis et al. (1993) suggested buffer zone distances of 12 to 24 m for the protection of *Pieris brassicae* from triazophos and cypermethrin, respectively, Marrs et al. (1993) suggested a 20-m distance for the protection of sensitive plants from glyphosate, and Marrs and Frost (1997) found 8-m setbacks to mitigate negative effects of glyphosate, mecoprop, and MCPA. De Snoo (1999) and De Snoo and De Wit (1998) interviewed farmers and found that field margins are often sprayed intensively to prevent invasion of crops by pests. Nonetheless, a 3-m setback from ditches was considered effective at mitigating 95% of the negative effects on these habitats, and a flexible approach to buffer zone distances was deemed to gain most farmer acceptance.

Vegetative Barriers

Plant barriers in the buffer zone can capture airborne spray drift, resulting in exposure to organisms within the barrier (Longley and Sotherton 1997b). However, these same barriers can also reduce drift deposits in sensitive areas by reducing effective wind velocities and capturing spray particles (Ucar and Hall 2001, Miller 1999). Wolf et al. (2005) documented 75 to 95% reductions in drift deposits up to 30 m downwind when setback distances were vegetated with grass, shrubs, or trees. Stephenson and co-workers (Brown and Stephenson 2001; Carter et al. 2000), utilizing 2.5-m high snow fencing to simulate uniform hedge structures of 50% and 25% porosities, studied the mitigation effects of buffer zones and hedgerows on spray drift deposition into simulated wetland environments (Table 7). Under moderate wind conditions (i.e., 2 to 4 m s^{-1}) for a 10-m wide buffer zone with or without artificial hedgerows, drift deposition was largely confined to the buffer zone for all trials, with trace deposits (0.01% or less) detected in the wetland area 20 to 40 m downwind of the downwind edge of the spray swath under some conditions. They concluded that a 10-m buffer zone with mixed woody vegetation would effectively protect a wetland from spray drift under wind conditions normally acceptable for spraying (i.e., less than 4 m s^{-1} or 14.4 km h^{-1}).

Table 7. Spray drift deposition in a simulated wetland as percent of within-swath deposition from a boom sprayer (boldface values are deposits within the buffer zone).

Distance from downwind edge of swath	No hedge	Sparse hedge	Dense hedge
------- m -------	------------ % of applied -------------		
1[a]	**0.71**	**0.38**	**0.2**
3	**0.15**	**0.04**	**0.03**
10	**0.03**	**0.02**	**0.01**
20	0.01	0	0
30	0	0	0
40	0	0	0
50[b]	0	0	0

[a] The 1-m sample location was on the upwind side of the hedgerow.
[b] No deposits were detected at sampling stations between 50 and 100 m.

Using the results of Roshon et al. (1999) and the data in Table 7, the level of deposition within the wetland area would correspond to a 10-fold safety factor for a sensitive water plant such as *Myriophyllum sibiricum* if 2,4-D was applied at the recommended field rate of 0.85 kg ha^{-1} to the swath. A much larger safety margin (> 10,000-fold) would result if glyphosate was applied at the recommended rate of 0.45 kg ha^{-1}. A dense hedge was a less effective barrier to drift deposition within the wetland area than a sparse hedge. Davis et al. (1994) have observed a similar situation where instead of attenuating the wind and removing airborne drift droplets, a dense hedgerow diverts the drift cloud up and over the hedge, resulting in higher deposits farther downwind. On the basis of the safety margins observed by Roshon et al. (1999), the use of vegetated buffer zones, coupled with low-drift application methods, have the potential to reduce drift deposition into sensitive habitat to non-significant levels.

Based on some of the work cited previously, buffer zones (Gilbert 2000) and "Conservation Headlands" (Sotherton 1992) have been implemented as effective mitigating tools for application drift. These practices may also mitigate other routes of pesticide transport. Vegetated buffer zones could capture wind-eroded soil resulting from surface creep, saltation and suspension and have been shown to allow infiltration of pesticide-contaminated surface runoff (Cole et al. 1997; Mersie et al. 1999; Watanabe and Grismer 2001; Webster and Shaw 1996).

Conclusions

This review has demonstrated that pesticides can move into non-target areas during and after their application to agricultural fields in measurable and biologically significant quantities. The routes of transport most likely to affect plants and animals in field margins include application drift, post-application vapour loss, wind erosion of soil and surface runoff. Because of their ability to capture spray drift and to minimize erosional and runoff processes, field margins play dual, but contrasting, roles in overall ecosystem health. The retention of pesticides by field margins helps to reduce the overall effect of pesticides in the larger environment but, at the same time, can also affect, either directly or indirectly, plants or animals within them. Both of these roles deserve consideration in understanding the long-term consequences of the agricultural use of pesticides.

Use of buffer zones has received much attention as a key strategy to lessen the effects on field margins by all four routes of pesticide transport. However, although a buffer zone may reduce pesticide inputs into field margins and other environmentally sensitive areas, it does not reduce the overall amount of pesticide lost from the agricultural site. Thus, use of buffer zones must be complemented by agricultural management practices that reduce initial inputs into the environment, especially to the atmosphere. From the spray drift, post-application vapour loss, and soil erosion perspectives, this would mean use of low-drift delivery technology, low vapour pressure pesticides and agronomic practices to minimize soil erosion, respectively. In the case of surface runoff, this would similarly include proper product selection combined with agronomic practices that minimize runoff and leaching. It is use of such management practices, either alone or in combination with buffer zones, that will help to ensure long-term ecosystem health with respect to agricultural pesticide use.

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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 2005). 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 2005; 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. 2005; Wolf et al. 2005). 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 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), 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 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).

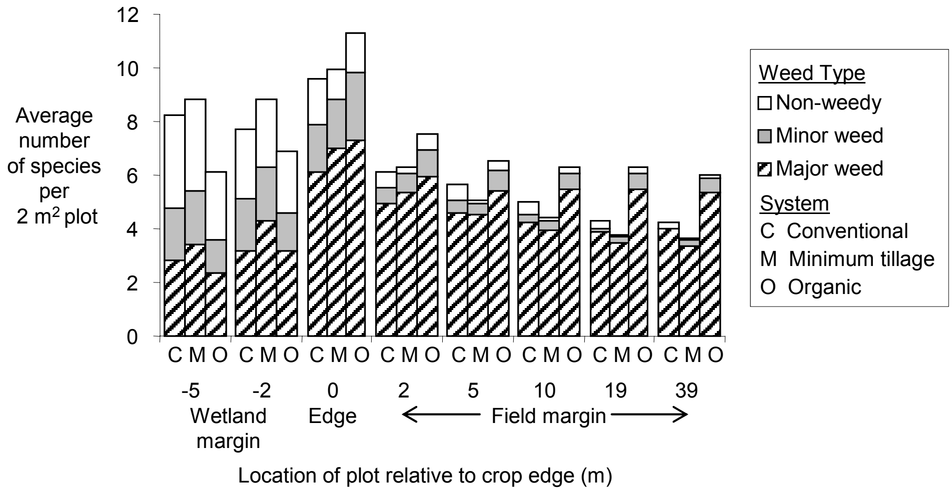

Figure 1. Average number of plant species per plot placed along four transects extending into the crop from each wetland. The edge plot was placed to include 0.5 m either side of the crop edge. Weed types are defined based on abundance in 1995 Saskatchewan provincial weed survey of cereal, oilseed and 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. 2005; 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 was 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. 2005). This difference could be attributed to the disturbance of wetland margins by tillage. With the exception of a few invasive

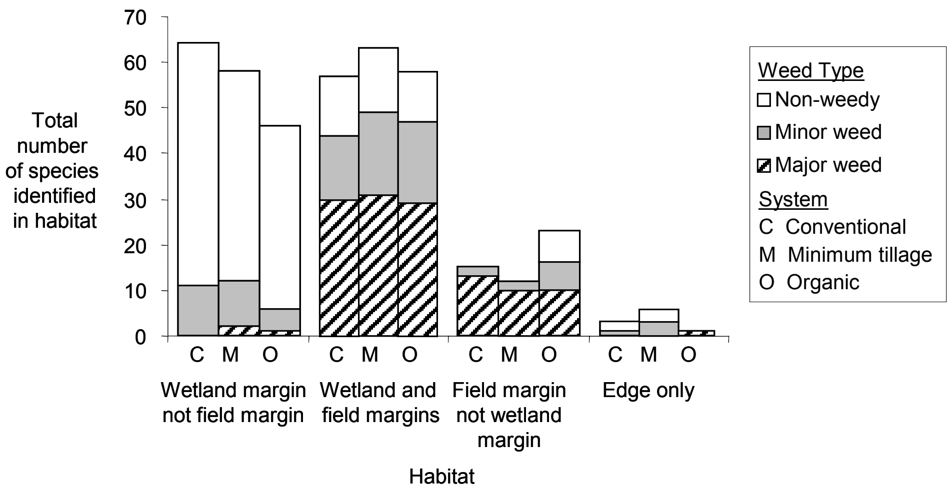

Figure 2. Total number of plant species identified in each habitat in each system. Data were collected on 72 transects in conventional and organic systems and 80 transects in minimum tillage systems. Weed types were based on abundance in 1995 Saskatchewan provincial weed survey of cereal, oilseed and 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. Arthropod 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 natural 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 natural 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 and Ontario, agriculture is mostly concentrated in the southern part along the St. Lawrence valley and the Great Lakes. It is dominated by intensive agriculture and dairy farming. 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.

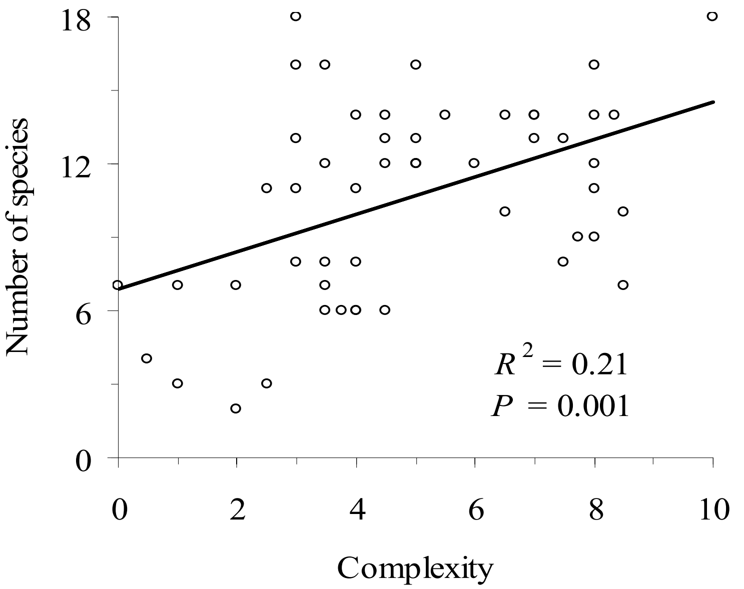

Figure 3. Relationship (r = +0.46, n = 48 wetlands) between number of terrestrial bird species detected in wetland boundary habitats and wetland complexity index on 36 farm sites and 12 natural wildlife habitat areas located in south-central Saskatchewan, Canada, 1996 and 1997. [Wetland complexity ranged 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 in Saint-Hyacinthe hedgerows, 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 (side), 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.

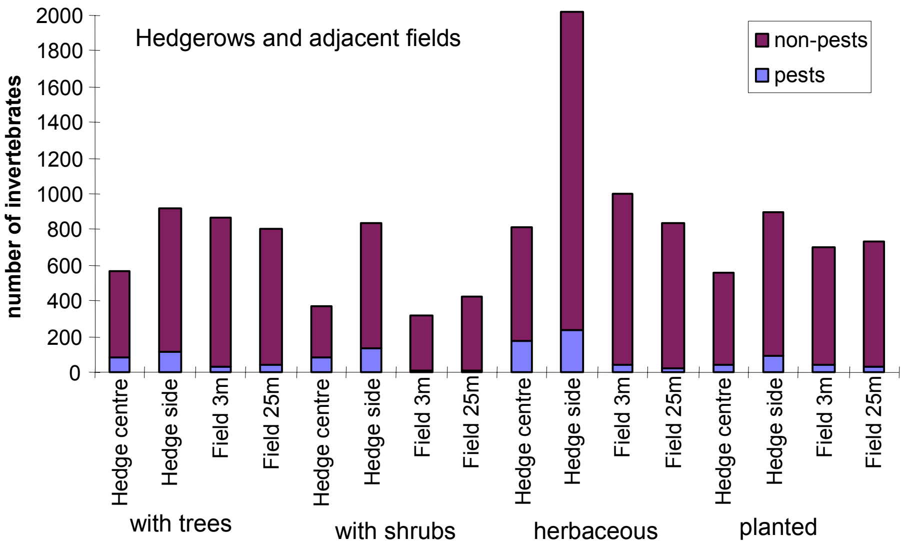

Figure 4. Total number of invertebrates found in hedgerows (centre and sides) and at 3 m and 25 m into adjacent fields in the different types of hedgerows studied near Saint-Hyacinthe, Québec, June 1996: natural with trees, with shrubs, herbaceous and planted with trees. Invertebrates considered pests 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 1988, 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 potential impacts on habitat quality and wildlife in relation to timing, frequency and severity of these practices must be considered.

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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Insect pests and arthropod diversity in field margins of western Canada

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The prairie ecosystem of the northern Great Plains is a major contributor to world food production. This has not come without ecological costs. Arable land of the prairie ecosystem is one of the most altered landscapes on this continent. Only small remnants of native short-grass prairie remain and field boundary habitats at best provide only narrow corridors between these remnant natural areas. The ecological role of field boundary habitats within the scope of extensive prairie agriculture has not been fully quantified. Sustainable management strategies, crop loss prevention and maintenance of soil health are central to our capacity to maintain the biological productivity of agricultural systems. Field boundary areas harbour many arthropods, including insects, spiders, mites, and other invertebrates, which are integral to crop loss and to soil health because they include both beneficial and pest species. These habitats represent an interface between farm practices and the ecosystem and contribute to an environment where farm inputs are able to enhance rather than replace natural processes. The implementation of buffer zones where pesticides are not permitted within cultivated habitats bordering potential wildlife refuges such as field margins, water bodies and shelterbelts will challenge IPM practitioners and researchers to search for more ecological and environmentally friendly strategies to manage potential pest insects. Several pest insects have aggregated spatial distribution patterns along field edges and chemical sprays are concentrated along such areas. Currently, the only control strategy available to growers to reduce insect pest populations along field perimeters is chemical control. However, some research progress has been made with the incorporation of trap crops for pest species such as grasshoppers (Orthoptera: Acrididae) and cabbage seedpod weevil (Coleoptera: Curculionidae). The advent of federal legislation in Canada to require buffer zones when pest control actions are employed will require the development of alternative non-chemical management strategies to manage the pest species within these areas.

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Introduction

The prairie ecozone (Figure 1) of the northern Great Plains is a major contributor to world food production. This has not come without ecological costs. Arable land of the prairie ecosystem is one of the most altered landscapes on this continent. Only small remnants of native short-grass prairie remain and field boundary habitats at best provide only narrow corridors between these remnant natural areas. Profitability, diminishing land resources and land degradation are major issues facing farmers in the grassland ecozone of the northern Great Plains. Crop diversification, reduced fallow and reduced inputs are being promoted in an effort to address these issues. Producers are encouraged to diversify away from monocultures, primarily cereals, to reduce the extent of land left in fallow and to reduce inputs, especially those with the greatest negative environmental impact. The fragmentation of the agroecosystem and habitat destruction associated with the clearing and cultivation of land for monoculture production have contributed to a loss of diversity. The role of field boundary habitats within the scope of extensive prairie agriculture has not been fully quantified. In general, there are a greater number of arthropod species inhabiting field margins as compared to the cultivated fields (Lewis 1969; Doane 1981). This difference has been attributed to a greater availability of microhabitats in the field margin, making them important in the source-sink dynamics of arthropod populations inhabiting the agroecosystem (Fry 1994). Since field boundary habitats represent an interface between farm practices and the ecosystem, it is desirable that the agriculture industry develop practices that enhance, rather than replace, these natural processes (Leaver 1994).

Much of the knowledge required to fully understand the complexities of relationships between insect pest populations, beneficial arthropods, and their habitat is still being developed for the northern Great Plains. Weed management practices have a direct effect on the natural enemy complex (Norris and Kogan 2000). Studies have demonstrated that fields with a high diversity of weeds tend also to have a higher diversity of parasitoids and predators because (1) pollen and nectar from weeds serve as supplementary food sources and (2) weeds are often hosts for alternative prey (Altieri 1994). So it is understood that conservation of biodiversity (i.e. natural enemies) through habitat management, plant structure, and diversity can positively impact on our ability to manage the pest species. Management strategies for control of insect pests have broadened into the concept of ecological pest management and are no longer focussed only on the pest species complex (Pimentel et al. 1992). Field boundary areas harbour many arthropods, including insects, spiders and mites, which are integral to crop loss and to soil health because they include both beneficial and pest species (Powell 1986). Sustainable management strategies, crop loss prevention and maintenance of soil health are central to our capacity to maintain the biological productivity of agricultural systems.

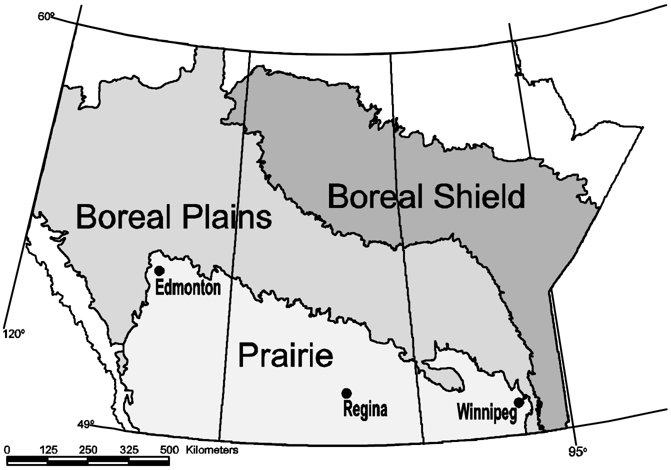

Figure 1. Ecozones of western Canada adapted from data in A national ecological framework for Canada: GIS data (Schut, P. 2003).

The requirement for buffer zones where pesticides are not permitted within cultivated habitats bordering potential wildlife refuges such as field margins, water bodies and shelterbelts will challenge pest management practitioners and researchers to search for more ecological and environmentally friendly strategies to manage potential pest insects. The advent of federal government legislation to require buffer zones when pest control practices are employed will necessitate that alternative non-chemical management strategies are developed if such areas are to remain pesticide free in order to protect beneficial arthropods or endangered species.

This paper will assess the current status of knowledge related to pest management and beneficial arthropods in the context of field boundary habitats and highlight research activities in western Canada that address the issues related to buffer zones.

Current Knowledge

The role of field boundary habitats (grass areas; remnant native prairie; windbreaks) in biodiversity and integrated pest management has received considerable attention in Europe (Lewis 1969; Stechman and Zwölfer 1988). Field margins, where cropping systems and non-crop habitat overlap is often critical to the conservation of beneficial arthropod diversity (van Emden 1965; Altieri et al.

1993). Non-crop habitats and field margins that remain pesticide free are an important component of sustainable cropping systems (Knauer 1988) and are commonly recommended in countries like Germany (Basedow 1988).

Within the vast array of arthropods which inhabit the Great Plains of North America, there are several economically-important pest insects, as well as an important complex of beneficial arthropods that populate field boundary habitats (Piper 1998). The diversity of plant species found in field boundary habitats is quite variable in the prairie ecozone of western Canada (Looman and Best 1979). As a result their significance as reservoirs of pest species and beneficial insects is also variable (Solomon 1981). Within the vast array of arthropods found in western Canada, there are several economically-important pest insects, as well as an important complex of beneficial arthropods that populate field boundary habitats (Piper 1998). Within the complex of beneficial arthropods (predators, pollinators, parasitoids and scavengers) the ground beetles (Coleoptera: Carabidae) and spiders (Arachnida: Araneae) are commonly enumerated for agro-ecological purposes because of their role as natural enemies, because their abundance, cosmopolitan distribution, and ease of capture (Kromp 1999) makes them good bioindicators (Stork 1990), and because of the availability of good taxonomic keys that facilitate species identification.

Pest Species

Diversified crop production systems tend to have a lesser problem with insect pest populations than do large monoculture systems (Coll and Botrell 1994); however, the dynamics of pest species associated within perennial grass ecosystems in much less well understood. Many of the major insect pests of field crops in western Canada interact with non-crop habitats. However, relatively few have been highly successful at exploiting field boundary habitats as sources of food and for overwintering refugia. These successful species include grasshoppers (Orthoptera: Acrididae) (Olfert 2000), flea beetles (Coleoptera: Chrysomelidae) (Lamb and Turnock 1982), cabbage seedpod weevil (Coleoptera: Curculionidae) (Dosdall et al. 2002), leafhoppers (Homoptera: Cicadellidae) (Olfert and Braun 2001), and root maggots (Diptera: Anthomyiidae) (Soroka et al. 2004). The impact of buffer zones on the pest status of these species should receive consideration prior to implementation of such programs. The main characteristics of each species are summarized in Appendix 1.

Beneficial Arthropods

There is growing global interest in the beneficial arthropods that suppress pest species at little cost and cause minimal harm to humans and the environment (Pimentel 1995; Stary and Pike 1999). In the context of extensive agriculture, field boundary habitats provide stable refugia for these species relative to crop land (Piper 1998). Species that can adapt to life in agroecosystems (crop and field boundaries) will tend to play a larger role than species associated primarily with natural areas. Weeds in fields and in non-crop habitat can also be important in the conservation of beneficial insects (Altieri and Whitcomb 1979). This paper focuses on spiders and carabid beetles due to their world-wide reputation as major contributors within natural enemy assemblages. Spiders are well adapted to life in virtually all types of habitats including non-crop habitat (Doane and Dondale 1979). Doane and Dondale (1979) and Doane (1981) compared activity and species diversity of spiders and carabids, respectively, in wheat fields and corresponding grassy borders near Clavet, Saskatchewan. For both taxa they found greater activity and abundance and species richness in the grassy border than in the field. More importantly, 20% and 30% of the spider and carabid species, respectively, were caught only in the grassy border. These studies demonstrate the importance of field margins as reservoir for these two groups of predators and other beneficial arthropods. Due to their sheer numbers and their carnivorous feeding habits, spiders are also one of the most beneficial of the arthropod groups. Sunderland (2002) reported that there is evidence of predation in over 200 species of carabids ranging from slugs to insect pests to weed seeds. Due to their involvement in predation of weed seeds, this guild of insects is of increasing interest to weed science (Tooley and Brust 2002). An inventory of the carabid beetles, representing 43 genera and 202 species (Appendix 2) and spiders, representing 127 genera and 305 species, (Appendix 3) associated with agricultural production systems of the prairie ecozone have been compiled to serve as baseline data for reference in assessing the impact of any proposed legislation to implement buffer zones.

Research Activities

While buffer zones bordering potential wildlife refuges such as field margins, water bodies and shelterbelts will have a positive impact on arthropod diversity, they will also require that IPM practitioners have access to environmentally-friendly tools to manage pests associated with these habitats. This is because pesticide applications in field boundary habitats are considered a component of pest management for a number of economically important insect pests (Appendix 1). The scope of this issue is not a trivial one. A province like Saskatchewan has 26,000 km of roads, which equals approximately 500 million square meters of grass margins (field boundary habitat); not to mention all of the grass margins that exist in conjunction with fence lines in the prairie ecozone.

Relative to our knowledge of pest species, our understanding of the ecology of beneficial arthropods in areas adjacent to crop land is incomplete. These same field boundaries adjacent to the many roads, fence lines and tree shelterbelts also provide a narrow corridor for beneficial arthropods between island habitats on the prairies. This section highlights recent studies that are relevant to a discussion of field boundary habitats, insect pest management and arthropod diversity within the prairie ecozone.

Pest Management Technologies

The implementation of buffer zones that preclude application of pesticides in roadsides and fence lines, as opposed to those that are designed to protect water bodies or brush/tree habitats, will necessitate the development of alternative non-chemical management strategies. This is because there are several pest insects, such as grasshoppers (Orthoptera: Acrididae) and cabbage seedpod weevil (Coleoptera: Curculionidae), that have an aggregated spatial distribution pattern along field edges and chemical sprays are concentrated along such areas. Currently the only control strategy available to growers to reduce insect pest populations along field perimeters is chemical control, although some research progress has been made with the incorporation of trap crops for grasshoppers and cabbage seedpod weevils as a component of integrated management. Trap cropping is a cultural control method that relies on the fact that insects exhibit preferences for certain plant species or growth stage of a plant (Hokkanen 1991). Trap crops are grown to attract an insect pest away from a nearby main crop and concentrate them where they can be controlled with minimum amounts of insecticides, biopesticides or biocontrol agents. When implemented as a component of buffer zones, trap cropping may provide an effective strategy for managing insect pests like grasshoppers and cabbage seedpod weevil.

Grasshoppers. Grasshoppers (Orthoptera: Acrididae) are native insects that have been a feature of prairie agriculture since settlement of the northern Great Plains (Riegert 1980). Only a small proportion of the more than 90 species described by Brooks (1958) in this region are of recurring economic importance. However, the need to control grasshopper populations has been a constant feature in the production of small-grain crops. The availability of suitable food plants in the crop and suitable oviposition sites in field boundary habitats has significantly contributed to a problem far greater than occurred in the grass prairie alone prior to settlement (Pickford 1963; Riegert 1980). As a result, the threat to production of small grains arises from migration of the hatchling populations into cropland from roadsides, headlands and field margins. The major pest species of grasshoppers that use non-crop habitat for oviposition and/or use the grasses and weeds present as source of food are listed in Appendix 1. The adjacent crops of grains, oilseeds and forages are later used as a food source for maturation.

"Trapping" grasshoppers was recommended as early as 1919 (Criddle 1920) and is still a recommended control practice today (Olfert 1986). In the case of grasshoppers, the vegetation in the trap strip can be a cereal crop such as barley, or it may consist of weeds left undisturbed during the weed management process. Trap strips, 10 m wide, adjacent to non-crop habitat were found to concentrate grasshopper nymphs by as much as 4.9 times the initial field density, allowing them to be effectively controlled with a minimum amount of insecticide (Olfert 1986) (Figure 2). This study also showed that the numbers of egg pods were about 60% less in the adjacent non-crop habitat that combined a trap strip with an insecticide application than in areas without a trap strip.

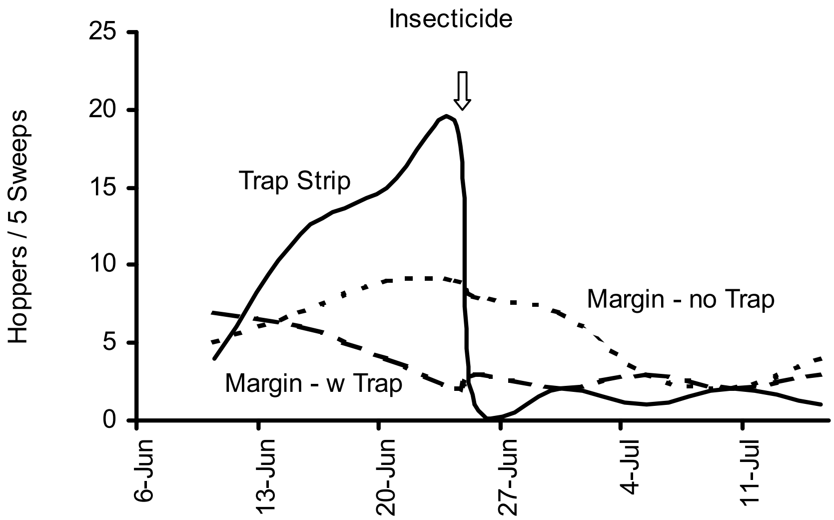

Figure 2. The number of grasshoppers per five sweeps in a trap strip adjacent to a grasshopper-infested field margin in Saskatchewan, June 6 to July 18, 1983. (Olfert 1986).

Cabbage seedpod weevil. The cabbage seedpod weevil, *Ceutorhynchus obstrictus* (Marsham) (Coleoptera: Curculionidae), is a serious pest of cruciferous seed crops, particularly canola and oriental/brown mustards in Europe and North America. It is a pest recently introduced into the prairie ecozone; it was first discovered infesting canola (*Brassica napus* L. and *Brassica rapa* L.) in southern Alberta near Lethbridge in 1995 (Butts and Byers 1996). Since that date, weevil populations have continued to disperse through crop land in the southern prairies (Cárcamo et al. 2001, Dosdall et al. 2002). Adult weevils overwinter underneath leaf litter in shelterbelts and field margins (Dmoch 1965; H. A. Cárcamo unpublished data). In the spring they migrate to early flowering cruciferous host weeds to feed before moving to canola fields where they have greater abundance and subsequent plant damage along the edges in the field boundary zones.

Trap cropping has been used successfully in Finland to manage the rape blossom beetle (*Meligethes aeneus*), a pest similar to the cabbage seedpod weevil. Hokkanen et al. (1986) showed that the blossom beetle can be concentrated in earlier flowering strips of a host *Brassica* crop and sprayed to maintain populations below the economic injury level in the adjacent main crop. A similar idea was tested by Buntin (1998) in Georgia, U.S.A. for the cabbage seedpod weevil. Although weevils were always higher in the trap crop, damage in the main crop could not be reduced below economic levels. He suggested that a larger area was needed to test the concept appropriately, such as commercial fields. Ongoing studies in the southern Alberta region (H. A. Cárcamo, unpublished data), are finding promising results in commercial fields (33+ ha) where a trap strip of canola is established by planting the outside perimeter (20-30 m) to an earlier flowering variety such as *B. rapa* or fall or early spring seeding of *B. napus* relative to the main crop. Preliminary results suggest that in most years a trap crop can substantially reduce the need to spray the entire field of canola. The challenge ahead, given impending federal government buffer zones legislation, will be to test how far away from the edge can the trap strips be deployed for them to remain effective and/or develop acceptable biologically-based methods to use in trap strips along the edges.

Arthropod Diversity

As was indicated earlier, our global knowledge of pest species greatly exceeds our understanding of the ecology of beneficial arthropods in areas adjacent to crop land. The prairie ecozone is no exception. In general, the ecological significance of biodiversity is that it acts as insurance by providing a buffer against periodic environmental fluctuations (White and Nekola 1992). A decline in biodiversity and reliance on agrochemical inputs are two consequences of conventional agriculture that have threatened the ecological, economic and social viability of the industry. Field boundary habitats are important source habitats responsible for maintaining the diversity of beneficial populations within cultivated areas (Dennis and Fry 1992). However, just what impact this loss of biotic diversity has on the ecological integrity of the prairie agroecosystem is unclear.

Influence of fragmented grasslands on arthropod diversity. The loss and fragmentation of natural grasslands on the prairies has created a patchwork of grassland areas surrounded by crop land. A two-year study was initiated to quantify the patterns of distribution and abundance of arthropods, notably beetles and spiders, in the fragmented native grasslands of southwestern Saskatchewan. The impact of replacing the natural disturbance regime with a human disturbance regime in the prairie region of Saskatchewan was also evaluated (Pepper 1999). Pitfall traps were used to sample beetles and spiders on seven pastures of native prairie that varied in size (7 - 17,800 ha) and range condition (poor-good). One hundred and fifty-seven beetle species and 118 spider species were identified from the pastures sampled. Range condition of different pastures was assessed to determine if cattle grazing had an effect on beetle and spider species richness. Although the overall trend indicated that intense grazing or poor range condition had a negative effect on spider richness, the differences were not statistically significant (J. Pepper, unpublished data). However, the size of the fragmented native grass areas did affect the presence and abundance of prairie arthropods. Pepper (1999) found that arthropod species richness was positively correlated to pasture area (Figure 3). The highest species richness was found on the largest pasture for both beetles and spiders. One might conclude from this that it would be most beneficial to concentrate on conservation of the larger native grass areas at the expense of the smaller areas. However, Pepper (1999) found that there was an unexpected high degree of species rarity of both spiders and beetles; there were only five species of beetles and two species of spiders that were common to all seven sites. It has been shown that isolation of fragmented ecosystems may present an insurmountable barrier to species' movement (Roth and Perfecto 1994; Hill et al. 1999). In this study, however, after controlling for the effects of range condition and area, the analysis indicated that beetle richness was not significantly related to isolation distance of the fragmented native grass areas (Pepper et al. unpublished data). Although the role of field boundaries has not been fully quantified, it stands to reason that they provide a corridor between native parcels in an otherwise, potentially, inhospitable environment.

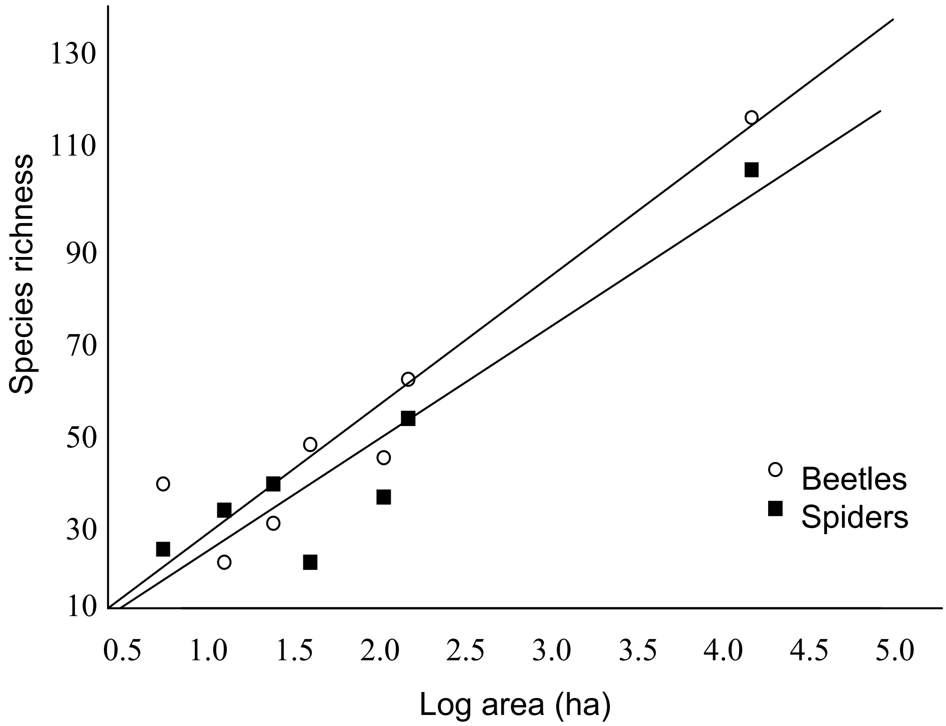

Figure 3. Grassland beetle and spider richness versus log area (Pepper 1999).

Prairie cropping systems. The range of agricultural practices within the prairie ecozone can be described by nine distinct farming systems, based on a matrix of crop rotation and production inputs (Olfert et al. 2002). Organic, Reduced and High represent the three levels of production inputs. The three levels of cropping diversity are described as Low, Annual Grains and Grain/Forage rotation. A biodiversity study was initiated which targeted eight commercial farms that met the criteria of the four extremes of the classification matrix: (i) annual-grain rotation with high inputs; (ii) annual-grain rotation with organic inputs; (iii) diversified grain-forage rotation with high inputs; and (iv) diversified grain-forage rotation with organic inputs. Arthropods were sampled in field boundary habitats once a month in mid-June, July and August, and sampling was replicated for three years (1994-1996). Vegetation-inhabiting arthropods were collected using a standard insect net, soil-dwelling arthropods were collected using pitfall traps (24 h per week). Although there were no significant differences in the species richness of the arthropod populations in field boundary habitats there were some interesting trends in the different guilds of beneficial arthropods. The results of the sweep sampling showed that herbivores outnumbered predators by about 2:1 in field boundary habitat (Figure 4). This same ratio in crop land is approximately 6:1 (Melnychuk et al. 2003), indicating a much more even balance of beneficial arthropods to pest species in field boundary habitat than in crops.

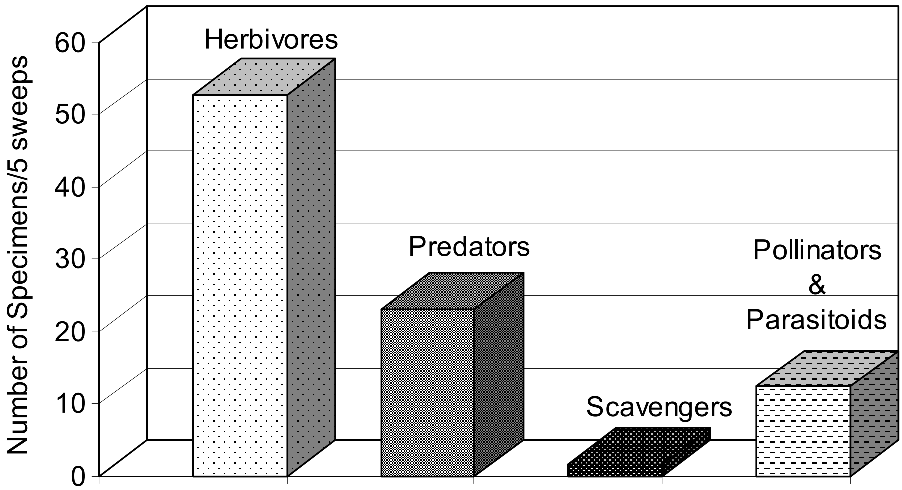

Figure 4. The mean number of arthropods per five sweeps taken from eight field boundary habitats in Saskatchewan, June to August, 1994 -1996.

The results of the pitfall trap samples revealed that field boundary habitats in the prairie ecozone contained a significant reservoir of beneficial arthropods relative to herbivores (Figure 5). Over the three years of the study (1994-1996), predators outnumbered herbivores about 5:1. The study confirmed that field boundary habitats within the prairie ecozone contain a significant population of beneficial arthropods in spite of the ecosystem disturbances associated with extensive agriculture.

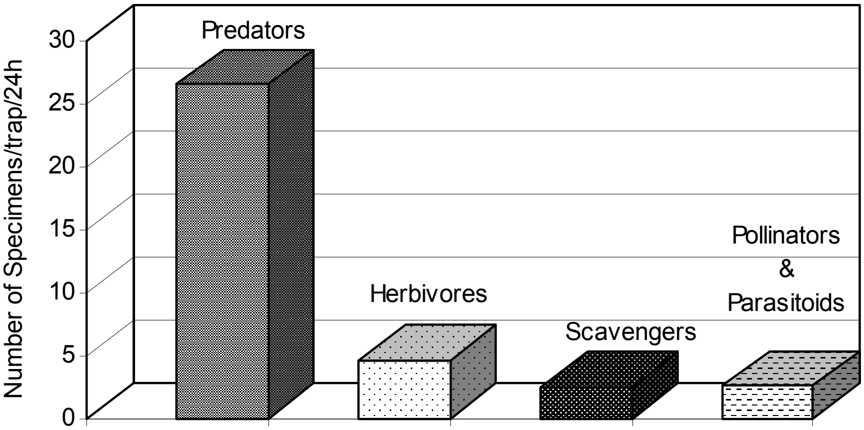

Figure 5. The mean number of arthropods per pitfall trap in a 24h period taken from eight field boundary habitats in Saskatchewan, June to August, 1994 -1996

Summary

This review paper discusses the major issues related to pest management and arthropod diversity in the context of field boundary habitats. In general, ecosystems with greater diversity of arthropods have a wider range of beneficial species and therefore a wider range of responses to pest pressure occurring within the ecosystem. The ecological significance of biodiversity is that it acts as insurance by providing a buffer against periodic environmental fluctuations. Given the large-scale cultivation of native habitat that is associated with prairie agriculture, species that can adapt to life in agroecosystems (crop and field boundaries) will tend to play a larger role than species associated primarily with natural areas. There is some evidence that field boundary habitats within the prairie ecozone contain a significant population of beneficial arthropods in spite of the ecosystem disturbances associated with extensive agriculture. The implementation of buffer zones may help to conserve the diversity of these populations. These benefits, however, will have to be balanced by the implementation of acceptable control strategies, such as trap strips, and biological approaches to manage the pest species which also utilize these same habitats.

Characterization of the arthropod complex in field boundary habitats is going to be a critical component of buffer zone implementation, especially if there is a requirement for site-specific buffer zones. Resources to monitor pest species tend to become more readily available during outbreak cycles, however, it is much more difficult to obtain the funding required to assess the diversity of beneficial arthropods. Given the limited funding available for biodiversity research, collaboration between agricultural and environmental agencies will be essential. A recent collaborative project involving the two disciplines successfully developed correlates of biodiversity in relation to different farming practices in Saskatchewan (Thomas et al. 1999). Similar joint research efforts may be required to identify and characterize those ecosystems that are most environmentally sensitive. Investments in the development of diversity indicators that best represent the economic and environmental significance of the arthropods in field boundary habitats would also be very beneficial.

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Appendix 1. Summary of major inspect pest species of the prairie ecozone in western Canada that are associated with field boundary habitats

Insect Pest	Species	Life Stage	Habitat Type	Current Control Recommendations
Grasshoppers	*Melanoplus sanguinipes* (Fabricius), *M. bivitattus* (Say) , *M. packardii* Scudder, *Camnula pellucida* (Scudder)	Overwinter as eggs. Nymphs utilize vegetation in boundary habitat as food.	Oviposition occurs mainly in roadsides, fence lines and pasture land. Nymphs feed on grasses and weeds.	Apply pesticides in boundary habitat.
Flea beetles	*Phyllotreta cruciferae* (Goeze), *P. striolata* (Fabricius)	Overwinter as adults.	Preferred overwintering site is beneath leaf litter in shelterbelts and poplar tree groves.	Apply seed dressings to plantings around field perimeters.
Cabbage seedpod weevil	*Ceutorhynchus obstrictus* (Marsham)	Overwinter as adults.	Preferred overwintering site is beneath leaf litter in shelterbelts.	Apply pesticides around field perimeters.
Leafhoppers	*Macrosteles fascifrons* Stål, *Aceratagalia sanguinolenta* (Provancher), *Diplocolenus configuratus* Uhler, *Endria inimicus* Say, *Euscelidius schenkii* (Kirschbaum)	Overwinter primarily as eggs. May also overwinter as adults under ideal conditions.	Oviposition occurs in roadsides. Preferred overwintering site for adults is beneath leaf litter in shelterbelts.	Apply pesticides in boundary habitat.
Root maggots	*Delia radicum* (L.), *D. floralis* (Fallén)	Overwinter as pupae.	Overwinters in soil beneath cruciferous weeds.	Control cruciferous weeds in boundary habitat.

Appendix 2. Inventory of carabid beetles in the prairie ecozone of Canada

Species	Habitat[a]
Acupalpus canadensis Casey	*Carex* vegetation at borders of ponds and pools
Agonum	
A. anchomenoides Randall	Moist, clay or muddy soil near water
A. corvus (LeConte)	Open prairie, margins of sloughs
A. cupreum Dejean	Abundant in open areas with sparse vegetation
A. cupripenne (Say)	Open areas, gravel or sandy soil that is not too dry
A. decorum (Say)	Margins of standing water with rich grass vegetation
A. errans (Say)	Edges of standing water, sandy soil
A. ferruginosum (Dejean)	Margins of standing water, soft clay/mud
A. gratiosum (Mannerheim)	Open areas, moderately moist soil/peat
A. lutulentum (LeConte)	Margins of standing or slowly running water
A. melanarium Dejean	Soft, wet clay with organic matter near water
A. mutatum G. & H.	Exclusively in peat bogs
A. nigriceps LeConte	Among plants close to open water
A. placidum (Say)	Open areas in sandy/cultivated soil
A. propinquum (Gemminger & Harold)	Margins of standing water/small pools
A. retractum LeConte	Forested areas and associated cultivated land
A. sordens Kirby	Moist soil, not necessarily near water
Amara	
A. aeneopolita Casey	Open dry grassland/firm soil
A. apricaria (Paykull)	Cultivated grassland[1]
A. avida (Say)	Cultivated grassland[1]
A. carinata (LeConte)	Cultivated grassland[1]
A. coelebs Hayward	Cultivated grassland[4]
A. convexa LeConte	Cultivated grassland[4]
A. cupreolata Putzeys	Cultivated grassland[4]
A. confusa LeConte	Cultivated grassland[4]
A. ellipsis LeConte	Cultivated grassland[4]
A. familiaris (Duftschmid)	Cultivated grassland[1]
A. farcta LeConte	Cultivated grassland[1]
A. impuncticollis (Say)	Open areas, moderately dry
A. lacustris LeConte	Cultivated grassland[1]
A. laevipennis Kirby	Cultivated grassland[2]
A. latior (Kirby)	Cultivated grassland[1]
A. littoralis Mannerheim	Cultivated grassland[1]
A. musculis (Say)	Open areas, dry sandy soil (sand pits)
A. obesa (Say)	Cultivated grassland[1]
A. patruelis Dejean	Cultivated grassland[2]
A. quenseli (Schönherr)	Cultivated grassland[2]
A. pallipes Kirby	Cultivated grassland[2]
A. scitula Zimmermann	Margins of saline waters with grass vegetation
A. thoracica Hayward	Cultivated grassland[1]
A. torrida (Panzer)	Cultivated grassland[1]
Amphasia sericea (T.W. Harris)	Open grassland
Anisodactylus	
A. discoideus Dejean	Sandy locations
A. merula (Germar)	Dry soil with scattered vegetation
A. nigrita Dejean	Sandy mixed clay soil near water with dense vegetation
A. rusticus (Say)	Dry sandy soils with tall vegetation
A. sanctaecrucis (Fabricius)	Near water with dense vegetation

(continued on next page)

Appendix 2. Inventory of carabid beetles in the prairie ecozone of Canada (continued)

Species	Habitat[a]
Badister	
B. neopulchellus Lindroth	Among leaf litter on moist shaded soil
B. obtusus LeConte	Among leaf litter on moist shaded soil
Bembidion	
B. aeneicolle (LeConte)	Alkaline soil
B. bifossulatum (LeConte)	Clay soil near water associated with grassland
B. bimaculatum (Kirby)	Moist clay mixed soil, sparse vegetation
B. canadianum Casey	Cultivated grassland[1]
B. castor Lindroth	Margins of running waters
B. chalceum Dejean	Barren lake shores
B. coloradense Hayward	Moist clay soil near water
B. concolor (Kirby)	Gravel or coarse sand near rivers
B. consimile Hayward	Clay soil margins of saline lakes
B. coxendix Say	Soft clay banks near rivers
B. diligens Casey	Margins of saline lakes and ponds
B. dorsale Say	Clay soil margins of lakes and ponds
B. fortestriatum (Motschulsky)	Swampy areas
B. gebleri turbatum Casey	Gravel banks near running water
B. graphicum Casey	Clay soil margins of lakes and ponds
B. grapii Gyllenhal	Dry gravel areas
B. inaequale Say	Margins of fresh running water, clay soil
B. incrematum LeConte	Margins of fresh standing water, sparse vegetation
B. insulatum (LeConte)	Margins of alkaline lakes and ponds
B. intermedium (Kirby)	Mixed clay soil near water
B. interventor Lindroth	Riparian areas
B. lachnophoroides Darlington	Stenotopic species; banks of rivers
B. mutatum Gemminger & Harold	Cultivated grassland[1]
B. nigripes (Kirby)	Margins of lakes and pools
B. nitidum (Kirby)	Sandy soil, moraine independent of water
B. nudipenne Lindroth	Xerophilus species; sandy soil
B. obscurellum (Motschulsky)	Dry areas of river banks
B. obtusangulum LeConte	Margins of saline lakes and pools
B. obtusidens Fall	Clay soil margins of saline lakes
B. patruele Dejean	Margins of slow moving/standing water, organic matter
B. planatum (LeConte)	Barren gravel banks of rivers
B. praecinctum LeConte	Margins of sloughs
B. punctatostriatum Say	Banks of large rivers
B. quadrimaculatum (LeConte)	Open areas, sandy or clay soils
B. rapidum (LeConte)	Moist soil with sparse vegetation
B. recticolle LeConte	Barren clay/gravel river banks
B. roosevelti Pic	Dense grass, distant from alkaline ponds
B. rupicola (Kirby)	Upper zones of river banks
B. salebratum (LeConte)	Banks of running waters
B. salinarium Casey	Margins of saline lakes and ponds
B. scudderi LeConte	Clay soil margins of saline lakes
B. sejunctum sejunctum Casey	Alberta prairie
B. sordidum (Kirby)	Cultivated grassland[1]
B. timidum (LeConte)	Diverse moist habitats
B. transparens (Gebler)	Margins of standing waters
B. umbratum (LeConte)	Banks of large rivers, clay/sand soil
B. versicolor (LeConte)	Moist areas near temporary waters
B. viridicolle (LaFerté-Sénectère)	Alkaline areas
Brachinus	
B. fumans (Fabricius)	River banks and shores

(continued on next page)

Appendix 2. Inventory of carabid beetles in the prairie ecozone of Canada (continued)

Species	**Habitat**[a]
B. quadripennis Dejean	Dense grass near artificial ponds
Bradycellus	
B. congener (LeConte)	Dry clay soil near water
B. lecontei Csiki	Northern coniferous areas and associated cultivated land
B. nigerrimus Lindroth	Margins of sloughs and ponds
Calathus ingratus Dejean	Leaf litter in more humid areas of grassland
Calleida viridis amoena (LeConte)	Dry open areas in grass prairie
Calosoma	
C. calidum (Fabricius)	Open dry areas with low vegetation
C. frigidum Kirby	All habitat, including open woodlands
C. lepidum LeConte	Xerophilus species; open prairie
C. luxatum Say	Xerophilus species; sandy prairie
C. moniliatum (LeConte)	Open areas; prairie
C. obsoletum Say	Open prairie; cultivated grassland
Carabus	
C. chamissonis Fischer von Waldheim	Dry, open prairie
C. maeander Fischer von Waldheim	Cultivated grassland[2]
C. serratus Say	Cultivated grassland[1]
C. taedatus agassii LeConte	Cultivated grassland[1]
Chlaenius	
C. alternatus G.H. Horn	Near slow rivers; firm soil
C. lithophilus lithophilus Say	Margins of slow/standing waters; dense vegetation
C. purpuricollis Randall	Cultivated grassland[1]
C. sericeus sericeus (Forster)	Moist firm soil; dense vegetation
C. tricolor Dejean	Near large rivers; firm soil; dense vegetation
Clivina fossor (Linné)	Cultivated, clay soil; parks and gardens
Cratacanthus dubius (Palisot de Beauvois)	Open, dry, cultivated fields
Cymindis	
C. borealis LeConte	Open sandy soil; short grass
C. cribricollis Dejean	Open sandy moraine
C. planipennis LeConte	Dry sandy prairie
Dicaelus laevipennis LeConte	moist soil; cultivated fields
Diplocheila	
D. oregona (Hatch)	Margins of alkaline/fresh water
D. striatopunctata (LeConte)	Margins of standing water; dense vegetation
Dyschirius	
D. campicola Lindroth	Alkaline areas
D. globulosus (Say)	Upper margins of river banks
D. integer LeConte	Moist clay soil near water; depressed vegetation
D. interior Fall	Margins of saline lakes
D. planatus Lindroth	Open prairie; sparse vegetation
D. quadrimaculatus Lindroth	Margins of river banks; clay/sand soil; no vegetation
D. setosus LeConte	Moist sandy/clay soil
D. sphaericollis (Say)	Barren margins of fresh water bodies
D. truncatus LeConte	Barren clay/sand near running water
Elaphrus	
E. americanus americanus Dejean	Moist soil near standing/running water
E. californicus Mannerheim	Margins of saline water/clay soil
E. fuliginosus Say	Margins of rivers and ponds
E. lapponicus lapponicus Gyllenhal	Margins of small water bodies/trickles; low vegetation
E. lecontei Crotch	Alkaline lakes and ponds
E. olivaceus LeConte	Margins of eutrophic waters; rich vegetation

(continued on next page)

Appendix 2. Inventory of carabid beetles in the prairie ecozone of Canada *(continued)*

Species	**Habitat**[a]
Euryderus grossus (Say)	Open, sandy areas in prairies
Geopinus incrassatus (Dejean)	Dry sandy soil; sparse vegetation
Harpalus	
H. amputatus Say	Dry, sandy grassland
H. desertus LeConte	Dry sandy soil; sparse vegetation
H. ellipsis LeConte	Sandy gravel pits
H. fraternus LeConte	Open dry areas; sparse vegetation
H. fuscipalpis Sturm	Open dry sandy soil; sparse vegetation
H. herbivagus Say	Open areas
H. nigritarsis C.R. Sahlberg	Open dry soil/gravel; dense, short vegetation
H. opacipennis (Haldeman)	Open dry areas; sand/gravel
H. paratus Casey	Sandy areas in open prairie
H. pensylvanicus (DeGeer)	Open dry areas; high vegetation with associated fields
H. reversus Casey	Open dry sandy soil
H. somnulentus Dejean	Open meadowland/grass vegetation
H. ventralis LeConte	Rolling prairie; sandy soil; grass vegetation
Lebia	
L. atriventris Say	Meadows and open forested areas
L. moesta LeConte	Shrubs/bushes; goldenrod
L. pumila Dejean	goldenrod flowers[1]
L. solea Hentz	Leaves of elder trees
L. viridis Say	Open sunny areas
L. vittata (Fabricius)	Shrubs/bushes; goldenrod
Leistus ferruginosus Mannerheim	Margins of running water
Loricera pilicornis pilicornis (Fabricius)	Cultivated grassland[2]
Microlestes linearis (LeConte)	Dry sandy soil; cultivated land
Nebria	
N. crassicornis intermedia Van Dyke	Wooded areas; margins of bogs
N. lacustris lacustris Casey	Margins of large running water; clay soil
Notiophilus	
N. aquaticus (Linné)	Cultivated grassland[1]
N. borealis T.W. Harris	Open areas; sparse vegetation
N. intermedius Lindroth	Open areas; sandy soil
N. semistriatus Say	Cultivated grassland[2]
Omophron	
O. americanus Dejean	Bare sandy/clay areas
O. ovalis G.H. Horn	Fine sand/clay areas; river banks
O. robustus G.H. Horn	Sandy lake shores
O. tessellatus Say	Barren sandy lakeshores
Opisthius richardsoni Kirby	River banks
Pasimachus elongatus LeConte	Open dry sandy prairie; low vegetation; rocks
Patrobus	
P. longicornis (Say)	Meadows; lightly forested areas next to cultivated land
P. lecontei Chaudoir	Cultivated grassland[2]
P. stygicus Chaudoir	Margins of lakes/ponds/rivers/marshes
Pelophila borealis (Paykull)	Soil with high organic matter near water
Piosoma setosum LeConte	Clay soil; prairie
Poecilus	
P. corvus (LeConte)	Cultivated grassland[1]
P. lucublandus (Say)	Cultivated grassland[1]
P. scitulus LeConte	Cultivated grassland[3]
Pterostichus	
P. femoralis (Kirby)	Cultivated grassland[2]

(continued on next page)

Appendix 2. Inventory of carabid beetles in the prairie ecozone of Canada *(continued)*

Species	Habitat[a]
P. patruelis (Dejean)	Eurytopic swamp species
P. adstrictus Eschscholtz	Open cultivated grassland[1]
P. mutus (Say)	Open dry areas, lightly forested next to cultivated land
P. pensylvanicus LeConte	Leaf litter and moss
P. corvinus (Dejean)	Margins of small standing water
P. luctuosus (Dejean)	Margins of eutrophic standing water/marshes
P. melanarius (Illiger)	Lightly forested areas, open meadow/cultivated land
P. caudicalis (Say)	Hygrophilus species
Stenolophus	
S. fuliginosus Dejean	Margins of pools of water
S. comma (Fabricius)	Open sandy areas near water; cultivated land[2]
S. lineola (Fabricius)	Dry sandy soil
S. conjunctus (Say)	Dry sandy soil; sparse vegetation
Syntomus americanus (Dejean)	Sunny sandy areas; sparse vegetation
Synuchus impunctatus (Say)	Open areas, lightly forested
Tecnophilus croceicollis peigani Larson	Dry alkaline soil; sparse vegetation
Trichocellus cognatus (Gyllenhal)	Forested areas, thinly wooded

[a] Habitat data is from Lindroth (1961-69) unless otherwise indicated by a superscript number.
[1] Cárcamo 1992
[2] Frank 1971
[3] Melnychuk et al. 2003
[4] Doane 1981

Appendix 3. Prairie spiders, June 1999[a]

Family	Genus	Species
Agelenidae	*Agelenopsis*	*A. actuosa* (Gertsch & Ivie)
		A. oklahoma (Gertsch)
		A. potteri (Blackwall)
		A. utahana (Chamberlin & Ivie)
	Cicurina	*C. arcuata* Keyserling
	Tegenaria	*T. domestica* (Clerck)
Amaurobiidae	*Titanoeca*	*T. nigrella* (Chamberlin)
		T. silvicola Chamberlin & Ivie
Anyphaenidae	*Anyphaena*	*A. pacifica* (Banks)
Araneidae	*Aculepeira*	*A. packardi* (Thorell)
	Araneus	*A. gemmoides* Chamberlin & Ivie
		A. marmoreus Clerck
		A. nordmanni (Thorell)
		A. trifolium (Hentz)
	Araniella	*A. displicata* (Hentz)
	Argiope	*A. trifasciata* (Forskal)
	Cyclosa	*C. conica* (Pallas)
	Eustala	*E. anastera* (Walckenaer)
	Hypsosinga	*H. funebris* (Keyserling)
		H. pygmaea (Sund.)
		H. rubens (Hentz)
	Larinia	*L. borealis* Banks
	Metepeira	*M. grandiosa* Chamberlin & Ivie
		M. palustris Chamberlin & Ivie
	Neoscona	*N. arabesca* (Walckenaer)
	Nuctenea	*N. cornuta* (Clerck)
		N. patagiata (Clerck)
	Singa	*S. keyserlingi* McCook
Clubionidae	*Agroeca*	*A. ornata* Banks
		A. pratensis (Emerton)
	Castianeira	*C. alteranda* Gertsch
		C. descripta (Hentz)
		C. longipalpa (Hentz)
	Clubiona	*C. abboti* Koch
		C. canadensis Emerton
		C. furcata Emerton
		C. johnsoni Gertsch
		C. kastoni Gertsch
		C. kulczynskii Lessert
		C. mixta Emerton
		C. moesta Banks
		C. mutata Gertsch
		C. norvegica Strand
		C. riparia Koch
	Phrurotimpus	*P. borealis* (Emerton)
		P. certus Gertsch
	Scotinella	*S. pugnata* (Emerton)

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Appendix 3. Prairie spiders, June 1999[a] *(continued)*

Family	Genus	Species
Dictynidae	*Argenna*	*A. obesa* Emerton
	Dictyna	*D. annulipes* Blackwall
		D. bostoniensis Emerton
		D. brevitarsus Emerton
		D. coloradensis Chamberlin
		D. completoides Ivie
		D. foliacea Hentz
		D. horta Gertsch & Ivie
		D. jonesae Roewer
		D. minuta Emerton
		D. personata Gertsch & Mulaik
		D. sancta Gertsch
		D. sublata Hentz
		D. terranea Ivie
		D. terrestris Emerton
	Tricholathys	*T. dakota* Chamberlin & Gertsch
Gnaphosidae	*Callilepis*	*C. pluto* Banks
	Drassodes	*D. mirus* Platnick
		D. neglectus (Keyserling)
		D. saccatus (Emerton)
	Drassyllus	*D. depressus* (Emerton)
		D. lamprus (Chamberlin)
		D. niger (Banks)
	Gnaphosa	*G. brumalis* Thorell
		G. parvula Banks
	Haplodrassus	*H. bicornis* (Emerton)
		H. eunis Chamberlin
		H. hiemalis (Emerton)
		H. signifer (Koch)
	Herpyllus	*H. ecclesiasticus* Hentz
		H. hesperolus Chamberlin
	Micaria	*M. coloradensis* Banks
		M. emertoni Gertsch
		M. foxi Gertsch
		M. gertschi Barrows & Ivie
		M. laticeps Emerton
		M. longipes Emerton
		M. mormon Gertsch
		M. pulicaria (Sundevall)
		M. rossica Thorell
	Sergiolus	*S. angustus* (Banks)
		S. decoratus Kaston
		S. montanus (Emerton)
		S .ocellatus (Walckenaer)
	Zelotes	*Z. fratris* Chamberlin
		Z. lasalanus Chamberlin
		Z. puritanus Chamberlin
		Z. sula Lowrie & Gertsch

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Appendix 3. Prairie spiders, June 1999[a] *(continued)*

Family	Genus	Species
Hahniidae	*Hahnia*	*H. ononidum* Simon
	Neoantistea	*N. agilis* (Keyserling)
		N. gosiuta Gertsch
		N. magna (Keyserling)
Linyphiidae (Linyphiinae)	*Agyneta*	*A. protrudens* (Chamberlin & Ivie)
	Allomengea	*A. pinnata* (Emerton)
	Aphileta	*A. misera* (O. Pickard-Cambridge)
	Bathyphantes	*B. pallidus* (Banks)
	Centromerus	*C. sylvaticus* (Blackwall)
	Frontinella	*F. pyramitela* (Walckenaer)
	Kaestneria	*K. pullata* (O. Pickard-Cambridge)
	Lepthyphantes	*L. alpinus* (Emerton)
		L. complicatus (Emerton)
		L. duplicatus (Emerton)
		L. leprosus (Ohlert)
		L. nebulosus (Sundevall)
	Macrargus	*M. multesimus* (O. Pickard-Cambridge)
	Meioneta	*M. fabra* (Keyserling)
		M. lophophor (Chamberlin & Ivie)
		M. simplex (Emerton)
	Microlinyphia	*M. impegra* (O. Pickard-Cambridge)
	Microlinyphia	*M. mandibulata mandibulata* (Emerton)
	Microlinyphia	*M. pusilla* (Sundevall)
	Neriene	*N. radiata* (Walckenaer)
	Pityohyphantes	*P. costatus* (Hentz)
		P. cristatus Chamberlin & Ivie
	Stemonyphantes	*S. blauveltae* Gertsch
	Tennesseellum	*T. formicum* (Emerton)
Linyphiidae (Erigoninae)	*Baryphyma*	*B. trifrons* (O. Pickard-Cambridge)
	Catabrithorax	*C. plumosus* (Emerton)
	Ceraticelus	*C. laetus* (O. Pickard-Cambridge)
	Ceratinella	*C. brunnea* Emerton
	Ceratinopsis	*C. stativa* (Simon)
	Cnephalocotes	*C. obscurus* (Blackwell)
	Dietrichia	*D. hesperia* Crosby & Bishop
	Diplocentria	*D. bidentata* (Emerton)
		D. rectangulata (Emerton)
	Diplocephalus	*D. subrostratus* (O. Pickard-Cambridge)
	Dismodicus	*D. decemoculatus* (Emerton)
	Eperigone	*E. trilobata* (Emerton)
		E. undulata (Emerton)
		E. aletris Crosby & Bishop
		E. atra Blackwall
		E. blaesa Crosby & Bishop
		E. dentigera O. Pickard-Cambridge
		E. zographica Crosby & Bishop
	Gnathonarium	*G. famelicum* (Keyserling)
	Gnathonaroides	*G. pedale* (Emerton)
	Gonatium	*G. crassipalpum* Bryant

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Appendix 3. Prairie spiders, June 1999[a] *(continued)*

Family	Genus	Species
	Grammonota	*G. gentilis* Banks
		G. pictilis (O. Pickard-Cambridge)
		G. vittata Barrows
	Hybauchenidium	*H. gibbosum* (Sorensen)
	Hypomma	*H. marxii* (Keyserling)
	Hypselistes	*H. florens* (O. Pickard-Cambridge)
	Islandiana	*I. flaveola* (Banks)
		I. princeps Braendegaard
	Pelecopsis	*P. mengei* (Simon)
		P. moesta (Banks)
	Phlattothrata	*P. parva* (Kulczynski)
	Pocadicnemis	*P. americana* Millidge
	Satilatlas	*S. carens* Millidge
	Scotinotylus	*S. boreus* Millidge
		S. pallidus (Emerton)
		S. sintalutus Millidge
		S. vernalis (Emerton)
	Soucron	*S. arenarius* (Emerton)
	Spirembolus	*S. spirotubus* (Banks)
	Subbekasha	*S. flabellifera* Millidge
	Tmeticus	*T. ornatus* (Emerton)
	Vermontia	*V. thoracica* (Emerton)
	Walckenaeria	*W. atrotibialis* O. Pickard-Cambridge
		W. auranticeps (Emerton)
		W. castanea (Emerton)
		W. digitata (Emerton)
		W. directa (O. Pickard-Cambridge)
		W. dondalei Millidge
		W. exigua Millidge
		W. fusciceps Millidge
		W. pinocchio (Kaston)
		W. palustris Millidge
		W. spiralis (Emerton)
		W. subspiralis Millidge
Lycosidae	*Alopecosa*	*A. aculeata* (Clerck)
		A. kochi (Keyserling)
	Arctosa	*A. alpigena* (Doleschall)
		A. emertoni (Gertsch)
		A. littoralis (Hentz)
		A. rubicunda (Keyserling)
	Geolycosa	*G. missouriensis* (Banks)
	Hogna	*H. frondicola* (Emerton)
	Pardosa	*P. bucklei* (Kronestedt)
		P. concinna (Thorell)
		P. distincta (Blackwall)
		P. dromaea (Thorell)
		P. fuscula (Thorell)
		P. mackenziana (Keyserling)

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Appendix 3. Prairie spiders, June 1999[a] *(continued)*

Family	Genus	Species
		P. modica (Blackwall)
		P. moesta Banks
		P. mulaiki Gertsch
		P. ontariensis Gertsch
		P. tesquorum Odenwall
		P. xerampelina (Keyserling)
	Pirata	*P. minutus* Emerton
		P. sedentarius Montgomery
	Piratica	*P. piraticus* (Clerck)
	Schizocosa	*S. cespitum* Dondale & Redner
		S. minnesotensis (Gertsch)
		S. mccooki (Montgomery)
	Trochosa	*T. pratensis* (Emerton)
Mimetidae	*Ero*	*E. canionis* Chamberlin & Ivie
	Mimetus	*M. epeiroides* Emerton
Oxyopidae	*Oxyopes*	*O. scalaris* (Hentz)
Philodromidae	*Ebo*	*E. bucklei* (Platnick)
		E. iviei Sauer & Platnick
		E. dondalei Sauer
		E. pipenensis Gertsch
	Philodromus	*P. alascensis* Keyserling
		P. cespitum (Walckenaer)
		P. histrio (Latreille)
		P. imbecillus Keyserling
		P. pernix Blackwall
		P. praelustris Keyserling
		P. rufus Walckenaer
		P. vulgaris (Hentz)
	Thanatus	*T. altimontis* Gertsch
		T. coloradensis Keyserling
		T. formicinus (Clerck)
		T. rubicellus (Mello-Leitao)
		T. striatus (Koch)
	Tibellus	*T. gertschi* (Chamberlin & Ivie)
		T. maritimus (Menge)
		T. oblongus (Walckenaer)
Pisauridae	*Dolomedes*	*D. triton* Walckenaer
Salticidae	*Eris*	*E. marginata* (Walckenaer)
	Euophrys	*E. monadnock* (Emerton)
	Evarcha	*E. hoyi* Peckham & Peckham
	Habronattus	*H. altanus* (Gertsch)
		H. americanus (Keyserling)
		H. cognatus (Peckham)
		H. cuspidatus Griswald
		H. decorus (Blackwall)
	Metaphidippus	*M. arizonensis* (Peckham & Peckham)
		M. flavipedes (Peckham & Peckham)

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Appendix 3. Prairie spiders, June 1999[a] *(continued)*

Family	Genus	Species
		M. insignis (Banks)
		M. protervus (Walck.)
	Neon	*N. nellii* (Peckham & Peckham)
	Peckhamia	*P. picata* (Hentz)
	Phidippus	*P. borealis* (Banks)
		P. purpuratus (Keyserling)
	Sitticus	*S. palustris* (Peckham)
	Talavera	*T. minuta* (Banks)
	Tutelina	*T. similis* Banks
Tetragnathidae	*Pachygnatha*	*P. clercki* Sundevall
		P. xanthosoma Koch
	Tetragnatha	*T. caudata* Emerton
		T. dearmata Thorell
		T. elongata Walckenaer
		T. extensa (Linnaeus)
		T. laboriosa Hentz
		T. shoshone Levi
		T. versicolor Walckenaer
Theridiidae	*Chrysso*	*C. nordica* (Chamberlin & Ivie)
	Crustulina	*C. sticta* (O. Pickard – Cambridge)
	Dipoena	*D. prona* (Menge)
	Enoplognatha	*E. intrepida* (Soerensen)
		E. joshua (Chamberlin & Ivie)
		E. marmorata (Hentz)
		E. ovata (Clerck)
	Euryopis	*E. saukea* Levi
	Latrodectus	*L. hesperus* (Chamberlin & Ivie)
	Robertus	*R. banksi* (Kaston)
	Steadota	*S. albomaculata* (De Geer)
		S. americana (Emerton)
		S. borealis (Hentz)
	Theridion	*T. aurantium* (Emerton)
		T. differens Emerton
		T. impressum Koch
		T. montanum (Emerton)
		T. murarium (Emerton)
		T. petraeum (L. Koch)
		T. pictum (Walckenaer)
	Thymoites	*T. minnesota* Levi
		T. unimaculatus (Emerton)
Thomisidae	*Coriarachne*	*C. utahensis* (Gertsch)
	Misumena	*M. vatia* (Clerck)
	Misumenops	*M. asperatus* (Hentz)
		M. celer (Hentz)
	Ozyptila	*O. conspercata* Thorell
		O. gertschi *Kurata*
		O. sincera canadensis Dondale & Redner

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Appendix 3. Prairie spiders, June 1999[a] *(continued)*

Family	Genus	Species
	Xysticus	*X. acquiescens* Emerton
		X. auctificus (Keserling)
		X. benefactor Keyserling
		X. cunctator Thorell
		X. discursans Keyserling
		X. elegans Keyserling
		X. ellipticus Turnbull, Dondale & Redner
		X. emertoni Keyserling
		X. ferox (Hentz)
		X. gertschi Schick
		X. gulosus Keyserling
		X. luctans (Koch)
		X. luctuosus (Blackwall)
		X. montanensis Keyserling
		X. nigromaculatus Keyserling
		X. obscurus Collett
		X. pellax O. Pickard-Cambridge
		X. punctatus Keyserling

[a] D. Buckle, unpublished data

Boundary areas and plant diseases

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Boundary areas adjacent to agricultural fields are very diverse. They may be cropped areas, tilled strips, stands of native plants, trees, or even roadways. Field margins and boundary areas provide diverse plant habitats that may create a 'green bridge' for pathogens. As a result, these areas can be a source of disease inoculum in the new crop and throughout the season. Polycyclic pathogens have many infection cycles per season and can move from boundary areas to field margins and then into the field throughout the entire season. Without disease control in boundary areas, there may be a greater need for in-field disease management. These habitats also create reservoirs for pathogens and their insect vectors and may increase the occurrence of some diseases, such as ergot of cereals and grasses. Management of other diseases may be aided by increases in boundary areas. The movement of residue-borne inoculum among fields may be reduced by physical barriers, such as a line of grasses and shrubs, or by larger boundary distances between fields, thus minimizing the need for in-field disease control of ascochyta blight of lentils. Disease management using crop rotation, cultivar resistance, and cultural management strategies will reduce the risk of losses, while preserving the ecological diversity in natural boundary areas.

Additional Keywords: ascochyta blight, ergot, disease control, field margins

Introduction

Modern agriculture can be viewed as a highly simplified ecological system focused on crop uniformity and maximum yield. However, farmers and government regulators are making changes to protect field boundary areas from pesticide applications by creating pesticide-free buffer zones, with the goals of increasing biodiversity and protecting the environment. Boundary areas adjacent to agricultural fields can be very diverse in shape and content. These boundary areas may contain domesticated species or native plants and trees, or even be comprised

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of tilled strips of varying widths, or roadways. For this discussion, boundary areas include all agricultural field margins, including the pesticide-free buffer zones.

Untreated field margins and cropped boundary areas are diverse plant habitats that can provide a ‘green bridge’ for pathogens and their insect vectors in the absence of a susceptible crop, as for example during winter or during the nonhost portions of crop rotations. The pathogen or insect vector becomes a source of inoculum as the new crop emerges and continues to be a source of infection throughout the season. Polycyclic pathogens have many infection cycles per season, thus allowing insect vectors to move from boundary areas to field margins and then into the field throughout the season. Without disease control in these areas, there may be a greater need for in-field disease management.

Research data on the impact of boundary areas on the occurrence and severity of plant diseases is limited. However, knowledge of a pathogen’s biology and disease cycle can help in understanding how boundary areas influence disease. For example, the physical structure of the boundary may reduce spread of residue-borne diseases, whereas the risk of insect-vectored diseases may increase because of larger pesticide-free boundaries. This short paper will explore how boundary areas may affect disease management by profiling two diseases that have very different disease cycles; ascochyta blight of lentil and ergot of cereals and grasses.

Residue-borne Diseases and Barrier Effects

Ascochyta blight, caused by *Ascochyta lentis* Vassilievsky, can result in significant reductions in seed yield and quality of lentil. Spot-like lesions develop on all plant parts, and small black pycnidia containing colorless, elliptical conidia develop on mature lesions. The spores are dispersed by splashing rain to other plants during the growing season, and also from overwintered crop residue to seedlings of subsequent lentil crops. The fungus remains viable on lentil residue for up to 3 years and attacks only lentil (Morrall 2003, CAB International 2002).

Management of ascochyta blight (and other residue-borne diseases) may be aided by boundary and buffer zone areas. After harvest, pieces of crop residue infested with the pathogen may be carried by wind to nearby fields, and act as a source of infection the following year. Movement of residue to adjacent fields may be reduced by physical barriers of nonhost plants such as tall grasses or trees in the boundary area or by larger boundary distances between fields caused by wide roadways or other factors. Barriers such as a fungicide strip on the field edge or a nonhost strip immediately adjacent to the lentil crop reduced disease severity and improved seed quality compared to no barrier or a ploughed strip (Pedersen and Morrall 1993, 1994). In commercial fields, a wide boundary (45 m) was required to completely prevent the spread of residue-borne inoculum from field to field for this low-growing crop. Therefore, tall dense barriers, or wide boundaries, may reduce transfer of inoculum and thus reduce the risk of requiring in-field disease management.

Insect-vectored Diseases and Boundary Areas

Boundary areas can support overwintering inoculum of pathogens, such as sclerotia, and also create reservoirs for insect vectors that carry certain pathogens to the crops in the field. After seeding, the disease moves incrementally from the edges to the centre of the field. The edges provide an important source of inoculum both initially and throughout the growing season. Repeated cycles of sporulation and infection spread the disease into the field, resulting in more infected plants and even more sporulation. The result is a greater risk of requiring in-field disease control with pesticides, and a greater risk of minor diseases such as ergot of cereals and grasses becoming more important.

Ergot is caused by the fungal pathogen, *Claviceps purpurea* (Fr.:Fr.) Tul., and can infect a range of cereals and perennial grasses (Knox and McLeod 2003). In particular, rye and triticale are highly susceptible to this disease. Hard, dark survival structures called sclerotia are produced in the head of affected plants after flowering. The sclerotia then fall to the ground or contaminate seed during harvest. The presence of ergot sclerotia in grain products can adversely affect the health of animals and humans, and so is a cause for downgrading of seed. The fungus produces lysergic acid, which can cause severe alkaloid poisoning to the central nervous system, so less than 0.1% contamination of sclerotia in seed is acceptable for human food. Sclerotia in the soil germinate and produce spores that infect plants during flowering. A sweet, sticky insect-attracting substance called "honeydew" is produced on infected florets. The honeydew contains the fungal spores, which stick to the insect's body and move spores from flower to flower and plant to plant. Ergot is generally a minor disease, but its incidence has increased in recent years (Fernandez et al. 2000). The proximity of highly susceptible grasses in the boundary area to the field increases the risk of ergot in the cereal crop. Grasses generally flower before cereals, and their period of flowering often coincides with spore release from the germinating sclerotia. Under cool wet conditions, abundant honeydew is produced on the infected grasses, which can rapidly spread fungal spores to nearby cereal crops.

Reducing Diseases Arising from Boundary Areas

Can we manage potential disease problems caused by edge habitats and boundary areas without the use of pesticides? Several practical solutions are available:

1) Use resistant or less susceptible crops and crop cultivars in the field, so that infection is prevented or delayed, and inoculum production by the pathogen is reduced.

2) Use diversified crop rotations, so that susceptible crops are not grown in the field the following year. Crop rotation helps to limit plant types that are similar in the field and adjacent boundary areas. For example, cereals planted adjacent to a grassy headland facilitates movement of ergot from grasses to cereals, because both plant types are susceptible. In contrast, canola is a nonhost and cannot be infected.

3) Plant border strips of a nonhost crop around the field edge to reduce infection within the field and limit pathogen dispersal. Barren areas increase the horizontal spread of residue-borne diseases and do not effectively stop the movement of most insect-vectored diseases, especially when green volunteer plants are present in the border strip or field.

4) Use high quality seed that is free of important diseases and does not contain contaminants such as sclerotia, which can initiate disease in the field.

5) Maintain soil fertility, to keep the crop healthy and vigorous as stressed plants are often more susceptible to disease. Also, some nutritional disorders increase susceptibility to disease. For example, copper deficiency increases ergot by inhibiting pollination, so flowers are open and exposed to infection for longer periods of time.

6) Restrict the number of volunteer plants, perennial weeds, and infected plants to prevent sources of infection. Depending on the circumstances, these plants may be removed by mowing, cultivation, or even roguing. For instance, mowing grassy headlands before they flower will reduce the risk of ergot spreading into cereal crops.

7) In some situations, harvest and store the crop from the edges of a field separately from the main portion of the field, because the edges are more likely to be infected with diseases coming from the boundary area and may have a lower grain quality.

Summary

Untreated field margins and cropped boundary areas are diverse plant habitats that can provide a 'green bridge' for pathogens and their insect vectors in the absence of a susceptible crop. The impact of boundary areas on the occurrence and severity of plant diseases is often limited, although knowledge on the pathogen's biology and disease cycle can help in understanding how boundary areas influence disease. For *A. lentis*, the physical structure of the boundary reduced the spread of residue-borne inoculum causing ascochyta blight, whereas the risk of insect-vectored diseases, such as ergot of cereals and grasses increases because of larger pesticide-free boundaries. Combining several disease management practices into a long-term strategy will reduce the risk of losses in yield and quality from these diseases, while preserving the ecological diversity in natural boundary areas.

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Weed fecundity in relation to distance from the crop edge

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Seed production of velvetleaf, lamb's-quarters, common ragweed, giant ragweed and giant foxtail was studied in corn and soybeans in relation to distance from the crop edge. Individual weeds were grown 0.5 m outside the last crop row, in the last crop row, 0.5 m into the crop, or 2.5 m into the crop. Plots either had no herbicide applied, or were treated with half rates of a pre- or post-emergence herbicide. Survival of emerged weeds to maturity was recorded. Basal stem diameter of the broad-leaved weeds, and number and length of inflorescences of giant foxtail were measured in late summer. Seed production per plant was estimated from these traits. Seedlings were more likely to survive to reproduce at or near the crop edge than within the crop, particularly in corn after herbicide application. Fecundity of all weeds was two to four times higher 0.5 m outside the last crop row, compared to 2.5 m within the crop. Seeds from weeds close to the crop edge are likely to be dispersed into the crop by the combine. These studies highlight the potential value of border sprays to control weed seed production where it is likely to be highest.

Additional Keywords: *Abutilon theophrasti*, *Ambrosia trifida*, *Chenopodium album*, *Setaria faberi*, weed seed production

Introduction

The crop edge, defined as the outer few metres of the crop (Marshall and Moonen 2002), is a transition zone between the crop and the field margin in terms of resource availability and microclimate. Edge effects on plant growth are well known, and most sampling designs avoid them. Edge habitats, however, can play an important role in the population dynamics of many weed species, which often thrive in the absence of crop competition.

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Studies of weed distribution have shown that some species occur primarily within the crop and others primarily along the field margin, but the highest density and diversity of species occur along the crop edge (Leeson et al. 2005; Marshall 1989; Rew et al. 1992; Wilson and Aebischer 1995). Crop competition is often least in headlands and near field edges because of uneven herbicide and fertilizer application and greater soil compaction (Kleijn and Verbeek 2000; Rew et al. 1992; Wilson and Aebischer 1995), and weeds in these areas therefore receive more light and have a greater opportunity to set seed. Weeds may also produce more pollen at field edges than within the crop, which has implications for models of gene flow. If weed growth along crop edges is uncontrolled, these areas may serve as sources of pollen and seeds that can be dispersed into the field or to adjacent fields. Seed production has been reported for a number of weed species within various crops (Colquhoun et al. 2001; Forcella et al. 2000; Lutman 2002; Mohler and Callaway 1995), but studies of weed fecundity along the crop edge are lacking. Although measurements of weed seed production are laborious and time consuming, estimates of fecundity can be made from plant dry weight or architectural traits (Fausey et al. 1997; Forcella et al. 2000; Lutman 2002; Mohler and Callaway 1995).

Herbicide application at less than the recommended rate is an increasingly common practice among growers (Thomas et al. 2002). Studies have shown that reduced rates can suppress weed growth and seed production within a crop (Ellis and Griffin 2002; Sikkema 2002; Vidrine et al. 2002). The effectiveness of reduced rates at the crop edge, where the crop provides less competition, is unclear. Furthermore, the use of border sprays to control weeds along crop edges may conflict with the need to leave unsprayed areas next to sensitive areas such as windbreaks or water courses (Boutin and Jobin 1998). To fully understand the implications of the current trend toward reduced herbicide rates and the use of unsprayed buffer zones at field edges adjacent to sensitive habitats, it is important to study weed survival and reproduction at the crop edge.

The main objective of this study was to examine weed fecundity and survival in relation to distance from the crop edge, with and without herbicide application. Three annual broad-leaved species and one annual grass that are typically found along crop edges in Ontario were tested in field corn and soybeans. A secondary objective was to find a non-destructive method of estimating fecundity of these species.

Materials and Methods

Experimental design and treatments

Experiments were conducted at the Agriculture and Agri-Food Canada research centre at Harrow, Ontario, on a Harrow fine sandy loam (Hapludalf subgroup; 76% sand, 12% silt, 12% clay; 1.6% organic matter, pH 6.3), from 2000 to 2002. A conventional tillage system was employed, with annual spring ploughing of a rye (*Secale cereale* L.) cover crop followed by disking and cultivation for seedbed preparation. Corn (*Zea mays* L.) and soybeans (*Glycine max* L.) were planted as separate, adjacent experiments and rotated within the field each year. Fertilizer was broadcast prior to planting according to soil test recommendations for each crop. In mid-May of each year, glyphosate tolerant field corn (DK 520RR) was sown at a population of 74,400 seeds ha^{-1}, and glyphosate tolerant soybeans (FirstLine 3201RR) were sown at a population of 432,800 seeds ha^{-1}. Row width was 76 cm for both crops.

The experimental design was a randomized complete block, with four replicate blocks. Plots consisted of 12 crop rows, 8 m in length, with 3 m roadways between plots. In corn, there were three herbicide treatments: a control (no herbicide), a PRE application of a formulated pre-mix of atrazine plus metolachlor at half the recommended rate (1 kg a.i. ha^{-1}), and a POST application of glyphosate at half the recommended rate (450 g a.i. ha^{-1}). In soybeans, there were two herbicide treatments: a control (no herbicide), and a PRE application of a formulated pre-mix of flumetsulam plus metolachlor at half the recommended rate (1.1 kg a.i. ha^{-1}). Herbicides were applied with a CO_2 pressurized handboom at 210 kPa and a water volume of 333 L ha^{-1}. PRE herbicides were applied shortly after planting. The POST herbicide in corn was applied when broad-leaved weeds had 6 to 8 leaves and giant foxtail (*Setaria faberi* Herrm.) had 3 to 6 leaves. Herbicides were applied at least 1 m beyond the edges of the plots to ensure that plants 0.5 m outside the last crop row were treated.

Within each plot, weed seeds were planted immediately after crop seeding and prior to herbicide application at four different positions: 0.5 m outside the last crop row (+0.5), in the last crop row (0), 0.5 m inside the last crop row (-0.5), and 2.5 m into the crop (-2.5). Lamb's-quarters (*Chenopodium album* L.), giant ragweed (*Ambrosia trifida* L.), giant foxtail, and velvetleaf (*Abutilon theophrasti* Medik) were sown in corn; and lamb's-quarters, common ragweed (*Ambrosia artemisiifolia* L.), giant foxtail, and velvetleaf in soybeans. Lamb's-quarters, giant ragweed and velvetleaf were grown in 2000 and 2001. Common ragweed and giant foxtail were grown in 2000, 2001 and 2002. The +0.5, 0, and –0.5 positions with respect to the crop edge were situated along all four sides of each plot, facing each cardinal direction. For each species, there were eight plants at each of the +0.5, 0, and –0.5 locations, and four plants at the inner (-2.5) location in each plot. Seedlings were thinned to one per location shortly after emergence. The distance between weed seedlings was 0.75 m. To control unwanted weeds, an overall application of glyphosate (0.9 kg ha^{-1}) was made at approximately the 2^{nd} trifoliate of soybeans and the 3-leaf stage of corn, after covering the target weeds with cardboard cups. Hand weeding was continued throughout the season as required.

Data Collection

Weed seedlings were enumerated after thinning and again in late August to determine the effect of herbicide treatment and position within the crop on survivorship. Percent survival was calculated per plot for each species and location based on the number of plants present at the initial census, i.e. a maximum of eight plants per species at each edge location and four plants per species at the central location. Plant height and basal stem diameter were measured in late August or early September on each surviving broad-leaved weed. The species used in this study have a single main stem. Basal stem diameter was measured with callipers approximately 1 cm above the soil surface. A sub-sample of plants was re-measured in late September, but no further increases in plant height or basal stem diameter had occurred. The number of capsules on each velvetleaf plant was counted in August. The number and length of each inflorescence were measured on giant foxtail plants in August.

Seed production was directly measured on a sub-sample of plants of each species from each crop over the size ranges represented in the experiment in each year of the study, using all treatments and locations. Seeds of lamb's-quarters and the ragweed species were harvested in late September when seed formation appeared to be complete and little dispersal had occurred. The seeds were cleaned and weighed, and total seed number per plant was calculated based on the mean seed weight of ten lots of 100 seeds from the harvested plants. The average number of seeds per capsule of velvetleaf was determined, and total seed production per plant was calculated as the number of capsules times the mean number of seeds per capsule. Inflorescences of giant foxtail were selected over the size range present, and the seeds counted on each. Relationships between observed seed production and architectural traits were determined by regression analyses.

Data Analyses

Regression analyses were conducted between measured seed or capsule production, basal stem diameter and height for lamb's-quarters, giant and common ragweed, and velvetleaf. The model with the best fit was used to estimate seed production per plant for all plants. In the case of giant foxtail, seed numbers were regressed against length of individual inflorescences. Once an appropriate model was found, seed production per plant was calculated as estimated seed number for each inflorescence summed over all the inflorescences on the plant. Tests were conducted to determine whether a common slope and intercept could be used over crops and years for each species. Where significant year effects were found, the regression coefficients specific to each year were used to estimate seed production.

The effects of herbicide treatment and distance from the crop edge (location) on percent survival, basal stem diameter or total inflorescence length (giant foxtail), and estimated seed production were analysed using PROC GLM in SAS. Data were examined for normality and transformed before analysis as required. When main effects were significant at the $P < 0.05$ level, adjusted means were separated by the Tukey-Kramer multiple comparison procedure. Year by treatment interactions generally were not significant, and so data were pooled over years. Untransformed means and standard errors are presented in the figures, but the figure captions indicate whether the analyses were based on transformed data.

Results and Discussion

Survival to Reproduction

In corn, survival of emerged seedlings depended on both distance from the crop edge and herbicide treatment for all species except lamb's-quarters (Figure 1). For velvetleaf and giant foxtail, percent survival generally decreased from 0.5 m outside the crop edge to 2.5 m within the crop on all plots. The effect was most pronounced on plots treated POST with 450 g ha^{-1} glyphosate, suggesting that recovery from a sub-lethal rate of herbicide was easier on the outside of the plots where competition for light was less. For giant ragweed, there was a significant interaction between herbicide treatment and location, and distance from the crop edge influenced survival only for glyphosate-treated plants. Seedlings of lamb's-quarters survived to maturity only in the control plots. The effect of location on survival of lamb's-quarters in the control plots was not significant.

In soybeans, survival of lamb's-quarters and velvetleaf seedlings was sharply reduced by the PRE herbicide application compared to the control, but did not vary with location (Table 1). Few lamb's-quarters seedlings emerged in herbicide-treated plots, whereas many velvetleaf seedlings emerged but died before maturity (data not shown). Neither the PRE herbicide treatment nor location influenced survival of common ragweed seedlings in soybeans. Giant foxtail seedlings, on the other hand, survived better 0.5 m outside the last crop row than 0.5 or 2.5 m within the crop, with or without herbicide treatment.

The greater effect of location with respect to the crop edge on weed survival in corn compared to soybeans may be due to differences in crop stature and canopy architecture, and therefore light availability. Meiners et al. (2002) found that survival of tree seedlings increased across a forest-old field edge gradient, and attributed higher survival in the old-field habitat primarily to increased light levels. In the present study, both crops were grown at the same row width, and it is possible that location might have influenced weed survival more in soybeans had they been grown at a narrower row width. Greater survival of most weeds at the crop edge in the herbicide-treated plots of corn, and for giant foxtail in soybeans, suggests that reduced rates may not be adequate for border sprays.

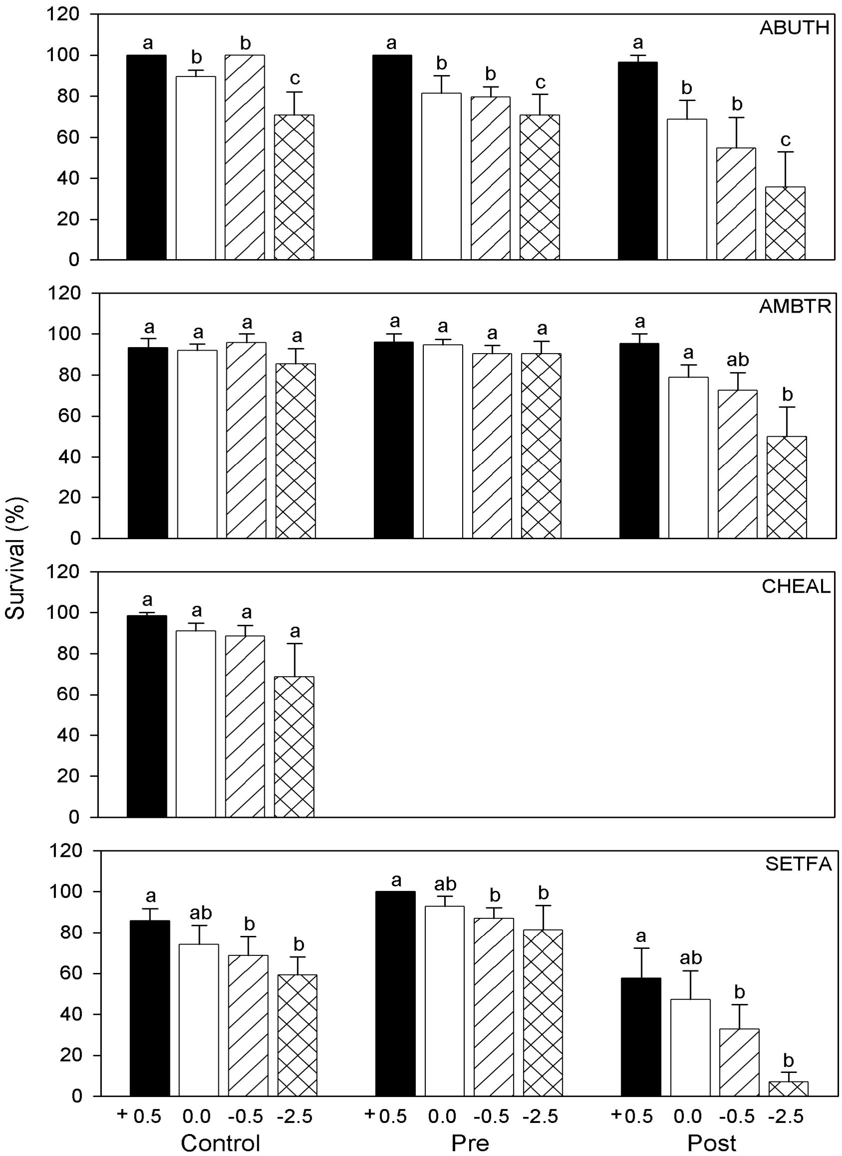

Figure 1. Mean percent survival (± S.E.) of velvetleaf (ABUTH), giant ragweed (AMBTR), lamb's-quarters (CHEAL), and giant foxtail (SETFA) in corn in relation to herbicide treatment and distance from the crop edge (m) pooled over years. Bars surmounted by the same letter within a species and herbicide treatment do not differ ($\alpha = 0.05$).

Table 1. Mean percent survival (± S.E.) of lamb's-quarters (CHEAL), velvetleaf (ABUTH), common ragweed (AMBEL) and giant foxtail (SETFA) in soybeans in response to herbicide treatment and location with respect to the crop edge. Data were pooled over years and main effects, as interactions were not significant. Values within a column and main effect followed by the same letter do not differ (α = 0.05).

Treatment	CHEAL	ABUTH	AMBEL	SETFA
Herbicide				
Control	93.7 ± 2.7 a	88.3 ± 3.4 a	90.2 ± 2.7 a	84.1 ± 3.7 a
PRE	< 0.1 b	29.4 ± 7.1 b	83.8 ± 2.8 a	81.1 ± 4.2 a
Location				
+0.5	93.3 ± 3.9 a	62.5 ± 10.1 a	80.3 ± 4.9 a	97.1 ± 1.4 a
0	94.9 ± 3.7 a	51.2 ± 11.0 a	86.8 ± 4.2 a	84.5 ± 4.0 ab
-0.5	96.7 ± 2.2 a	49.9 ± 11.9 a	89.3 ± 3.0 a	75.3 ± 5.5 b
-2.5	90.6 ± 9.4 a	78.0 ± 8.7 a	91.7 ± 3.3 a	73.4 ± 8.2 b

Seed Production

Seed production of each weed species could be estimated from architectural traits (Figures 2 and 3). Basal stem diameter was a good predictor of seed production for lamb's-quarters and ragweed species, and of capsule number for velvetleaf, when both variables were log transformed (Figure 2). Basal stem diameters ranged from 2 to 4 mm for plants from herbicide-treated plots and within-crop locations, to 40 to 45 mm for control plants on crop edges. Mohler and Callaway (1995) had used both basal stem diameter and plant height to estimate seed production of lamb's-quarters and redroot pigweed (*Amaranthus retroflexus* L.), but height was not a good indicator of seed production in our study, either alone or in combination with basal diameter. Nagashima and Terashima (1995) examined allometric relationships between stem diameter, height and weight of lamb's-quarters, and found them to be non-linear because of "height convergence" in dense stands. In our study, relationships between basal stem diameter and seed production were consistent over crops (for CHEAL, SETFA, and ABUTH), years, herbicide treatments and locations, with one exception. In 2001, the intercept of the regression equation for common ragweed was higher than in the other two years, although the slope was similar (data not shown). The intercept indicates the basal stem diameter below which plants fail to reproduce. The reason for the higher intercept estimate for common ragweed in 2001 is unclear.

The relationship between seed number per inflorescence of giant foxtail and the length of the inflorescence (Figure 3) was nonlinear and was consistent over years, crops and experimental treatments. Fausey et al. (1997) and Forcella et al. (2000) also reported a curvilinear relationship between seed number and inflorescence length of giant foxtail, but their regression coefficients did not fit our data. Empirical relationships established by regression analysis may not apply to conditions other than those under which the data were collected. The range of panicle lengths in our study differed somewhat from that in previous studies, which may affect the functional form of the equation, and biotype differences may exist between Ontario, Michigan (Fausey et al. 1997) and Minnesota (Forcella et al. 2000) populations.

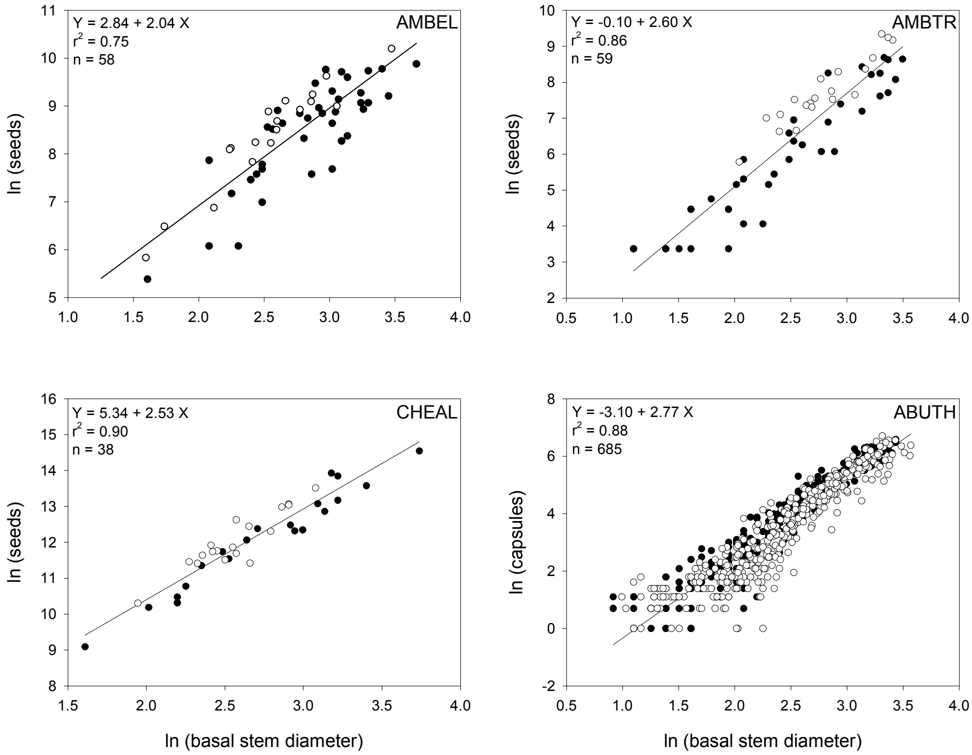

Figure 2. Estimated seed or capsule production per plant of common ragweed (AMBEL), giant ragweed (AMBTR), lamb's-quarters (CHEAL), and velvetleaf (ABUTH) as a function of basal stem diameter (cm) on a log/log scale. Closed and open symbols represent different years. The 2001 data were omitted for AMBEL (see text). Data were pooled over herbicide treatment, location and crop.

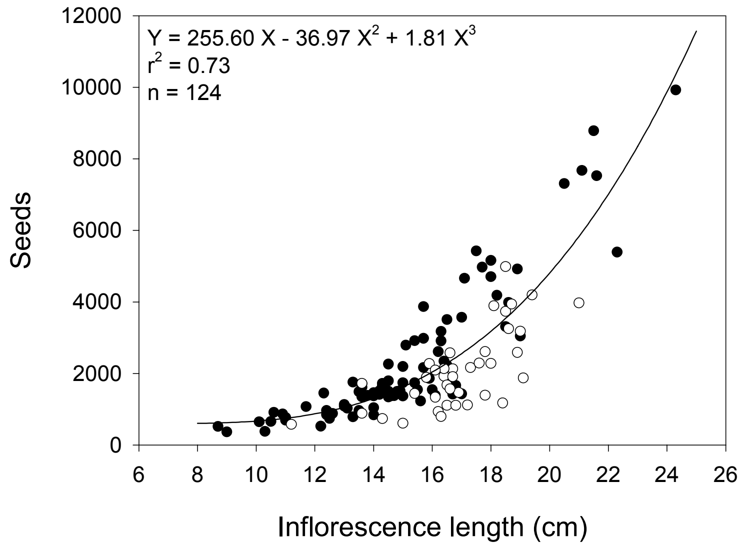

Figure 3. Estimated seed production per inflorescence of giant foxtail in relation to length of the inflorescence. Closed and open symbols represent different years. Data were pooled over herbicide treatment, location and crop.

Fecundity of all species in corn declined markedly from 0.5 m outside the last crop row to 2.5 m within the crop (Figure 4). The results of the analyses of variance were the same for basal stem diameter, or total inflorescence length (giant foxtail), and estimated seed production, so only the data on estimated seed production are presented. Herbicide application reduced fecundity overall, but treated plants growing 0.5 m outside the last crop row produced far more seeds than untreated plants within the crop, except in the case of lamb's-quarters where there were no survivors. The number of giant foxtail seedlings surviving herbicide application was low, and the variability on these plots too high to detect an effect of location. However, the interaction between herbicide treatment and location was not significant for any of the species.

A similar pattern of marked reduction in weed fecundity within the crop compared to 0.5 m outside the last crop row was observed in soybeans (Figure 5). Application of the PRE herbicide reduced fecundity overall, but plants that survived the herbicide at the crop edge produced as many seeds as plants within the crop which were not treated. Again, the herbicide by location interaction was not significant. Although seed production in corn and soybeans cannot be statistically compared because they were separate experiments, fecundity of these species was generally higher in soybeans than in corn even at the edges of the plots.

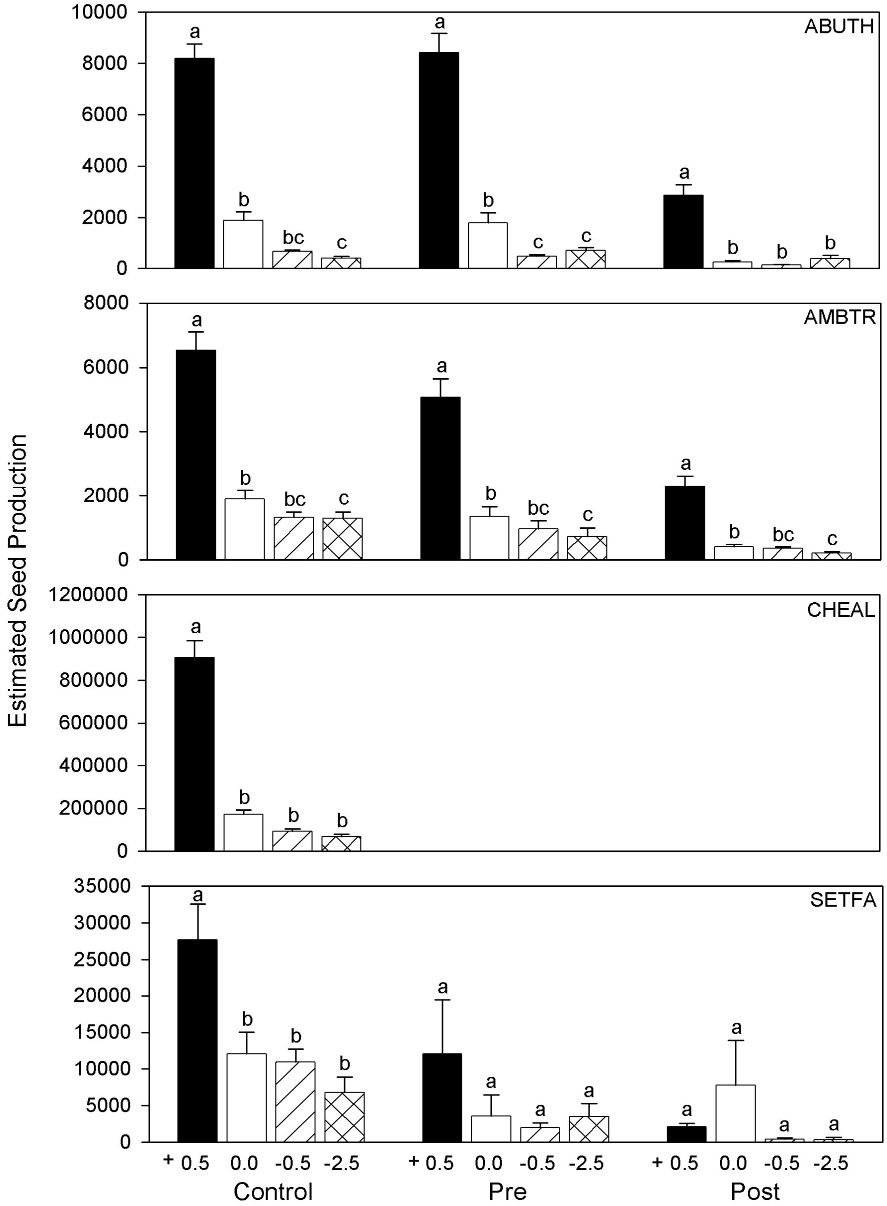

Figure 4. Mean estimated seed production per plant (+ S.E.) of velvetleaf (ABUTH), giant ragweed (AMBTR), lamb's-quarters (CHEAL), and giant foxtail (SETFA) in corn in relation to herbicide treatment and distance from the crop edge pooled over years. Bars surmounted by the same letter within a species and herbicide treatment do not differ (α = 0.05) based on analyses of log-transformed data.

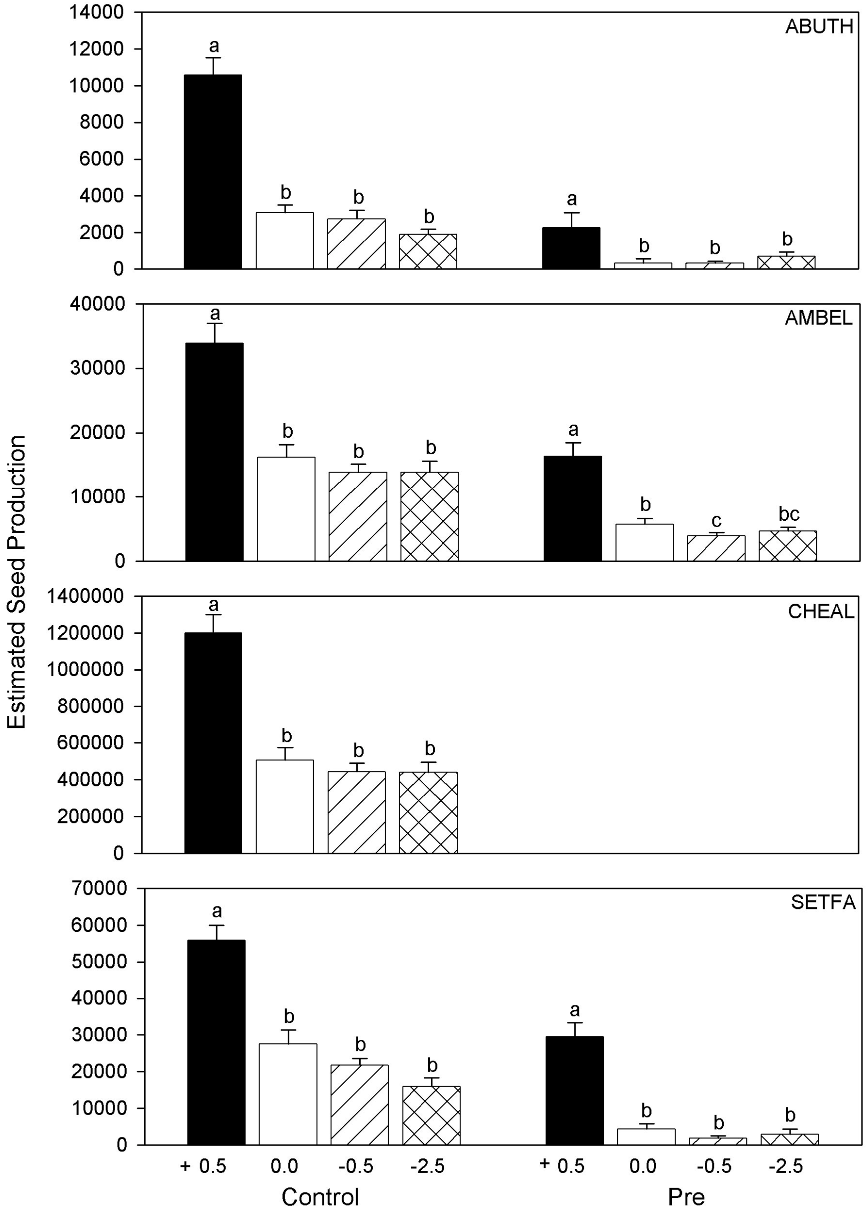

Figure 5. Mean estimated seed production per plant (± S.E.) of velvetleaf (ABUTH), common ragweed (AMBEL), lamb's-quarters (CHEAL), and giant foxtail (SETFA) in soybeans in relation to herbicide treatment and distance from the crop edge pooled over years. Bars surmounted by the same letter within a species and herbicide treatment do not differ (α = 0.05) based on analyses of log-transformed data.

These results indicate that weed survival in general, the ability to escape reduced herbicide rates, and weed seed production are all likely to be higher at the crop edge than within the crop. Because of the ability of arable weeds to thrive at crop edges, management to discourage weed growth is particularly important in these areas. Border sprays may be effective at controlling weeds along edges, but management practices need to be developed that prevent weed establishment, particularly if unsprayed buffer zones are necessary to protect adjacent habitats. These practices could include mowing, cultivation, or sowing field edges with perennial grasses (Marshall and Moonen 2002; Rew et al. 1992).

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Weed distribution across field boundaries adjacent to roadsides

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Grassy roadside ditches form one of most common types of field boundaries in the Canadian prairies; however, little information is available documenting weed distribution across these boundaries. In 1995, a survey was conducted of 74 ditches adjacent to annual crop fields in conventional and organic farming systems located throughout Saskatchewan. Weeds were assessed along four transects placed perpendicular to the ditch in each field. On each transect, species were identified in eight 1 m by 2 m plots; two in the ditch, one at the boundary of the field and ditch, and five in the field. Weeds were categorized based on abundance in the 1995 Saskatchewan weed survey as: major (ranked 1-50), minor (ranked >50) and non-weedy (not listed in survey). One hundred and fifty-one species were identified in the study including 47 major weeds, 40 minor weeds and 64 non-weedy species. The major weeds tended to be found in all three habitats or in both the boundary and field. Most species found in the ditch only or in both the ditch and boundary were non-weedy. The proportion of weeds found in all three habitats was least in the organic sites, where more weed species were found only in the field or in both the boundary and field, possibly due to different management of the ditches. Of the major weed species identified, 79% were found in the ditch of at least one system. Most perennials were found more frequently in the ditch than the field. Several major weed species, particularly in conventional fields, were most often found at the boundary of fields. Ditches and field boundaries should be monitored as they are potential sources of future infestation and may play a role in maintaining the weed seedbank in the field.

Additional Keywords: farming systems, species diversity, field margins, survey, on-farm research

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Introduction

Field margins are an important part of agroecosystems. The diverse flora found in field margins serves as a sanctuary for beneficial animals (Fry 1994). For example, Povey et al. (1993) showed that small mammals which reside in densely vegetated field margins removed a significant proportion of large weed seeds. Field margins increase the diversity of arthropod populations and have been shown to increase polyphagous predator populations (Largerlof and Wallin 1993). In Europe, the use of unsprayed crop edges is endorsed to promote biodiversity in field margins (de Snoo and Chaney 1999).

Studies in Europe (Marshall 1988, 1989) have shown that margins are a potential source of weeds. Intensive use of herbicides has been associated with increased numbers of weed species in woodlot edges and hedgerows in Québec (Boutin and Jobin 1998). Herbicides, sprayed either purposefully or drifted by accident, may create microsites favourable for the establishment of weeds adjacent to fields (Fielder and Roebuck 1987). Fertilizers may also favour arable weeds (Boatman et al. 1994, Wilson 1999). Once weeds are established in the margin, they may spread back into the field.

On the Canadian prairies, field margins are primarily viewed as a source of weeds; however, little information is available documenting weed distribution across margins. The majority of research on field boundary vegetation originates in Europe (Marshall and Moonen 2002) and, although some work has been done in eastern Canada (Jobin et al. 1997; Boutin and Jobin 1998; Boutin et al. 2001), typical margins in these areas may be expected to be different from those on the Canadian prairies. The Canadian prairies generally receive less precipitation and experience harsher winters than eastern Canada (Ecological Stratification Working Group 1995). Also, the majority of field boundaries on the prairies are relatively new in comparison to those in Eastern Canada and certainly Europe (Marshall and Moonen 2002), as the prairies were more recently settled. Grassy roadside ditches form one of the most common types of field boundaries on the prairies. This paper describes plant diversity and distribution across such boundaries adjacent to fields managed by conventional and organic systems.

Materials and Methods

Study Sites

The margins of 74 fields and adjacent grassy roadside ditches were surveyed. The fields were located on 28 farms situated throughout Saskatchewan (Figure 1), representing each of the four major agricultural ecoregions (Acton et al. 1998). Ecoregions are areas of similar landforms, climate, natural vegetation, soils and land use. The farms followed either an organic (20 fields, 8 farms) or conventional (54 fields, 20 farms) management system. The organic management system was distinguished from the conventional system by the absence of herbicides and chemical fertilizers. The conventional system included both zero and conventional tillage systems. The management systems were described in more detail by Leeson et al. (1999). The fields surveyed were planted to annual cereal, oilseed or pulse crops in the year of the survey. The ditches were at least 8 m wide.

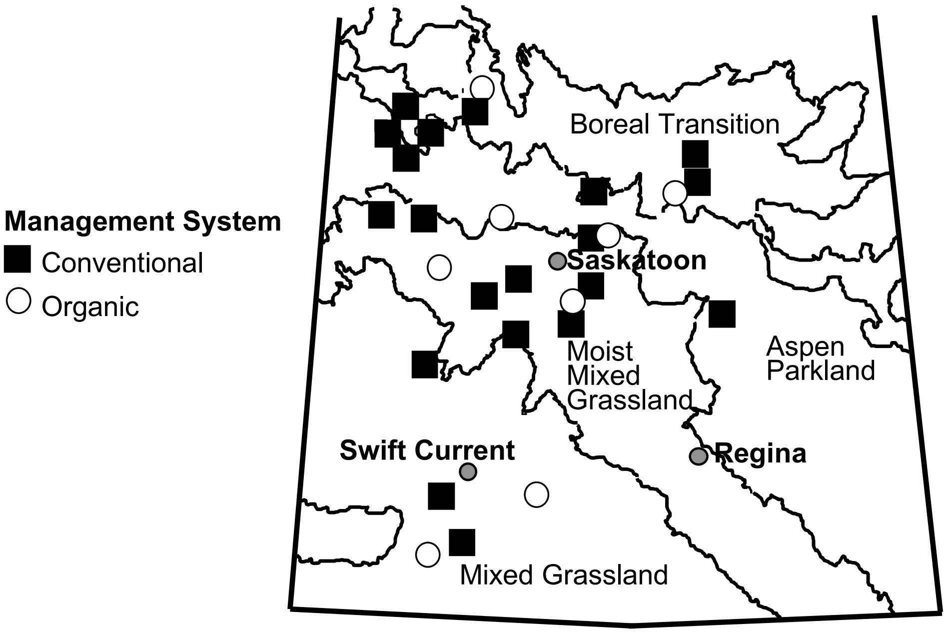

Figure 1. Location of farms in Saskatchewan ecoregions: Boreal Transition, Aspen Parkland, Moist Mixed Grassland and Mixed Grassland.

Survey Methods

Four transects were placed perpendicular to each field boundary, passing through three habitats defined here as: ditch, boundary and field (Figure 2). Each transect consisted of eight plots: two in the ditch, one at the boundary between the ditch and field, and five in the field. The species present in each 1 m by 2 m plot were identified. The survey was conducted from late August to early September 1995.

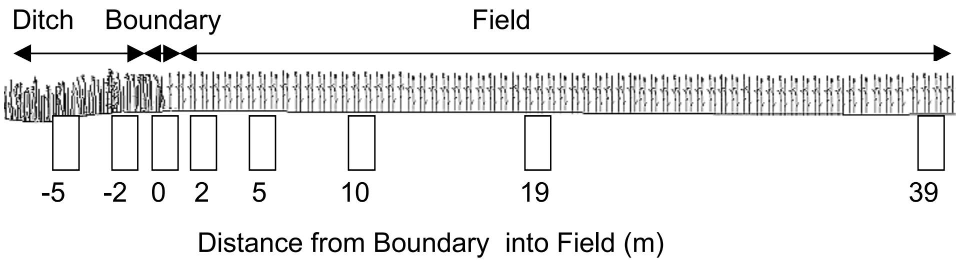

Figure 2. Position of plots on transects relative to boundary of field and the three habitats.

Species Infestation Characterization

Species were categorized based on their relative abundance values as presented in the 1995 Saskatchewan Weed Survey of Cereal, Oilseed and Pulse Crops (Thomas et al. 1996). This provincial weed survey ranked weeds found within 1178 fields based on weed frequency, density and uniformity. Species that ranked amongst the top 50 in Saskatchewan were categorized as major weeds. Other species identified in the provincial survey but not ranked within the top 50 species were considered minor weeds. Species not identified in the provincial survey were considered to be non-weedy.

Species richness was calculated as the average number of species per plot found at each distance along the transects in each field margin. The richness of each category of species was compared between systems using t-tests (Sokal and Rohlf 1995). When the variances were unequal based on an F-test of homogeneity of variances ($P \geq 0.05$), Welch's approximate t-test was used to compare species richness.

The number of species characteristic of each habitat in each system was expressed as a proportion of the total number of species identified in that system. The proportion of species of each category occupying each habitat was compared between management systems using the G-test of independence (Sokal and Rohlf 1995). Williams's correction was used to reduce the chance of a type I error.

Major weeds occurring in at least 10% of the surveyed transects in one of the management systems were grouped into distribution patterns, determined by how often the species occurred in each habitat in each management system, in a similar manner to Marshall (1985) and Joenje and Kleijn (1994). Frequency values were calculated for each species based on the proportion of transects in which each species occurs.

Results and Discussion

Species Richness

One hundred and fifty-one species were identified in the study including 47 major weeds, 40 minor weeds and 64 non-weedy species (see Appendix: Tables A, B and C). One hundred and eleven species were identified in the organic system as compared to 131 in the conventional system. Species found in only one system were generally found at low frequencies.

The species richness in all plots within the field was significantly ($P \leq 0.005$) higher in the organic system than the conventional system (Figure 3). The organic system had significantly more species of major weeds per plot within the field ($P \leq 0.005$). The number of minor weed species found per plot in the field also tended to be higher in the organic system, although the difference was only significant 10 m or further into the field ($P \leq 0.05$). These results were similar to a previous report where greater weed species richness was found in the interior of the organic fields in comparison to conventional fields (Leeson 1998).

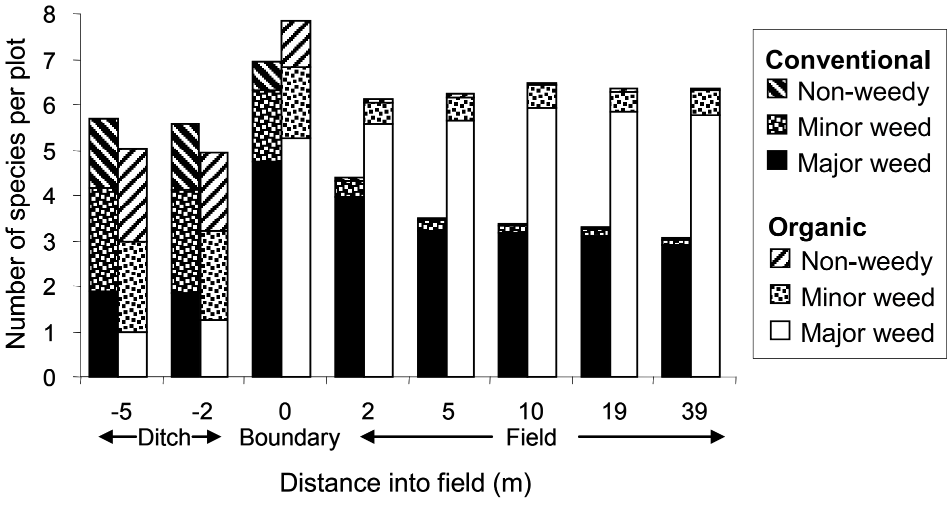

Figure 3. Average species richness at each position along transects.

Total species richness did not significantly differ between systems in the plots in the boundary or ditch (Figure 3). However, the ditches adjacent to conventional fields tended to have more major weed species than the ditches adjacent to the organic system. The difference was significant five meters into the ditch ($P \leq 0.05$). These results are similar to those observed in hedgerows and woodlots in Québec (Boutin and Jobin 1998).

Species Type Distribution

Most species were found either in all three habitats or only in the ditches (Figure 4). The majority of species found in the ditch only or both in the ditch and the boundary were non-weedy. Major weeds tended to be found in all three habitats or in both the boundary and the field.

A significantly higher proportion of species was found in all three habitats in the conventional system than the organic system ($P \leq 0.05$). This may be attributable, in part, to the significantly higher number of minor species found in all three habitats of the conventional field boundaries. On the other hand, the organic fields had a significantly higher proportion of species found only in the field ($P \leq 0.05$). The difference may be attributable to the higher number of major species occurring only in the field ($P \leq 0.05$).

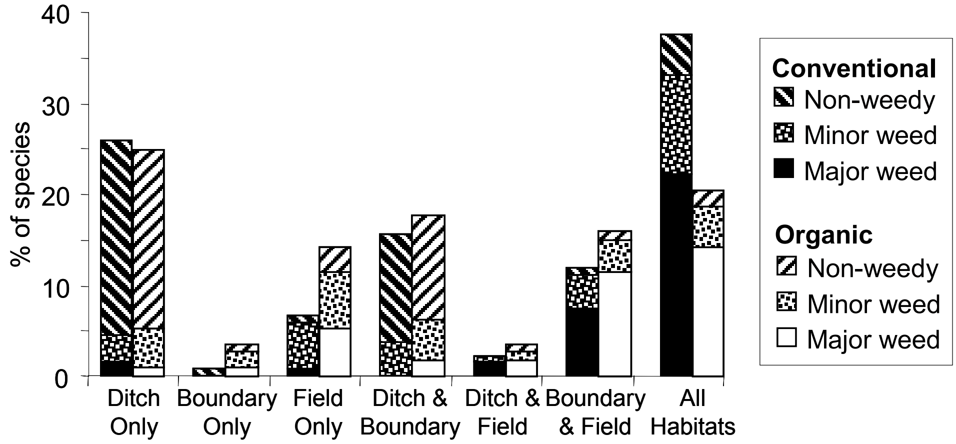

Figure 4. Distribution of species types across field boundaries in conventional and organic systems expressed as a percentage of the total number of species in each system (organic, 111; conventional, 131).

Species Distribution Patterns of Major Weeds

The distribution of the major weed species across the field boundaries were categorized into four distinct occurrence patterns; ditch, boundary and ditch, boundary and field, and field species, based on where they most often occur. These categories differ slightly from those previously defined by Marshall (1985) and Joenje and Kleijn (1994), as very few of the major weed species occurred exclusively in one habitat (Figure 4).

Ditch species. These species were most often found in the ditch but were also found within the field in both systems (Table 1). The common species following this distribution are perennials that tend to reproduce by seed. Dandelion and rose followed similar patterns in the organic and conventional system. American vetch was more common at the boundary of the field than the ditch in the organic system. The reason for this difference is unclear.

Boundary and ditch species. These species were most often found in the boundary and more frequently found in the ditch than the field (Table 1). These species were also perennials but commonly reproduce from rhizomes as well as seed. Quack grass exhibited this distribution in both systems. In the organic system, Canada thistle followed this distribution, although in the conventional system this species followed the boundary and field pattern. However, the frequency of Canada thistle in the conventional system decreased to levels lower than the organic system at 10 m and further into the field. Perennial sow-thistle followed the boundary and ditch pattern in the conventional system, but was rarely found in the ditch in the organic system. However, this species was abundant in the field in the organic system suggesting that the differences in management of margins or adjacent fields associated with these systems may play a role in the establishment of this species in the ditch.

Boundary and field species. These species were most often found in the boundary and more frequently found in the field than the ditch. All of these species, with the exception of redroot pigweed, were also occasionally found in the ditch. These species were generally annuals or winter annuals. Winter annuals and biennials may be expected at the boundary of fields, as this habitat may be less disturbed enhancing chances of survival. Several of the species that followed this distribution in the conventional system tended to be found more often in the field in the organic system. These species were likely readily controlled by herbicide in the conventional fields.

Field species. Field species included volunteer crops and annual grasses most often found in the field habitat. While most of the species were also occasionally found in the ditch, several were isolated to the field and boundary, particularly in the organic system. With the exception of volunteer canola in the conventional system, most volunteer crops were not found in the ditch in either system. In the conventional system, wild oats, green foxtail and volunteer canola were most frequently found 2 m into the field. European studies have also indicated that the abundance of some weed species decreases with increasing distance into the field in intensively managed systems (Marshall 1985, Wilson and Aebischer 1995), while the weed community is not affected by distance from the boundary in organic fields (Dutoit et al. 1999).

Table 1. Frequency (% of transects in system) and distribution pattern of common major weed species identified in each farming system.

		Conventional		Organic	
Common name[a]	Latin name[a]	Pattern[b]	%	Pattern[b]	%
Dandelion	*Taraxacum officinale* G. H. Weber ex Wiggers	D	43.5	D	33.8
Rose species	*Rosa* spp.	D	29.2	D	28.8
American vetch	*Vicia americana* Muhl. ex Willd. var. *americana*	D	21.3	BD	21.3
Quack grass	*Elytrigia repens* (L.) Desv. ex B. D. Jacks	BD	42.6	BD	30.0
Perennial sow-thistle	*Sonchus arvensis* L.	BD	35.6	F	20.0
Canada thistle	*Cirsium arvense* (L.) Scop.	BF	52.8	BD	27.5
Redroot pigweed	*Amaranthus retroflexus* L.	BF[c]	15.3	BF[c]	28.8
Flixweed	*Descurainia sophia* (L.) Webb ex Prantl	BF	22.7	BF	20.0
Kochia	*Kochia scoparia* (L.) Schrad.	BF	19.4	BF	17.5
Biennial wormwood	*Artemisia biennis* Willd.	BF	12.0		2.5
Wild buckwheat	*Polygonum convolvulus* L.	BF	64.8	F	91.3
Lamb's-quarters	*Chenopodium album* L.	BF	47.2	F	97.5
Stinkweed	*Thlaspi arvense* L.	BF	58.8	F	78.8
Russian thistle	*Salsola kali* L. subsp. *ruthenica* (Iljin) Soó	BF	27.8	F	63.8
Wild oats	*Avena fatua* L.	F	55.6	F[c]	76.3
Green foxtail	*Setaria viridis* (L.) P. Beauv.	F	54.2	F	81.3
Volunteer wheat	*Triticum aestivum* L.	F[c]	12.0	F[c]	20.0
Volunteer canola	*Brassica napus* L.	F	26.4		6.3
Shepherd's-purse	*Capsella bursa-pastoris* (L.) Medik.	F	25.9		5.0
Common groundsel	*Senecio vulgaris* L.	F	20.8		1.3
Narrow-leaved hawk's-beard	*Crepis tectorum* L.	F	19.4		5.0
Bluebur	*Lappula squarrosa* (Retz.) Dumort.		6.5	F	38.8
Wild mustard	*Sinapis arvensis* L.		6.9	F[c]	32.5
Volunteer flax	*Linum usitatissimum* L.		6.0	F[c]	25.0
Prostrate pigweed	*Amaranthus blitoides* S. Watson		4.6	F	18.8
Night-flowering catchfly	*Silene noctiflora* L.		9.3	F[c]	13.8
Cow cockle	*Vaccaria hispanica* (Mill.) Rauschert			F[c]	12.5
Prostrate knotweed	*Polygonum aviculare* L.		2.3	F	10.0

[a] Common and botanical names are those listed in Darbyshire et al. (2000).
[b] Distribution pattern: D= ditch, BD= boundary and ditch, BF= boundary and field, F= field
[c] Does not occur in the ditch

Summary

The diversity of non-weedy species was similar in conventional and organic field boundaries, suggesting that beneficial effects of plant diversity in the boundary and ditch would be similar in each system. Organic field margins had a higher diversity of major and minor weeds than conventional field margins; however, ditches adjacent to conventional fields tended to have a higher number of weedy species. Most major weed species found in Saskatchewan fields resided in ditches adjacent to conventional fields. Several major weed species, particularly in conventional fields, were most often found at the boundary of fields. Both these habitats should be monitored as they are potential sources of future infestation and may play a role in maintaining the weed seedbank in the field, particularly in the case of herbicide-resistant weed biotypes (Fogelfors 1985).

The presence of species, usually restricted to fields, in the ditches adjacent to the conventional system may indicate that disturbance has occurred in the ditch, exposing areas where weeds can become established. Further research to determine the cause of the observed differences between management systems would enable recommendations for the reduction of weedy species in ditches.

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Appendix

Table A. Frequency (% of transects in system and overall) of major weed species in each farming system.

Common name[a]	Botanical name[a]	Frequency (%)		
		Conventional	Organic	All
Wild buckwheat	*Polygonum convolvulus* L.	64.8	91.3	72.0
Stinkweed	*Thlaspi arvense* L.	58.8	78.8	64.2
Green foxtail	*Setaria viridis* (L.) P. Beauv.	54.2	81.3	61.5
Wild oats	*Avena fatua* L.	55.6	76.3	61.1
Lamb's-quarters	*Chenopodium album* L.	47.2	97.5	60.8
Canada thistle	*Cirsium arvense* (L.) Scop.	52.8	27.5	45.9
Dandelion	*Taraxacum officinale* G. H. Weber ex Wiggers	43.5	33.8	40.9
Quack grass	*Elytrigia repens* (L.) Desv. ex B. D. Jacks	44.4	30.0	40.5
Russian thistle	*Salsola kali* L. subsp. *ruthenica* (Iljin) Soó	27.8	63.8	37.5
Perennial sow-thistle	*Sonchus arvensis* L.	35.6	20.0	31.4
Rose species	*Rosa* spp.	29.2	28.8	29.1
Flixweed	*Descurainia sophia* (L.) Webb ex Prantl	22.7	20.0	22.0
American vetch	*Vicia americana* Muhl. ex Willd. var. *americana*	21.3	21.3	21.3
Volunteer canola	*Brassica napus* L.	26.4	6.3	20.9
Shepherd's-purse	*Capsella bursa-pastoris* (L.) Medik.	25.9	5.0	20.3
Redroot pigweed	*Amaranthus retroflexus* L.	15.3	28.8	18.9
Kochia	*Kochia scoparia* (L.) Schrad.	19.4	17.5	18.9
Narrow-leaved hawk's-beard	*Crepis tectorum* L.	19.4	5.0	15.5
Common groundsel	*Senecio vulgaris* L.	20.8	1.3	15.5
Prostrate knotweed	*Polygonum aviculare* L.	6.5	38.8	15.2
Volunteer wheat	*Triticum aestivum* L.	12.0	20.0	14.2
Bluebur	*Lappula squarrosa* (Retz.) Dumort.	6.9	32.5	13.9
Wild mustard	*Sinapis arvensis* L.	6.0	25.0	11.1
Prostrate pigweed	*Amaranthus blitoides* S. Watson	9.3	13.8	10.5
Biennial wormwood	*Artemisia biennis* Willd.	12.0	2.5	9.5
Volunteer flax	*Linum usitatissimum* L.	4.6	18.8	8.4
Chickweed	*Stellaria media* (L.) Vill.	9.7	2.5	7.8
Cleavers	*Galium aparine* L.	9.7		7.1
Volunteer barley	*Hordeum vulgare* L.	8.8	2.5	7.1
Volunteer peas	*Pisum arvense* L.	6.5	6.3	6.4
Foxtail barley	*Hordeum jubatum* L.	7.4		5.4
Canada fleabane	*Conyza canadensis* (L.) Cronquist	4.6	6.3	5.1
Hemp-nettle	*Galeopsis tetrahit* L.	6.9		5.1
Tumble pigweed	*Amaranthus albus* L.	5.6	2.5	4.7
Field horsetail	*Equisetum arvense* L.	4.6	5.0	4.7
Night-flowering catchfly	*Silene noctiflora* L.	2.3	10.0	4.4
Round-leaved mallow	*Malva pusilla* Sm.	4.2	1.3	3.4
Cow cockle	*Vaccaria hispanica* (Mill.) Rauschert		12.5	3.4
Pale smartweed	*Polygonum lapathifolium* L.	4.2		3.0
Spiny annual sow-thistle	*Sonchus asper* (L.) Hill	3.7	1.3	3.0
Thyme-leaved spurge	*Euphorbia serpyllifolia* Pers.	3.7		2.7
Corn spurry	*Spergula arvensis* L.	2.3	2.5	2.4
Persian darnel	*Lolium persicum* Boiss. & Hohen. ex Boiss.	0.5	5.0	1.7
Barnyard grass	*Echinochloa crusgalli* (L.) P. Beauv.		3.8	1.0
Dog mustard	*Erucastrum gallicum* (Willd.) O.E. Schultz	0.5	2.5	1.0
Scentless chamomile	*Matricaria perforata* Merat	0.9		0.7
Absinth	*Artemisia absinthium* L.	0.5		0.3

[a] Common and botanical names are those listed in Darbyshire et al. (2000).

Table B. Frequency (% of transects in system and overall) of minor weed species in each farming system.

Common name[a]	Botanical name[a]	Frequency (%)		
		Conventional	Organic	All
Brome species	*Bromus* spp.	90.7	90.0	90.5
Volunteer alfalfa	*Medicago sativa* L.	53.2	32.5	47.6
Kentucky blue grass	*Poa pratenis* L.	39.4	56.3	43.9
Yellow sweet-clover	*Melilotus officinalis* (L.) Pall.	21.8	22.5	22.0
White sweet-clover	*Melilotus albus* Medik.	23.1	13.8	20.6
Blue grass species	*Poa* spp.	19.4	23.8	20.6
Blue lettuce	*Lactuca tatarica* (L.) C.A. Mey. subsp. *pulchella* (Pursh) Stebbins	12.0	5.0	10.1
Volunteer lentils	*Lens culinaris* Medic.	2.8	22.5	8.1
Goat's-beard	*Tragopogon dubius* Scop.	6.5	11.3	7.8
Russian pigweed	*Axyris amaranthoides* L.	6.9	1.3	5.4
Black medick	*Medicago lupulina* L.	5.6	5.0	5.4
Red clover	*Trifolium pratense* L.	3.2	11.3	5.4
Cream-colored vetchling	*Lathyrus ochroleucus* Hook.	2.8	6.3	3.7
Broad-leaved plantain	*Plantago major* L.	2.8	5.0	3.4
Wild tomato	*Solanum triflorum* Nutt.	2.8	5.0	3.4
Prickly lettuce	*Lactuca serriola* L.	3.7	1.3	3.0
Sticky willowherb	*Epilobium ciliatum* Raf.	3.2	1.3	2.7
Sunflower	*Helianthus annuus* L.	3.7		2.7
Skeletonweed	*Lygodesmia juncea* (Pursh) D. Don ex Hook.	2.8	2.5	2.7
Pineappleweed	*Matricaria discoidea* D.C.	3.2	1.3	2.7
Water smartweed	*Polygonum amphibium* L. subsp. *laevimarginatum* Hultén	1.9	5.0	2.7
Wormseed mustard	*Erysimum cheiranthoides* L.	2.8	1.3	2.4
Common pepper-grass	*Lepidium densiflorum* Schrad.	1.9	2.5	2.0
Rough cinquefoil	*Potentilla norvegica* L.	2.8		2.0
Volunteer fall rye	*Secale cereale* L.	1.9	2.5	2.0
Tall meadow-rue	*Thalictrum dasycarpum* Fisch. & Lall.	2.8		2.0
Wood whitlow-grass	*Draba nemorosa* L.	2.3		1.7
Tumble mustard	*Sisymbrium altissimum* L.	0.9	3.8	1.7
Gumweed	*Grindelia squarrosa* (Pursh) Dunal		5.0	1.4
Ball mustard	*Neslia paniculata* (L.) Desv.		5.0	1.4
Drummond's milk vetch	*Astragalus drummondii* Douglas ex Hook.	1.4		1.0
American dragonhead	*Dracocephalum parviflorum* Nutt.	0.9	1.3	1.0
Bicknell's geranium	*Geranium bicknellii* Britton	0.5	2.5	1.0
Volunteer white mustard	*Sinapis alba* L.	1.4		1.0
Manitoba maple	*Acer negundo* L.		2.5	0.7
Purple milk-vetch	*Astragalus agrestis* Douglas ex G. Don	0.9		0.7
Low cudweed	*Gnaphalium uliginosum* L.	0.9		0.7
Curled dock	*Rumex crispus* L.	0.5	1.3	0.7
Striate knotweed	*Polygonum achoreum* S.F. Blake	0.5		0.3
Aspen poplar	*Populus tremuloides* Michx.	0.5		0.3

[a] Common and botanical names are those listed in Darbyshire et al. (2000).

Table C. Frequency (% of transects in system and overall) of species that are non-weedy in each farming system.

Common name[a]	Botanical name[a]	Frequency (%) Conventional	Organic	All
Goldenrod species	*Solidago* spp.	28.2	45.0	32.8
Crested wheat grass	*Agropyron cristatum* (L.) Gaertn.	20.4	38.8	25.3
Common yarrow	*Achillea millefolium* L.	14.8	17.5	15.5
Northern bedstraw	*Galium boreale* L.	14.4	15.0	14.5
Western snowberry	*Symphoricarpos occidentalis* Hook.	18.1	5.0	14.5
Lindley's aster	*Aster ciliolatus* Lindl.	15.3	8.8	13.5
Many-flowered aster	*Aster ericoides* L. var. *pansus* (S. F. Blake) B. Boivin	10.6	20.0	13.2
Willow aster	*Aster hesperius* A. Gray	10.2	8.8	9.8
Wild strawberry	*Fragaria virginiana* Mill.	6.9	11.3	8.1
Golden-bean	*Thermopsis rhombifolia* (Nutt. ex Pursh) Nutt. ex Richardson	6.9	5.0	6.4
Timothy	*Phleum pratense* L.	6.0	5.0	5.7
Prairie sage	*Artemisia ludoviciana* Nutt.	7.4		5.4
Early blue violet	*Viola adunca* J. E. Smith	6.9	1.3	5.4
Small-leaved everlasting	*Antennaria parvifolia* Nutt.	5.6	3.8	5.1
Hairy golden-aster	*Chrysopsis villosa* (Pursh) Nutt.	6.9		5.1
Sandbar willow	*Salix exigua* Nutt.	3.2	10.0	5.1
Flodman's thistle	*Cirsium flodmanii* (Rydb.) Arthur	2.8	5.0	3.4
Pasture sage	*Artemisia frigida* Willd.	3.2	2.5	3.0
Collomia	*Collomia linearis* Nutt.	4.2		3.0
Low everlasting	*Antennaria aprica* Greene	2.3	2.5	2.4
Scouring-rush	*Equisetum hyemale* L.	0.9	6.3	2.4
Pygmyflower	*Androsace septentrionalis* L.	1.4	3.8	2.0
Volunteer coriander	*Coriandrum sativum* L.	2.8		2.0
Hooker's oat grass	*Helictotrichon hookeri* (Scribn.) Henr.	2.3		1.7
Umbellate hawkweed	*Hieracium umbellatum* L.	1.4	2.5	1.7
Sweet grass	*Hierochloe odorata* (L.) Beauv.		6.3	1.7
Bearberry	*Arctostaphylos uva-ursi* (L.) Spreng.	0.5	3.8	1.4
Harebell	*Campanula rotundifolia* L.	0.5	3.8	1.4
Philadelphia fleabane	*Erigeron philadelphicus* L.	1.9		1.4
Volunteer buckwheat	*Fagopyrum esculentum* Moench		5.0	1.4
Balsam poplar	*Populus balsamifera* L. subsp *balsamifera*	1.9		1.4
Willow species	*Salix* spp.	0.5	3.8	1.4
Canada anemone	*Anemone canadensis* L.	0.9	1.3	1.0
Plains wormwood	*Artemisia campestris* L. var. *scouleriana* (Bess.) Cronq.	1.4		1.0
Linear-leaved wormwood	*Artemisia dracunculus* L.	1.4		1.0
Rayless aster	*Brachyactis ciliata* (Ledeb.) Ledeb. subsp. *angusta* (Lindl.) A.G. Jones		3.8	1.0
Black mustard	*Brassica nigra* (L.) W.D.J. Koch		3.8	1.0
Wooly sedge	*Carex lanuginosa* Michx.		3.8	1.0
Bastard toadflax	*Comandra umbellata* (L.) Nutt. subsp. *umbellata*	0.5	2.5	1.0
Wild licorice	*Glycyrrhiza lepidota* Pursh	1.4		1.0
Back's sedge	*Carex backii* Boott		2.5	0.7
Sedge species	*Carex* spp.	0.9		0.7
Green tansy mustard	*Descurainia pinnata* (Walter) Britton subsp. *brachycarpa* (Richardson) Detling	0.9		0.7
Rush species	*Juncus* spp.	0.9		0.7

Table continued on next page

Table C. Frequency (% of transects in system and overall) of species that are non-weedy in each farming system. *(continued)*

Common name[a]	Botanical name[a]	Frequency (%) Conventional	Organic	All
Two-leaved Solomon's-seal	*Maianthemum canadense* Desf. var. *interius* Fern	0.9		0.7
Silverweed	*Potentilla anserina* L.	0.5	1.3	0.7
Spangletop	*Scholochloa festucacea* (Willd.) Link.	0.9		0.7
Poison suckleya	*Suckleya suckleyana* (Torr.) Rydb.		2.5	0.7
Giant-hyssop	*Agastache foeniculum* (Pursh) Kuntze		1.3	0.3
Purple rock cress	*Arabis divaricarpa* A. Nels.	0.5		0.3
Atriplex species	*Atriplex* spp.	0.5		0.3
Field chickweed	*Cerastium arvense* L.	0.5		0.3
Silverberry	*Elaeagnus commutata* Bernh. ex Rydb.	0.5		0.3
Red fescue	*Festuca rubra* L. var. *rubra*		1.3	0.3
American hedysarum	*Hedysarum alpinum* L. var. *americanum* Michx.		1.3	0.3
Baltic rush	*Juncus balticus* Willd.		1.3	0.3
Yellow evening-primrose	*Oenothera biennis* L.	0.5		0.3
White evening-primrose	*Oenothera nuttallii* Sweet	0.5		0.3
Locoweed species	*Oxytropis* spp.		1.3	0.3
Witch grass	*Panicum capillare* L.	0.5		0.3
Fowl-meadow grass	*Poa palustris* L.		1.3	0.3
Creeping yellow cress	*Rorippa sylvestris* (L.) Besser		1.3	0.3
Wild red raspberry	*Rubus idaeus* L. subsp. *melanolasius* (Dieck) Focke	0.5		0.3
Field dock	*Rumex pseudonatronatus* (Borbás) Murb.		1.3	0.3

[a] Common and botanical names are those listed in Darbyshire et al. (2000) or Looman and Best (1979).

Riparian vegetation reduces spray drift deposition into water bodies

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Spray drift deposition into water bodies may pose environmental and health hazards, and buffer zones have been suggested as a means of mitigating water contamination. Current models for calculating buffer zone distances do not account for application method or the presence of vegetative barriers between the application site and the sensitive area. Field trials were conducted to determine the effect of nozzle type and riparian vegetation on spray drift deposition into wetlands. Three riparian vegetative types, minimal vegetation (grass), low vegetation (willow shrubs), and high vegetation (aspen trees) were compared with open field conditions. Spray was released upwind of wetlands with these riparian characteristics with conventional and air-induced low-drift nozzles. Spray drift deposits were collected in petri-plates that were arranged in three parallel rows up to 46 m downwind of the spray swath. Deposits were analyzed using fluorescence spectrophotometry. Results indicated that the log of drift deposit followed a linear relationship with the log of distance downwind. Low-drift nozzles reduced drift deposits by about 75% in the absence of any vegetation, and by 88 to 99% when vegetation was present. Dense willow shrubs resulted in anomalous downwind deposits, possibly because of air turbulence caused by low porosity characteristics. By considering vegetation effects, a 15-m buffer zone could be reduced to 5 to 7 m for conventional, and 1 to 4 m for low-drift nozzles without increasing deposits at the edge of the sensitive habitat. Based on these findings, it is expected that contamination of water bodies by airborne spray drift could be significantly reduced by maintaining appropriately vegetated riparian zones and using low-drift nozzles. Both variables should be considered by regulatory bodies in their risk assessment procedures.

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Additional Keywords: low-drift nozzles, buffer zones, wetlands, pesticides

Introduction

Airborne transport is an important vector for movement of pesticides from agricultural land to receiving waters. In an effort to maintain low pesticide levels in water bodies in accordance to risk assessment protocols, the Pest Management Regulatory Agency (PMRA) is mandating minimum setback distances (buffer zones) from water bodies during a spray operation. Several additional variables can complement buffer zones in preventing spray drift, including low-drift sprays and riparian vegetation. Germany and the United Kingdom already account for these characteristics in their buffer zone regulations (Kappel and Taylor 2002).

Vegetation has been shown to be effective at mitigating droplet spray drift in several recent studies and reviews (Richardson et al. 2002, Hewitt 2001, Ucar and Hall 2001) by reducing wind velocities and intercepting spray. The documented magnitude of the spray drift deposit reduction in these studies ranges from 50 to >95%, dependent on a number of variables that include vegetation height, porosity and orientation relative to wind direction, and wind speed.

In this project, the integrated effect of buffer zones, vegetative barriers, and low-drift sprays was investigated to determine the overall impact of spray drift deposition onto downwind water bodies. From this work Beneficial Management Practices that integrate various complementary or interchangeable strategies to protect water bodies from pesticide drift can be developed. These can ultimately be considered for inclusion in buffer zone policies.

Materials and Methods

Overview and Site Description

This study was conducted in 2001 on a farm field near Aberdeen, SK. Sprays were applied upwind of a water body, and drift deposits were collected on petri-plates placed near ground level. To examine the influence of riparian vegetation characteristics on spray drift, experimental sites were chosen to represent different vegetation heights and types around the body of water in question: low (uncut grass), intermediate (willow shrubs), and tall (aspen trees). These were compared to nearby open-field conditions. Two sprayer nozzle types were used in the study: conventional flat fan nozzles and venturi-type low-drift nozzles.

The grass barrier was comprised of a mix of grasses dominated by brome (*Bromus* spp.) growing to a height of 75 cm. Willows (*Salix* spp.) were approximately 3 m tall with a density of about 0.15 m^{-2} and presented a fully foliated barrier for their full height. Willows extended for a width of about 7 m toward the edge of the water body. Aspen poplar (*Populus tremuloides* Michx.) were approximately 8 m tall, with foliation beginning 1.5 m above ground. Trees were present at a density of about 0.25 m^{-2}, and extended for 8 m toward the water edge.

Spray Equipment and Application Method

A Melroe Spra-Coupe 220[1] was used to make the applications. This sprayer was equipped with conventional flat fan nozzles (XR8003[2]) and air-induced low-drift nozzles (TD11003[3]). A pre-orifice design in air-induced nozzles reduces internal spraying pressure, and an internal jet draws air into the mix. This produces a very coarse spray that has been the subject of considerable study for both drift reduction and good pesticide efficacy (Wolf, 2000). The spray boom was 10 m wide and nozzles were 75 cm above ground.

Prior to application, all nozzles were calibrated by collecting the output from each tip for 30 s and recording the output. Nozzles with an output that deviated from the mean by more than 5% were replaced. Pressures were slightly adjusted so that both nozzle types had the identical flow rates, and travel speed could be kept constant. Final spray pressures were about 275 kPa for both nozzles. Sprayer travel speed was 12.9 km h^{-1}, at which the application volume was 100 L ha^{-1}.

The sprayer had a stainless steel tank with three compartments that contained a mixture of 2,4-D amine[4] (4 g L^{-1}) and Rhodamine WT[5] (2 mL L^{-1}), a fluorescent tracer dye which would be used to quantify the deposits. 2,4-D acted to photostabilize the dye, and also provided a spray formulation with physico-chemical properties representative of agricultural pesticides.

Application was made in a direction approximately perpendicular to the prevailing wind, with the downwind edge of the spray boom at the edge of the wetland's riparian vegetation. This was usually about 15 m upwind of the edge of the water body (due to severe drought conditions, the wetland did not contain any water at the time of the trials). Three consecutive passes were made along the same swath in a 10-min period to obtain average meteorological conditions for all three vegetation types. Wind speed and direction, temperature and relative humidity were monitored during application using a portable micrometeorological station.

Sampler Layout

Downwind of the spray swath, there were 3 parallel lines of eleven 15-cm diameter glass petri-plate samplers starting underneath the sprayer boom and extending 46 m downwind from the edge of the spray swath (Figure 1). Samplers were separated by 5 m within the line, and lines were about 2 m apart.

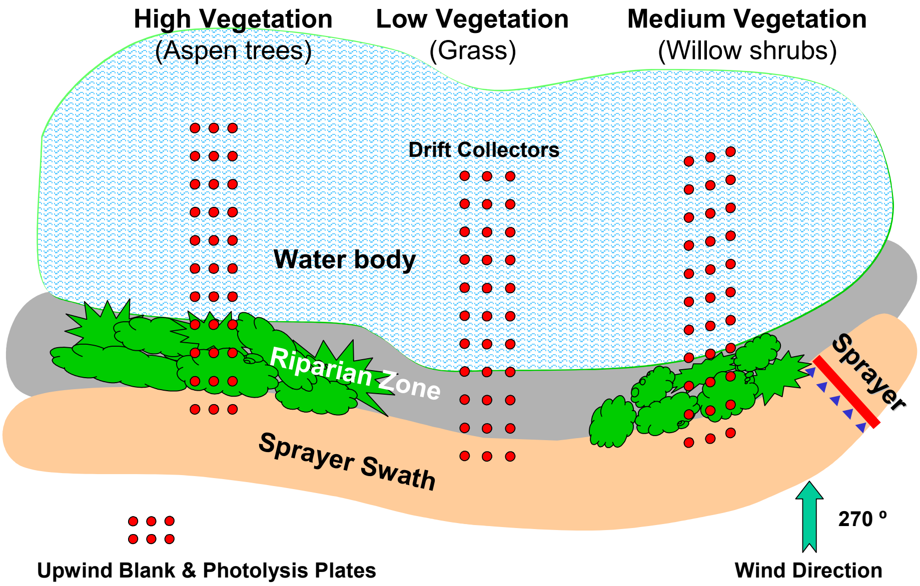

Figure 1. Petri-plate sampler layout at field site (not to scale). Sampler separations were 5 m within each row, and rows were 2 m apart.

There were four samplers upwind of the wetland: The first sampler was directly underneath the sprayer boom, the second to fourth samplers were in the riparian zone. The remaining seven samplers were positioned in the wetland, placed at about the level of grass vegetation in the wetland (30 cm above ground) on 5 cm square wooden stakes.

The deposition profile was also assessed under open field conditions, using the same sampler layout but on cropland with no riparian vegetation. These are referred to as 'bare soil, or 'reference' samplers in this report and served as a baseline to determine the impact of the riparian vegetation. Three of these sampler lines were dry petri-plates while a fourth row of plates containing water was added to simulate a water body. Deposits into the two sampler types were compared to determine the effect of water in the sampling dish on spray deposit collection efficiency (data not shown).

Photolysis was quantified during these trials. At the time of spraying, additional petri-plates containing standard amounts of the spray mixtures (10 μL dispensed as about 100 small droplets) were either exposed to sun or left in the dark, upwind of the drift trial. When spraying was completed and all plates were picked up and placed in the dark, these photolysis samplers were also returned to the dark. Comparison of these with the standards that had remained in the dark permitted quantification of photolysis during the trials as well as recovery efficiencies of the wash procedure. All data were adjusted for photolysis documented during the trial procedure. Blank plates were placed upwind of the trial area to quantify background deposits.

Sample Collection and Analysis

Sample collection began 5 minutes after spray application was complete (See Table 2 for trial times). Beginning with the furthest downwind locations, petri-plates were covered with a plastic lid, and placed into dark boxes. Water samples were immediately transferred into amber bottles and stored in a cool location upon return to the laboratory. Spray deposits on the samplers were washed off in the laboratory using 95% ethanol in three 15-mL washes. Final samples were made up to 50 mL and two 20-mL sub-samples were collected in borosilicate vials and stored in the dark.

Within 24 h, subsamples were analyzed using a fluorescence spectrophotometer with excitation and emission wavelengths of 545 and 570 nm, respectively (Shimadzu Model RF-1501 spectrofluorometer equipped with Model ASC-5 auto-sampler[6]). Instrument readings were converted to $\mu g\ L^{-1}$ using standard curves, and expressed as a percent of the applied dosage under the field sprayer.

Data Reduction

The fluorescence spectrophotometer data were averaged over the three replicate sampling lines, adjusted for photolysis, and expressed as a percentage of the amount applied on-swath. Relationships of spray drift deposits with downwind distance were first visualized by plotting all data points, and then mathematically related through appropriate regression techniques.

Results

Recoveries and Photolysis

Overall recoveries of Rhodamine WT from petri-plates with a 95% ethanol wash were greater than 95% for these trials (data not shown). The extent of photolysis depended on the weather conditions during the trial. Due to prevailing cloudy conditions and/or low solar azimuth angles for most trials, photolysis averaged below 15%. For Trial 3, photolysis was 29% (Table 1).

Table 1. Rhodamine recovery from fortified upwind photolysis samples and deposits on upwind background samplers during trials.

	Rhodamine recovery (%)					
	Aug. 29, XR8003		Aug. 29, TD11003		Sept. 5, XR8003	
Samples	**Mean**	**S.D.**	**Mean**	**S.D.**	**Mean**	**S.D.**
Tank Charge Spikes	98.6	4.4	89.2	6.0	71.0	2.9
Background Blanks	-0.1	0.2	-0.2	0.0	0.1	0.1

	Sept. 5, TD11003		Sept. 20, XR8003		Sept. 20, TD11003	
Samples	**Mean**	**S.D.**	**Mean**	**S.D.**	**Mean**	**S.D.**
Tank Charge Spikes	91.3	3.0	88.2	9.4	98.5	2.3
Background Blanks	0.1	0.0	-		-	

Meteorological Conditions

Weather conditions were favourable during the trials. Wind speed and direction were appropriate for the sampler layout and the experimental objectives. Mean wind direction varied by up to 44º from the ideal (270º) in 6 out of 12 trials, and was within 30º for the remaining 6 trials (Table 2). Mean wind velocities were consistently between about 17 and 21 km h^{-1} in all but one trial. Air temperature and relative humidity fluctuated between 14 to 22º C and 31 to 80%, respectively, on the trial dates.

Table 2. Meteorological conditions during the drift trials.

Trial	Type	Nozzle	Date	Start Time	Wind speed (km)	Wind direction (º)	Temp (Cº)	RH (%)
1	Vegetation	XR8003	29-Aug-01	9:58	18.4	290	16.1	79.6
2	Vegetation	TD11003	29-Aug-01	11:11	19.8	305	17.7	67.5
3	Vegetation	XR8003	05-Sep-01	12:48	16.6	314	21.2	31.1
4	Vegetation	TD11003	05-Sep-01	13:14	18.3	306	21.5	31.1
5	Vegetation	XR8003	20-Sep-01	13:03	17.3	309	14.3	66.2
6	Vegetation	TD11003	20-Sep-01	13:31	16.5	298	14.6	65.5
7	Bare soil	XR8003	29-Aug-01	10:22	17.6	290	16.8	76.3
8	Bare soil	TD11003	29-Aug-01	10:38	19.0	301	17.2	72.0
9	Bare soil	XR8003	05-Sep-01	13:55	18.6	315	21.5	30.7
10	Bare soil	TD11003	05-Sep-01	14:17	21.4	311	21.7	31.4
11	Bare soil	XR8003	20-Sep-01	14:09	19.1	285	15.2	62.2
12	Bare soil	TD11003	20-Sep-01	14:39	13.3	272	16.4	58.8

Deposition Profiles

A visual review of the raw data suggested that a linear regression of the log of deposit amount and log of downwind distance would be appropriate. It was noted that for willow, the deposit profile tailed upwards after the 26 m mark. Based on a survey of the site, it was concluded that this tail was probably caused by the length of the spray pass exceeding the length of protection offered by vegetation. In other words, beyond the 26 m sample, drift had not been attenuated by a vegetative barrier. It is also possible that the airflow was deflected up over the low, non-porous barrier and returned to ground level beyond the 26 m distance (Carter et al. 2001).

As a result of the questionable data for this vegetation type, it was decided that it would be misleading to include the furthest downwind data points. Implications of this observation will be discussed later in the manuscript. The regression and its parameters are shown in Table 3 and Figure 2. All regressions were statistically significant, explaining between 61 and 99% of the observed variation. In five of eight trials, more than 90% of variation was explained.

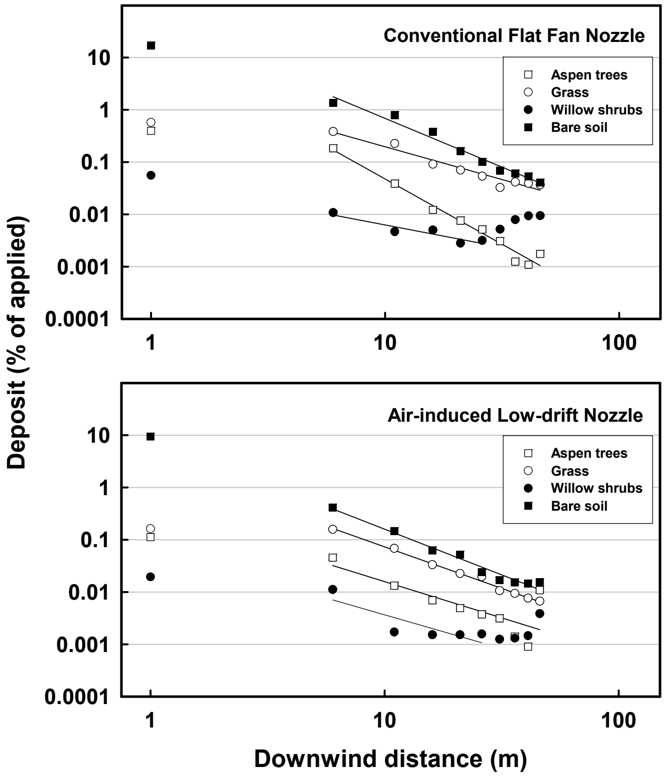

Figure 2. Deposit profiles of spray drift from two application systems and four vegetation types. The deposition data for the willow were regressed from 6 to 26 m, all others were taken to 46 m (see text for explanation).

Drift Mitigation by Riparian Vegetation and Application Method

The predicted drift deposit at 15 m was calculated for all trials based on the regression parameters (Table 3). For the conventional sprayer on bare soil, the deposit amount was 0.322% of the applied dose. The distance at which this specific deposit amount would be achieved was then calculated for all other trials. This value is the buffer zone distance at which equivalent protection to the reference system was offered. Buffer zones could therefore be reduced by 55% (grass), 99% (willow) and 69% (aspen) using the conventional nozzle and 56% (bare soil), 74% (grass), 98% (willow) and 92% (aspen) for the low-drift nozzle.

Table 3. Regression parameters for log spray drift deposits and log downwind distance.

		Regression (log deposit = a+b*log distance)				Predicted deposit at 15 m	Distance at 0.322% deposit	Buffer zone reduction
Nozzle	**Barrier**	**Distance**	**Intercept**	**Slope**	r^2	**(% of applied)**	**(m)**	**(% from reference)**
XR8003	**Bare Soil**	6-46 m	1.704	-1.867	0.975	**0.322**	15.0	0.0
	Grass	6-46 m	0.546	-1.254	0.942	0.118	6.7	55.1
	Willow	6-26 m	-1.345	-0.856	0.878	0.004	0.1	99.3
	Aspen	6-46 m	1.178	-2.500	0.974	0.017	4.7	69.0
TD11003	**Bare Soil**	6-46 m	0.946	-1.745	0.973	0.078	6.7	55.5
	Grass	6-46 m	0.451	-1.586	0.992	0.039	3.9	73.8
	Willow	6-26 m	-1.151	-1.286	0.723	0.002	0.3	98.0
	Aspen	6-46 m	-0.415	-1.387	0.608	0.009	1.1	92.4

The calculated buffer zone reductions were not equivalent to the observed drift reductions due to the unique regression slopes of each deposition line. For example, expected drift deposits at 15 m downwind on bare soil were reduced by 77% when the air-induced low-drift nozzles were used (Table 4), whereas buffer zone distances could only be reduced by 56% (Table 3). Furthermore, the effectiveness of the grass vegetation diminished with distance, reducing drift by 64, 50, and 28% at distances of 15, 25, and 45 m, respectively. Therefore, a complete deposition profile will be required for each vegetation scenario to adjust buffer zones accurately.

Riparian vegetation was typically more effective than low-drift nozzles in protecting water bodies from drift deposition. While grass reduced deposition by 28 to 64% from the conventional nozzle (depending on the downwind distance), willow and aspen reduced deposition by between 95 and 99% (Table 4). The willow was not considered at further distances since the data used for the regression were truncated at 26 m. Low-drift sprays provided some additional protection in all cases except for trees at the 45 m distance, where deposits increased slightly relative to the conventional spray.

Table 4. Drift deposits expressed as a percent of the reference deposition line for two application methods, four vegetation types, and three downwind distances. All numbers are the mean of three separate experiments on the same location.

		Downwind Distance					
		15 m		25 m		45 m	
Nozzle	**Vegetation**	**% Reduction**	**% Reduction (XR basis)**	**% Reduction**	**% Reduction (XR basis)**	**% Reduction**	**% Reduction (XR basis)**
XR8003	**Bare Soil**	0.0		0.0		0.0	
	Grass	63.5		50.1		28.4	
	Willow	98.6		97.7		-[1]	
	Aspen	94.6		96.1		97.3	
TD11003	**Bare Soil**	0.0	76.7	0.0	74.1	0.0	72.2
	Grass	51.8	88.0	46.7	86.2	41.4	83.7
	Willow	97.2	99.3	96.5	99.1	-[1]	-[1]
	Aspen	88.5	97.2	86.2	96.4	83.0	95.3

[1] Data for regression extended only to 26 m downwind

Discussion

The aerodynamics of vegetative barriers are a complex phenomenon. Wind, upon reaching a solid barrier, is diverted up and over giving strongly turbulent conditions on the leeward side and a rapid return to free wind speed. For a permeable barrier like a hedge, the return to free wind speed is more gradual since some air filters through, reducing the pressure differential and allowing for less turbulence (Davis et al. 1994). Wind speed reduction is most pronounced for a distance of 5 H upwind and 30 H downwind at the 1 H height, where H is the height of the barrier (Rider 1951). Nonetheless, there may still be an upward diversion of air (and spray drift) that may simply delay, not eliminate, sedimentation (Hewitt 2001, Ucar and Hall 2001), particularly for dense hedges (Carter et al. 2001). However, Richardson et al. (2002) did not notice such a deflection up to 10 m height.

The reduction in drift deposition by riparian vegetation in this study is clearly significant, but is subject to some interpretation. These data were generated at a single site, and while this site was carefully selected to be representative and trials were repeated three times, it does not necessarily constitute an average result. There are clearly many possible arrangements of trees, shrubs and grass, and additional vegetative or landscape features that would influence drift deposition behaviour. However, due to the consistent nature of the data of this study, some confidence is attained in that the numbers are at least reliable for the given set of conditions. In this study, three spray passes were made along the same swath at the edge of the water body. Results could have been different had adjacent spray swaths been used, owing to the possible change in contribution of upwind swaths with the altered airflows under vegetated conditions.

Since the water body was dry, additional grass vegetation that had grown up could have made an effective collector of spray drift, possibly reducing deposit values beyond those that would have occurred in a water body. It is recommended that efforts be made to repeat these studies when water is present at normal values.

The mitigating effect of vegetation depends on the aerodynamic features of the vegetation, as well as the collection efficiency of their leaves, twigs, etc. This poses some difficulties because there are no absolute measures of these features. Permeability, for example, varies with wind speed owing to the movement of leaves, and winds speed itself varies with height (Davis et al. 1994). Collection efficiency of the vegetation varies similarly with target size, its movement, wind speed, and droplet size spectrum (Hewitt 2001). However, there are opportunities for improved characterization with specialized equipment, such as that used by Richardson et al. (2002). Their LIDAR instrument was able to help calculate tree height and width, mean area index and mean area density. Further work to characterize vegetation will prove useful in future efforts to understand its mitigating potential.

Low vegetation, such as grass, has not received the recent attention of hedges and trees, but it also has been documented to reduce spray drift significantly. A study by Miller et al. (2000) documented significant reductions in airborne drift concentrations above uncut grass canopies, even at low plant densities. Bache (1980) documented similar reductions in spray drift when sprays were applied over a mature wheat crop compared to bare soil. Therefore, the filtering effects of "low" canopies may be very significant and should be the subject of further study.

Riparian areas are regions of high biological activity and diversity, not only protecting adjacent water from outside influence, but also providing food and shelter for many species of wildlife. These areas must themselves be protected from harmful effects, which can include pesticides. Their efficient capture of sprays suggests some risk from pesticides capable of controlling perennial vegetation. Likewise, pesticide residues in this vegetation have the potential to be ingested by wildlife or be washed off with precipitation, resulting in movement into the water body. These effects must be considered when using vegetation to mitigate airborne drift.

Conclusions and Recommendations

- Vegetative barriers reduced spray drift deposition from conventional or low-drift nozzles into water bodies by 24 to 99%.
- Low-drift sprays reduced deposition by about 75%.
- Of the vegetation types, shrubs and trees had similar effects, reducing deposition from open-field conditions by an average of more than 95%. Low-drift sprays improved on this reduction.
- Calculated buffer zone reductions were less than drift deposit reductions. Accurate determination of buffer zone distances requires that the entire deposition profile be characterized.
- It is suggested that both riparian vegetation and sprayer technologies are important components of water body protection. Both should be considered in BMP and regulation development whenever the impact of pesticide applications near water bodies is to be estimated or mitigated.

Sources of Materials

[1] AGCO Corporation, 4205 River Green Parkway, Duluth, GA 30096
[2] Spraying Systems Co, P.O Box 7900, Wheaton, IL 60189-7900
[3] Greenleaf Technologies, P.O. Box 1767, Covington, LA 70434
[4] Nufarm Agriculture Inc. 5507 1st Street SE, Calgary, AB T2H 1H9
[5] Keystone Aniline Corp., 2501 W. Fulton Street, Chicago, IL 60612
[6] Shimadzu Instruments, Inc., Columbia MD 21046

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Index

This is the first volume of *Topics in Canadian Weed Science* published by the Canadian Weed Science Society - Société canadienne de malherbologie (CWSS-SCM). The chapters in this volume are based on papers and posters presented at a symposium entitled *Field Boundary Habitats: Implications for Weed, Insect, and Disease Management in Canada* held during the inaugural meeting of CWSS-SCM in Saskatoon, Saskatchewan in November 2002. The symposium provided a forum for members of CWSS-SCM to explore this multidisciplinary topic and hear the viewpoints of researchers, regulators, managers, consultants, and farmers. Field boundary habitats are ubiquitous features of the agricultural landscape that have received very little research attention in most of Canada. The chapters reflected the structural diversity of field boundary habitats in the Canadian agricultural landscape and emphasized the complexity of pest management in relation to these habitats. The symposium highlighted the need to clarify the terms used to describe field boundary habitats in Canada. Understanding the role of field margins in maintaining species and habitat diversity, protecting sensitive areas, preserving air and water quality, and reducing soil erosion, while managing weed, insect and disease pests, will continue to be a challenge in Canada.

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