SOPHIE ROCHEFORT

IMPACT DE DIFFÉRENTS TYPES D'ENTRETIEN DE PELOUSES SUR L'ABONDANCE ET LA DIVERSITÉ DES ARTHROPODES, ET POTENTIEL DES GRAMINÉES ENDOPHYTIQUES DANS LA LUTTE AUX INSECTES RAVAGEURS

Thèse présentée
à la Faculté des études supérieures de l'Université Laval
dans le cadre du programme de doctorat en biologie végétale
pour l'obtention du grade de Philosophiae Doctor (Ph.D)

DÉPARTEMENT DE PHYTOLOGIE
FACULTÉ DES SCIENCES DE L'AGRICULTURE ET DE L'ALIMENTATION
UNIVERSITÉ LAVAL
QUÉBEC

2006

Résumé

Les surfaces gazonnées constituent des écosystèmes importants de notre environnement urbain, mais leur écologie a été très peu étudiée au Québec. Le type d'entretien des pelouses peut influencer grandement la stabilité du milieu en affectant les interactions entre les communautés d'arthropodes. Ce projet de doctorat visait d'abord à caractériser les communautés d'arthropodes, et plus particulièrement les collemboles et les carabes. Par la suite, l'effet de différents programmes phytosanitaires sur les arthropodes a été évalué. Sur une période de trois ans, les arthropodes de deux surfaces gazonnées, une pelouse nouvellement établie et une pelouse établie depuis une dizaine d'années ont été échantillonnés. Quatre types d'entretien de pelouse ont été testés soit : i-entretien sans contrôle des organismes nuisibles (témoin), ii-entretien avec pesticides de synthèse, iii-entretien avec l'approche de lutte intégrée et iv-entretien écologique. Dans un autre volet, le potentiel des graminées endophytiques pour lutter contre un insecte nuisible, la punaise velue, a été évalué. À partir d'expériences au champ, la survie de ces graminées et de leur endophyte aux hivers québécois a d'abord été déterminée. Par la suite, des expériences en serres ont permis de déterminer le potentiel de différentes combinaisons de ray-grass endophytiques et de pâturin du Kentucky sur la survie de la punaise velue.

Les résultats ont révélé que la diversité des arthropodes en général, et celle des collemboles et des carabes en particulier, était similaire dans les deux types de pelouses malgré une composition végétale différente. Aucune différence entre les quatre types d'entretien de pelouse n'a été détectée à moyen terme concernant l'abondance des arthropodes. Cependant, à court terme, l'application d'insecticides (diazinon et carbaryl) a entraîné une réduction des populations de collemboles et de carabes. Le ray-grass vivace et la fétuque élevée ont la capacité de survivre aux hivers québécois. Toutefois, alors que l'endophyte *Neotyphodium lolii* vivant en association avec le ray-grass vivace est demeuré à un niveau stable suite à deux hivers, l'association *N. coenophialum* -fétuque élevée n'a pas persistée. Les expériences en serres ont révélé que le ray-grass vivace endophytique 'SR 4220' n'a pas d'effet négatif sur la punaise velue.

Abstract

Turfgrass lawns are important ecosystems in urban areas, but the ecology of cool-season lawns has not been extensively studied in Quebec. Turfgrass management may influence ecosystem stability and arthropod communities. The first objective of this thesis was to characterize arthropod communities associated with turfgrass in Québec, and more specifically Collembola and ground beetle assemblages. Second, the effect of different turfgrass management practices on arthropods was evaluated. In a three-year field study, arthropods were sampled in two turfgrass lawns: a newly established lawn and a 10-year old lawn. Four turfgrass management were tested: i-management without pest control (control), ii-management with chemical pesticides, iii-integrated pest management, and iv-ecological management. Another aspect of this thesis was the evaluation of the potential of endophytic turfgrasses for the control of the hairy chinch bug, an important insect pest in Québec. Overwinter survival of endophytes and their host plants was first tested in two ecologically different areas under natural conditions. Furthermore, the influence of different combinations of endophytic perennial ryegrass and Kentucky bluegrass on hairy chinch bug survival and development was determined under greenhouse conditions.

The study indicates that the diversity of arthropods in general, and of Collembola and ground beetle in particular was similar for both lawns even if plant composition differed. After three years, no difference between the four turfgrass management practices was detected. However, short term effects following insecticide (diazinon and carbaryl) applications appeared for Collembola and ground beetles communities. Perennial ryegrass and tall fescue have the capacity to overwinter under Québec winter conditions. The endophyte *Neotyphodium coenophialum* found in tall fescue didn’t persist over time while the association *N. lolii*–perennial ryegrass remained stable after two winters. Greenhouse experiments revealed that endophytic perennial ryegrass ‘SR 4220’ did not negatively affect hairy chinch bug survival and development.

Avant-Propos

Cette thèse renferme le manuscrit d'un article publié dans le journal scientifique ***Pedobiologia*** (2006, 50:61-68 ; Chapitre II de la thèse). L'article intitulé 'Species diversity and seasonal abundance of Collembola in turfgrass ecosystems of North America' fut rédigé par Sophie Rochefort. Les co-auteurs de cet article sont Fernand Thérrien, David Shetlar et Jacques Brodeur. Le Chapitre III est un manuscrit qui a été soumis au journal scientifique ***Environmental Entomology*** (Avril 2006). L'article intitulé 'Ground beetle assemblages (Coleoptera: Carabidae) and their seasonal abundance in turfgrass ecosystems in North America' fut également rédigé par Sophie Rochefort et les co-auteurs sont David Shetlar et Jacques Brodeur. Le quatrième chapitre a été soumis au journal scientifique ***Crop Science*** (Mai 2006). L'article intitulé 'Overwinter survival and establishment of endophyte-infected and uninfected tall fescue and perennial ryegrass in turfgrass lawns of north eastern North America' a été rédigé par Sophie Rochefort. Les co-auteurs de ce manuscrit sont Yves Desjardins, David Shetlar et Jacques Brodeur. Les autres chapitres de cette thèse sont des manuscrits qui seront éventuellement soumis à des journaux scientifiques et l'étudiante Sophie Rochefort est l'auteure principale de tous ces manuscrits. Au début de chaque chapitre, le nom des co-auteurs est mentionné.

Remerciements

Ce projet de doctorat a été réalisé sous la direction du Dr. Jacques Brodeur et sous la co-direction du Dr. David Shetlar. Je tiens d'abord à souligner les qualités professionnelles et humaines de mon directeur de recherche. Merci Jacques pour ton support, tes conseils, ta générosité et ainsi que pour ton positivisme rayonnant qui fait que tes étudiants ont le goût d'avancer, de se dépasser. A special thank to my co-advisor for his precious collaboration and help all along my project. I am grateful to David "BugDoc" for his suggestions on this project, availability, and concern about my future.

J'aimerais remercier les membres de mon comité d'évaluation qui ont accepté généreusement de lire cette thèse : Mme Michèle Roy, M. Yves Desjardins et M. Doug Richmond.

Ce projet n'aurait pu être réalisé sans l'assistance technique des tous les étudiants et professionnels de recherche au cours des trois dernières années : Maxime Leblond, Violaine Joly-Séguin, Manon Desjardins, Paul Deschênes, Sébastien Jacob, Éric Dugal, Marie-Pierre Lamy et Simon Boudreault. Sincères remerciements à vous tous. Un merci particulier à Annie-Ève Gagnon, Roselyne Labbé et Luc lamontagne pour leur aide dans l'identification des collemboles, identification qui d'ailleurs n'aurait pas été possible sans l'expertise de M. Fernand Therrien. Vous avez tous ma plus grande reconnaissance.

J'aimerais tout spécialement remercier M. Jean Tremblay, président du Groupe Vertdure et du Fonds de Recherche en Écologie Urbaine (FRÉU), qui a cru en ce projet et qui a fait en sorte que celui-ci puisse se réaliser entre autres, sans tracas financiers. Je suis également reconnaissante au Fonds québécois de recherche sur la nature et les technologies (FQRNT) pour leur appui financier durant ces trois années. Sincères remerciements à M. René Pronovost de la ville de Québec ainsi qu'à M. Jean Pagé de la ville de Boucherville pour avoir si gentiment accepté le déroulement d'expériences sur des terrains de leur ville. Merci à M. Christian Hébert, Centre de Foresterie des Laurentides, M. Claudel Lemieux, Agriculture et Agro-Alimentaire Canada et Doug Richmond, Purdue University, pour leurs précieux conseils dans l'élaboration de ce projet. Un merci au Dr. Alan K. Watson de l'Université McGill pour sa collaboration tout au long de ce projet.

Ces trois années d'études n'auraient pu être aussi plaisantes sans l'amitié de plusieurs collègues du laboratoire d'entomologie et plus particulièrement sans mes amis(es) Renée, Annie-Ève et Benjamin, puisse cette amitié se préserver au fil des années. Également, ce projet ambitieux d'entreprendre des études graduées de 3^{e} cycle avec une jeune famille n'aurait pu se faire sans un conjoint et des enfants merveilleux. Sylvain, Ève-Marie et Olivier, mes trois soleils, merci pour votre amour, votre compréhension et votre support. Enfin merci à mes parents, Pierre et Pierrette, et mes deux sœurs, Christine et Marie-Josée pour leur encouragement.

À mes trois amours, Sylvain, Olivier et Ève-Marie

Table des matières

CHAPITRE I

INTRODUCTION GÉNÉRALE

CHAPITRE II

SPECIES DIVERSITY AND SEASONAL ABUNDANCE OF COLLEMBOLA IN TURFGRASS ECOSYSTEMS OF NORTH AMERICA

CHAPITRE III

GROUND BEETLE ASSEMBLAGES (COLEOPTERA: CARABIDAE) AND THEIR SEASONAL ABUNDANCE IN TURFGRASS ECOSYSTEMS IN NORTH AMERICA

CHAPITRE IV

IMPACT OF TURFGRASS MANAGEMENT ON ARTHROPOD ABUNDANCE AND DIVERSITY

CHAPITRE V

OVERWINTER SURVIVAL AND ESTABLISHMENT OF ENDOPHYTE-INFECTED AND UNINFECTED TALL FESCUE AND PERENNIAL RYEGRASS IN TURFGRASS LAWNS OF NORTH EASTERN NORTH AMERICA

CHAPITRE VI

EFFECT OF ENDOPHYTIC PERENNIAL RYEGRASS AND KENTUCKY BLUEGRASS MIXTURES ON HAIRY CHINCH BUG, BLISSUS LEUCOPTERUS HIRTUS (HEMIPTERA: LYGAEIDAE) SURVIVAL AND DEVELOPMENT

CHAPITRE VII

CONCLUSION GÉNÉRALE

Liste des tableaux

Liste des figures

CHAPITRE I

INTRODUCTION GENERALE

1.1 Introduction

Les surfaces gazonnées occupent une place importante de notre environnement urbain en Amérique du Nord (Tashiro 1987). Au Québec, on estime à environ 200 000 hectares la superficie totale engazonnée, ce qui génère des retombées économiques de près de 275 millions de dollars (Bédard et Desjardins 1991). Cette popularité des graminées à gazon en milieu urbain s'explique par différents facteurs. Dans un premier temps, ces plantes se cultivent facilement, tolèrent des tontes courtes et le piétinement (Beard 1973). Il existe maintenant un large éventail d'espèces de graminées à gazon adaptées à différents climats (Tashiro 1987). Dans un deuxième temps, les surfaces gazonnées apportent des bienfaits au niveau de l'environnement et de la santé des citadins. Entre autres, les gazons favorisent un rafraîchissement de l'air ambiant, une réduction de l'érosion des sols, une diminution du bruit, une augmentation du niveau de matière organique des sols, une réduction des allergies, etc (Beard et Green 1994). Outre ces bienfaits environnementaux, les graminées à gazon constituent des surfaces de jeux idéales et sécuritaires comparativement aux plantes dicotylédones (Powell 1987). Finalement, il a été démontré que les surfaces gazonnées contribuent à améliorer la santé physique et mentale des citadins (Lewis 1995, Matsuo 1995).

Afin de préserver la qualité des surfaces gazonnées, les gestionnaires d'espaces verts (surintendants de terrains de golf, responsables municipaux, compagnies d'entretien de pelouses et citoyens) ont recours aux pesticides de synthèse pour lutter contre divers organismes indésirables. Depuis une quinzaine d'années, l'utilisation de ces produits en milieu urbain est fortement critiquée au Québec et dans le reste du Canada. En 1991, la Ville de Hudson, à l'ouest de Montréal, fut la première municipalité au Québec à adopter un règlement interdisant l'application de pesticides sur les terrains résidentiels. Cette réglementation fut contestée en Cour Suprême du Canada par deux compagnies d'entretien de pelouses ainsi que par la Fédération Interdisciplinaire de l'Horticulture Ornementale du Québec (FIHOQ). La Cour Suprême du Canada rendit son verdict en juin 2001 et donna raison à la Ville de Hudson. Le jugement[1] mentionne que la ville est en droit d'interdire l'usage des pesticides lorsqu'elle estime que la santé de ses citoyens est en danger, cela en se basant sur le principe de précaution. Après ce jugement, plusieurs municipalités du Québec et du Canada ont emboîté le pas avec des règlements limitant ou interdisant l'utilisation des pesticides.

Par la suite, en avril 2003, le Ministère du développement durable, de l'environnement et des parcs adopta un *Code de gestion des pesticides*[2]. Ce Code spécifie que plusieurs pesticides utilisés pour l'entretien des gazons seront interdits, et ce progressivement. Par exemple, pour les terrains publics, parapublics et municipaux, l'utilisation de certains pesticides fut interdite dès 2003. En 2005, cette interdiction toucha la vente libre et finalement, depuis avril 2006, ce sont les terrains résidentiels et commerciaux qui sont affectés par cette loi (Ministère du développement durable, de l'environnement et des parcs du Québec 2003).

Le Code de gestion et les règlements municipaux apportent des changements majeurs dans la gestion des pelouses québécoises. Les différents gestionnaires d'espaces verts ainsi que les propriétaires de résidence devront avoir recours à des méthodes alternatives de lutte pour régler un problème phytosanitaire. Cependant, la disponibilité de ces méthodes de lutte est très limitée au Canada et leur efficacité n'est souvent pas rigoureusement démontrée.

Le Québec s'avère un leader dans l'adoption de lois restrictives concernant l'utilisation de pesticides en milieu urbain. Ce leadership entraîne cependant un besoin urgent de développement de méthodes alternatives. Ce projet de doctorat s'inscrit dans cette problématique de développement d'alternatives aux pesticides chimiques, mais également dans un contexte où nos connaissances de base de l'écosystème 'gazon' demeurent très fragmentaires. La caractérisation de cet écosystème urbain permettra de décrire la

---

[1] 2001 S.R.C. 0241

[2] L..R.Q. c. P-9.3, r.0.01

structure des communautés de plantes et d'arthropodes et aussi de mieux comprendre les relations plantes-insectes. L'écologie des surfaces gazonnées a été très peu étudiée comparativement à d'autres cultures agricoles ou écosystèmes naturels; plus particulièrement pour les pelouses des régions froides tel qu'au Québec. De plus, nos connaissances sur les interactions directes et indirectes entre les différents arthropodes du gazon sont limitées. L'écosystème 'gazon' est relativement simple et donc, en théorie, peu stable. L'impact des pratiques culturales et des traitements phytosanitaires devrait ainsi influencer grandement le maintien de l'équilibre au sein du système.

Ce projet de recherche porte essentiellement sur trois aspects soit : i-la caractérisation des communautés d'arthropodes dans les pelouses québécoises, ii-l'effet de différentes stratégies phytosanitaires sur les populations d'arthropodes, et iii-le potentiel des graminées endophytiques sur les densités de populations d'un insecte ravageur des pelouses.

1.2 Volet I – Caractérisation des communautés d'arthropodes et effet des traitements phytosanitaires

1.2.1 Caractéristiques d'une pelouse

En Amérique, la pelouse est généralement constituée de plantes faisant partie d'une seule et même famille : les Graminées. Au Québec, les nouvelles pelouses établies avec du gazon en plaque présentent un milieu encore plus simplifié, avec une seule espèce végétale présente soit le pâturin du Kentucky, *Poa pratensis* L. La pelouse est également constituée d'un seul niveau de végétation, la strate herbacée, comparativement à d'autres habitats (ex. milieu forestier) où il existe différentes strates végétatives qui assurent ainsi une plus grande diversité et un meilleur équilibre entre les communautés d'organismes vivants. Finalement, comme la majorité des plantes en milieu urbain, les pelouses sont soumises à des stress biotiques et abiotiques importants. La simplicité de ce milieu ainsi que les stress qu'il subit le rend davantage instable. Ceci à pour effet d'entraîner à l’occasion d’importants problèmes phytosanitaires suite à une perturbation importante (ex. tonte, sécheresse, pesticide) du milieu.

La pelouse est constituée principalement de racines, de tiges et de feuilles de graminées à gazon (Beard 1973). Elle se divise en trois strates soit les parties aériennes, la zone de feutre et le sol. Le feutre est une couche dense constituée de tiges, de feuilles et de racines mortes et vivantes (Beard 1973). L’humidité et la température élevée du feutre en font un micro habitat de prédilection pour le développement de certains groupes de microorganismes et d’arthropodes (Tashiro 1987). Dans chacune de ces trois strates, se retrouve une diversité d’arthropodes représentés par différents groupes tel que les prédateurs, les phytophages, les décomposeurs, les parasites, etc. (Cockfield et Potter 1984a, Vavrek et Niemczyk 1990, Braman et Pendley 1993). Chacun de ces groupes contribue directement ou indirectement au fonctionnement et à la stabilité de l’écosystème.

Selon des études réalisées principalement aux États-Unis dans des pelouses de pâturin du Kentucky, les principaux groupes d’arthropodes bénéfiques retrouvés dans l’écosystème gazon étaient : les fourmis, les carabes, les araignées, les staphylins, les cicadelles et les chrysomèles (Cockfield et Potter 1984a, Arnold et Potter 1987). L’étude de Wang et al. (2001) a permis de caractériser les populations d’arthropodes présentes à différents niveaux de l’écosystème gazon. On y a recensé jusqu’à 424 368 arthropodes répartis dans 49 sous-ordres et familles. Les acariens oribates, les collemboles (famille des Isotomidae et Sminthurididae) et les staphylins représentaient 97% du total des captures. À la surface du sol, les arthropodes étaient constitués des principales familles suivantes: Lycosidae (araignées), Chrysomelidae, Coccinellidae, Nabidae, Lygaeidae, Curculionidae et Miridae. Au niveau du feutre, on retrouvait des Oribatida, des Scydmaenidae (Coleoptera) et des Phoridae (Diptera). Finalement dans le sol, les Collembolla, Staphylinidae, Formicidae, Carabidae et Elateridae représentaient les groupes les plus abondants. Un tel type de caractérisation des arthropodes aux différents niveaux de l’écosystème gazon n’a pas été réalisé au Canada.

Dans le premier volet de ce projet de doctorat, les groupes des collemboles et des carabes ont été échantillonnés et les individus identifiés à l'espèce. Les collemboles, un des groupes les plus abondants de la pédofaune, sont des insectes ubiquistes jouant des rôles écologiques importants (décomposeurs, fongivores, 'ingénieurs' du sol) dans les écosystèmes (Christiansen 1964, Hopkin 1997). Les carabes regroupent des insectes prédateurs et omnivores sensibles aux changements de qualité de leur habitat, donc de bons bio-indicateurs de perturbations du milieu (Descender et al. 1994). Pour ces deux groupes d'insectes, il n'existe aucune étude portant sur leur abondance saisonnière et leur diversité dans les pelouses.

1.2.2 Effets des traitements phytosanitaires sur les populations d'arthropodes

Les graminées à gazon en milieu urbain nécessitent un niveau d'entretien intensif afin de répondre à un standard élevé d'esthétisme (Hull et al. 1994). Cela signifie l'utilisation importante de fertilisants, d'insecticides et d'herbicides. L'entretien des surfaces gazonnées est principalement réalisé par les professionnels des terrains de golf, les responsables d'espaces verts municipaux, les entreprises d'entretien de pelouses et finalement, les propriétaires de résidence. Au Québec, il existe actuellement près de 300 compagnies d'entretien de pelouses qui offrent différents services tel que la fertilisation annuelle et le contrôle des organismes nuisibles (insectes, mauvaises herbes et maladies fongiques). Au début des années '80, l'application des traitements phytosanitaires se faisait généralement de manière routinière, sans égard à la présence ou non de fortes populations d'organismes nuisibles. Suite aux réglementations municipales et à la conscientisation environnementale des citoyens, plusieurs entreprises offrent maintenant des programmes adaptés aux besoins réels de la pelouse. Jusqu'au moment de l'application du Code de gestion des pesticides, les insecticides et les herbicides de synthèse étaient les méthodes de contrôle les plus utilisées par ces entreprises, mais également par les particuliers. Selon le Ministère du développement durable, de l'environnement et des parcs (Lefebvre 2002), la quantité totale d'insecticides utilisés pour l'entretien des espaces verts par les entreprises professionnelles, les terrains de golf et les terrains municipaux était de 5 698 kg de matière active en 1998 et de 8 816 kg en 1999. Pour le secteur domestique, la vente totale d'insecticides (pesticides de classe 4 et 5) pour les pelouses était respectivement en 1998 et 1999 de 4 334 kg et 8 595 kg de matière active. De 1998 à 1999, la quantité totale est passée de 27 686 kg de matière active en 1998 à 24 157 kg en 1999. Pour le secteur de l'entretien des espaces verts, il y a eu une légère augmentation de 1998 à 1999 (101 970 kg en 1998 et 102 174 kg en 1999). De façon générale, à cette époque, le nombre de traitements phytosanitaires effectués sur une pelouse résidentielle était de deux à cinq traitements par année.

La croissance de l'industrie du gazon au cours des 35 dernières années a entraîné une augmentation de l'utilisation d'insecticides organophosphorés et carbamates dans l'environnement urbain. L'impact écologique de ces pesticides est toutefois peu documenté. Dans d'autres systèmes agricoles, il a été démontré que les pesticides altèrent les interactions entre les espèces d'arthropodes et conséquemment, modifient la stabilité des communautés (Pimentel et Edwards 1982).

Les insecticides généralement utilisés pour l'entretien des pelouses ont pour la plupart une activité à large spectre d'action sur les arthropodes, affectant du même coup les populations d'arthropodes bénéfiques et nuisibles (Streu 1969 et 1973, Potter et al. 1985, Cockfield et Potter 1983). Les arthropodes bénéfiques, tels les ennemis naturels, contribuent généralement à réduire les populations d'insectes ravageurs (Potter 1998). Par exemple, l'application de chlordane entraîne une résurgence des populations de punaise velue, *Blissus leucopterus* Montandon (Hemiptera : Lygaidae) tandis que des applications répétées de carbaryl provoque une augmentation du nombre de tétranyque des grains, *Penthaleus major* (Dugès) (Acarinae : Penthaleidae) suite à la destruction des prédateurs naturels de ces deux ravageurs (Streu 1969, Streu et Gingrich 1972). Une autre étude menée par Reinert (1978) démontre que les populations de *Blissus insularis* Barber (Hemiptera : Lygaeidae) ont été maintenues sous le seuil de nuisibilité par les prédateurs présents naturellement dans une pelouse non traitée. Ces études n'ont toutefois pas mesuré l'effet direct de la disparition d'un ou de plusieurs prédateurs sur les populations d'insectes ravageurs. Toutefois, Cockfield et Potter (1984b) ont démontré qu'une pelouse traitée avec l'insecticide chlorpyrifos entraînait une réduction significative de l'abondance des prédateurs des pelouses ainsi qu'une réduction du niveau de prédation des œufs de pyrale des prés (Lepidoptera : Pyralidae) comparativement à une pelouse non traitée.

Les traitements pesticides entraînent différentes réponses chez divers groupes d'arthropodes. Ces effets sont visibles à court terme (quelques jours ou semaines suivant l'application du traitement) ou à moyen terme (effets cumulatifs d'applications répétées d'un insecticide ou effet déclencheur d'évènements suite à une seule application). Terry et al. (1993), ont démontré que l'insecticide isazofos pouvait entraîner d'importantes baisses de populations de prédateurs à court terme comparativement aux autres insecticides à l'étude soit le cyphlutrin et le carbaryl. Ces baisses ont été observées chez les araignées, les fourmis, les staphylins et les carabes. Ces mêmes auteurs ont aussi mesuré le temps de re-colonisation de ces arthropodes suite aux traitements. Six à dix semaines après les traitements, les arthropodes les plus mobiles (araignées, staphylins, etc.) avaient re-colonisé les parcelles traitées. Ce phénomène a également été observé par Cockfield et Potter (1983). Une telle re-colonisation est caractéristique des terrains résidentiels où les surfaces gazonnées sont souvent fragmentées et bordées de zones non traitées telle que les plates-bandes. Ces zones offrent des refuges à plusieurs arthropodes (Shrewsbury et Raupp 2000, Tooker et Hanks 2000).

En plus des traitements pesticides, certaines études se sont penchées sur l'effet de la régie (intensive et modérée) sur les populations d'arthropodes bénéfiques (Arnold et Potter 1987, Braman et al. 2000, Braman et Pendley 1993, Potter et al. 1985). Ces études démontrent que certains groupes d'arthropodes présentent une plus grande sensibilité à une régie intensive (plusieurs insecticides et herbicides appliqués durant la saison ainsi que des fertilisants) comparativement à un témoin dans lequel uniquement la tonte était pratiquée. Les araignées et les staphylins furent les groupes d'arthropodes les plus affectés dans les parcelles traitées. L'ensemble de ces études démontre qu'il existe une très grande variabilité de l'effet des traitements ou de la régie sur les populations d'arthropodes et ce, durant une même saison. Le type de pesticide, le type d'arthropodes ainsi que la composition végétale des parcelles expérimentales sont autant de facteurs de variabilité.

À ce jour, une seule étude a évalué l'effet de traitements naturels ou biologiques sur les populations d'arthropodes des pelouses. Wang et al. (2001) ont étudié l'effet à long terme de l'utilisation de nématodes (genre *Sternernema* et *Heterorhabditis*) et d'un champignon entomopathogène, *Beauveria bassiana* (Balsamo) Vuillemin sur les insectes non ciblés et les nématodes phytophages se trouvant dans le sol. Certains groupes d'arthropodes étaient plus abondants dans les parcelles traitées avec les produits biologiques que dans les parcelles traitées au chlorpyrifos, alors que d'autres groupes d'arthropodes, tels les Sminthurididae (Collembola), étaient plus abondants dans les parcelles traitées avec le chlorpyrifos. Les auteurs expliquent ce phénomène par la réduction de l'abondance d'un ou de plusieurs prédateurs des Sminthurididae.

Finalement, une seule étude a comparé un programme de lutte intégrée à un programme conventionnel (application de pesticides selon un calendrier de traitements) pour l'entretien d'aménagements paysagers commerciaux (Stewart et al. 2002). Cette étude souligne les bénéfices apportés par l'une ou l'autre des régies du point de vue économique (quantité totale de pesticides appliqués et niveau de contrôle des ravageurs), mais ne mentionne pas les différences observées entre ces régies quant à l'abondance ou la diversité des arthropodes bénéfiques.

Mon projet de doctorat constitue donc la première étude comparant l'effet de régies conventionnelles, écologique et de lutte intégrée sur les populations d'arthropodes bénéfiques et nuisibles des surfaces gazonnées des régions froides.

1.2.4 Hypothèse de recherche

Les interventions avec des pesticides de synthèse perturbent grandement l'écosystème 'gazon' entraînant une perte de diversité des espèces d'arthropodes, une plus grande instabilité et donc des problèmes récurrents de ravageurs.

1.2.5 Objectifs

Objectif principal : Déterminer les effets, à court et moyen termes, de différents programmes d'entretien de pelouses sur les populations d'arthropodes.

Objectifs spécifiques :

1. Caractériser les populations d'arthropodes des surfaces gazonnées qui colonisent deux des principaux habitats: surface du sol et sol;
2. Comparer l'abondance et de la diversité des arthropodes d'une pelouse nouvellement établie et d'une pelouse établie depuis une dizaine d'années;
3. Suivre l'évolution des communautés d'arthropodes suite à l'implantation d'une pelouse;
4. Déterminer l'impact et l'efficacité des traitements chimiques et écologiques sur l'abondance et la diversité des arthropodes à court (1 semaine et 3 semaines après les interventions phytosanitaires) et moyen (après trois années) termes.

Afin de répondre à ces objectifs, j'ai opté pour l'expérimentation sur le terrain en reproduisant le plus possible la situation réelle d'un terrain résidentiel ou municipal. Les traitements phytosanitaires, le type de terrains sélectionnés, la régie de tonte et de fertilisation ont tous été choisis en fonction des pratiques actuelles de l'entretien des surfaces gazonnées. Cette étude, qui s'est déroulée sur trois ans (2003-2005), a permis d'observer graduellement les modifications engendrées par les différentes régies sur les principaux groupes d'arthropodes.

1.3 Volet II - Graminées endophytiques

Le deuxième volet de mon projet de doctorat portait sur l'utilisation des graminées endophytiques afin de réduire les populations d'un insecte ravageur des pelouses. Avec l'adoption du Code de gestion des pesticides, le développement et l'utilisation de méthodes alternatives deviennent une priorité pour les gestionnaires d'espaces verts. L'introduction de graminées endophytiques dans les pelouses déjà établies offre une voie intéressante de lutte naturelle aux insectes ravageurs au Québec. En effet, l'ajout de graminées endophytiques aux pelouses constituées de pâturin du Kentucky (principale espèce cultivée au Québec) en plus d'augmenter la diversité végétale confère une protection accrue contre les insectes phytophages. La polyculture (introduction d'une ou de plusieurs espèces végétales dans une culture) est une approche déjà utilisée dans plusieurs systèmes agricoles. Une combinaison de plantes hôtes et non-hôtes dans une culture, permet entre autres : i-une réduction des densités de populations d'insectes ravageurs et, conséquemment, des dommages, ii-une modification des déplacements et des comportements de recherche des ravageurs et iii-une plus grande susceptibilité de ces derniers aux ennemis naturels (Coll et Bottrell 1994). Un des principes associés à la diversification des cultures dans la réduction des populations d'insectes ravageurs est que ces derniers passeront plus de temps à rechercher un hôte convenable pour leur nutrition et leur développement, et s'exposeront davantage aux prédateurs, parasitoïdes et pathogènes.

L'effet de la polyculture sur les populations d'insectes ravageurs des pelouses a été peu étudié. Richmond et Shetlar (2000) ont été les premiers a démontré lors d'expériences sur le terrain, qu'un mélange de graminées endophytiques et non endophytiques pouvait réduire significativement les populations de punaises velues, au stade larvaire, et les dommages associés à ce ravageur. Les auteurs expliquent cette réduction par des modifications dans la distribution et le comportement de l'insecte, mais également par une augmentation de la prédation. Ainsi, la punaise prédatrice *Geocoris* sp., un prédateur important de la punaise velue (Tashiro 1987), capture plus de proies puisque les punaises velues doivent se déplacer davantage pour se nourrir dans une pelouse constituée de plusieurs espèces de graminées endophytiques et non endophytiques.

Les endophytes sont des organismes d'origine fongique ou bactérienne passant en partie ou en totalité leur cycle de vie à l'intérieur des tissus d'une plante sans causer de symptômes apparents (Wilson 1995). La découverte des endophytes dans les graminées et dans divers groupes de plantes telles que le souchet (Cyperaceae) et certains conifères (Pinaceae) remonte à plus d'un siècle (Breen 1994). Cependant, le potentiel des champignons endophytiques en agriculture et comme moyen de lutte biologique n'a été que récemment démontré soit depuis une trentaine d'années. L'endophyte du genre *Neotyphodium* a été très étudié car il est à la fois associé à la résistance aux insectes et aux toxicoses chez le bétail (Breen 1994). Pour les gazons, la présence d'endophytes est bénéfique, car elle permet une certaine résistance aux insectes ravageurs des pelouses. En contre partie, dans les pâturages, la présence de graminées avec endophytes, telles les fétuques élevées, *Festuca arundinacea* Shreb. et les ray-grass, *Lolium perenne* L., est problématique car elle provoque des intoxications chez le bétail, ainsi qu'une baisse de lactation et une perte de poids chez les vaches laitières (Bacon et al. 1977, Fletcher et Harvey 1981).

Au cours de leur évolution, les graminées ont développé des associations de nature symbiotique avec les endophytes du genre *Neotyphodium*. Cet endophyte, de la famille des Clavicipitaceae appartenant à la tribu des Balansieae, ne produit pas de conidies et ne réduit aucunement la vigueur et la qualité de la plante infectée. C'est d'ailleurs pour ces raisons que ce type d'endophyte a fait l'objet de nombreuses études. Cette relation entre le champignon endophytique et la plante est une association de mutualisme car l'endophyte assure une protection à la plante contre les herbivores et parallèlement, la plante apporte les nutriments nécessaires à la croissance de l'endophyte (Clay 1988 et 1991). Cette association bénéfique entre les graminées et les endophytes fut rapportée pour la première fois au début des années '80. Des études réalisées par Prestidge et al. (1982) ont démontré que des parcelles avec ray-grass endophytiques entraînaient des baisses significatives de populations du charançon argentin de la tige, *Listronotus* *bonariensis* (Kuschel), ainsi que des dommages qui lui étaient associés. La fétuque élevée et le ray-grass vivace sont les deux principales espèces de graminées à gazon infectées avec des endophytes du genre *Neotyphodium* (Seigel et al. 1987), mais on retrouve également des endophytes dans les fétuques fines telles que les fétuques rouge traçante, *Festuca rubra* L. et de Chewing, *F. rubra* var. *commutata* Gaud. (Saha et al. 1987, Siegel et al. 1990).

La résistance aux herbivores engendrée par les endophytes du genre *Neotyphodium* résulte de la production de composés alcaloïdes par l'endophyte. Les principaux composés alcaloïdes produits par les endophytes sont : la peramine, l'ergovaline, le lolitrem (indoles diterpènes) et la loline (Dahlman 1991). Ces alcaloïdes engendrent chez les insectes herbivores des réactions d'antibiose et/ou d'antixénose. L'antibiose est l'effet négatif qu'engendrent les caractéristiques d'une plante sur la biologie de l'insecte (ex. : augmentation de la mortalité, réduction de la fécondité, etc.). L'antixénose pour sa part, se définit comme étant les caractéristiques d'une plante ayant un effet répulsif chez les insectes (Pedigo 2002). La nature des composés alcaloïdes produits par un endophyte, dépend de son association avec son hôte. Par exemple, dans le ray-grass infecté avec *N. lolii*, les lolitrems, l'ergovaline et la peramine sont les trois principaux composés produits (Seigel et al 1990, Christensen et al. 1993, Schardl et al 1994). Chez les fétuques élevées infectées par *N. coenophialum*, on retrouvera principalement la peramine, la loline et l'ergovaline (Cheplick et Clay 1988, Clay 1990, Seigel et al. 1990, Christensen et al. 1993). La distribution des composés alcaloïdes dans la plante est étroitement liée à la localisation du mycélium dans les tissus. Ces composés se retrouvent donc en concentration élevée au niveau des feuilles (plus particulièrement au niveau de la gaine), des tiges et des semences. La production des composés alcaloïdes *in planta* sera également affectée par des facteurs biotiques tel que le génotype de la plante, et abiotiques tel que la sécheresse, la fertilisation, etc. (Malinowski et Belesky 2000). Lyons et al (1986) ont observé, en serre, une concentration en alcaloïdes de type 'ergot' significativement plus élevée chez des plants de fétuques élevées fertilisés avec un engrais azoté que chez des plants non fertilisés. Cette concentration était également plus élevée dans la gaine de la feuille de ces plants que dans la feuille. De plus, Belesky et al. (1988)

ont démontré, lors d'expériences en champ, que la concentration de ces composés alcaloïdes variait selon la saison, étant plus élevée au printemps qu'à l'automne, avec une baisse substantielle au milieu de l'été.

Jusqu'à ce jour, plusieurs études ont démontré la relation qui existe entre le niveau d'infection d'une plante avec un endophyte, la mortalité des ravageurs et les dommages engendrés par ces derniers (Breen 1993, Johnson-Cicalese et White 1990, Murphy et al. 1993). Parmi les insectes ravageurs des graminées à gazon, la punaise velue, *Blissus leucopterus hirtus* Montandon (Hemiptera : Lygaeidae) et la calandre du pâturin, *Sphenophorus parvulus* Gyllenhal (Coleoptera : Curculionidae) seraient parmi les espèces les plus affectées par la présence d'endophyte. Ces deux ravageurs se nourrissent des parties aériennes de la plante là où la concentration en composés alcaloïdes est la plus élevée. En effet, les punaises velues se nourrissent à la base des tiges de graminées tandis que les larves et les adultes de la calandre du pâturin s'alimentent respectivement au niveau de la couronne du gazon et du feuillage (Tashiro 1987). Des études menées en laboratoire par Carrière et al. (1998) ont démontré une diminution du taux de survie de la punaise velue en présence de l'endophyte. La punaise velue était en mesure de détecter la présence de l'endophyte dans les plants de graminées et par le fait même, d'éviter ces plants. Une autre étude réalisée sur le terrain par Murphy et al. (1993) a démontré que les populations de calandres, *Sphenophorus sp*, étaient également affectées négativement (diminution du taux de survie et de l'alimentation) par la présence de graminées endophytiques. Ahmad et al. (1986) et Johnson-Cicalese et White (1990) avaient obtenu des résultats similaires. Murphy et al. (1993) ont également observé une baisse des populations de pyrales des prés dans les parcelles avec endophyte comparativement aux parcelles sans endophyte. Cette réponse des pyrales des prés à la présence d'endophyte avait aussi été observée par Funk et al. (1983). Jusqu'à présent, parmi les insectes se nourrissant des racines des graminées endophytiques, seules les larves de scarabée japonais, *Popilla japonica* Newman, ont démontré une sensibilité aux alcaloïdes de type ergot dans une étude menée sur diète artificielle par Patterson et al. (1991). Potter et al. (1992) ont pour leur part obtenu des résultats variables lors d'expériences menées sur le terrain avec deux Scarabeidae, *Popillus japonica* et *Cyclocephala lurida*. Aucune différence significative au niveau de la survie de ces deux espèces n'a été observée entre les parcelles avec endophyte, sans endophyte et avec pâturin du Kentucky. Jusqu'à ce jour, une quarantaine d'insectes ont démontré une sensibilité à la présence d'endophyte dans les ray-grass et les fétuques élevées (Breen 1994).

Outre la résistance aux insectes phytophages, les graminées endophytiques apportent d'autres avantages à la plante. Les plantes infectées ont une plus grande tolérance à la sécheresse (Arachevaleta et al. 1989, Belesky et al 1987, West et al. 1988, White et al. 1992), une croissance et une vigueur accrues (Latch et al. 1985), ainsi qu'une meilleure résistance à certaines maladies fongiques (Gwinn et Gavin 1992, Ford et Kirkpatrick 1989, Seigel et al. 1987).

Enfin, il est important de déterminer sous les conditions hivernales du Québec, le potentiel d'établissement et de survie du ray-grass vivace et de la fétuque élevée. Selon Gusta (1980), chez les espèces de graminées à gazon de climat froid, le ray-grass vivace possède la plus faible rusticité alors que la fétuque élevée présente une rusticité modérée. Cependant, la survie à l'hiver des graminées à gazon augmente lorsque le couvert de neige est important (Dionne 2001). Toutefois, aucune étude n'a examiné le niveau de tolérance au froid des endophytes associés aux graminées à gazon sous les conditions hivernales du Québec. Ces données sont essentielles afin d'évaluer le potentiel d'utilisation des graminées endophytiques pour le contrôle des insectes ravageurs.

Ce second volet de mon projet de doctorat vise dans un premier temps à évaluer i-la survie hivernale de deux graminées endophytiques lorsqu'elles sont sur-semées dans une pelouse déjà existante et ii-leur potentiel d'établissement à court et moyen termes. Dans un deuxième temps, j'ai mesuré l'effet de différentes combinaisons de graminées endophytiques et de pâturin du Kentucky sur la survie et le développement de la punaise velue, un ravageur important des pelouses québécoises (Rochefort et al. 1998, Rochefort et al. 2003).

1.3.1 Hypothèses de recherche

1) Le ray-grass vivace 'Palmer III' et la fétuque élevée 'Bonsaï 2000' ont la capacité de survivre aux conditions hivernales du Québec. La survie sera plus grande sous un couvert de neige important.

2) Les pelouses mixtes composées de graminées endophytiques réduisent les populations de punaises velues.

1.3.2 Objectifs

Objectif principal : Évaluer le potentiel des graminées endophytiques comme méthode alternative aux insecticides de synthèse pour le contrôle de la punaise velue lorsqu'en mélange avec le pâturin du Kentucky.

Objectifs spécifiques :

1. Déterminer la survie hivernale de deux graminées et de leurs endophytes lorsqu'elles sont sur-ensemencées dans une pelouse de pâturin du Kentucky;
2. Évaluer le pourcentage d'établissement de ces graminées et de leurs endophytes au cours des trois années de l'étude (évolution dans le temps) en fonction : du taux d'ensemencement et de la zone géographique;
3. Évaluer le potentiel de différentes combinaisons de ray-grass endophytiques et de pâturin du Kentucky pour la gestion d'un ravageur des pelouses.

L'approche privilégiée pour mesurer la survie hivernale des deux graminées et de leurs endophytes fut la réalisation d'expériences sur le terrain. Des essais en serre ont été réalisés afin de déterminer l'effet de différents mélanges de ray-grass endophytiques et de pâturin du Kentucky sur la survie de la punaise velue.

1.4 Description des chapitres

Les chapitres II et III présentent les résultats d'une étude descriptive des communautés de collemboles et de carabes retrouvés aux deux sites à l'étude ainsi que leur abondance saisonnière. L'effet des différentes stratégies phytosanitaires sur les populations d'arthropodes bénéfiques et nuisibles est présenté au chapitre IV. Dans ce chapitre, l'effet à moyen terme (après trois années) des différents traitements phytosanitaires est présenté pour les principaux groupes d'arthropodes tandis que l'effet à court terme (une et trois semaines après l'intervention) de deux insecticides a été mesuré sur les collemboles et les carabes. Le cinquième chapitre présente les résultats de l'expérience sur la survie à l'hiver du ray-grass vivace et de la fétuque élevée ainsi que de leur endophyte respectif. Finalement, le chapitre VI présente les résultats des essais réalisés en serre sur l'effet de différentes combinaisons de ray-grass endophytiques et de pâturin du Kentucky sur la survie et le développement de la punaise velue.

1.5 Références

Ahmad, S., M.J. Johnson-Cicalese, W.K. Wilson et C.R. Funk. 1986. Endophyte-enhanced resistance in perennial ryegrass to the bluegrass billbug, *Sphenophorus parvulus*. Entomol. Exp. Appl. 41: 3-10.

Arachevaleta, M., C.W. Bacon, C.S. Hoveland et D.E. Radcliffe. 1989. Effect of the tall fescue endophyte on plant response to environment stress. Agron. J. 81: 83-90.

Arnold, T.B. et D.A. Potter. 1987. Impact of high-maintenance lawn-care program on nontarget invertebrates in Kentucky bluegrass turf. Environ. Entomol. 16: 100-105.

Bacon, C.W., J.K. Porter, J.D. Robbins et E.S. Luttel. 1977. *Epichloë typhina* from toxic tall fescue pastures. Appl. Environ. Microbiol. 34: 576-581.

Beard, J.B. 1973. Turfgrass: science and culture. Prentice-Hall, Englewood Cliffs. NJ. 672p.

Beard, J.B. et R.L. Green. 1994. The role of turfgrass in the environment protection and their benefits to humans. J. Environ. Qual. 23: 452-460.

Bédard, R. et Y. Desjardins. 1991. Les bienfaits des gazons. Rapport rédigé pour la Fédération Interdisciplinaire de l'Horticulture Ornementale du Québec (FIHOQ). Centre de Recherche en Horticulture, Université Laval. 33p.

Belseky, D.P., O.J. Devine, J.E. Pallas, Jr et W.C. Stringer. 1987. Photosynthetic activity of tall fescue as influenced by a fungal endophyte. Photosynthetica 21: 82-87.

Belesky, D.P., J.A. Stuedemann, R.D. Plattner et S.R. Wilkinson. 1988. Ergopeptine alkaloids in grazed tall fescue. Agron. J. 80 : 209-212.

Braman, S.K. et A.F. Pendley. 1993. Relative and seasonal abundance of beneficial arthropods in centipede grass as influenced by management practices. J. Econ. Entomol. 86: 494-504.

Braman, S.K., J.G. Latimer, R.D. Oetting, R.D. McQeen, T.B. Eckberg et M. Prinster. 2000. Management strategy, shade, and landscape composition effects on urban landscape plant quality and arthropod abundance. J. Econ. Entomol. 93: 1464-1472.

Breen, J.P. 1994. *Acremonium* endophyte interactions with enhanced plant resistance to insects. Annu. Rev. Entomol. 39: 401-423.

Carrière,Y., A. Bouchard, S. Bourassa et J. Brodeur. 1998. Effect of endophyte incidence in perennial ryegrass on distribution, host-choice, and performance of the hairy chinch bug (Hemiptera : Lygaeidae). J. Econ. Entomol. 91: 324-328.

Cheplick, G.P. et K. Clay. 1988. Acquired chemical defenses in grasses : the role of endophytes. Oikos 52: 309-319.

Christiansen, K.A. 1964. Bionomics of Collembola. Annu. Rev. Entomol. 9: 147-178.

Christensen, M.J., A. Leuchtmann, D.D. Rowan et B. A. Tapper. 1993. Taxonomy of *Acremonium* endophytes of tall fescue (*Festuca arundinacea*), meadow fescue (*F. pratensis*), and perennial ryegrass (*Lolium perenne*). Mycol. Res. 97: 1083-1092.

Clay, K. 1988. Fungal endophytes of grasses: a defensive mutualism between plants and fungi. Ecology 69: 1016.

Clay, K. 1990. Insects, endophytic fungi and plants, pp.331-357. *Dans :* J.J. Burdon et S.R. Leather (Eds). Pests, pathogens and plant communities. Blackwell, Oxford, UK.

Clay, K. 1991. Fungal endophytes, grasses and herbivores, pp.199-226. *Dans:* Microbial mediation of plant-herbivore interactions. P.Barbosa, V. Krischik et C.G. Jones (eds). Wiley, NY.

Cockfield, S.D. et D.A. Potter. 1983. Short term effects of insecticidial applications on predaceous arthropods and orbatid mites in Kentucky bluegrass turf. Environ. Entomol. 12: 1260-1264.

Cockfield, S.D. et D.A. Potter. 1984a. Predatory insects and spiders from suburban lawns in Lexington, Kentucky. Great Lakes Entomol. 17: 179-184.

Cockfield, S.D. et D.A. Potter. 1984b. Predation on sod webworm (Lepidoptera : Pyralidae) eggs as affected by chlorpyrifos application to Kentucky bluegrass turf. J. Econ. Entomol. 77:1542-1544.

Coll, M. et D.G. Bottrell. 1994. Effects of nonhost plants on an insect herbivore in diverse habitats. Ecology 75 : 723-731.

Dahlman, D.L., H. Eichenseer et M.R. Seigel. 1991. Chemical perspectives on endophyte-grass interactions and their implications to insect herbivory, pp.227-252. *Dans:* Microbial mediation of plant-herbivore interactions. P.Barbosa, V. Krischik et C.G. Jones (eds). Wiley, NY.

Descender, K. M. Dufrene et J.-P. Maelfait. 1994. Long term dynamics of carabid beetles in Belgium: a preliminary analysis on the influence of changing climate and land use by means of a database covering more than a century, pp.247-252. *Dans*: Carabid beetles: Ecology and evolution. K. Descender (ed.), Kluwer Academic Publishers.

Dionne, J. 2001. Protection hivernale et tolérance au froid du pâturin annuel (*Poa annua* var. *reptans*). Thèse de doctorat. Université Laval, Québec.

Fletcher, L.R. et I.C. Harvey. 1981. An association of *Lolium* endophyte with ryegrass staggers. N. Z. Vet. J. 29: 185-186.

Ford, V.L. et T.L. Kirkpatrick. 1989. Effects of *Acremonium coenophialum* in tall fescue on host disease and insect resistance and allelopathy to *Pinus taeda* seedlings. Proc. Ark. Fescue Toxicosis Conf. 140: 29-34.

Funk, C.R., P.M. Halisky, M.C. Johnson, M.R. Seigel, A.V. Stewart, S. Ahmad, R.H. Hurley et I.C. Harvey. 1983. An endophytic fungus and resistance to sod webworms: association in *Lolium perenne* L. Bio/Technology 1: 189-191.

Gusta, L.V., J.D. Butler, C. Rajashekar et M.J. Burke. 1980. Freezing resistance of perennial turfgrasses. HortScience 15: 494-496.

Gwinn, K.D. et A.M. Gavin. 1992. Relationship between endophyte infection level of tall fescue seed lots and *Rhizoctonia zeae* seedling disease. Plant Dis. 76: 911-914.

Hopkin, S.P. 1997. Biology of springtails (Insecta: Collembola). Oxford University Press, Oxford, UK. 344p.

Hull, R.J., S.R. Alm et N. Jackson. 1994. Toward sustainable lawn turf, pp.3-15. *Dans:* A. Leslie (ed.). Handbook of integrated pest management for turf and ornementals. CRC/Lewis, Boca Raton, FL.

Johnson-Cicalese, J.M. et R.H. White. 1990. Effect of *Acremonium* endophytes on four species of billbug (Coleoptera: Curculionidae) found on New Jersey turfgrasses. J. Am. Soc. Hort. Sci. 115: 602-604.

Latch, G.C.M., W.F. Hunt et D.R. Musgrave. 1985. Endophytic fungi affect growth of perennial ryegrass. N.Z. J. Agric. Res. 28: 129-132.

Lefebvre, Y. 2002. Bilan des ventes de pesticides : suivi des transactions au Québec pour 1998 et 1999. Ministère du développement durable, de l'environnement et des parcs du Québec. Dir. des politiques du secteur agricole, Services des pesticides.

Lewis, C.A. 1995. Human health and well-being: The psychological, physiological, and sociological effects of plants on people. Acta Hort. 391: 31-39.

Lyons, P.C., R.D. Plattner et C.W. Bacon. 1986. Occurrence of peptide and clavine ergot alkaloids in tall fescue grass. Science 232 : 487-489.

Malinowski, D. A. et D.P. Belesky. 2000. Adaptations of endophyte-infected cool-season grasses to environmental stresses: mechanisms of drought and mineral stress tolerance. Crop Sci. 40: 923-940.

Matsuo, E. 1995. Horticulture helps us to live as human beings: Providing balance and harmony in our behaviour and thought and life worth living. Acta Hort. 391: 19-29.

Ministère du développement durable, de l'environnement et des parcs du Québec. 2000. Lutte intégrée dans les espaces verts. Les publications du Québec, Québec.

Murphy, J.A., S. Sun et L.L. Betts. 1993. Endophyte-enhanced resistance to billbug (Coleoptera: Curculionidae), sod webworms (Lepidoptera: Pyralidae), and white grub (Coleoptera: Scarabaeidae) in tall fescue. Environ. Entomol. 22: 699-703.

Patterson, C.G., D.A. Potter et F.F. Fannin. 1991. Feeding deterrency of alkaloids from endophyte-infected grasses to Japanese beetle (Coleoptera : Scarabaeidae) grubs. Entomol. Exp. Appl. 61: 285-289.

Pedigo, L.P. 2002. Entomology and pest management. Prentice Hall, New Jersey. 742p.

Pimentel, D. et C.A. Edwards. 1982. Pesticides and ecosystems. Bioscience 32 : 595-600.

Potter, D.A., B.L. Bridges et F.C. Gordon. 1985. Effect of N fertilization on earthworm and microarthropod populations in Kentucky bluegrass turf. Agron. J. 77: 367-372.

Potter, D.A., C.G. Patterson et C.T. Redmond. 1992. Influence of turfgrass species and tall fescue endophyte on feeding ecology of Japanese beetle and southern masked chafer grubs (Coleoptera : Scarabaeidae). J. Econ. Entomol. 85: 900-909.

Potter, D.A. 1998. Destructive turfgrass insects: biology, diagnosis and control. Ann Arbor Press. Chelsea, Michigan. 344p.

Powell, J.W. 1987. Incidence of injury associated with playing surfaces in the national Football league 1980-1985. J. Ntl. Athl. Train. Ass. 22: 202-206.

Prestidge, R.A. 1982. An association of the *Lolium* endophyte with ryegrass resistance to Argentine stem weevil. Proc. N.Z. Weed Pest Control Conf. 35: 119-122.

Reinert, J.A. 1978. Natural enemy complex of the southern chinch bug in Florida. Ann. Entomol. Soc. Am. 71: 728-731.

Richmond, D.S., H.D. Niemczyk et D.J. Shetlar. 2000. Overseeding endophytic perennial ryegrass into stands of Kentucky bluegrass to manage bluegrass billbug (Coleoptera : Curculionidae). J. Econ. Entomol. 93 : 1662-1668.

Richmond, D.S. et D.J. Shetlar. 2000. Hairy chinch bug (Hemiptera: Lygaeidae) damage, population density, and movement in relation to the incidence of perennial ryegrass infected *Neotyphodium* endophytes. J. Econ. Enomol. 93:1167-1172.

Rochefort, S., Y. Carrière, J. Brodeur et Y. Desjardins. 1998. Projet-pilote de lutte intégrée dans les pelouses. Rapport d'étape. Centre de Recherche en Horticulture, Université Laval. 59p.

Rochefort, S., Y. Carrière, D.J. Shetlar et J. Brodeur. 2003. Écologie saisonnière du complexe d'espèces de pyrales des prés (Lepidoptera : Pyralidae) associé aux graminées à gazon au Québec. Phytoprotection 84 : 69-75.

Saha, D.C., J.M. Johnson-Cicalese, P.M. Halisky, M.I. Van Heemstra et C.R. Funk. 1987. Occurrence and significance of endophytic fungi in the fine fescues. Plant Dis. 71: 1021-1024.

Seigel, M.R., G.C.M. Latch, L.P. Bush, N.F. Fannin, D.D. Rowan, B.A. Tapper, C.W. Bacon et M.C. Johnson. 1990. Fungal endophyte infected grasses: alkaloid accumulation and aphid response. J. Chem. Ecol. 16: 3301-3315.

Seigel, M.R., G.C.M. Latch et M.C Johnson. 1987. Fungal endophytes of grasses. Annu. Rev. Phytopathol. 25: 293-315.

Shardl, C.L., A. Leuchtmann, H.-F. Tsai, M.A. Collet, D.M. Watt et D.B. Scott. 1994. Origin of a fungal symbiont of perennial ryegrass by interspecific hybridization of a mutualist with the ryegrass choke pathogen *Epichloë typhina*. Genetics 136: 1307-1317.

Shrewsbury, P.M. et M.J. Raupp. 2000. Evaluation of components of vegetational texture for predicting azalea lace bug, *Stephanitis pyrioides*, abundance in managed landscapes. Environ. Entomol. 29: 919-926.

Smith, C.M. 1989. Plant resistance to insects: a fundamental approach. Wiley, New York. 286p.

Sogley, R.C. et C.D. Sawyer. 1992. Field Research, pp.589-614. *Dans:* Turfgrass. D.V. Waddington, R.N. Carrow et R.C. Shearman (eds). ASA, CSSA et SSSA. Madison, WC :

Stewart, C.D., S.K. Braman, B.L. Sparks, J.L. Williams-Woodward, G.L. Wade et J.G. Latimer. 2002. Comparing an IPM pilot program to a traditional cover spray program in commercial landscapes. J. Econ. Entomol. 95: 789-796.

Streu, H.T. 1969. Some cumulative effects of pesticides in the turfgrass ecosystem, pp.53-59. *Dans:* Proceedings, Scotts Turfgrass Research Conference. I. Entomol. Marysville, Ohio.

Streu, H.T. et J.B. Gingrich. 1972. Seasonal activity of the winter grain mite in turfgrass in New Jersey. J. Econ. Entomol. 65: 427-430.

Streu, H.T. 1973. The turfgrass ecosystem: impact of pesticides. Bull. Entomol. Soc. Am. 19: 89-91.

Tashiro, H. 1987. Turfgrass insects of United States and Canada. Cornell University Press. Ithaca, N.Y. 391p.

Terry, L.A., D. Potter et P.G. Spicer. 1993. Insecticides affect predatory arthropods and predation on Japanese beetle (Coleoptera: Scarabaeidae) eggs and fall armyworm (Lepidoptera: Noctuidae) pupae in turfgrass. 1993. J. Econ. Entomol. 86: 871-878.

Tooker, J.F. et L.M. Hanks. 2000. Influence of plant structure on natural enemies of pine needle scale in urban landscapes. Environ. Entomol. 29: 1305-1311.

Vavrek, R.C. et H.D. Niemczyk. 1990. Effect of isofenphos on nontarget invertebrates in turfgrass. Environ. Entomol. 19: 1572-1577.

Wang, Y., R.L. Crocker, L.T. Wilson, G. Smart, X. Wei, W.T. Nailon Jr. et P.P. Cobb. 2001. Effect of nematode and fungal treatment on nontarget turfgrass-inhabiting arthropod and nematode populations. Environ. Entomol. 30: 196-203.

West, C.P., E. Izekor, D.M. Oosterhuis et R.T. Robbins. 1988. The effect of *Acremonium coenophialum* on the growth and nematode infestation of tall fescue. Plant Soil 112: 3-6.

White, R.H., M.C. Engelke, S.J. Morton et B.A. Ruemmele. 1992. Competitive turgor maintenance in tall fescue. Crop Sci. 32: 251-256.

Wilson, D. 1995. Endophyte – the evolution of a term, and clarification of its use and definition. Oikos 73: 274-276.

CHAPITRE II

SPECIES DIVERSITY AND SEASONAL ABUNDANCE OF COLLEMBOLA IN TURFGRASS ECOSYSTEMS OF NORTH AMERICA*

*This chapter has been published in ***Pedobiologia*** 50:61-68 (2006). The authors are Sophie Rochefort (Centre de Recherche en Horticulture, Université Laval), Fernand Therrien (Laval, Québec), David J. Shetlar (Ohio State University), and Jacques Brodeur (Institut de recherche en biologie végétale, Université de Montréal).

2.1 Résumé

En Amérique du Nord, les graminées à gazon sont les plantes les plus communes en milieu urbain. Malgré l'ubiquité et les rôles écologiques des arthropodes de l'écosystème gazon, plusieurs aspects de leur diversité et de leur abondance demeurent méconnus. Dans la Ville de Québec, Canada, nous avons étudié l'assemblage des espèces de collemboles ainsi que les fluctuations saisonnières de leurs populations au sein d'une pelouse nouvellement établie et d'une pelouse établie depuis une dizaine d'années. En 2003 et 2004, des échantillons de sol ont été prélevés à chacun des deux sites et les collemboles extraits à l'aide d'appareils de Berlese. Un total de 21 espèces représentant 17 genres et 9 familles a été identifié. Quatre espèces sont des nouvelles mentions pour le Québec : *Brachystomella parvula*, *Mesaphorura simplex*, *Isotomodes productus*, and *Sphaeridia pumilis*. Trois espèces de collemboles de la famille des Isotomidae étaient plus abondantes, représentant 73,5% de tous les collemboles échantillonnés durant l'étude : *Parisotoma notabilis*, *Isotoma viridis*, et *Cryptopygus thermophilus*. Les collemboles étaient deux fois plus abondants dans la nouvelle pelouse que dans la pelouse établie, mais la diversité des espèces était similaire entre les deux sites à chacune des années. Aucun patron spécifique d'abondance saisonnière ne fut observé pour l'ensemble des espèces de collemboles ainsi que pour les trois espèces dominantes. L'écosystème gazon procure un habitat adéquat pour les collemboles épi-édaphiques et hémi-édaphiques, tel que les Isotomidae, principalement par l'apport constant en matière organique provenant de la tonte ainsi que par la succession naturelle des feuilles, des tiges et des racines.

2.2 Abstract

In North America, lawns are the most widely used plantings in urban areas. However, despite the ubiquity and ecological roles of turfgrass soil arthropods, many aspects of their composition and diversity have been neglected. We investigated assemblages of Collembola and their seasonal fluctuations in a newly established lawn and a ten-year-old lawn located in Québec City, Canada. Collembola were sampled every month from May to October in 2003 and 2004 by extracting individuals from soil cores using a modified Berlese funnel. A total of 21 species representing 17 genera and nine families were identified. Four species are new records for the province of Quebec: *Brachystomella parvula*, *Mesaphorura simplex*, *Isotomodes productus*, and *Sphaeridia pumilis*. Turfgrass supports mainly three cosmopolitan species from the Isotomidae family, which represent 73.5% of all Collembola collected during the survey: *Parisotoma notabilis*, *Isotoma viridis*, and *Cryptopygus thermophilus*. Collembola were twice more abundant at the newly established site, but there were minor differences in species diversity between sites and years. No clear patterns of seasonal relative abundance were observed for the whole Collembola populations, as well as for the three dominant species. Turfgrass ecosystem provides a suitable habitat for epedaphic and hemiedaphic Collembola, such as the Isotomidae, most likely because turfgrass mowing and natural leaf, stem and root replacement produces large amounts of decaying organic matter.

2.3 Introduction

Urbanized landscapes are the most rapidly expanding type of habitat throughout the world (McKinney 2002). Urbanization causes the fragmentation of large rural and natural areas and the development of semi-artificial ecosystems that are strongly shaped by anthropogenic factors. The urban environment is therefore characterized by high spatial heterogeneity with residential and commercial properties, parks, gardens, cemeteries, highway borders, and other types of land-use. The vegetation is much diversified, with a large proportion of non-indigenous species (Pickett et al. 2001). In North America, grassy lawns have become the most widely used plantings in the urban landscape (Potter and Braman 1991). They cover more then 20 million hectares in United States, with an estimate value of $40 billion annually (Anonymous 2003). Lawns are made up of perennial, intensively managed turfgrass species and are typically structured of roots, stems, and leaves, together with a layer of organic debris, the thatch. Turfgrass support a diverse fauna of microorganisms and invertebrates including herbivores, natural enemies, and decomposers (Potter et al. 1985). Most of the research in turfgrass entomology has been devoted to insect pest management. Despite their ubiquity and ecological importance, aspects of the biology of beneficial microarthropods, such as Collembola, have comparatively been ignored.

Studies by Potter et al. (1985), Vavrek and Niemczyk (1990), Braman and Pendley (1993), Byrne and Bruns (2005), have evaluated the impact of different turfgrass management on the abundance and diversity of families or ecological assemblages of Collembola. However, high level taxonomic resolution is essential for carefully describing communities, assessing the effect of natural and anthropogenic perturbations on biodiversity, and identifying bioindicator species. The objectives of the present study are to characterize, to species level, the composition of the collembolan community in turfgrass and to examine patterns of seasonal abundance of the most common species. The present study is part of a larger research program, designed to assess the impact of different turfgrass management practices on arthropod diversity and abundance.

2.4 Materials and Methods

2.4.1 Study sites

Sampling was conducted during 2003 and 2004 at two different sites in Québec City, Québec, Canada (46° 49' N; 71° 13' W). The study area lies within the Southern Laurentians ecoregion (Ecoregions Working Group 1989), which is characterized by a mid-boreal ecoclimate with warm summers and cold, snowy winters. Mean summer and winter temperatures are 14°C and -11°C, respectively. Mean annual precipitation is 1000 mm near Québec City. Snow generally covers ground from November to April. Surficial deposits are composed mainly of varying thickness of till and fluvioglacial sediments. Humo-Ferric Podzols are the dominant soils, and significant inclusions are Ferro-Humic Podzols, Dystric Brunisols on drier, coarse-textured outwash, and Mesisols on feng-bog sequences. A layer of filling up soil is usually spread at the soil surface when a lawn is established.

One site was located at Laval University, and consisted of a new Kentucky bluegrass (*Poa pratensis* L.) lawn established in June 2003 from turfgrass sod. The soil was a well-drained shale loam, with a pH of 6.5, and 3.2% of organic matter. Broadleaf weed cover was less than 2% in 2003 and 2004, and made up of *Taraxacum officinale* Weber, *Trifolium repens* L., and *Oxalis stricta* L. The other experimental site was a ten-year-old municipal lawn located in Beauport, a suburb of Québec City. The lawn consisted of a mixture of Kentucky bluegrass (30%), bentgrass (*Agrostis stolonifera* L.; 4%), fine and tall fescues (*Festuca rubra* and *F. arundinacea* Shreb.; 20%). The soil was characterized as poorly-drained clay, with a pH of 6.9, and 3.2% of organic matter. No pesticide or fertilizer had been applied on this lawn five years prior to the experiment. Broadleaf weed cover was very high (>40%), with mainly *T. officinale* Weber (19.5%), *Cerastium vulgatum* L. (7.5%), *T. repens* L. (7%), *Medicago lupulina* L. (6.5%), *Fragaria vesca* L. (3.5%), and *Plantago major* L. (2%).

Both sites (3,000 m^2) were exposed to full sun, and received three organic fertilizer (9%N-2%P-5%K) applications per year (0.34 kg N / 100m^2 in spring and summer; 0.57 kg N/ 100m^2 in fall) for an annual rate of 1.25 kg N / 100m^2. The lawns were mowed weekly at 5-8 cm height, and clippings were left on lawns. Experimental plots were not irrigated, and did not receive pesticide treatments.

2.4.2 Sampling

Collembola were sampled every month from May to October (six sampling dates), except at the university site in 2003 where sampling was initiated after turfgrass establishment (four sampling dates). Each site was subdivided in five plots (8 x 12 m), and three cores (5.1 cm in diameter by 9 cm in depth; 184 cm^3 each core) were randomly taken from each plot. The cores (consisting of grass, thatch and soil) were pooled, broken apart, and placed, grass side down, in a modified Berlese funnel at room temperature. Each Berlese funnel contained a 5 mm wire mesh on the bottom of a plastic funnel (21.5 cm diameter and 27 cm long). A 500 ml jar containing 100 ml of 70% ethyl alcohol was attached to the bottom of the funnel to collect Collembola. A 25-W incandescent light bulb used as a heat source was placed 5 cm above each funnel. The funnels were covered with a very fine nylon net curtain to prevent collembolan escape. The extraction lasted 72 h. Collembola were stored in glass vials until their identification and counting.

Adult and juvenile Collembola were observed at 400x and 1000x magnifications and identified to species level using the Christiansen and Bellinger (1998) key. Forms that could not be identified confidently were given temporary specific appellations and are characterized in the Appendix. Voucher specimens are deposited at the Collection d'insectes du Québec, Sainte-Foy (Québec), Canada. The classification used in Tables 1 and 2 follows the system adopted by Bellinger (http://www.collembola.org). The abundance of each species is presented as the mean number of individuals (± standard error) per square meter.

2.5 Results

2.5.1 Collembola fauna

Collembola were twice more abundant at the university site (72,672) than at the municipal site (28,639) over the two years. A total of 21 species representing 17 genera and nine families were identified. There were relatively small differences in species richness between sites and years. At the university site totals of 11 and 15 species were collected in 2003 and 2004, respectively. In contrast, 13 and 19 species were collected at the municipal site in 2003 and 2004, respectively. Complete lists of species from each site and their mean abundance per year are presented in Tables 2.1 and 2.2. Two species (*Isotomodes productus* and *Mesaphorura macrocheata*) were only found at the university site, whereas six other species (*Folsomia* near *bisetosa*, *Folsomia candida, Folsomides parvulus, Anurida* sp., *Mesaphorura simplex* and *M. silvicola*) were only collected at the municipal site.

Three species were commonly observed at both sites: *Isotoma viridis*, *Parisotoma notabilis* and *Cryptopygus thermophilus*, all from the Isotomidae (Tables 2.1, 2.2). They together represent 74-80% (2003-2004) of the total number of Collembola collected at the university site, and 62-68% (2003-2004) at the municipal site.

The second most abundant families were the Katiannidae and the Sminthurididae (7-20% of all Collembola in 2003 and 2004), mainly represented by *Sminthurinus elegans* and *Sphaeridia pumilis*, respectively. The next most abundant family was the Entomobryidae (2-17% in 2003 and 2004) with *Lepidocyrtus violaceus* and *Lepidocyrtus fernandi* as the more common species.

2.5.2 Seasonal abundance

There were strong seasonal fluctuations of total Collembola abundance in turfgrass at both sites in 2003 and 2004. However, consistent patterns do not emerge over the seasons at both sites (Fig.2.1). For instance, at the municipal site in 2003, population densities increased rapidly early in the season, peaking in June, before declining from July to September, and increasing again in October. However, in 2004, populations remained low throughout the first four months before increasing towards the end of the season. At the species level, inconsistent seasonal patterns of abundance were also observed for *I. viridis*. This is most obvious at the university site where patterns were reversed in 2003 and 2004, with the highest densities being recorded late in the season in 2003 and much earlier in 2004. In contrast, the abundance of *P. notabilis* and *C. thermophilus* remains fairly constant throughout the season at both sites (Fig. 2.1).

2.6 Discussion

Cosmopolitan, ubiquistous, and frequently abundant, *P. notabilis*, *C. thermophilus* and *I. viridis* are found in the majority of studies describing Collembola assemblages. *Parisotoma notabilis* is a holartic species that can reach high densities in natural and managed ecosystems (Detsis 2000, Potapov 2001). It was the most abundant species observed at the municipal site. *Cryptopygus thermophilus*, a palaeartic species, is distributed throughout Europe, Africa, Australia, and America (Poinsot 1971). It was found to be the most frequent and abundant species in several very diverse habitats, including disturbed open and forest sites, meadows and others (Potapov 2001, Sousa et al. 2004). This species predominated the Collembola community at the university site in 2004. *Isotoma viridis*, a holarctic species, is abundant in meadows and agricultural fields (Potapov 2001). As with other Isotomidae, *I. viridis* feeds on fungal hyphae and decaying leaf matter, but when such food are in short supply, it may prey on other microarthropods (Poole 1959).

The most abundant families of Collembola collected in turfgrass (Isotomidae, Katiannidae, Sminthuridae and Entomobryidae) are mostly epedaphic or hemiedaphic Collembola (Winkler and Kampichler 2000, Lindberg and Bengtsson 2005). Epedaphic organisms live at the surface and on vegetation, whereas hemiedaphic organisms colonize superficial soil layers and leaf litter (Hopkin 1997). The turfgrass ecosystem appears to provide a suitable habitat for these Collembola that feed on fungal hyphae, bacteria, dead or decaying plants, and insect frass. Frequent mowing produces large amounts of grass clippings that turn into decaying organic matter and resources for soil fauna. The most common and abundant Collembola species are likely to live in upper layers of the soil and within the thatch layer where habitat productivity is maximum due to high level of organic matter and thereby a high level of decomposition. Moreover, turfgrass species grown in Québec are perennial and thus provide a permanent ground cover, which may reduce variations in humidity and temperature in thatch and soil, thereby providing a more stable environment for Collembola populations.

In terms of species diversity, the Collembola in turfgrass lawn (21 species; this study) compares to the fauna reported from grassland soils (16-32 species; reviewed by Butcher et al. 1971). More recent studies confirm this pattern as Brand and Dunn (1997) identified 27 Collembola species in Michigan and Illinois tall grass prairies, while Winkler and Kampichler (2000) found 23 species in a dry grassland in Austria. Collembola diversity in turfgrass lawns is however much lower than in forest ecosystems. In Canada, Addison et al. (2003) identified 75 species from temperate forests on Vancouver Island, British Columbia, while Therrien et al. (1999) and Chagnon et al. (2000) found more than 90 species in maple forests of Québec.

Anthropogenic disturbances, abiotic factors (temperature, humidity), structures of the soil (pore volume, abrasive property, organic content, compaction), soil microbial communities and, to a lesser extent, vegetation above ground have been recognized as important determinants of the species diversity and abundance of Collembola (Christiansen 1964, Hopkin 1997). The two study sites differed in a number of these determinants: a newly established lawn (mono-species sod with few other plants) at the university site placed on a well-drained loam soil, whereas the municipal site had more diversified vegetation (both grass and weed species). Although our study was not primarily designed to test for differences between sites and to identify factors of population regulation, two major patterns can be observed. First, the variety of Collembola was similar at the university (15 species) and municipal (19 species) sites, with the three same dominant species. This suggests that the new lawn, established with turfgrass sod grown for 1.5 to 2.5 years in a nursery, had already acquired its own community of Collembola, which was similar to the one found in the older turfgrass lawn. It also indicates, as observed in other studies, that communities of Collembola in different soils at a same locality are fairly uniform (Butcher et al. 1971). Finally, the data suggest that a more complex plant community in turfgrass, such as the one observed at the municipal site, does not necessarily translate into a much more diversified assemblage of Collembola over a short period. These results may contribute to the open debate on the relationship between the above ground vegetation and species richness of Collembola (see Wardle 2002 and Salamon et al. 2004 for a review). The second major observation arising from a comparison between sites is that Collembola were twice more abundant at the university site than at the municipal site. Factors responsible for this difference remain unknown. Critical studies using multivariate analyses have yet to be conducted in turfgrass to assess the long-term effects of environmental determinants on assemblages of collembolan species, their succession and abundance.

Populations of Collembola largely fluctuated throughout the season but no clear patterns in relative abundance were observed. In his seminal paper, Christiansen (1964) concluded that '… comprehensive studies (of seasonal population trends) give a very confusing picture, and … present indications of anything like clear seasonal fluctuations.' Recent large scale studies, either conducted at the community or species level, also revealed marked, unpredictable seasonal changes in Collembola populations (e.g., Wolters 1998, Chagnon et al. 2000, Renaud et al. 2004). Although soil might be considered as a relatively stable environment, the surface layers are subject to large fluctuations in moisture and temperature. A sound understanding of the seasonal ecology of Collembola is also hampered by partial knowledge of their bionomics. For instance, the absence of field data on longevity, phenology, and seasonal patterns of reproduction prevent a meaningful discussion on the ecological significance of these variations.

2.7 Aknowledgements

This study was supported by the Fonds de recherche en écologie urbaine, and the Fonds québécois pour la recherche sur la nature et les technologies. We thank the Ville de Québec for the opportunity to conduct our research at their municipal site; A.-È. Gagnon, and R. Labbé for technical assistance, and Dr. K. Christiansen who confirmed several specimen identifications.

2.8 References

Addison, J.A., J.A. Trofymow, V.G. Marshall. 2003. Abundance, species diversity, and community structure of Collembola in successional coastal temperate forests on Vancouver Island, Canada. Appl. Soil Ecol. 24: 233-246.

Anonymous. 2003. The National turfgrass research initiative. National Turfgrass Federation, Maryland, USA.

Braman, S.K., A.F. Pendley. 1993. Relative and seasonal abundance of beneficial arthropods in centipedegrass as influenced by management practices. J. Econ. Entomol. 86: 494-504.

Brand, R.H., C.P. Dunn. 1997. Diversity and abundance of springtails (Insecta: Collembola) in native and restored tallgrass prairies. Am. Midl. Nat. 139: 235-242.

Butcher, J.W., R. Snider, R.J. Snider. 1971. Bioecology of edaphic Collembola and Acarina. Annu. Rev. Entomol. 16: 249-288.

Byrne, L.B., M.A. Bruns. 2005. The effects of lawn management on soil microarthropods. J. Agric. Urban Entomol. 21 : 150-156.

Chagnon, M., C. Hébert, D. Paré. 2000. Community structures of Collembola in sugar maple forests: relations to humus type and seasonal trends. Pedobiologia 44:148-174.

Christiansen, K.A. 1964. Bionomics of Collembola. Annu. Rev. Entomol. 9: 147-178.

Christiansen, K. A., P.F. Bellinger. 1998. The Collembola of North America north of the Rio Grande. 2nd edition. Grinnell College, Iowa, USA.

Detsis, V., 2000. Vertical distribution of Collembola in deciduous forests under Mediterranean climatic conditions. Belgian J. Zool. 130: 55-59.

EcoRegions Working Group. 1989. Ecoclimatic Regions of Canada, First Approximation. Ecological Land Classification Series, No. 23, Environment Canada, Ottawa, Canada.

Hopkin, S.P. 1997. Biology of springtails (Insecta: Collembola). Oxford University Press, Oxford, UK. 344p.

Lindberg, N., J. Bengtsson. 2005. Population responses of oribatid mites and collembolans after drought. Appl. Soil Ecol. 28: 163-174.

McKinney, M.L. 2002. Urbanization, biodiversity, and conservation. Bioscience 52: 883-890.

Pickett, S.T.A., M.L. Cadenasso, J.M. Grove, C.H. Nilon, R.V. Pouyat, W.C. Zipperer, R. Costanza. 2001. Urban ecological systems: linking terrestrial ecological, physical, and socioeconomic components of metropolitan areas. Annu. Rev. Ecol. Syst. 32: 127-157.

Poinsot, N. 1971. Ethologie de quelques espèces de Collemboles Isotomides de Provence. Annales de l'Université de Provence, Sciences, 45 : 33-53.

Poole,T.B.. 1959. Studies on the food of Collembola in a Douglas fir plantation. Proc. Zool. Soc. Lond. 132, 71-82.

Potapov, M., 2001. Synopses on Palaearctic Collembola, Volume 3. Isotomidae. Abhandlungen und Berichte des Naturkundemuseums Görlitz, Band 73, Heft 2.

Potter, D.A., S.K. Braman. 1991. Ecology and management of turfgrass insects. Annu. Rev. Entomol. 36: 383-406.

Potter, D.A., B.L. Bridges, F.C. Gordon. 1985. Effect of N fertilization on earthworm and microarthropod populations in Kentucky bluegrass turf. Agron. J. 77 : 367-372.

Renaud, A., N. Poinsot-Balaguer, J. Cortet, J. Le Petit. 2004. Influence of four soil maintenance practices on Collembola communities in Mediterranean vineyard. Pedobiologia 48: 623-630.

Salamon, J-A., M. Schaefer, J. Alphei, B. Schmid, S. Scheu. 2004. Effects of plant diversity on Collembola in an experimental grassland ecosystem. Oikos 106: 51-60.

Skidmore, R.E. 1995. Checklist of Collembola (Insecta: Apterygota) of Canada and Alaska. Proc. Entomol. Soc. Ont 126: 45-76.

Sousa, J.P., M.M. da Gama, C. Pinto, A. Keating, F. Clhôa, M. Lemos, C. Castro, T. Luz, Leitão, L. Dias. 2004. Effects of land-use on Collembola diversity patterns in a Mediterranean landscape. Pedobiologia 48: 609-622.

Therrien, F., M. Chagnon, C. Hébert. 1999. Biodiverity of Collembola in sugar maple (Aceraceae) forests. Can. Entomol. 131: 613-628.

Vavrek, R.C., H.D. Niemczyk. 1990. Effect of isofenphos on nontarget invertebrates in turfgrass. Environ. Entomol. 19: 1572-1577.

Wardle, D.A. 2002. Communities and ecosystems – Linking the aboveground and belowground components. Princeton University Press, Princeton, USA.

Winkler, H., C. Kampichler. 2000. Local and regional species richness in communities of surface-dwelling grassland Collembola: indication of species saturation. Ecography 23: 385-392.

Wolters, V.. 1998. Long-term dynamics of a collembolan community. Appl. Soil Ecol. 9: 221-227.

2.9 Taxonomic remarks

Folsomia near *bisetosa*

This form keys to *F. bisetosa* in the works of Christiansen and Bellinger (1998) and Potapov (2001). The posterior position of the body sensillae, the microsensillar formula and the dens chaetotaxy also match the description given for Palaearctic specimens. However, the 2+2 manubrial anterior setae are clearly not arranged one behind the other but at an angle of about 20 degrees and the dens to manubrium ratio is 1 : 0.8. (16 specimens).

Anurida sp.

Though this form keys to *A. martynovae* in Christiansen and Bellinger (1998), it does not match the description of any of the species of *Anurida* presented in this work. The abdominal fourth segment has p1 to p5 setae all present with strongly developed p3. All the longest posterior abdominal setae are weakly clavate. Most peculiar is that the mandible is identical to the figure 247 F given for *A. granaria* in the work previously mentioned. (four specimens).

Faunistic note

Based on Skidmore (1995) and Therrien et al. (1999), four species previously known to occur in Canada are newly recorded from the province of Québec: *Brachystomella parvula, Mesaphorura simplex, Isotomodes productus* and *Sphaeridia pumilis.*

Table 2.1. Mean abundance (±se) per square meter of Collembola species collected in soil samples of turfgrass at the university site in 2003 and 2004 in Québec city, Canada.

Family and species	**Sampling year**	
	2003	**2004**
Brachystomellidae		
Brachystomella parvula (Schäffer, 1896)	1,092 ± 194	639 ± 178
Onychiuridae		
Protaphorura armata (Tullberg, 1869)	0	100 ± 66
Tullbergiidae		
Mesaphorura macrocheata Rusek, 1976	0	22 ± 13
Isotomidae		
Isotoma viridis Bourlet, 1839	10,542 ± 3,961	1,778 ± 3,278
Parisotoma notabilis (Schäffer, 1896)	7,192 ± 1,877	17,644 ± 2,272
Cryptopygus thermophilus (Axelson, 1900)	3,658 ± 1,264	4,672 ± 1,207
Isotomodes productus (Axelson, 1906)	0	61 ± 61
Isotomiella minor (Schäffer, 1896)	25 ± 18	22 ± 13
Entomobryidae		
Pseudosinella violenta (Folsom, 1924)	758 ± 221	956 ± 253
Pseudosinella alba (Packard, 1873)	0	667 ± 199
Lepidocyrtus violaceus (Fourcroy, 1785)	758 ± 221	3,906 ± 996
Lepidocyrtus fernandi Christiansen & Bellinger, 1998	292 ± 94	2,356 ± 600
Bourletiellidae		
Bourletiella arvalis (Fitch, 1862)	208 ± 111	11 ± 11
Katiannidae		
Sminthurinus elegans Fitch, 1862	1,017 ± 137	2,217 ± 460
Sminthurididae		
Sphaeridia pumilis Krausbauer, 1898	1,458 ± 430	872 ± 169

Table 2.2. Mean abundance (± SE) per square meter of Collembola species collected in soil samples of turfgrass at the municipal site in 2003 and 2004 in Québec city, Canada.

Family and species	**Sampling year**	
	2003	**2004**
Brachystomellidae		
Brachystomella parvula (Schäffer, 1896)	1,489 ± 417	211 ± 41
Neanuridae		
Anurida sp. Laboulbène, 1865	0	6 ± 6
Onychiuridae		
Protaphorura armata (Tullberg, 1869)	200 ± 173	1,244 ± 552
Tullbergiidae		
Mesaphorura simplex (Gisin, 1958)	0	6 ± 6
Mesaphorura silvicola (Folsom, 1932)	6 ± 6	11 ± 8
Isotomidae		
Cryptopygus thermophilus (Axelson, 1900)	7,744 ± 3,232	2,239 ± 499
Isotoma viridis Bourlet, 1836	3,656 ± 659	2,656 ± 688
Parisotoma notabilis (Schäffer, 1896)	1,950 ± 741	750 ± 313
Folsomia near *bisetosa* Gisin, 1953	372 ± 350	244 ± 233
Folsomia candida Willem, 1902	0	78 ± 78
Folsomides parvulus Stach, 1922	0	11 ± 8
Isotomiella minor (Schäffer, 1896)	0	22 ± 13
Entomobryidae		
Pseudosinella violenta (Folsom, 1924)	44 ± 18	6 ± 6
Pseudosinella alba (Packard, 1873)	0	211 ± 71
Lepidocyrtus violaceus (Fourcroy, 1785)	200 ± 112	44 ± 19
Lepidocyrtus fernandi Christiansen & Bellinger, 1998	67 ± 20	117 ± 39
Bourletiellidae		
Bourletiella arvalis (Fitch, 1862)	439 ± 173	172 ± 95
Katiannidae		
Sminthurinus elegans Fitch, 1862	1,850 ± 825	500 ± 127
Sminthurididae		
Sphaeridia pumilis Krausbauer, 1898	1,617 ± 627	478 ± 163

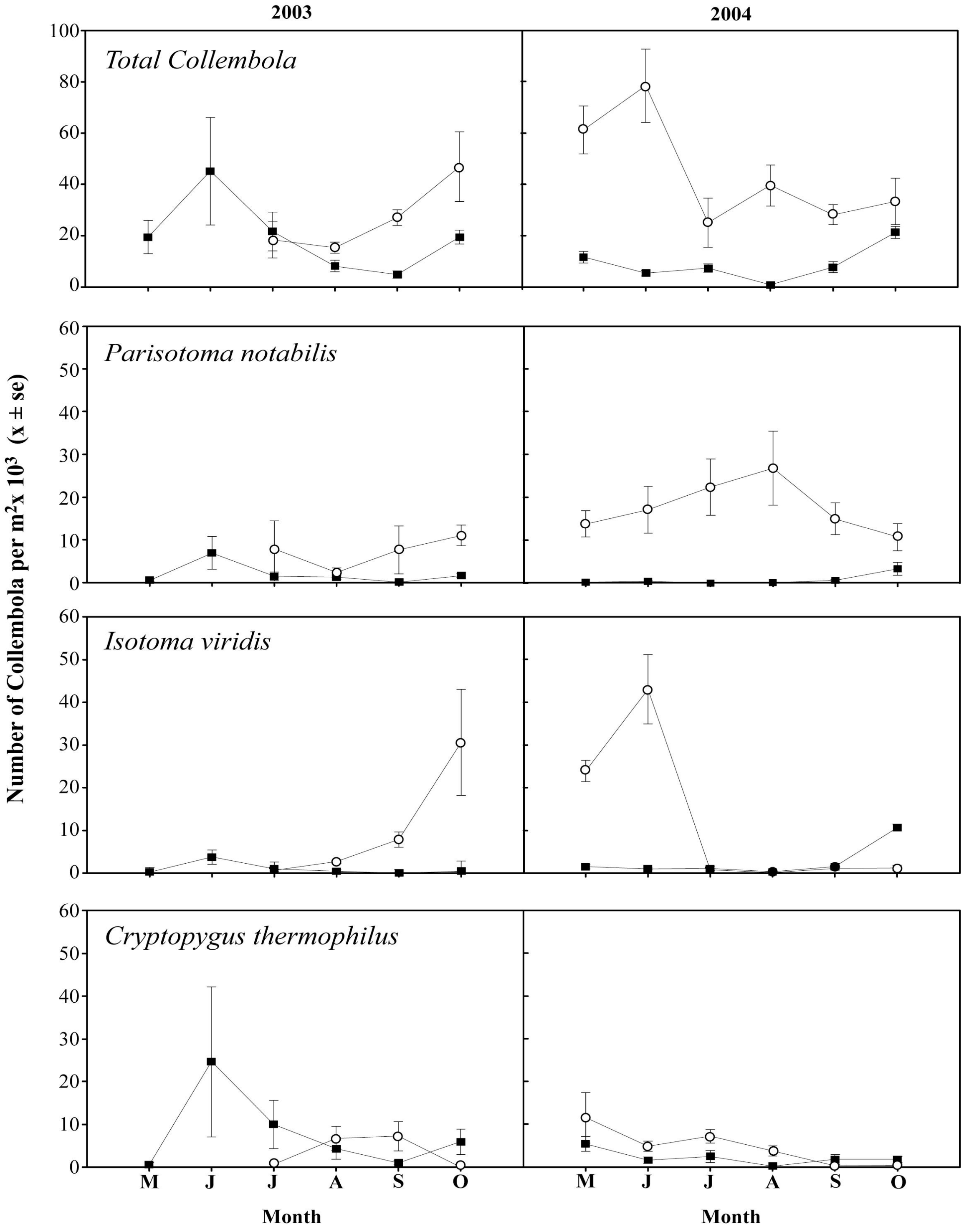


Figure 2.1. Seasonal abundance (mean number / m^2 ± se) of total Collembola, and of the three most abundant species in turfgrass lawns extracted from soil cores in 2003 and 2004 at the university (○) and municipal (●) sites. At the university site in 2003, sampling was undertaken from July to October, after turfgrass establishment.

CHAPITRE III

GROUND BEETLE ASSEMBLAGES (COLEOPTERA: CARABIDAE) AND THEIR SEASONAL ABUNDANCE IN TURFGRASS ECOSYSTEMS IN NORTH AMERICA*

*This article has been submitted to ***Environmental Entomology*** (April 2006). The authors are Sophie Rochefort (Centre de Recherche en Horticulture, Université Laval), David J. Shetlar (Ohio State University), and Jacques Brodeur (Institut de recherche en biologie végétale, Université de Montréal).

3.1 Résumé

Dans les pays industrialisés, les aménagements urbains forment une mosaïque d'écosystèmes fragmentés. Les pelouses urbaines abritent une faune diversifiée d'arthropodes incluant les carabes, un groupe important d'insectes prédateurs et granivores. Malgré leur ubiquité et leurs rôles écologiques, seules quelques études ont porté sur la diversité des carabes retrouvés dans les pelouses. Cette étude visait à décrire l'assemblage des communautés de carabes ainsi que de leur abondance saisonnière dans une pelouse nouvellement établie et une pelouse établie depuis une dizaine d'années de la région de Québec, Canada. À l'aide de pièges-fosses, les carabes ont été échantillonnés de mai à novembre 2003, 2004 et 2005. Un total de 17 espèces représentant 10 genres et sept tribus a été identifié. Dans la pelouse nouvellement établie, trois espèces représentaient 72% du total des captures de carabes : *Harpalus rufipes* (30%), *Clivina fossor* (30%) et *Amara aenea* (12%). Dans la pelouse d'une dizaine d'années, les espèces dominantes étaient *Amara aenea* (31%), *Bembidion mimus* (21%) et *Dyschirius brevispinus* (19%), représentant 71% de tous les carabes échantillonnés sur ce site. L'abondance des carabes était six fois plus importante dans la pelouse âgée que dans la nouvelle pelouse, mais la diversité entre les sites et les années était similaire. Pour les espèces dominantes, les patrons d'abondance saisonnière étaient similaires pour *A. aenea* et *B. mimus* avec un pic d'abondance en juillet-août. Les effectifs de *H. rufipes* étaient plus importants en 2003 et 2005, indiquant un cycle bi-annuel chez cette espèce au Québec. Un pourcentage élevé de plantes à feuilles larges, plus particulièrement le pissenlit, ainsi que des caractéristiques du sol semblent être des facteurs importants régulant les assemblages et l'abondance des carabes dans l'écosystème 'gazon'.

3.2 Abstract

In industrialized countries land transformation into urban landscapes results in fragmented mosaics of managed ecosystems. Turgrass lawns support a diverse fauna of arthropods including ground beetles, a major predator and seed feeding group. Despite their ubiquity and ecological roles, few studies have looked at ground beetle diversity and composition within lawns. We investigated assemblages of Carabidae and their seasonal abundance in a newly established and a 10-year old lawn located in Québec City, Canada. Carabids were sampled from May to November in 2003, 2004, and 2005 using pitfall traps. A total of 17 species in ten genera and seven tribes were identified. In the new lawn, three ground beetle species represented 72% of total Carabidae: *Harpalus rufipes* (30%), *Clivina fossor* (30%), and *Amara aenea* (12%). In the older lawn, the most abundant species were *Amara aenea* (31%), *Bembidion mimus* (21%), and *Dyschirius brevispinus* (19%), representing 71% of total Carabidae. Ground beetles were six times more abundant at the older site, but there were minor differences in species diversity between sites and years. For the most abundant Carabidae collected, seasonal abundance patterns were similar for *A. aenea* and *B. mimus* with a higher abundance in July and/or August. For *Harpalus rufipes*, seasonal abundance was higher in 2003 and 2005, indicating a biennial life cycle. Presence of a high percent of broadleaf weeds, especially dandelion, and soil characteristics appear to be important factors for ground beetle assemblages and abundance in turfgrass ecosystems.

3.3 Introduction

Urbanization is an important component of human land usage. In industrialized countries such as in North America, 80% of the human population lives in cities (Vandruff et al. 1995). It is projected that in the next 30 years, the world's population living in cities will rose near to 60% (Douglas 1992). Moreover, the size of cities increases dramatically with 300 cities having more than 10^6 inhabitants (Pickett et al. 2001). Urbanization and resulting urban landscapes differ dramatically from native and agricultural landscapes. Urban landscapes are fragmented into a mosaic of small, managed ecosystems that are strongly shaped by anthropogenic factors. The vegetation found in urban environments is diversified with a large proportion of non-indigenous species reflecting the affection of urban residents for introduced ornamental plants (Tonteri and Haila 1990, Pickett et al. 2001). Residential and commercial properties, parks, gardens, cemeteries, highway borders, and other types of land-use further characterize the heterogeneous urban environment. In North America, grassy lawns are the most used plantings in urban landscapes (Potter and Braman 1991). More than 20 million hectares are covered with turfgrass lawns in the United States (Anonymous 2003). Turfgrass lawn ecosystems are made up of perennial grass species and even when intensively managed, support a diverse fauna of arthropods including herbivores, natural enemies, and decomposers (Braman and Pendley 1983, Cockfield and Potter 1984, Heng-Moss et al. 1998, Rochefort et al. 2006). The presence of natural enemies is particularly important in habitats where a high level of disturbance has occurred as predators may help prevent insect pest outbreaks, thereby resulting in more sustainable systems. Ground beetles are one of these beneficial insects found in turfgrass ecosystems.

Ground beetles represent a large and diversify group of arthropods. More than 40,000 species of Carabidae have been described (Lövei and Sunderland 1996). They are the largest family of adephagan beetles (Kromp 1999) and of the epigaeic insects. Most carabids are typically polyphagous, with insect prey predominating but plant matter also being ingested (Kromp 1999). Carabid populations are sensitive to anthropogenic changes in habitat quality and are considered to have bioindicative value for assessments of environmental pollution, habitat classification for nature protection or land use (Descender et al. 1994).

Despite their ubiquity and ecological importance, aspects of ground beetle biology in turfgrass entomology have been largely ignored. To date, studies on ground beetles of turfgrass ecosystems have been devoted to the impact of turfgrass pesticides and general management on their densities (Arnold and Potter 1987, Braman and Pendley 1993). Data are scarce concerning the seasonal abundance of ground beetles at species level. To assess the effect of natural and anthropogenic perturbations on biodiversity, and identifying bioindicator species, a better understanding of ground beetle biology and diversity is crucial. The objectives of the present study were to characterized, to species level, the composition of the carabid community in turfgrass and to examine patterns of seasonal abundance of the most common species. The present study is part of a larger research program, designed to assess the impact of different turfgrass management practices on arthropod diversity and abundance.

3.4 Materials and Methods

3.4.1 Study sites

Sampling was conducted during 2003, 2004, and 2005 at two different sites in Québec City, Québec, Canada (46° 49' N; 71° 13' W). The study area is characterized by a mid-boreal ecoclimate with warm summers and cold, snowy winters. Mean summer and winter temperatures are 14°C and -11°C, respectively. Mean annual precipitation is 1000 mm near Québec City. Snow generally covers ground from November to April (Ecoregions Working Group 1989).

One site was located at Laval University, and consisted of a new Kentucky bluegrass (*Poa pratensis* L.) lawn established in June 2003 from turfgrass sod. The soil was a well-drained shale loam, with a pH of 6.5, and 3.2% of organic matter. Broadleaf weed cover was 2% or less for the three year study and consisted of *Taraxacum officinale* Weber (dandelion), *Trifolium repens* L. (white clover), and *Oxalis stricta* L (European wood-sorrel). The other experimental site was a ten-year-old municipal lawn located in Beauport, a suburb of Québec City. The lawn consisted of a mixture of Kentucky bluegrass (30%), bentgrass (*Agrostis stolonifera* L.; 4%), fine and tall fescues (*Festuca rubra* and *F. arundinacea* Shreb.; 20%). The soil was characterized as poorly-drained clay, with a pH of 6.9, and 3.2% of organic matter. No pesticide or fertilizer had been applied on this lawn five years prior to the experiment. Broadleaf weed cover was very high (>40%), with mainly *T. officinale* (19.5%), *Cerastium vulgatum* (7.5%; mouse-eared chickweed), *T. repens* (7%), *Medicago lupulina* L. (black medic; 6.5%), *Fragaria vesca* L. (wild strawberry; 3.5%), and *Plantago major* L. (broad-leaved plantain; 2%).

Both sites (3,000 m^2) were exposed to full sun, and received three organic fertilizer (9%N-2%P-5%K) applications per year (0.34 kg N / $100m^2$ in spring and summer; 0.57 kg N / $100m^2$ in fall) for an annual rate of 1.25 kg N / $100m^2$. The lawns were mowed weekly at 5-8 cm height, and clippings were left on lawns. Experimental plots were not irrigated, and did not receive pesticide treatments.

3.4.2 Sampling

Carabidae were sampled using pitfall traps as described by Morill (1975). Briefly, the trap consists of a 500 ml plastic cup with a top diameter of 92 mm and a depth of 122 mm in which a 125 ml plastic cup is placed inside the 500 ml cup. The top funnel is a coffee cup liner with the bottom cut off to form a funnel. Traps were installed at the beginning of May in 2003 by digging a hole with a golf cup cutter (11 cm in diameter by 20 cm in depth). The top of the 500 ml cup was installed at ground level and soil was used to fill all spaces around the trap. The inner container of each trap was filled with 100 ml of a solution made of 400 ml ethylene glycol and 600 ml water. Sampling was performed every year from mid-May to mid-November (27 sampling dates), except at the university site in 2003 where sampling was initiated after turfgrass establishment (21 sampling dates). Each site was subdivided into five plots (8 x 12 m) in which two pitfall traps, one meter apart, were placed in the middle of the plot. Every week, the content of the inner container was removed and replaced by a new one with ethylene glycol solution. Samples were returned to the lab and Carabidae adults were identified to species level using Larochelle (1976) and Lindroth (1961-1969) keys. Specimens are deposited at the Collection d'insectes du Québec, Sainte-Foy (Québec), Canada. The abundance of each species is presented as the mean number of individuals per trap (± standard error) for the three sampling years while the seasonal abundance is presented as the mean number of individuals per trap (± standard error) for a period of three weeks (a total of nine periods).

3.5 Results

3.5.1 Carabidae fauna

Ground beetles were six times more abundant at the municipal site (1,763) than at the university site (297) over the three years. A total of 17 species representing ten genera and seven tribes were identified. The species richness between sites and years was quite similar. At the university site, nine, ten and eleven species were collected in 2003, 2004, and 2005, respectively. At the municipal site, twelve, thirteen, and fifteen species were identified in 2003, 2004, and 2005, respectively. Complete lists of species from each site and their mean abundance per year are presented in Tables 3.1 and 3.2. *Agonum cupripenne* was only found at the municipal site, while *Bradycellus lecontei* was only collected at the university site. *Amara aenea* was commonly found at both sites but was more abundant at the municipal site, especially in 2005 (Table 3.1). This species represents 12% of total number of Carabidae collected at the university site, and 31% at the municipal site. At the university site, two other species were more abundant than *A. aenea*: *Harpalus rufipes* and *Clivina fossor* each represented 30% of the total Carabidae fauna (Table 3.2). Together, they represent 72% of total Carabidae collected. At the municipal site, the second abundant species, after *A. aenea,* were: *Dyschirius brevispinus* and *Bembidion mimus* representing 19 and 21% of total Carabidae collected in the traps. These three species together represented 71% of Carabidae fauna at the municipal site.

3.5.2 Seasonal abundance

Seasonal abundance of total Carabidae in turfgrass was variable between sites and between years (Fig. 3.1). At the university site, the abundance remained low (<10 beetles/trap) throughout the experiment with a slight decrease from 2003 to 2005 (Fig. 3.1A). The abundance was higher in June, July, and August. At the municipal site, variations were observed between years for total Carabidae. In 2003, the highest capture recorded in June was 32 beetles per trap. A first peak of abundance appeared in May 2004 (25 ind./trap) and a second one in August 2004 (33 ind./trap) with a decrease in July (10 ind./trap) for total. Mean abundance of total Carabidae in July 2005 was higher than the two previous years with up to 65 beetles per trap. For the three study years, densities of Carabidae decreased in August and September (Fig. 3.1A). Variations between sites and years were also observed for *A. aenea*. In 2003 and 2004, densities of *A. aenea* remained generally low (≤10 / trap) at both sites with a small peak of abundance at municipal site at the end of June 2003. In 2005, an obvious increase of *A. aenea* density (46 beetles / trap) appeared in July followed by a decrease in August, while its abundance remained low at the university site (Fig. 3.1B).

The density of *Bembidion mimus*, the second most abundant species at the municipal site, varied between years (Fig. 3.1C). In 2003, the density was less than five individuals per trap throughout the season, while it reached 13 individuals per trap in 2004 and in 2005. Moreover, no peak was observed in July 2003 as observed in 2004 and 2005. The density of *B. mimus* in May 2005 was higher than the two previous years, but an important decrease occurred in June before the other peak in July. This pattern was not observed in 2004, with a single peak appearing in July.

Harpalus rufipes had a higher density in July and August 2003 with more than 2 beetles per trap (Fig. 3.1D). The abundance decreases rapidly after this period with no beetle trapped till the end of the season. In 2004, density of *H. rufipes* remained low throughout the season with less than one beetle per trap. In 2005, the abundance of *H. rufipes* increased with a higher density in July till the end of August (>2.5 beetles per trap), and a decrease of abundance in September. *Clivina fossor*, the second most abundant species at the university site, had a higher density in July in 2003 and 2004 with more than 3 beetles per trap. As for *H. rufipes*, the abundance decreases after this period. Abundance of *C. fossor* was higher in 2003 and 2004 than in 2005 where less than 1 beetle trapped throughout the season.

3.6 Discussion

Our study found that more Carabidae were collected at the municipal site than at the university site. At the municipal site, mean abundance of total Carabidae was six times higher, and this higher abundance was mainly caused by *A. aenea* in 2005. This European species is Holartic and restricted to the north eastern part of North America. In Canada, this species is found in four east provinces (Nova Scotia, Newfoundland, Quebec, and Ontario), while in the United Sates, *A. aenea* as been recorded in more than 30 states (Bousquet and Larochelle 1993). *Amara aenea* colonizes different habitats, including grasslands, hedges near field crops, golf courses, urban areas, and others (Kegel 1990, Fournier et Loreau 1999, Jo and Smitley 2003, O'Neal et al. 2005). This carabid prefers dry, open grassland, and sandy soils. It is often collected on lawns, parks, and gardens. The adults are generally considered herbivorous (Lindroth 1961-1969) with a high preference for weed seeds, but can also feed on other insects (Hagley et al. 1982, Larochelle 1990). Honek et al. (2005) demonstrated that *A. aenae* has a preference for dandelion seeds while Hůrka and Jorošík (2003) demonstrated that the larval stage is omnivorous, feeding on insects as well as on seeds.

The second most abundant species collected at the municipal site during this study was the carnivourous beetle *B. mimus*. *Bembidion mimus* is mostly found in the eastern part of North America (Lindroth 1961-1969), but specimens have also been collected in Saskatchewan, Canada (Bousquet and Larochelle 1993). *Bembidion mimus* inhabits different ecosystems but in the contrary to *A. aenea*, is not an abundant and frequent species (Boivin and Hance 2003, Bellocq and Smith 2003, French et al. 2004, Goulet et al. 2004). The abundance of *B. mimus* at the municipal site was higher than at the university site where only two specimens were collected over the three-year study. At municipal site, the type of soil (clay) has probably provided a better environment for *B. mimus* which is known to prefer organic and clay soils (Lindroth 1961-1969).

Harpalus rufipes, the most abundant carabid beetle species at the university site, is an European Paleartic species, frequently found in many agricultural crops, waste places, court yards, etc. (Lindroth 1961-1969, Luff 1980). *Harpalus rufipes* is mostly distributed in the east part of North America (Bousquet and Larochelle 1993). Larvae of *H. rufipes* are seed-feeders with a preference for small seeds such as for dandelion, ryegrass, and lamb's-quarters seeds (Hartke et al. 1998), while the adults are omnivorous, feeding on other invertebrates (Larochelle 1990). Our data suggest that *H. rufipes* have a biennial life cycle in the province of Quebec with a peak of abundance in July and August. Biennial life cycle of *H. rufipes* was also observed in other studies conducted in Europe and England (Jones 1979, Luff 1980, Kádár and Szentkirályi 1998).

In terms of species diversity, we found 17 different species in our study. Previous studies (Braman and Pendley 1993, Heng-Moss et al. 1998, Braman et al. 2002) primarily sampling warm-season turfgrasses such as centipedgrass [*Eremochloa ophiuroides* (Munro) Hack], bermudagrass (*Cynodon dactylon*), and buffalograss [*Buchloe dactyloides* (Nutall)], found up to 21 species of ground beetles with *A. aenea* as a frequent species. A recent study by Niemelä et al. (2002) in different urban-rural gradients in three countries, listed 18 species in Finland, 25 in Canada, and 44 in Bulgaria in the urban gradient. In another study, Kegel (1990) recorded 77 species in the urban area of West Berlin, Germany. Ground beetle diversity in turfgrass lawns appears to be consistently lower than in meadows and tallgrass prairies. In Switzerland, Grandchamp et al. (2005) identified 62 species from mowed meadows, while Larsen et al. (2003) found 91 species in northeastern Iowa prairies. In field crops, ground beetle diversity is more variable (26 to 85 species) than in other ecosystems, depending on the type of crops and on field management evaluated (Rivard 1966, Thiele 1977, Larsen et al. 2003).

Temperature or humidity extremes, food availability, presence and distribution of competitors, life history, season, and weed cover are some factors that influenced ground beetles habitat distribution and abundance (Speight and Lawton 1976, House 1989, Burel and Baudry 1994, Lövei and Sunderland 1996, Kromp 1999, Irmler and Hoernes 2003, Purtauf et al. 2005). Our two study sites differed in a number of these determinants: a newly established lawn (mono-species sod with less than 2% of weed cover) at the university site was placed on a well-drained loam soil, whereas the municipal site had more diversified vegetation (more than 40% weeds and different grass species) and a poor-drained soil. Although our study was not primarily designed to test for differences between sites and to identify factors of population regulation, some patterns can be observed. First, the diversity of ground beetle was similar at the university (11 species) and municipal (15 species) sites, but not with the same dominant species. The data suggest that a more complex plant community in a lawn (defined here as a regularly mowed sward of plants), such as observed at the municipal site, does not translate into a much more diversified assemblage of ground beetle but the plant diversity probably influenced abundance of herbivourous species such as *A. aenea*. Dandelion was the most abundant weed species at the municipal site with 19.5% of total covering. Previous studies that looked on the impact of vegetation diversity on ground beetles assemblages and dynamics (e.g., Speight and Lawton 1976, House 1989) showed that a high percent of weeds surrounding field crops as well as the presence of highly diversified hedges, enhance ground beetle survival by providing different food sources (especially for phytophagous ground beetles), refuges, and in protecting them from extremes of climate. Moreover, abundance of Carabidae increased throughout the study at the municipal site. Prior to our study, the municipal site had not received any fertilizer application for the past five years. Fertilizers improve plant growth, including broadleaf weeds (Brede 2000), and this positive effect on weeds at municipal site, through our application of fertilizer, resulted in a weed cover of more than 60% by the end of the study, in 2005. On the other hand, at the university site, Carabidae abundance decreased over time with two times less Carabidae in 2005 than in 2003. This suggests that the newly established lawn is a less suitable habitat, on a short term period, for Carabidae. The second major observation arising from a comparison between sites is that ground beetles were six times more abundant at the municipal site than at the university site.

Populations of some ground beetles fluctuated between years, and for some species, within the season, but for the most abundant species, seasonal abundance was quite similar with a peak of adults in June-July and a decrease in August-September till the end of the season. This pattern was also observed in other ecosystems where spring-breeding ground beetles were abundant (Luff 1980, Heng-Moss et al. 1998, O'Neal et al. 2005). Fluctuations during a season can be caused by abiotic and biotic factors such as predation, weather, and food availability, but further investigations are needed to assess the importance of these factors on ground beetles that colonize turfgrass ecosystems and determine their ecological importance in this major urban ecosystem in North America.

3.7 Acknowledgments

We thank Dr. C. Hébert for helpful suggestions on the experimental design; M. Leblond, V. Joly-Séguin, M. Desjardins and P. Deschênes for technical assistance; and M. Fréchette who confirmed several specimen identifications. We thank the Ville de Québec for the opportunity to conduct our research at their municipal site. This work was supported by grants from the Fonds québécois de recherche sur la nature et les technologies, and the Fonds de recherche en écologie urbaine.

3.8 References

Anonymous, 2003. The National turfgrass research initiative. National Turfgrass Federation, Maryland, USA.

Arnold, T.B. and D.A. Potter. 1987. Impact of high-maintenance lawn-care program on nontarget invertebrates in Kentucky bluegrass turf. Environ. Entomol. 16:100-105.

Bellocq, M.I. and S.M. Smith. 2003. Convergence in arthropod assemblages with various restoration approaches for Canadian deciduous forests. J. Insect Cons. 7:99-109.

Boivin, G. and T. Hance. 2003. Ground beetle assemblages in cultivated organic soil and adjacent habitats: temporal dynamics of microspatial changes. Pedobiologia 47:193-202.

Bousquet, Y. and A. Larochelle. 1993. Catalogue of the geadephaga (Coleoptera : Trachypachidae, Rhysodida, Carabidae including Cicindelini) of America north of Mexico. Memoirs Entomol. Soc. Canada 167: 397p.

Braman, S.K. and A.F, Pendley. 1993. Relative and seasonal abundance of beneficial arthropods in centipedegrass as influenced by management practices. J. Econ. Entomol. 86:494-504.

Braman, S.K., A.F. Pendley, and W. Corley. 2002. Influence of commercially available wildflower mixes on beneficial arthropod abundance and predation in turfgrass. Environ. Entomol. 31:564-572.

Brede, D. 2000. Turfgrass maintenance reduction handbook. Ann Arbor Press, Chelsea, MI. 374p.

Burel, F. and J. Baudry. 1994. Reaction of ground beetles to vegetation changes following grassland dereliction. Acta Oecologica 15:401-415.

Cockfield, S.D. and D.A. Potter. 1984. Predatory insects and spiders from suburban lawns in Lexington, KY. Great Lakes Entomol. 17:179-184.

Descender, K. M. Dufrene, and J.-P. Maelfait. 1994. Long term dynamics of carabid beetles in Belgium: a preliminary analysis on the influence of changing climate and land use by means of a database covering more than a century, pp.247-252. *In*: Carabid beetles: Ecology and evolution. K. Descender (ed.), Kluwer Academic Publishers.

Douglas, I. 1992. The case of urban ecology. Urban Nat. Mag. 1:15-17.

EcoRegions Working Group. 1989. Ecoclimatic Regions of Canada, First Approximation. Ecological Land Classification Series, No. 23, Environment Canada, Ottawa, Canada.

Fournier, E. and M. Loreau. 1999. Effects of newly planted hedges on ground-beetle diversity (Coleoptera, Carabidae) in an agricultural landscape. Ecography 22:87-97.

French, B.W., L.D. Chandler, and M.M. Ellsbury. 2004. Ground beetle (Coleoptera: Carabidae) assemblages in a transgenic corn-soybean cropping system. Environ. Entomol. 33:554-563.

Goulet, H., L. Lesage, N. Bostanian, C. Vincent, and J. Lasnier. 2004. Diversity and seasonal activity of ground beetles (Coleoptera: Carabidae) in two vineyards of Southern Quebec, Canada. Ann. Entomol. Soc. Am. 97:1263-1272.

Grandchamp, A.-C., A. Bergamini, S. Stofer, J. Niemelä, P. Duelli, and C. Scheidegger. 2005. The influence of grassland management on ground bettles (Carabidae, Coleoptera) in Swiss montane meadows. Agric. Ecosys. Environ. 110:307-317.

Hagley, E.A.C., N.J. Holliday, and D.R. Barber. 1982. Laboratory studies of the food preferences of some orchard carabids (Coleoptera: Carabidae). Can. Entomol. 114:431-437.

Hartke, A., F.A. Drummond, and M. Liebman. 1998. Seed feeding, seed caching, and burrowing behaviors of *Harpalus rufipes* De Geer larvae (Coleoptera: Carabidae) in the Maine potato agroecosystem. Biol. Cont. 13:91-100.

Heng-Moss, T., F. Baxendale, and T. Riordan. 1998. Beneficial arthropods associated with buffalograss. J. Econ. Entomol. 91:1167-1172.

Honek, A., Z. Martinkova, and P. Saska. 2005. Post-dispersal predation of *Taraxacum officinal* (dandelion) seed. J. Ecol. 93:345-352.

House, G.J. 1989. Soil arthropods from weed and crop roots of an agroecosystem in a wheat-soybean-corn rotation: impact of tillage and herbicides. Agric. Ecosyst. Environ. 25:233-244.

Hůrka, K. and V. Jarošík. 2003. Larval omnivory in *Amara aenea* (Coleoptera: Carabidae). Eur. J. Entomol. 100 :329-335.

Irmler, U. and U. Hoernes. 2003. Assignment and evaluation of ground beetle (Coleoptera: Carabidae) assemblages to sites on different scales in a grassland landscape. Biodiversity Conserv. 7:1405-1419.

Jo, Y.-K. and D.R. Smitley. 2003. Predation of *Ataenius spretulus* (Coleoptera: Scarabaeidae) eggs and grubs by species of Carabidae and Staphylinidae on golf courses in Michigan. Environ. Entomol. 32:1370-1376.

Jones, M. 1979. The abundance and reproductive activity of common Carabidae in a winter wheat crop. Ecol. Entomol. 4:31-43.

Kádár, F. and F. Szentkirályi. 1998. Seasonal flight pattern of *Harpalus rufipes* (De Geer) captured by light traps in Hungary (Coleoptera: Carabidae). Acta Phytopath. Entomol. Hungarica 33:367-377.

Kegel, B. 1990. The distribution of carabid beetles in the urban area of West Berlin, pp. 325-329. *In*: The role of ground beetles in ecological and environmental studies, N. Stork (ed.), Intercept, Londres.

Kromp, B. 1999. Carabid beetles in sustainable agriculture: a review on pest control efficacy, cultivation impacts and enhancement. Agric. Ecosyt. Environ. 74:187-228.

Larochelle, A. 1976. Manuel d'identification des Carabidae du Québec. Cordulia, Supplément 1, 127p.

Larochelle, A. 1990. The food of carabid beetles, including Cicindellinae. Fabrerie Supp. 5:1-132.

Larsen, K.J., T.T. Work, and F.F. Purrington. 2003. Habitat use patterns by ground beetles (Coleoptera: Carabidae) of northeastern Iowa. Pedobiologia 47:288-299.

Lindroth, C.H. 1961-1969. The ground-beetles (Carabidae, excluding Cicindellinae) of Canada and Alaska. Opusc. Entomol., Suppl. Parts 1-6. 1192p.

Lövei, G.L. and K.D. Sunderland. 1996. Ecology and behavior of ground beetles (Coleoptera: Carabidae). Annu. Rev. Entomol. 41:231-256.

Luff, M.L. 1980. The biology of the ground beetle *Harpalus rufipes* in a strawberry field in Northumberland. Ann. Appl. Biol. 94:153-164.

Morill, W.L. 1975. Plastic pitfall trap. Environ. Entomol. 4: 596.

Niemelä, J., D.J. Kotze, S. Venn, L. Penev, I. Stoyanov, J. Spence, D. Hartley, and E. Montes de Oca. 2002. Carabid beetle assemblages (Coleoptera: Carabidae) across urban-rural gradients: an international comparison. Landscape Ecol. 17:387-401.

O'Neal, M.E., K.S. Mason, and R. Isaacs. 2005. Seasonal abundance of ground beetles in highbush blueberry (*Vaccinium corymbosum*) fields and response to a reduced-risk insecticide program. Environ. Entomol. 34:378-384.

Pickett, S.T.A., M.L., Cadenasso, J.M., Grove, C.H., Nilon, R.V., Pouyat, W.C., Zipperer, and R., Costanza. 2001. Urban ecological systems: linking terrestrial ecological, physical, and socioeconomic components of metropolitan areas. Annu. Rev. Ecol. Syst. 32:127-157.

Potter, D.A., S.K., Braman. 1991. Ecology and management of turfgrass insects. Annu. Rev. Entomol. 36:383-406.

Purtnauf, T., J. Dauber, and V. Wolters. 2005. The response of carabids to landscape simplification differs between trophic groups. Oecologia 142:458-464.

Rivard, I. 1966. Ground beetles (Coleoptera: Carabidae) in relation to agricultural crops. Can. Entomol. 98:189-195.

Rochefort, S., F. Therrien, D.J. Shetlar, and J.Brodeur. Species diversity and seasonal abundance of Collembola in turfgrass ecosystems of North America. Pedobiologia 50:61-68.

Speight, M.R. and J.H. Lawton. 1976. The influence of weed-cover on the mortality imposed on artificial prey by predator ground beetles in cereal fields. Oecologia 23:211-223.

Thiele, H.U. 1977. Carabid beetles in their environments, Berlin/Heidelberg, Springer, 369p.

Tonteri, T. and Y. Haila. 1990. Plants in a boreal city: ecological characteristics of vegetation in Helsinki and its surroundings, southern Finland. Ann. Bot. Fennici 27:337-352.

Vandruff, L.W., D.L. Leedy, and F.W. Stearns. 1995. Urban wildlife and human well-being, pp. 203-211. *In*: Urban ecology as the basis for urban planning. Sikopp, H., M. Numata, and A. Huber (eds.), SPB Academic Publishing. The Hague, The Netherlands.

Table 3.1. Mean abundance (±se) per pitfall trap of carabid beetle species of turfgrass at the municipal site from mid-May to mid-November in 2003, 2004, and 2005 in Québec City, Canada.

Tribe and species	**Sampling year**		
	2003	**2004**	**2005**
Tribe Zabrini			
Amara aenea (DeGeer, 1774)	2.93±0.98	2.10±0.76	10.20±2.96
Amara sp.	0	0	0.03±0.03
Tribe Platynini			
Agonum muelleri (Herbst, 1784)	1.00±0.54	0.38±0.13	0.58±0.29
Agonum affine Kirby, 1837	1.15±0.43	0.23±0.12	0.23±0.08
Agonum cupripenne (Say, 1823)	0	0	0.03±0.03
Tribe Morionini			
Pterostichus melanarius (Illiger, 1798)	0.53±0.16	0	0.40±0.11
Tribe Clivinini			
Dyschirius brevispinus LeConte, 1878	2.35±0.55	3.60±0.86	1.78±0.45
Clivina fossor (Linné, 1758)	0.1±0.05	0. 1±0.05	0.45±0.22
Tribe Bembidiini			
Bembidion quadrimaculatum oppositum Say, 1823	0.45±0.20	0.38±0.21	0.45±0.14
Bembidion mimus Hayward, 1897	1.78±0.55	3.53±1.27	3.85±1.66
Bembidion properans (Stephens, 1827)	0.30±0.11	0.63±0.23	0.33±0.11
Elaphropus incurvus (Say, 1830)	1.10±0.36	0.63±0.17	0.30±0.11
Tribe Harpalini			
Harpalus affinis (Schrank, 1781)	0.68±0.27	0.23±0.12	0.78±0.21
Harpalus rufipes (DeGeer, 1774)	0.08±0.04	0.10±0.05	0.25±0.10
Bradycellus rupestris (Say, 1823)	0	0.05±0.05	0
Stenolophus conjunctus (Say, 1823)	0	0.03±0.03	0.03±0.03
Total	12.45±2.10	11.99±2.06	19.70±3.96

Table 3.2. Mean abundance (±se) per pitfall trap of carabid beetle species of turfgrass at the university site from mid-May to mid-November in 2003, 2004, and 2005 in Québec City, Canada.

Tribe and species	**Sampling year**		
	2003	**2004**	**2005**
Tribe Zabrini			
Amara aenea (DeGeer, 1774)	0.13±0.06	0.35±0.15	0.38±0.15
Tribe Platynini			
Agonum muelleri (Herbst, 1784)	0	0.08±0.04	0.03±0.03
Agonum affine Kirby, 1837	0.03±0.03	0.03±0.03	0.13±0.06
Tribe Morionini			
Pterostichus melanarius (Illiger, 1798)	0	0	0.03±0.03
Tribe Clivinini			
Dyschirius brevispinus LeConte, 1878	0	0	0.10±0.05
Clivina fossor (Linné, 1758)	1.43±0.37	1.13±0.25	0.15±0.07
Tribe Bembidiini			
Bembidion quadrimaculatum oppositum Say, 1823	0.07±0.05	0.03±0.03	0.23±0.10
Bembidion mimus Hayward, 1897	0	0	0.05±0.03
Bembidion properans (Stephens, 1827)	0.10±0.06	0.03±0.03	0
Elaphropus incurvus (Say, 1830)	0.57±0.22	0.05±0.03	0.03±0.03
Tribe Harpalini			
Harpalus affinis (Schrank, 1781)	0.30±0.10	0.23±0.08	0.15±0.08
Harpalus rufipes (DeGeer, 1774)	1.00±0.27	0.60±0.16	0.83±0.23
Bradycellus lecontei Csiki, 1932	0.10±0.06	0.05±0.03	0
Total	**3.73±0.76**	**2.58±0.45**	**2.11±0.40**

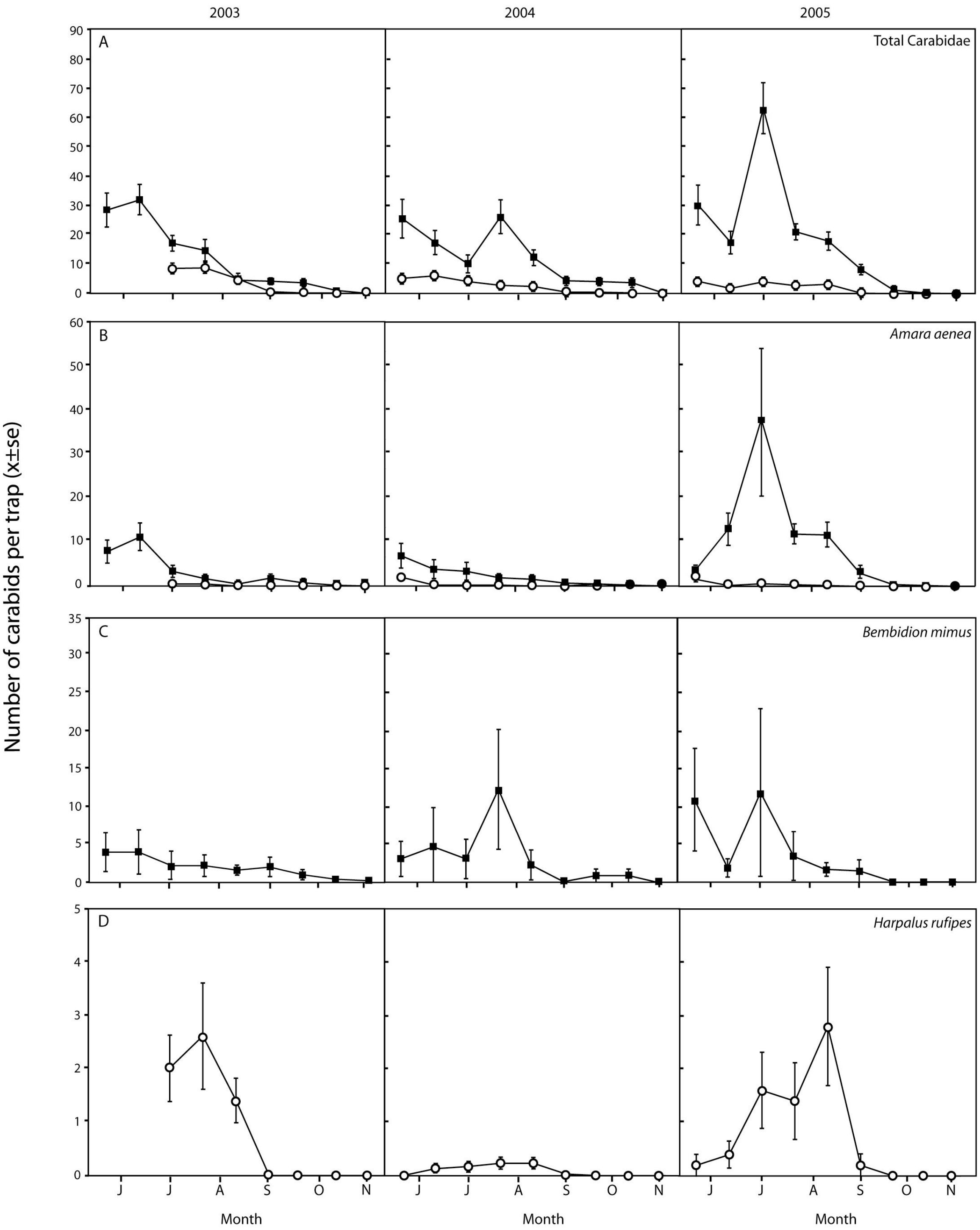


Fig. 3.1. Seasonal abundance (mean number / pitfall trap ± se) of total Carabidae, and of the three most abundant species in turfgrass lawns collected in 2003, 2004, and 2005 at the university (**O**) and municipal (■) sites. At the university site in 2003, sampling was undertaken from July to October, after turfgrass establishment.

CHAPITRE IV

IMPACT OF TURFGRASS MANAGEMENT ON ARTHROPOD ABUNDANCE AND DIVERSITY

The authors of this chapter are Sophie Rochefort (Centre de Recherche en Horticulture, Université Laval), David J. Shetlar (Ohio State University), and Jacques Brodeur (Institut de recherche en biologie végétale, Université de Montréal).

4.1 Résumé

Les pelouses abritent une faune diversifiée de microorganismes et d'invertébrés lesquels jouent des rôles écologiques importants dans cet écosystème. Les pelouses de graminées sont entretenues sous une régie intensive et pendant plusieurs années, la gestion des problèmes phytosanitaires reposait sur l'application d'herbicides et d'insecticides. Souvent intensives, les pratiques d'entretien de pelouses, plus spécifiquement l'utilisation des pesticides, peuvent engendrer des effets négatifs sur les populations d'arthropodes bénéfiques tel que les prédateurs et les décomposeurs, ce qui crée une instabilité au sein des communautés et parfois la résurgence d'insectes ravageurs. Nous avons étudié l'impact à court et moyen termes de quatre types d'entretien de pelouses sur les communauté d'arthropodes: faible entretien (fertilisation), entretien intensif (fertilisation et applications d'herbicides et d'insecticides), entretien avec une approche de lutte intégrée (fertilisation et pesticides lorsque nécessaire) et entretien écologique (fertilisation et utilisation de méthodes biologiques et culturales). Les traitements ont été évalués en 2003, 2004 et 2005 sur deux sites: une nouvelle pelouse (gazon en plaques constitué de 100% de pâturin du Kentucky avec moins de 2% de mauvaises herbes à feuilles larges) et une pelouse établie depuis 10 ans (composée d'un mélange de graminées à gazon et plus de 40% de mauvaises herbes à feuilles larges). Les arthropodes à la surface du sol et dans le sol ont été respectivement échantillonnés à l'aide de pièges-fosses et d'appareils de

Berlese. Plus de 34 000 arthropodes ont été échantillonnés annuellement à chacun des sites à l'aide des pièges-fosses. Neuf taxons d'arthropodes (ordres et familles) représentaient 95% de tous les arthropodes échantillonnés. Les Formicidae et les Araneae étaient les taxons les plus abondants aux deux sites, représentant 74 à 80% du total des captures dans les pièges-fosses. Sauf exception, le type d'entretien de pelouses n'a pas affecté l'abondance des arthropodes durant les trois années de l'étude. L'insecticide diazinon a réduit significativement l'abondance des carabes et des collemboles une et/ou trois semaines après le traitement en 2003 et 2004, alors que le carbaryl a réduit les populations de collemboles en 2003.

4.2 Abstract

Turfgrass lawns support a diverse fauna of microorganisms and invertebrates which play major ecological roles in this ecosystem. Turfgrass management practices, especially the use of chemical pesticides, may be detrimental to beneficial arthropods such as predators and decomposers, thereby causing instability of arthropod communities and pest outbreaks. We investigated the short- and mid-term impact of four different turfgrass management regimes on the arthropod community. The four management regimes tested were: low maintenance turf (fertilizers), high maintenance turf (fertilizers, herbicides, insecticides), integrated pest management (fertilizers and pesticides used after sampling), and ecological management (biological and cultural practices). These management regimes were evaluated in 2003, 2004, and 2005 on two different lawns: a newly established lawn (100% Kentucky bluegrass sod with less than 2% broad-leaf weed cover) and a 10-year old lawn (mix of different turfgrasses and with >40% of weed cover). To determine turfgrass management impacts on ground-dwelling and soil arthropods, pitfall traps and Berlese funnels were used respectively. More than 34,000 arthropods were sampled in pitfall traps in both lawns. Nine major arthropod taxa (orders and families) made up 95% or more of all arthropods sampled. Formicidae and Araneae were the most abundant taxa at both sites, representing 74 to 80% of total captures in pitfall traps. With a few exceptions, turfgrass management did not affect arthropod abundance during the

study. Diazinon insecticide significantly reduced Carabidae and Collembola abundance one and/or three weeks after the treatment in 2003 and 2005, while carbaryl negatively affected Collembola abundance only in 2003.

4.3 Introduction

Turfgrass is a complex ecosystem made up of perennial turfgrass species and consisting typically of the roots, stems, and leaves, together with a layer of organic debris, the thatch. Cool-season turfgrass lawns are known to support a diverse fauna of microorganisms and invertebrates including herbivores, natural enemies, and decomposers (Potter et al. 1985). Many of these arthropods play major roles in regulating pest populations (Reinert 1978), improving soil properties (Turgeon et al. 1975), or helping in the decomposition of thatch (Potter et al. 1985). In North America, turfgrass lawns have become the most widely and intensely used plantings in the urban landscape (Potter and Braman 1991). Lawns cover more than 20 million hectares in the United States (Anonymous 2003). Public demands for a dense uniform turf have stimulated the growth of a robust turfgrass industry over the last 30 years (Cockfield and Potter 1983). For years, turfgrass pest management has relied mostly on regular application of pesticides on residential, commercial, and institutional lawns in urban and suburban areas (Cockfield and Potter 1983, Potter and Braman 1991). However, government and public concerns about the negative environmental effects of the excessive use of these chemicals in urban areas have resulted in a tendency towards turfgrass management strategies of low environmental impact such as integrated pest management and organic (ecological) or biological management.

Application of broad-spectrum insecticides can result in significant reductions of beneficial arthropod abundance and cause instability of arthropod communities (Pimentel and Edwards 1982). Previous studies in turfgrass lawns (Cockfield and Potter 1983 and 1984, Arnold and Potter 1987, Vavrek and Niemczyk 1990) have shown detrimental effects of chemical management practices on beneficial invertebrates of cool-season turfs, but none have looked at the impact of other turfgrass management (ecological and integrated) on these arthropods. Understanding the influence of different management regimes on the abundance of beneficial and nuisance arthropods of turfgrass ecosystem is of major concern for the development of ecological and economical turf practices; but, also in the interest of conservation, to maintain and/or increase biodiversity in urban landscapes.

The objectives of the present study were to: characterize arthropod communities in two different turfgrass lawn types: a newly established sodded lawn and a 10-year-old lawn; to assess the effects of four different turfgrass management regimes on the abundance of representative groups of arthropods over a three-year period; and, to determine short-term effect of two commonly used insecticides on two representative groups of arthropods.

4.4 Materials and Methods

4.4.1 Study sites

Sampling was conducted during 2003, 2004, and 2005 at two different sites in Québec City, Québec, Canada (46° 49' N; 71° 13' W). The study area is characterized by a mid-boreal ecoclimate with warm summers and cold, snowy winters. Mean summer and winter temperatures are 14°C and -11°C, respectively. Snow generally covers the ground from November to April (Ecoregions Working Group 1989).

One site was located at Laval University, and consisted of a new Kentucky bluegrass (*Poa pratensis* L.) lawn established in June 2003 using turfgrass sod. The soil was a well-drained shale loam, with a pH of 6.5, and 3.2% of organic matter. Broadleaf weed cover was 2% or less for the three-year study and consisted of *Taraxacum officinale* Weber (dandelion), *Trifolium repens* L. (white clover), and *Oxalis stricta* L (European wood-sorrel). The other experimental site was a ten-year-old municipal lawn located in Beauport, a suburb of Québec City. The lawn consisted of a mixture of Kentucky bluegrass (30%), bentgrass (*Agrostis stolonifera* L.; 4%), fine and tall fescues (*Festuca* *rubra* and *F. arundinacea* Shreb.; 20%). The soil was characterized as poorly-drained clay, with a pH of 6.9, and 3.2% of organic matter. No pesticide or fertilizer had been applied on this lawn five years prior to the experiment. Broadleaf weed cover was very high (>40%), with mainly *T. officinale* (19.5%), *Cerastium vulgatum* (7.5%; mouse-eared chickweed), *T. repens* (7%), *Medicago lupulina* L. (black medic; 6.5%), *Fragaria vesca* L. (wild strawberry; 3.5%), and *Plantago major* L. (broad-leaved plantain; 2%). Both sites (3,000 m^2), exposed to full sun, were not irrigated, and were mowed weekly at 5-8 cm height with clippings left on the surface.

4.4.2 Treatment description

During 2003, 20 plots, each 96 m^2 (8x12 m), were delimited at both sites. Plots received one of the four treatments and were arranged in a completely randomized block designed with five replications per site. Plots were each separated with a 2-m untreated turfgrass border. The four different turfgrass management regimes used in this study were: 1-untreated control; 2-chemical management; 3-integrated pest management (IPM); and 4-ecological management (see Table 4.1 for details about treatment description). Plots in regimes 1, 2, and 3 received three organic fertilizer (9%N-2%P-5%K) applications per year (0.34 kg N / 100m^2 in spring and summer; 0.57 kg N / 100m^2 in fall) for an annual rate of 1.25 kg N / 100m^2. Plots under the ecological management received one application of corn gluten meal (0.45 kg N/100m^2/application), a granular pre-emergent herbicide (Christians 1993), in May and in September, and a summer application (0.34 kg N / 100m^2) of the same organic fertilizer used in the other plots. Chemical management plots also received 2 to 3 herbicides (2,4-D, mecoprop, MCPA, TRILLION™) and two insecticide applications (diazinon and carbaryl) as cover sprays per year. Pesticides were applied using a backpack sprayer (SOLO®) with a 1-m width boom with two flat nozzles at the extremities. The sprayer was calibrated to deliver 10 liters/100 m^2 of spray volume at a 242.32 kPa pressure (35 psi). The ramp was held at 0.5 m over the turf to apply the pesticides. For the IPM plots, alternative methods were first used to control weeds (e.g., corn gluten meal and broadleaf biological control) and insect pests (pyrethrin), and when these methods were not effective, spot treatments with chemical pesticides were applied. Finally, for the ecological management plots, only alternative methods were used. For weed control, combined to corn gluten meal applications, a mycoherbicide, *Sclerotinia minor* Jagger was used as a post-emergent broad leaf control. *Sclerotinia minor* is an ascomycete plant pathogen which has shown biocontrol potential for dandelion in turfgrass (Stewart-Wade et al. 2002, Abu-Dieyeh et al. 2005). The fungus, which is inoculated on millet seeds, was provided by Dr. A. K. Watson, from McGill University, Sainte-Anne-de-Bellevue, Québec, Canada.

Table 4.1. Experimental treatments tested at municipal and university sites in 2003, 2004 and 2005.

Treatment	**Municipal site**			**University site**		
description	**2003**	**2004**	**2005**	**2003**	**2004**	**2005**
Untreated control	-	-	-	-	-	-
Chemical management	3 cover herbicides[1] (May, July, Sept.) 2 insecticides (July, August)	2 cover herbicides (May, Sept.) 2 insecticides (July, August)	2 cover herbicides (May, Sept.) 2 insecticides (July, August)	1 cover herbicide (September) 2 insecticides (July, August)	2 cover herbicides (May, Sept.) 2 insecticides (July, August)	2 cover herbicides (May, Sept.) 2 insecticides (July, August)
IPM	2 aerations (May, Sept.) 2 spot herbicides[1] (May and Sept.) 1 insecticide (pyrethrin)[2]	2 aerations (May, Sept.) 2 spot herbicides (May and Sept.)	2 aerations (May, Sept.) 2 spot herbicides (May and Sept.)	1 aeration (September)	2 aerations (May, Sept.)	2 aerations (May and Sept.)
Ecological management	2 aerations (May, Sept.) Corn gluten[3] meal (May, Sept.) 1 application of *S. minor*[4] (Sept.)	2 aerations (May, Sept.) Corn gluten meal (May, Sept.) 2 applications of *S. minor* (June, Sept.)	2 aerations (May, Sept.) Corn gluten meal (May, Sept.) 1 application of *S. minor* (Sept.)	1 aeration (Sept.) Corn gluten meal (Sept.)	2 aerations (May, Sept.) Corn gluten meal (May, Sept.)	2 aerations (May, Sept.) Corn gluten meal (May, Sept.)

---

[1] Cover = entire plot sprayed, Spot = only weeds sprayed; 2,4-D, mecoprop, MCPA, TRILLION™ at label rate with a spray volume per plot of 1.6 litres

[2] Pyrethrin: at a rate of 500 ml of a.i. per plot (TROUNCE™)

[3] Corn gluten meal: 5 kg per plot

[4] *Sclerotinia minor*: application of 6 kg per plot of sterilized millet seeds inoculated with *S.minor.*

4.4.3 Sampling

4.4.3.1 Ground-dwelling arthropods

Arthropods were sampled using uncovered pitfall traps as described by Morill (1975). Briefly, each trap consists of a 500 ml plastic cup with a top diameter of 92 mm and a depth of 122 mm with a 125 ml plastic cup placed inside. The top funnel is a coffee cup liner with the bottom cut off to form a funnel. Traps were installed at the beginning of May in 2003 by digging a hole with a golf cup cutter (11 cm in diameter by 20 cm in depth). The top of the 500 ml cup was installed at ground level and soil was used to fill all spaces around the trap. The inner cup of each trap was filled with 100 ml of a solution made of 400 ml ethylene glycol and 600 ml water. Two pitfall traps, one meter apart, were placed in the middle of each plot, and all 40 traps per site were operated every year from mid-May to mid-November (27 sampling dates), except at the university site in 2003 where sampling was initiated after turfgrass establishment (21 sampling dates). Every week, the content of the inner container was removed and replaced by a new one with ethylene glycol solution. Samples were returned to the lab and arthropod adults were identified to order, family or species level. The proportion of each group (family or order) is presented as the mean percent of each group for total arthropods captured during the season of the three-year study. Because Araneae and Formicidae represented two third of total captures at both sites, their seasonal abundance is presented separately from total arthropods. Carabidae, Staphylinidae, Araneae and Formicidae were grouped together as soil surface predators, while the herbivore group included hairy chinch bug, *Blissus leucopterus hirtus* Montandon, grass billbugs, *Sphenophorus parvulus* and *ineaqualis*, and *Tipula* sp. Seasonal abundance of total Carabidae and of *Amara aenea* (DeGeer), the most abundant species at the municipal site (Rochefort et al., submitted), are presented separately from total arthropod results. Seasonal abundance is presented as the mean number of arthropods per trap (± standard error) at each sampling period (a total of nine periods) for each study year.

4.4.3.2 Soil arthropod sampling

Because of their ecological importance and their abundance in turfgrass ecosystem, Collembola were chosen as a representative group of turfgrass soil arthropods in this study (Rochefort et al. 2006). At the municipal site, Collembola were sampled once a month, from May to October (six sampling dates). At the university site, in 2003 sampling was performed from July to October (four sampling dates) after turfgrass establishment. Three cores (5.1 cm in diameter by 9 cm in depth; 184 cm^3 each core) were randomly taken from each plot. The cores (consisting of grass, thatch and soil) were pooled, broken apart, and placed, grass side down, in a modified Berlese funnel at room temperature. Each Berlese funnel contained a 5 mm wire mesh on the bottom of a plastic funnel (21.5 cm diameter and 27 cm long). A 500 ml jar containing 100 ml of 70% ethyl alcohol was attached to the bottom of the funnel to collect Collembola. A 25-W incandescent light bulb used as a heat source was placed 5 cm above each funnel. The funnels were covered with a very fine nylon net curtain to prevent collembolan escape and the extraction lasted 72 h. Collembola were stored in glass vials until their identification and counting. Seasonal abundance of total Collembola is presented as the mean number of individuals (± se) per m^2 for each sampling date.

4.4.4 Data analysis

Weekly counts were pooled within each sampling period (three weeks by period), and means (arthropod abundance) of the four treatments were compared within each sampling period in separate years with Fisher LSD multiple comparison tests ($P<0.05$) using the PROC GLM procedure (SAS Institute 2002-2003). Mid-term effects (after three years) of treatments on total arthropods were analyzed with analysis of variance through repeated-measures (ANOVA) using the PROC MIXED procedure. Short-term effects (one and three weeks after treatments) of diazinon and carbaryl on total ground beetle and on Collembola, were also analyzed with analysis of variance through repeated-measures using the PROC MIXED procedure.

4.5 Results

4.5.1 Proportion of arthropods

At the municipal site, an annual mean of 34,071 ground-dwelling arthropods were captured for the three-year study. Nine major taxa, representing different classes, families and orders, constituted 95% of the captures (Fig. 4.1). Formicidae (51%) and Araneae (23%) were the most abundant taxa representing a combined 74% of total arthropods in pitfall traps. Carabidae, Staphylinidae, Diplopoda, and Chilopoda constitute 6, 5, 4, and 2% of total captures, respectively. Herbivore abundance (hairy chinch bug, bluegrass billbug and *Tipula* sp.) was low at this experimental site throughout the study, representing less than 5% of total arthropods. Tipulid larval captures were higher in 2005 with up to 1,246 larvae. Other arthropods such as Elateridae, Chrysomelidae, Lepidoptera, and Curculionidae together represent 5% of the captures. For Collembola, an annual mean of $1,849X10^3$ Collembola / m^2 were sampled at the municipal site.

The same major arthropod taxa were collected at the university site with an annual mean number of 34,778 arthropods per year (Fig. 4.1). Formicidae and Araneae were also the most abundant arthropods at this site representing a combined 80% of total captures. Araneae abundance at the university site was similar (42%) to Formicidae (38%). Diplopoda was the third most abundant group with 9% of total arthropods. Similar numbers of Staphylinidae (5%) were found at both sites, while Carabidae and Chilopoda represented 2% and 1% of arthropods captured, respectively. Finally, the herbivores (hairy chinch bugs and bluegrass billbugs) represented less than 1% of the captures. Collembola abundance was higher at the university site than at the municipal site with an annual mean of $5, 953X10^3$ individuals / m^2.

4.5.2. Seasonal abundance and treatment effect

4.5.2.1 Total arthropods

The abundance of total arthropods at the municipal site was higher in 2003 and 2005 than in 2004 (Fig. 4.2). The highest captures appeared during the first six sampling periods of each year which correspond to the period of May to the beginning of October. When years were analyzed separately and treatments compared at each sampling period, some significant differences occurred between treatments, but these were very transient with usually no difference the following sampling period (Fig. 4.2). In 2005, the abundance of total arthropods in the untreated control was generally higher than in the other treatments, but a significant difference was only observed at the sixth sampling period between the chemical treatment and the untreated control (*F=10.29, df=3, P=0.046*).

At the university site, abundance of total arthropods was higher in 2005 than in the two previous years (Fig. 4.2; even when using the later sampling periods of 2003). Arthropod numbers were greatest between the second (end of June) and the sixth (mid-September) period of each year. As observed at the municipal site no treatment was consistently different from the others. Differences were observed during some specific periods appeared like in 2005, after the carbaryl application at the seventh and eighth periods, where the abundance of arthropods was significantly lower in the chemical treatment than in the other ones (*F=4.85, df=3, P<0.05*). However, this difference between treatments disappeared at the ninth period (*F=1.42, df=3, P=0.29*).

Analysis of variance with repeated-measures (ANOVA) did not detect a long term effect of treatment over the three-year study (*F=1.27, df=3, P=0.31*), but time (*F=98.67, df=14, P<0.0001*) and site effect (*F=26.17, df=2, P=0.0009*) were significant. An interaction between site and time was also significant (*F=13.54, df=13, P<0.001*), indicating that differences between sites are related to time of year.

4.5.2.2 Formicidae

Ants at the municipal site were found throughout the year but were most abundant from the first (mid-May) to the sixth (September) period (Fig. 4.3). Abundance of ants was higher in 2003 and in 2005 (with up to 250 ants per trap in 2005) than in 2004 (<200 ants/trap). Significantly more ants were collected in the ecological treatment in 2003 at the sixth period (*F=5.19, df=3, P<0.04*). At the first sampling period in 2004 and 2005, abundance of ants was still higher in the ecological treatment than in the other ones (*2004: F=2.78, df=3, P<0.04; 2005: F=3.31, df=3, P<0.03*), but these differences disappeared after this period. In 2005, abundance of ants was significantly lower in the chemical treatment than in the control after the carbaryl application at the sixth period (*F=4.08, df=3, P=0.03*).

Abundance of ants at the university site was similar to what was observed at the municipal site with around 200 ants or less per trap each year (Fig. 4.3). Ants were generally more abundant from the third to the fifth period, except at the fourth period in 2003 where captures were higher (>300 ants/trap) than the two other years (<200 ants/trap). No difference between treatments was detected in 2003 and 2004, while abundance of ants in 2005 was lower in the chemical treatment compared to the control and to the ecological treatment at the fourth period (*F=3.91, df=3, P<0.02*). No other difference between the four treatments appeared after this period in 2005.

4.5.2.3 Araneae

As observed for Formicidae, spiders were captured throughout the season with greatest numbers for the first five periods (Fig. 4.4). At the municipal site, abundance of spiders increased over the three-year study with the highest density in 2005 at the fifth period (August) with up to 175 individuals/trap while in 2003 and 2004, their abundance remained lower than 100 individuals/trap throughout the season (Fig. 4.4). In 2003, a difference between the chemical treatment and the untreated control was detected at the fifth (*F=2.68, df=3, P=0.01*) and sixth periods (*F=2.37, df=3, P=0.03*), but disappeared at the seventh period. In 2004, differences between the chemical treatment and the control were also observed at the fourth (*F=3.52, df=3, P=0.01*) and fifth periods (*F=2.12, df=3, P=0.03*) with lower numbers of spiders in the chemical plots. As observed in 2003, this difference between the chemical and untreated plots disappeared at the seventh period in 2004, but a higher numbers of spiders was recorded in the chemical than in the IPM and ecological plots (*F=4.97, df=3, P<0.05*) at this same period. In 2005, no difference between the four treatments was detected.

Abundance of spiders at the university site was also higher in 2005 than in the two previous years with more than 200 individuals/trap from the third to the fifth period, compared to less than 150 spiders/trap in 2003 and 2004 (Fig. 4.4). In 2003, the only difference detected between treatments appeared at the sixth period with higher numbers of spiders in the IPM plots than in the chemical and ecological plots (*F=3.44, df=3, P<0.05*). In 2004, at the first period, spiders were in higher numbers in the ecological treatment (*F=12.33, df=3, P<0.001*). Finally, in 2005, in the chemical treatment, spider abundance was lower at the seventh period (*F=2.99, df=3, P<0.04*).

4.5.2.4 Carabidae

Ground beetle abundance at the municipal site was highest during the first five periods of the season of each study year, and thereafter, decreased through the end of the season (Fig. 4.5). The abundance of ground beetles was particularly high in 2005 at the third period in the untreated control with 62 beetles/trap, while for the other periods and years, it remained lower than 45 beetles/trap. In 2003, Carabidae abundance was lower in the chemical than in the ecological plots at the sixth period (*F=1.91, df=3, P=0.04*) and than in the untreated plots at the seventh period (*F=2.82, df=3, P=0.035*). Difference between chemical and untreated plots was only detected at the fourth period in 2004 (*F=1.87, df=3, P=0.04*) with lower numbers in the chemical plots. In 2005, from the third to the fifth period, ground beetle numbers were higher in the untreated plots than in the other treatments (3rd period: *F=5.77, df=3, P=0.01*; 4th period: *F=18.28, df=3, P<0.0001*; 5th period: *F=7.56, df=3,*

$P=0.004$). *Amara aenea*, a Carabidae species that was very abundant at the municipal site (see Chapter III, Fig. 3.1B), also had higher abundance in the untreated control than in the other treatments during the same five periods (*$F>2.78$, $df=3$, $P<0.05$*).

At the university site, ground beetles were less abundant than at the municipal site with less than 12 beetles/trap (Fig. 4.5). As observed at the municipal site, abundance of ground beetles was higher in the first five periods, but decreased after that through the end of the season. No difference between treatments was detected in 2003 and 2004; while in 2005, in contrast to what had been observed at the municipal site, numbers of ground beetles in the untreated controls were significantly lower than in the chemical treatment at the second (*$F=1.81$, $df=3$, $P=0.04$*) and sixth period (*$F=2.55$, $df=3$, $P=0.02$*).

4.5.2.5 Collembola

Abundance of Collembola at the municipal site varied between years and treatments. In 2003, a peak of abundance was present from June to July (>40,000 Collembola/m^2), while in 2004, it appeared in October (Fig. 4.6). In 2005, Collembola abundance was lower than the two previous years with less than 25,000 individuals/m^2. In October 2003, Collembola abundance was lower in the chemical treatment than in the three others (*$F=5.06$, $df=3$, $P=0.01$*). In 2004, abundance of Collembola in the ecological treatment was higher than in the other treatments in May (*$F=6.62$, $df=3$, $P=0.007$*) and again in October (*$F=3.02$, $df=3$, $P<0.05$*). The only difference detected in 2005 was in June between the untreated control and the chemical treatment, in which Collembola were more abundant (*$F=2.21$, $df=3$, $P=0.04$*).

Variations of Collembola seasonal abundance between years and treatments were also observed at the university site (Fig. 4.6). In 2003, their abundance was lower than 80,000 individuals per m^2, while in 2004 and 2005, it reached 170,000 and 120,000 individuals per m^2 respectively. As for the municipal site, peaks of abundance did not appear at the same periods in 2004 (June and July) and in 2005 (May and August). In the chemical treatment, after carbaryl application, Collembola abundance was significantly lower in August ($F=11.47$, $df=3$, $P=0.0008$), in September ($F=3.79$, $df=3$, $P=0.04$), and in October 2003 ($F=4.26$, $df=3$, $P=0.02$). This difference re-appeared the next year in May 2004 ($F=7.89$, $df=3$, $P=0.004$), but in June, Collembola abundance was higher in the chemical treatment than in the untreated control and in the ecological management plots ($F=4.18$, $df=3$, $P=0.03$). After diazinon application in July 2004, abundance of Collembola in the chemical treatment decreased as for the untreated control and for the IPM treatment. In 2005, at the first sampling period in May, significant lower numbers of Collembola were observed in the chemical treatment ($F=4.08$, $df=3$, $P<0.05$) than in the other treatments. This difference re-appeared another time in August 2005 after carbaryl application ($F=12.85$, $df=3$, $P=0.0005$).

4.5.2.6 Soil surface predators

For this group, which includes ants, spiders, ground and rove beetles, abundance at the municipal site was higher for the first five periods for all years, and generally lower in 2004 compared to 2003 and 2005 (Fig. 4.7). In 2003, at the municipal site, predators were more abundant in the ecological than in the chemical treatment at the fifth period ($F=2.05$, $df=3$, $P=0.04$) and then in the IPM and chemical plots at the sixth period ($F=4.32$, $df=3$, $P<0.05$). In 2004, at the sixth period, abundance of predators was again higher in the ecological plots than in the other treatments ($F=3.16$, $df=3$, $P<0.05$). No differences between treatments appeared in 2005 at the municipal site.

At the university site, abundance of predators was generally higher between the second and sixth period (Fig. 4.7). In 2003, predators were less abundant in the chemical treatment at the fifth period than in the untreated control and the IPM treatment ($F=3.63$, $df=3$, $P<0.05$). In 2004, the only difference between treatments was at the first period with more predators in the ecological treatments than in the others ($F=7.67$, $df=3$, $P<0.05$). Finally, in 2005 abundance of predators in the chemical treatment was lower than in the other treatments at the seventh period (*F=2.83, df=3, P<0.05*).

4.5.2.7 Herbivores

At the municipal site, hairy chinch bugs, billbugs and crane fly larvae were included in the herbivore group, while only hairy chinch bugs and billbugs composed this group at the university site. At both experimental sites, herbivore abundance was generally lower than predator abundance, except for the municipal site in 2005, where herbivore abundance reached 80 individuals/trap at the end of the season (Fig. 4.8). This high number of herbivores at this period was caused by captures of *Tipula* larvae. Hairy chinch bugs were the second most abundant herbivore at the municipal site, especially in 2003 where a pyrethrin treatment (TROUNCE™) was applied in the IPM and ecological plots to reduce their numbers. In 2004 and 2005, their population remained low throughout the season. At the university site, herbivore abundance was less than 10 individuals/trap during the three-year study (Fig. 4.8). Hairy chinch bugs were the most abundant herbivore at the university site but their density didn't reach a critical level (more than 10 chinch bugs/m^2; Rochefort et al. 1998) to treat in the IPM and ecological plots. In 2003 and 2004, no difference between treatments appeared at the university site for the herbivore group, while in 2005, significantly more herbivores were captured in the chemical than in the untreated plots at the seventh period (*F=2.44, df=3, P=0.03*).

4.5.3 Short term effects of diazinon and carbaryl applications

4.5.3.1 Carabidae

At the municipal site, a short term effect of pesticides on carabid abundance was only detected with diazinon in 2003 with a significant decrease of their abundance one week after the application (*F=12.90, df=16, P=0.009*; Fig. 4.9). In 2004, reduction of the abundance of Carabidae in the treated plots from the first (before the treatment) and the second period (one week after) was not significant, but a significant difference between the treated and untreated plots was detected one week after diazinon treatment (*F=5.14, df=16, P=0.007*).

At the university site, the abundance of Carabidae increased after diazinon application in 2003 (one and three weeks after) and in 2004 (three weeks after), while in 2005, diazinon did not affect ground beetle abundance over time (Fig. 4.9). As observed at the municipal site, carbaryl application had no short term effect on ground beetle abundance for the three years.

4.5.3.2 Collembola

Diazinon had variable effects over years on Collembola abundance at the municipal site. In 2003, a significant reduction of their abundance appeared between the first (before treatment) and the third period (three weeks after) in treated plots (*F=2.90, df=16, P=0.01*; Fig. 4.10). In 2004, this pesticide did not affect Collembola abundance while in 2005, one week after diazinon application, Collembola abundance was higher in the treated but also in the untreated plots (*F=10.63, df=16, P<0.01*) than before the application. As for Carabidae, carbaryl had no effect on Collembola abundance at the municipal site.

At the university site in 2003, diazinon application reduced numbers of Collembola one and three weeks after the treatment *(F=13.90, df=15, P=0.004*; Fig. 10). In 2004, a reduction of Collembola abundance was observed after diazinon application in the treated plots but also in the untreated plots. In 2005, abundance of Collembola in treated plots remained stable over the three periods, but was significantly lower than in the untreated plots in which, abundance reached more than 100,000 individuals per m^2 one and three weeks after diazinon application (*F=29.47, df=4, P<0.003*). Carbaryl effect on Collembola appeared only in 2003 with less individuals per m^2 one and three weeks after its application compared to the period before the application (*F=20.01, df=16, P<0.03*). In 2004 and 2005, carbaryl had no effect on Collembola.

4.6 Discussion

A variety of arthropods, including predators, decomposers, and herbivores was found in this study. Our data showed similar abundance of arthropods at both sites despite their differences in plant composition (more diversified at the municipal site than at the university site). Moreover, the same taxa, ants and spiders, were predominant at both sites. This result indicates that a specific arthropod community is associated with turfgrass ecosystems regardless of the complexity of the plant community of the lawns. Other studies conducted in different parts of the United States and with different turfgrass species found the same representative taxa in similar abundance (Cockfield and Potter 1985a & b, Arnold and Potter 1987, Braman and Pendley 1993, Heng-Moss et al. 1998) as were found in the present study. Regular mowing and large amounts of decaying plant material in turfgrass lawns appear to provide suitable habitat and food for these invertebrates.

Surprisingly, our data showed little difference between the four different turfgrass management regimes after a three-year period. Repetitive usage of herbicides and insecticides such as 2,4-D, diazinon and carbaryl did not significantly reduce numbers of arthropods in experimental plots. Moreover, integrated pest management and ecological management were not significantly different from the untreated control and from the chemical management. Differences observed between treatments at some specific sampling periods were detected, but for a short period of time, with recovery usually found in the following sampling period. Different results were obtained in other studies using turfgrass lawns. In an experiment performed by Arnold and Potter (1987), significantly lower density of predatory arthropods were found in lawns under high maintenance (with herbicide, insecticide and fertilizer applications) compared to low maintenance (only mowing). In their study, spiders, rove and ground beetles were reduced by insecticide applications, especially after a granular application of diazinon followed by irrigation. Terry et al. (1993) also demonstrated a reduction of spider and staphylinid abundance following a carbaryl application. A single application of the insecticide chlorpyrifos has also suppressed populations of spiders, staphylinid beetles, and predatory mites for at least 5 to 6 weeks in a study conducted in Kentucky bluegrass lawns (Cockfield and Potter 1983). Depending of the type of pesticide and the frequency of its application, variable responses by turfgrass arthropods can be observed. More persistent insecticides seem to be more harmful to beneficial arthropods than short residual insecticides. Vavrek and Niemczyck (1990) found that isofenphos, a relatively persistent insecticide, reduced populations of Acari, Collembola, Diplopoda, and Staphylinidae for several weeks to ten months. In the present study, for all groups of ground-dwelling arthropods, the chemical management regimes (e.g. applications of liquid diazinon and carbaryl) did not reduce arthropod density for more than a month. Many insecticides have been shown to have detrimental effects on Carabidae in turfgrass ecosystem (Cockfield and Potter 1985, Kunkel et al. 2001) and in agricultural fields (Frampton and Çilgi, 1994), but pesticides used in these experiments (bendiocarb, chlorpyrifos and deltamethrin) were different than in the present study. As for Carabidae, adverse effects of insecticides on Collembola abundance have been demonstrated. Frampton (2002) showed a significant reduction of Collembola abundance in a rotation with grass and wheat after the application of five organophosphorus insecticides. A study by Endlweber et al. (2006) demonstrated that sensitivity of different collembolan species to chlorpyrifos application varies considerably. Species, especially *Isotoma* spp., recovered quickly while Sminthurididae took more than four months to recover after the last insecticide application. In the present study, only diazinon at few periods (in 2003 and 2005) and for a short time reduced Collembola abundance. Quick recovery of Collembola populations may be explained by the presence of *Parisotoma notabilis*, the most abundant species found in our turfgrass lawns (Rochefort et al. 2006), which reproduces by parthenogenesis and therefore has a high reproduction rate and recovery potential (Petersen 1971).

Absence of differences between turfgrass management regimes evaluated in this study may also be explained by other factors. First, small plots used in this experiment probably favored rapid recolonization by arthropods. These small plots are however representative of many home lawns that are fragmented and often bordered by untreated areas which provide good refuges for arthropods after disruptions. Second, many factors (drift, volatilization, photodecomposition, degradation) determine the fate of a pesticide in the environment (Petrovic and Borromeo 1994). Diazinon and carbaryl are known to be short residual insecticides, with diazinon having a half-life of one week (Khur and Tashiro 1978) and complete degradation within 14 days (Sears and Chapman 1979). Foliar insecticide applications used in our experiment were not followed by irrigation, and probably were more rapidly degraded than if a granular formulation had been used, thereby explaining the short term effects observed for diazinon on Collembola and Carabidae. Third, turfgrass management practices used in the untreated control, the IPM and ecological plots, especially at the university site, were not sufficiently different to produce measurable differences during the three seasons of this study. Finally, high variance in the seasonality of arthropods, abiotic factors (temperature and humidity), and avoidance behaviour may also explain the absence of detectable differences between turfgrass management regimes on arthropods.

Soil surface predator group was not significantly affected by turfgrass management regime as was observed for ants and spiders, the two major groups representing more than 70% of the predators. Herbivore densities remained low at both sites and during the three-year study. Only one application of pyrethrin insecticide was required at the municipal site the first year to reduce hairy chinch bug populations in the integrated pest management and ecological plots. *Tipula* larvae were in high numbers at the municipal site in 2005, but did not cause any damage to turf and then no control was needed. Predators have probably regulated pest densities in experimental plots regardless of the type of turfgrass management used because no pest outbreaks have been observed following insecticide applications in our plots. Reinert (1978) and Cockfield et Potter (1984) have shown pest outbreaks after insecticide applications, which is caused by the disappearance of predators.

Even though our study didn't detect adverse affects of diazinon and carbaryl on arthropods, these products can cause detrimental affects on other organisms not considered in this study. Diazinon and carbaryl can cause important earthworm population reductions (40 to 80%) when applied on Kentucky bluegrass lawns (Potter et al. 1990), and *Harmonia axyridis* (a lady beetle) populations can be significantly reduced following carbaryl applications under laboratory tests (Galvan et al. 2005). Finally, when applied to turfs mixed with white clover, carbaryl negatively affects bumble bee development and activity (Gels et al. 2005).

Our study was the first to look at the impact of chemical, ecological and integrated pest management regimes on turfgrass arthropods at the same time. Some studies have looked at the impact of biological controls (entomopathogenic nematodes and fungae) on beneficial arthropods (Shetlar et al. 1993, Wang et al. 2001) or the effect of chemical herbicides, insecticides, fertilizers, and combined inputs on them (Braman et al. 1993) but none have looked at the use of multiple practices (cultural, chemical, biological and natural) on these arthropods. This study was also the first one in Québec to characterize the arthropod community associated with Kentucky bluegrass lawns. Knowledge of this community is essential to understand their roles in this ecosystem and the interactions between them. The identification of factors (biotic or abiotic) that contribute to their conservation or their dispersion will help in the future to determine appropriate practices to be used in turfgrass lawn maintenance.

4.7 Aknowledgments

We thank Dr. C. Hébert for helpful suggestions on the experimental design; Éric Dugal, M. Leblond, V. Joly-Séguin, M. Desjardins and P. Deschênes for technical assistance; and M.-P. Lamy for statistical assistance. We thank the Ville de Québec for the opportunity to conduct our research at their municipal site. This work was supported by grants from the Fonds québécois de recherche sur la nature et les technologies, and the Fonds de recherche en écologie urbaine.

4.8 References

Abu-Dieyeh, M.H., J. Bernier, and A.K. Watson. 2005. *Sclerotinia minor* advances fruiting and reduces germination in dandelion (*Taraxacum officinale*). Bio. Sc. Tech. 15: 815-825.

Anonymous, 2003. The National turfgrass research initiative. National Turfgrass Federation, Maryland, USA.

Arnold, T.B. and D.A. Potter. 1987. Impact of high-maintenance lawn-care program on nontarget invertebrates in Kentucky bluegrass turf. Environ. Entomol. 16:100-105.

Braman, S.K. and A.FPendley. 1993. Relative and seasonal abundance of beneficial arthropods in centipedegrass as influenced by management practices. J. Econ. Entomol. 86:494-504.

Christians, N.E. 1993. The use of corn gluten meal as a natural preemergence weed control in turf. Intl. Turfgrass Soc. Res. J. 7: 284-290.

Cockfield, S.D. and D.A. Potter. 1983. Short-term effects of insecticidal applications on predaceous arthropods and oribatid mites in Kentucky bluegrass turf. Environ. Entomol. 12:1260-1264.

Cockfield, S.D. and D.A. Potter. 1985a. Predatory arthropods in high- and low-maintenance turfgrass. Can. Entomol. 117: 423-429.

Cockfield, S.D. and D.A. Potter. 1985b. Predatory insects and spiders from suburban lawns in Lexington, KY. Great Lakes Entomol. 17:179-184.

Cockfield, S.D. and D.A. Potter. 1984. Predation on sod webworm (Lepidoptera: Pyralidae) eggs as affected by chlorpyrifos application to Kentucky bluegrass turf. J. Econ. Entomol. 77:1542-1544.

EcoRegions Working Group. 1989. Ecoclimatic Regions of Canada, First Approximation. Ecological Land Classification Series, No. 23, Environment Canada, Ottawa, Canada.

Endlweber, K., M. Schädler, and S. Scheu. 2006. Effects of foliar and soil insecticide applications ont the collembolan community of an early set-aside arable field. App. Soil. Ecol. 31:136-146.

Frampton, G.K. and T. Çilgi. 1994. Long-term effects of pesticides on Carabidae in U.K. farmland: some initial results from the "SCARAB" project, pp. 433-438. *In*: Carabid beetles: Ecology and Evolution. K. Descender (ed.), Kluwer Academic Publishers, Netherlands.

Frampton, G.K. 2002. Long-term impacts of an organophosphate-based regime of pesticides on field and field-edge Collembola communities. Pest Manag. Sci. 58:991-1001.

Galvan, T.L., R.L. Koch, and W.D. Hutchison. 2005. Toxicity of commonly used insecticides in sweet corn and soybean to multicolored Asian lady beetle (Coleoptera: Coccinellidae). J. Econ. Entomol. 98:780-789.

Gels, J.A., D.W. Held, and D.A. Potter. 2002. Hazards of insecticides to the bumble bees *Bombus impatiens* (Hymenoptera: Apidae) foraging on flowering white clover in turf. J. Econ. Entomol. 95:722-728.

Heng-Moss, T., F. Baxendale, and T. Riordan. 1998. Beneficial arthropods associated with buffalograss. J. Econ. Entomol. 91:1167-1172.

Honek, A., Z. Martinkova, and P. Saska. 2005. Post-dispersal predation of *Taraxacum officinal* (dandelion) seed. J. Ecol. 93:345-352.

Kunkel, B.A., D.W. Held, and D.A. Potter. 2001. Lethal and sublethal effects of bendiocarb, halofenozide, and imidacloprid on *Harpalus pennsylvanicus* (Coleoptera: Carabidae) following different modes of exposure in turfgrass. J. Econ. Entomol. 94:60-67.

Khur, R.J. and H. Tashiro. 1978. Distribution and persistence of chlopyrifos and diazinon applied to turf. Bull. Environ. Cont. Toxicol. 20:652-656.

Morill, W.L. 1975. Plastic pitfall trap. Environ. Entomol. 4: 596.

Petersen, H. 1971. Parthenogenesis in two common species of Collembola: *Tulbergia krausbaueri* Börner and *Isotomoa notabilis* Schäffer. Rev. Ecol. Biol. Sol. 8:133-138.

Petrovic, A.M. and N.R. Borromeo. 1994. Fate of pesticides in turfgrass environment, pp.29-44. *In:* Handbook of integrated pest management for turf and ornementals. A.R. Leslie (ed.). Lewis Publishers, CRC Press, FL.

Pimentel, D. and C.A. Edwards. 1982. Pesticides and ecosystems. BioScience 32: 595-600.

Potter, D.A., B.L. Bridges, and F.C. Gordon. 1985. Effect of N fertilization on earthworm and microarthropod populations in Kentucky bluegrass turf. Agron. J. 77:367-372.

Potter, D.A., M.C. Buxton, C.T. Redmond, C.G. Patterson, and A.J. Powell. 1990. Toxicity of pesticides to earthworms (Oligochaeta: Lumbricidae) and effect on thatch degradation in Kentucky bluegrass turf. J. Econ. Entomol. 83: 2362-2369.

Potter, D.A., S.K., Braman. 1991. Ecology and management of turfgrass insects. Annu. Rev. Entomol. 36:383-406.

Reinert, J.A. 1978. Natural enemy complex of the southern chinch bug in Florida. Ann. Entomol. Soc. Am. 71: 728-731.

Rochefort, S., F. Therrien, D.J. Shetlar, and J. Brodeur. 2006. Species diversity and seasonal abundance of Collembola in turfgrass ecosystems of North America. Pedobiologia 50:61-68

SAS Institute Inc. 2002-2003. SAS/STAT User's Guide, version 9.1. SAS Institute Inc., Cary North Carolina.

Sears, M.K. and R.A. Chapman. 1979. Persistence and movement of four insecticides applied to turfgrass. J. Econ. Entomol. 72:272-274.

Shetlar, D.J., K.T. Power, and H.D. Niemczyk. 1993. Effect of a subsurface application of entomopathogenic nematodes on non-target arthropods in turfgrass. International Turfgrass Soc. Res. Journal. 7: 385-390.

Stewart-Wade, S.M., S. Green, G.J. Boland, M.P. Teshler, I.B. Teshler, A.K. Watson, M.G. Sampson, K. Patterson, A. DiTommaso, and S.Dupont. *Taraxacum officinal* (Weber), Dandelion (Asteraceae), pp.427-430. *In:* P.G. Mason, J.T. Huber (eds.). Biological control programs in Canada, 1981-2000. Wallingford, UK, CABI Publishing, CAB International. .

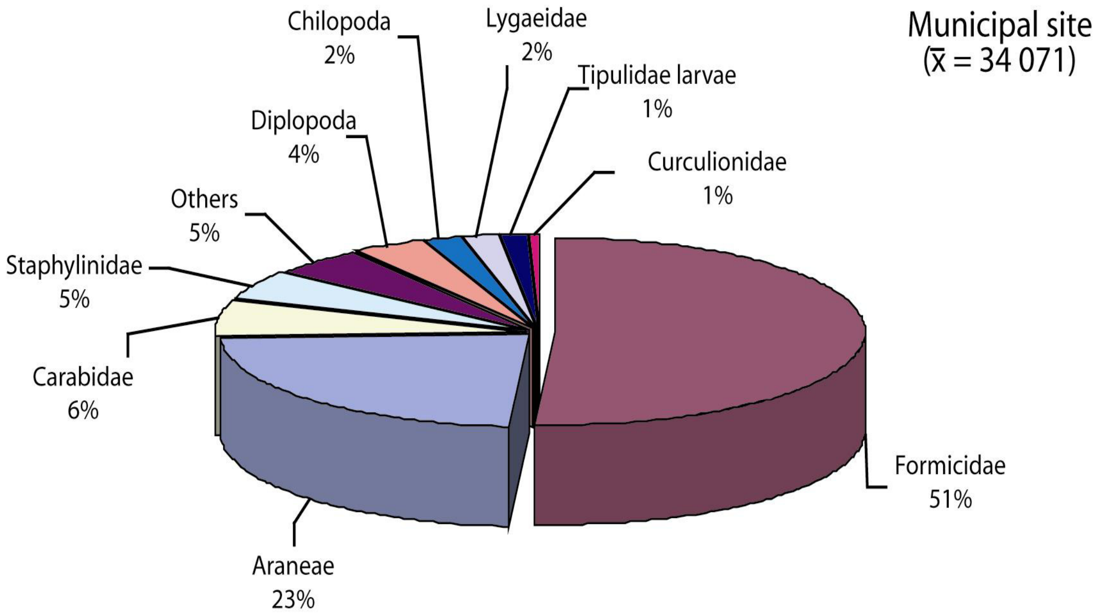
Terry, L.A., D.A. Potter, and P.G Spicer. 1993. Insecticides affect predatory arthropods and predation on Japanese beetle (Coleoptera: Scarabaeidae) eggs and fall armyworm (Lepidoptera: Noctuidae) pupae in turfgrass. J. Econ. Entomol. 86:871-873.

Turgeon, A.J., R.P. Freeborg, and W.N. Bruce. 1975. Thatch development and other effects of preemergence herbicides in Kentucky bluegrass turf. Agron. J. 67:563-565.

Vavrek, R.C. and H.D. Niemczyk. 1990. The impact of isofenphos on non-target invertebrates in turfgrass. J. Econ. Entomol. 81:484-487.

Wang, Y, R.L. Crocker, L.T. Wilson, G.Smart, X. Wei, W.T. Nailon Jr., and P.P. Cobb. 2001. Effect of nematode and fungal treatments on nontarget turfgrass-inhabiting arthropod and nematode populations. Environ. Entomol. 30: 196-203.

Fig. 4.1. Proportion (%) of different groups of arthropods sampled in pitfall traps at the municipal and university sites. Percents represent the total seasonal mean of arthropods for the three-year study.


Municipal site
(x̄ = 34 071)
Chilopoda
2%
Lygaeidae
2%
Tipulidae larvae
1%
Diplopoda
4%
Curculionidae
1%
Others
5%
Staphylinidae
5%
Carabidae
6%
Formicidae
51%
Araneae
23%

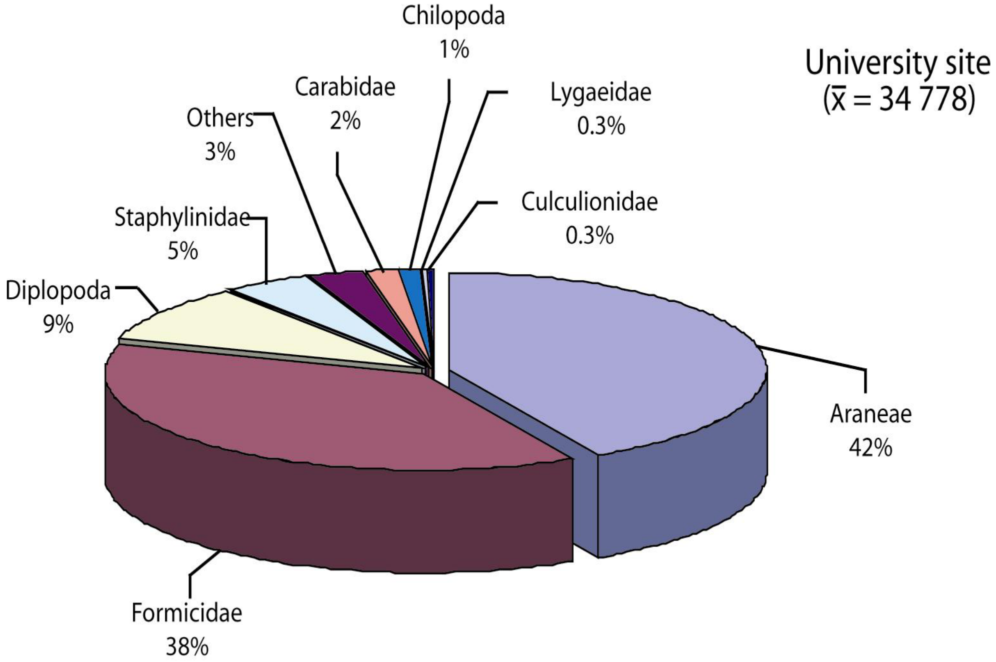

Chilopoda
1%
University site
(x̄ = 34 778)
Carabidae
2%
Lygaeidae
0.3%
Others
3%
Staphylinidae
5%
Culculionidae
0.3%
Diplopoda
9%
Araneae
42%
Formicidae
38%

Fig. 4.2. Seasonal abundance (mean number/pitfall trap ± se) of total arthropods sampled in 2003, 2004, and 2005 at the municipal and university sites. At the university site in 2003, sampling was undertaken from the fourth period, after turfgrass establishment.

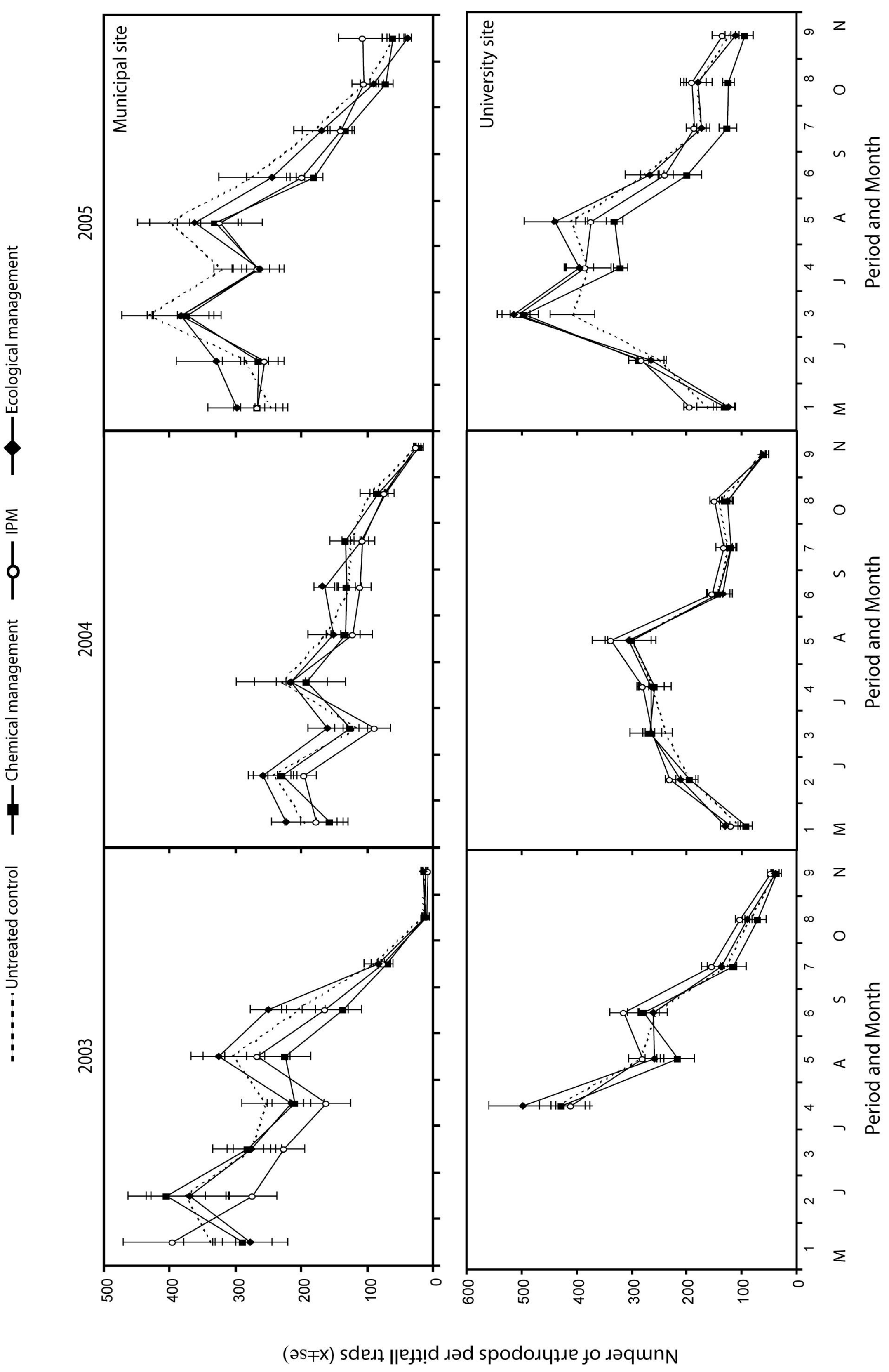

Untreated control
Chemical management
IPM
Ecological management
2003
2004
2005
Municipal site
University site
Number of arthropods per pitfall traps (x±se)
500
400
300
200
100
0
600
Period and Month
1 2 3 4 5 6 7 8 9
M J J A S O N

Fig. 4.3. Seasonal abundance (mean number/pitfall trap ± se) of ants sampled in 2003, 2004, and 2005 at the municipal and university sites. At the university site in 2003, sampling was undertaken from the fourth period, after turfgrass establishment.

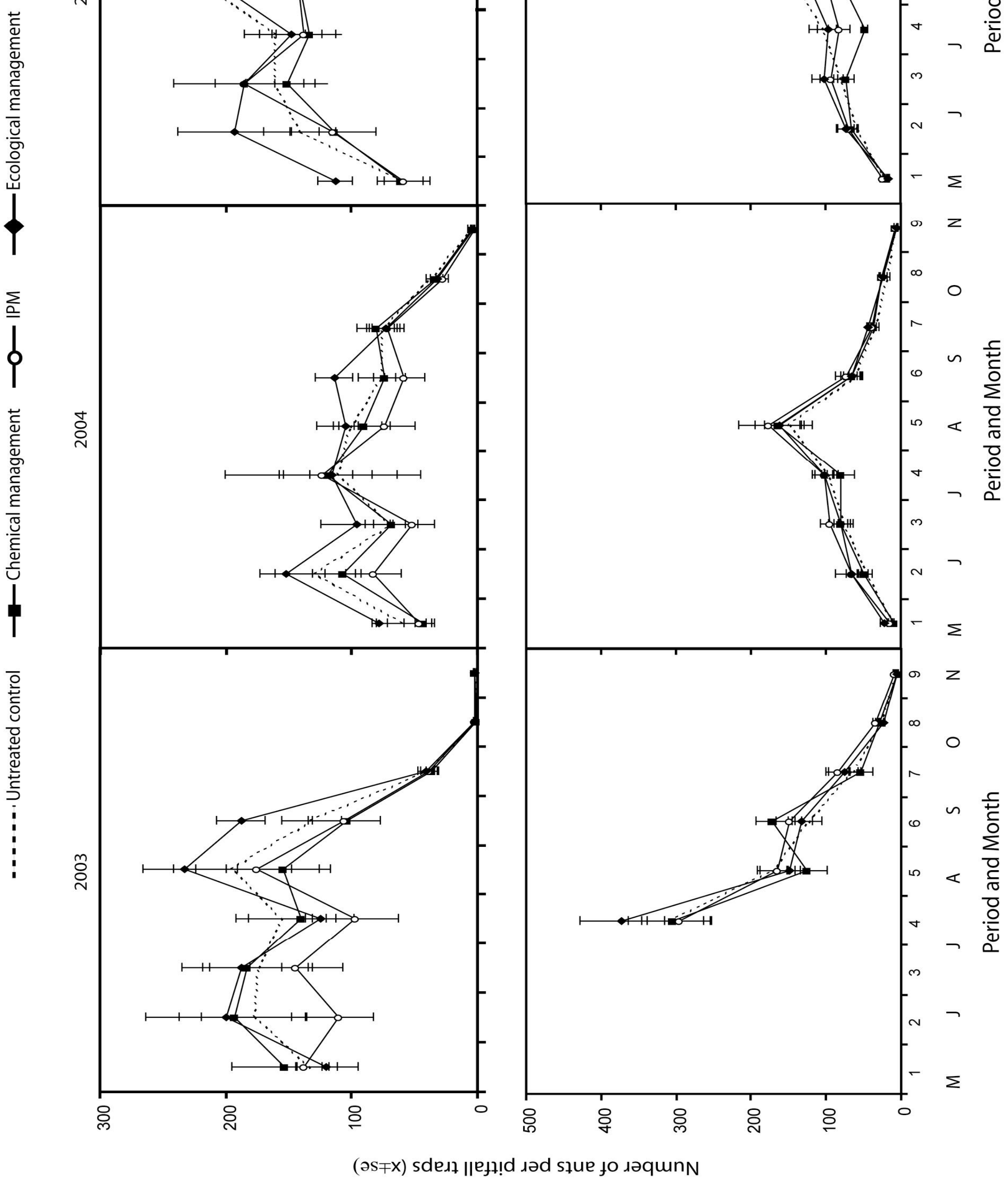

Untreated control
Chemical management
IPM
Ecological management
2003
2004
2005
Municipal site
University site
Number of ants per pitfall traps (x±se)
300
200
100
0
500
400
300
200
100
0
1 2 3 4 5 6 7 8 9
M J J A S O N
Period and Month

Fig. 4.4. Seasonal abundance (mean number/pitfall trap ± se) of spiders sampled in 2003, 2004, and 2005 at the municipal and university sites. At the university site in 2003, sampling was undertaken from the fourth period, after turfgrass establishment.

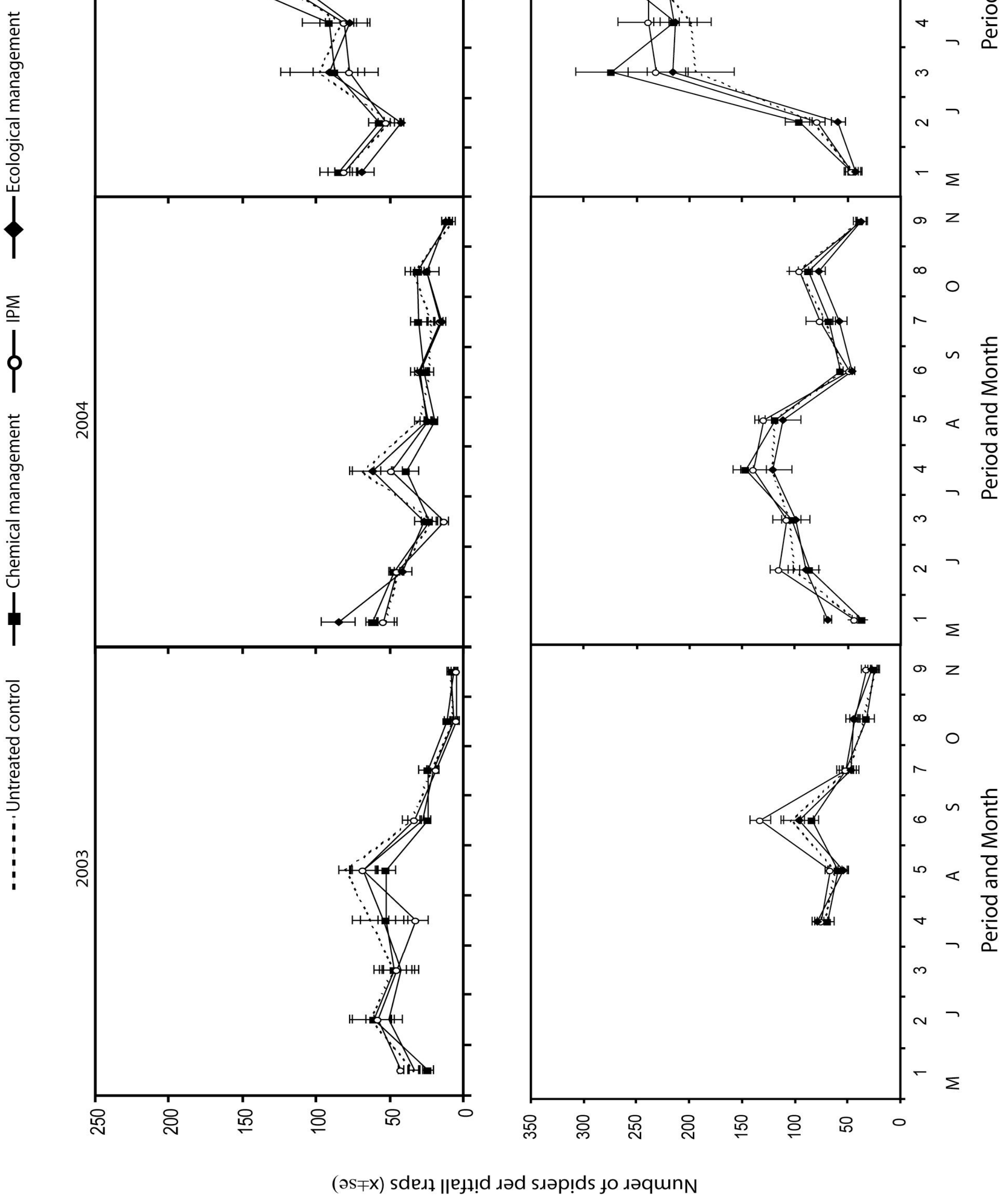

Untreated control
Chemical management
IPM
Ecological management
2003
2004
2005
Municipal site
University site
Number of spiders per pitfall traps (x±se)
250
200
150
100
50
0
350
300
250
200
150
100
50
0
1 2 3 4 5 6 7 8 9
M J J A S O N
Period and Month

Fig. 4.5. Seasonal abundance (mean number/pitfall trap ± se) of Carabidae sampled in 2003, 2004, and 2005 at the municipal and university sites. At the university site in 2003, sampling was undertaken from the fourth period, after turfgrass establishment.

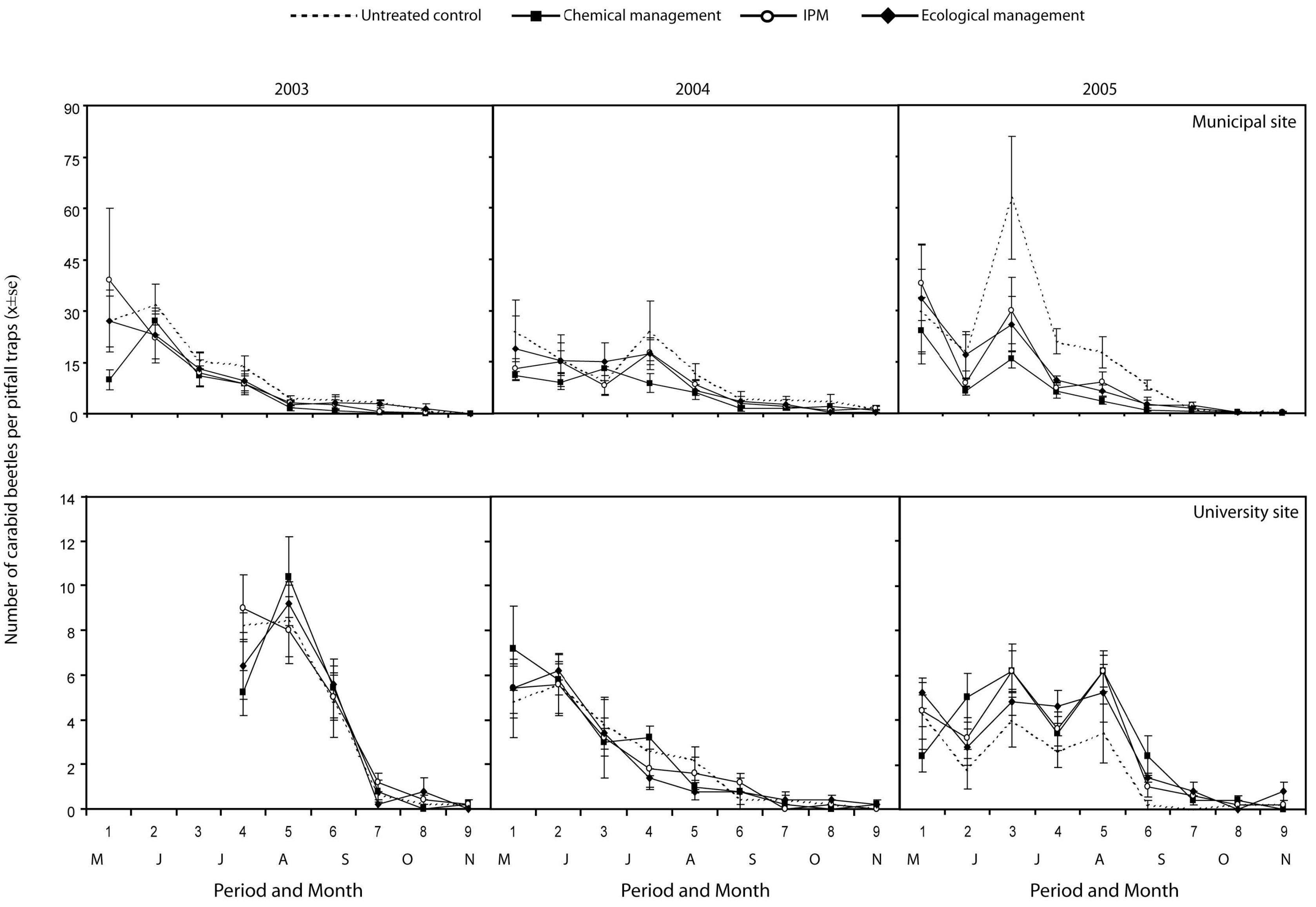

Untreated control
Chemical management
IPM
Ecological management
2003
2004
2005
Municipal site
University site
Number of carabid beetles per pitfall traps (x±se)
90
75
60
45
30
15
0
14
12
10
8
6
4
2
0
1 2 3 4 5 6 7 8 9
M J J A S O N
Period and Month

Fig. 4.6. Seasonal abundance (mean number / m^2 ± se) of Collembola sampled in 2003, 2004, and 2005 at the municipal and university sites. At the university site in 2003, sampling was undertaken from the fourth period, after turfgrass establishment.

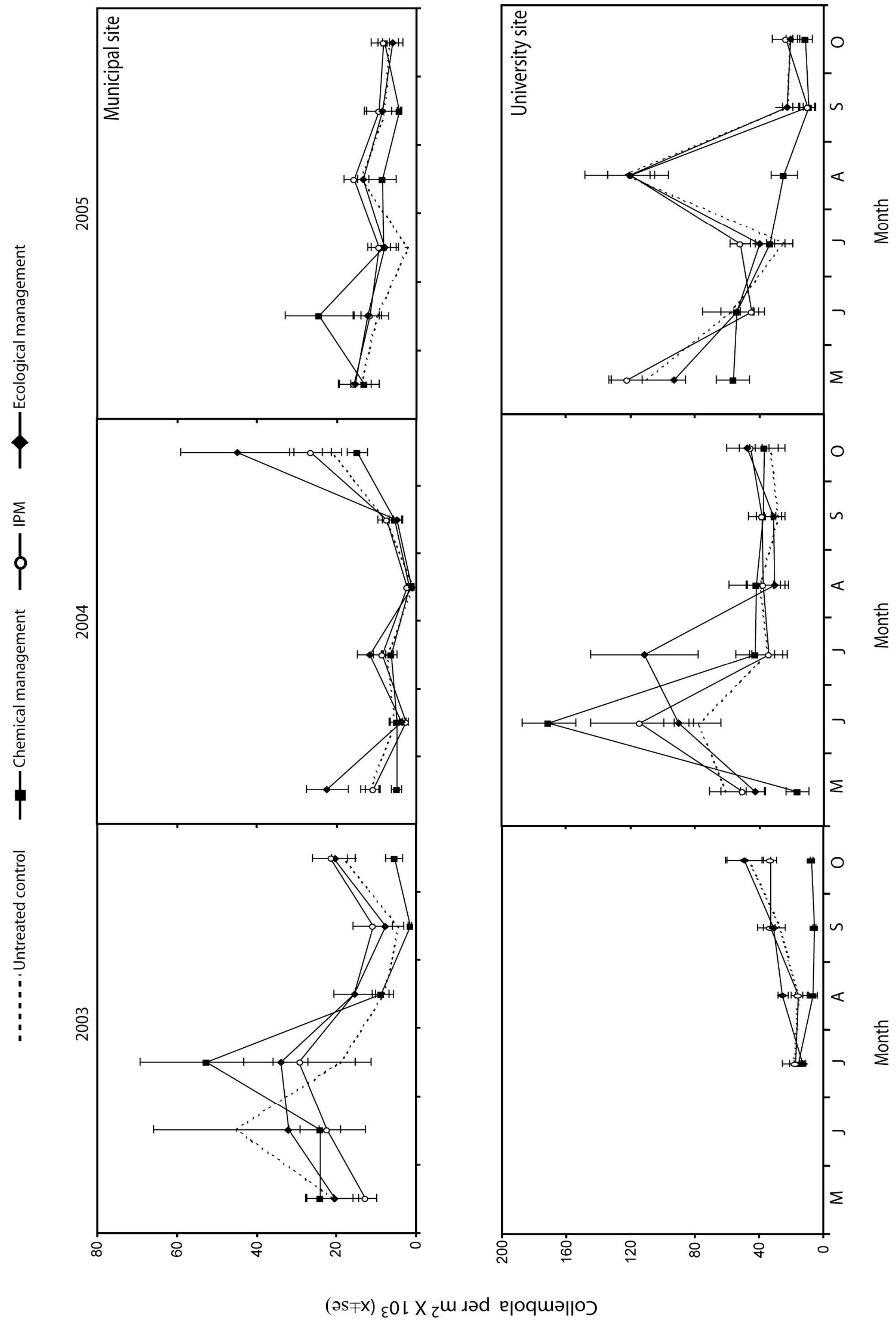

Untreated control
Chemical management
IPM
Ecological management
2003
2004
2005
Municipal site
University site
Collembola per m^2 X 10^3 (x±se)
80
60
40
20
0
200
160
120
80
40
0
M
J
J
A
S
O
Month

Fig. 4.7. Seasonal abundance (mean number/pitfall trap ± se) of soil surface predators sampled in 2003, 2004, and 2005 at the municipal and university sites. At the university site in 2003, sampling was undertaken from the fourth period, after turfgrass establishment.

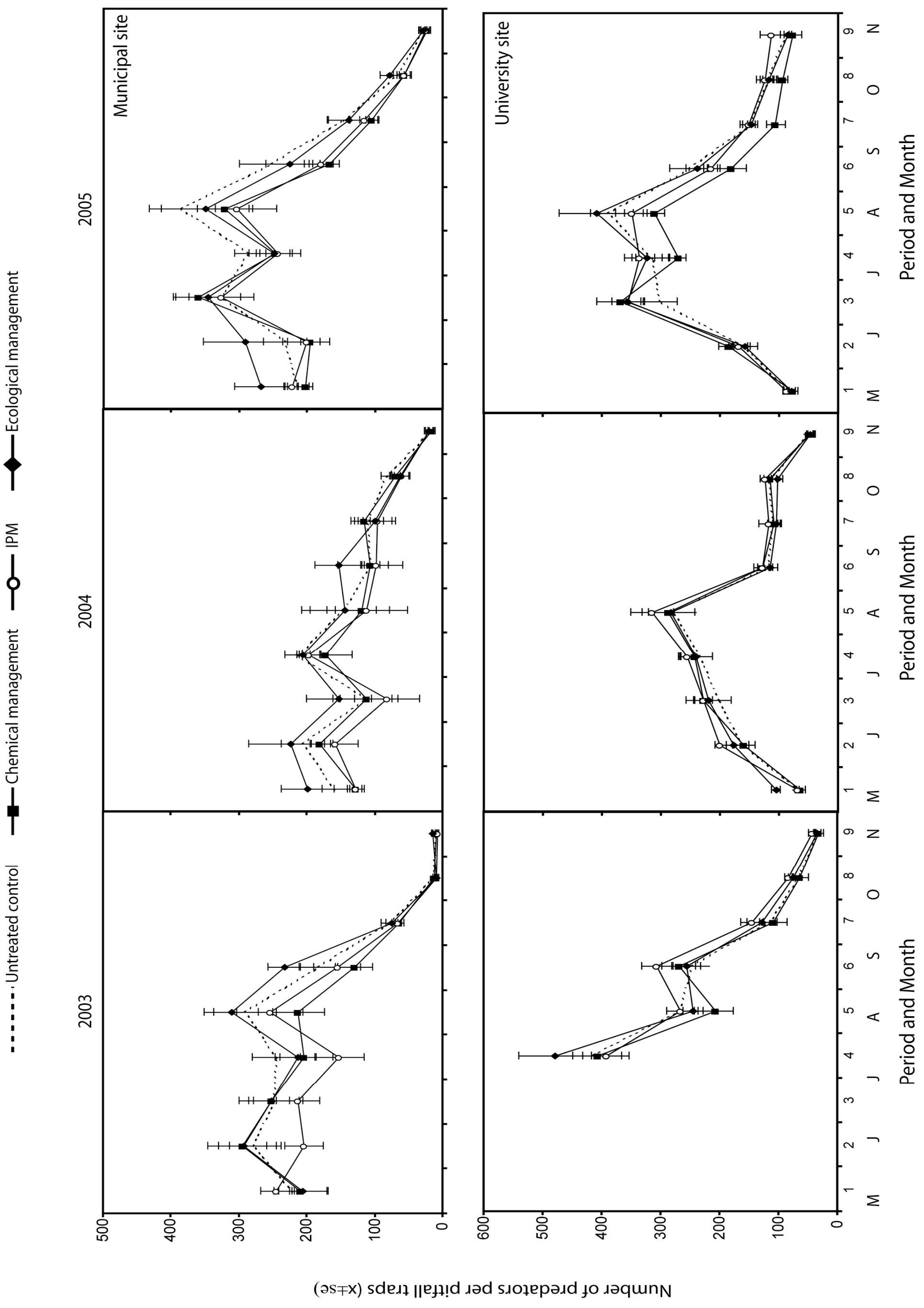

Untreated control
Chemical management
IPM
Ecological management
2003
2004
2005
Municipal site
University site
Number of predators per pitfall traps (x±se)
0
100
200
300
400
500
600
1
2
3
4
5
6
7
8
9
M
J
J
A
S
O
N
Period and Month

Fig. 4.8. Seasonal abundance (mean number/pitfall trap ± se) of herbivores sampled in 2003, 2004, and 2005 at the municipal and university sites. At the university site in 2003, sampling was undertaken from the fourth period, after turfgrass establishment.

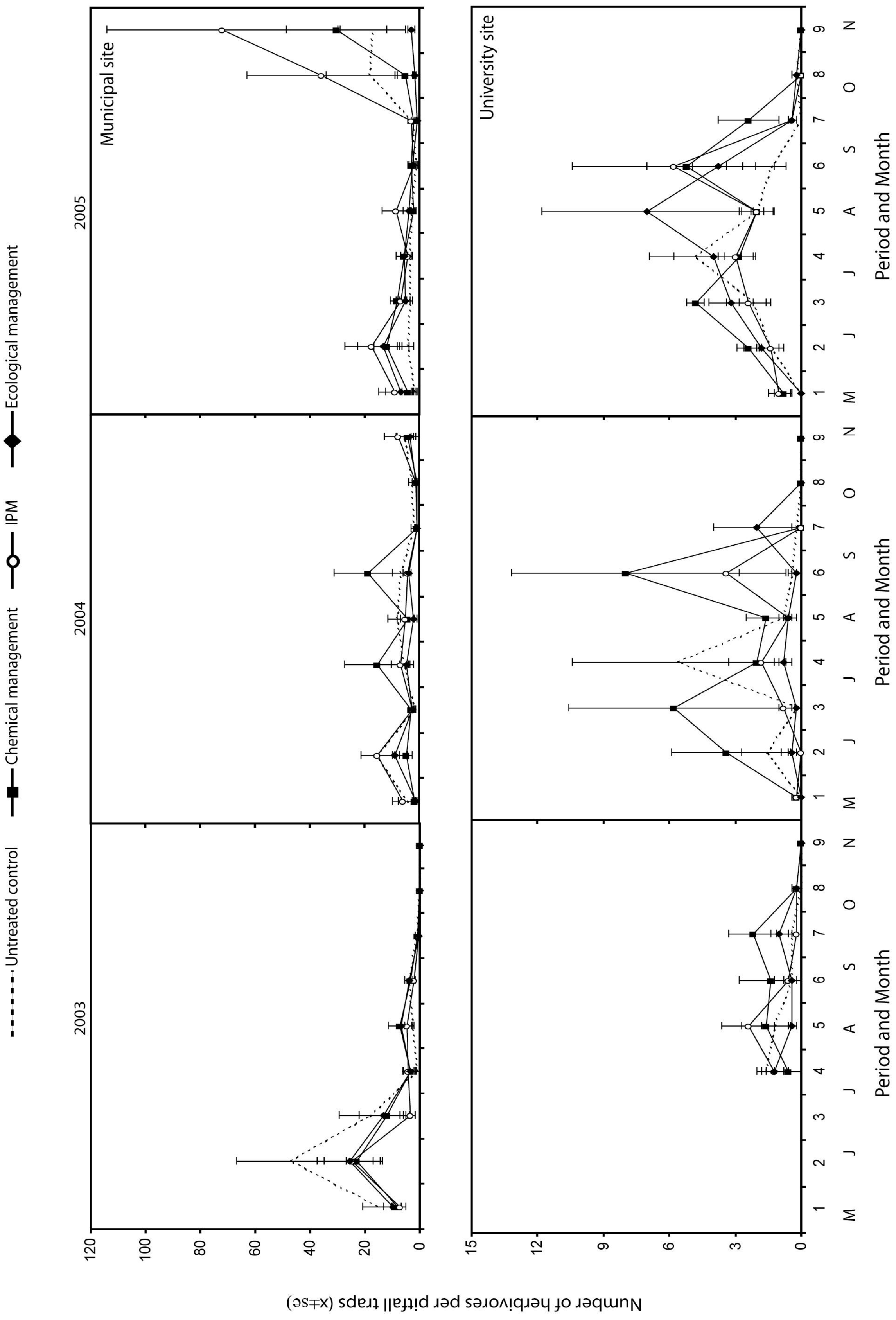

Untreated control
Chemical management
IPM
Ecological management
2003
2004
2005
Municipal site
University site
Number of herbivores per pitfall traps (x±se)
120
100
80
60
40
20
0
15
12
9
6
3
0
1 2 3 4 5 6 7 8 9
M J J A S O N
Period and Month

Fig. 4.9. Short term effect of diazinon and carbaryl applications on Carabidae abundance (mean number/pitfall trap ± se) sampled in 2003, 2004, and 2005 at the municipal and university sites, compared to the untreated control.

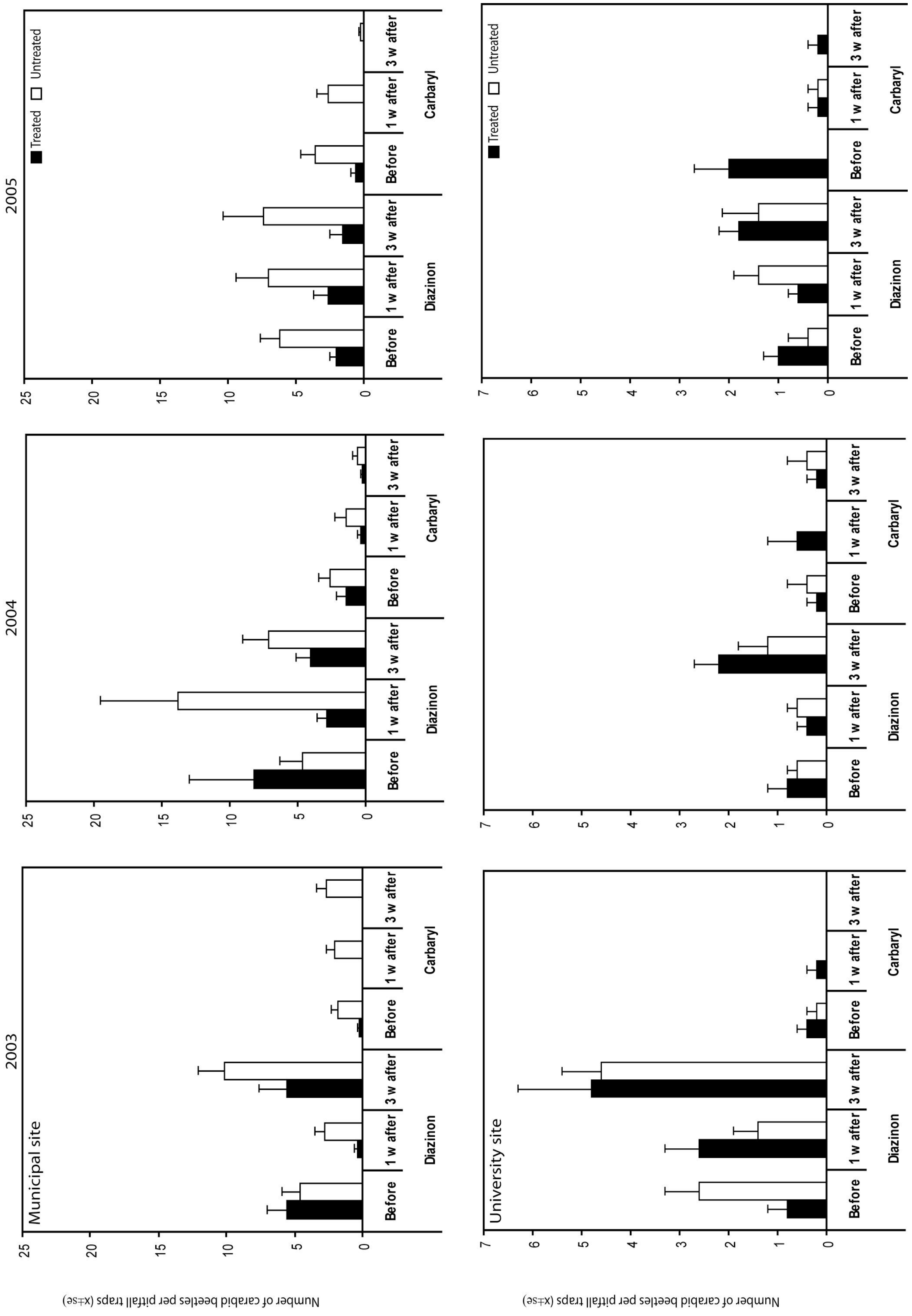
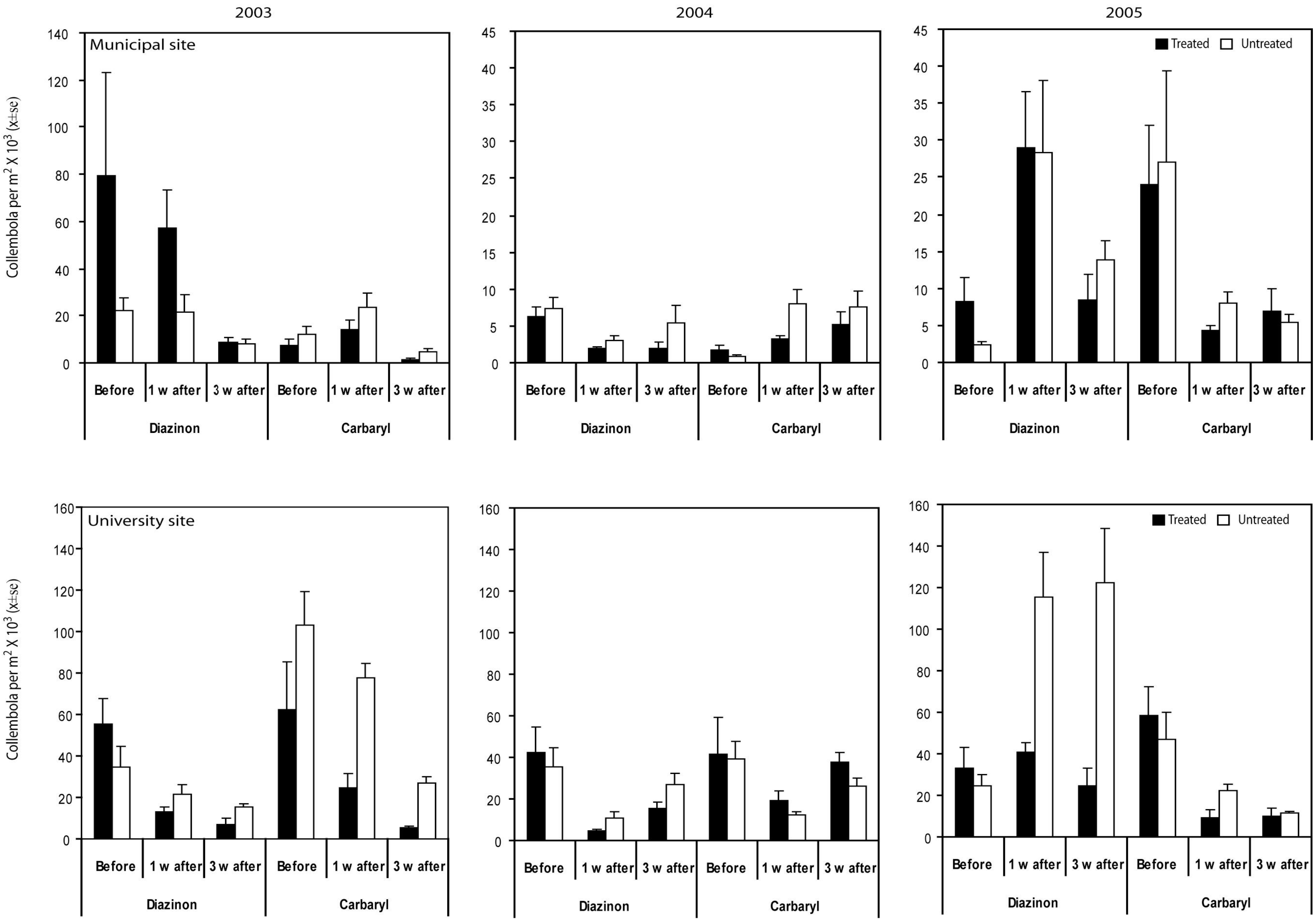

2003
2004
2005
Municipal site
University site
Treated
Untreated
Number of carabid beetles per pitfall traps (x±se)
Number of carabid beetles per pitfall traps (x±se)
0
5
10
15
20
25
0
1
2
3
4
5
6
7
Before
1 w after
3 w after
Diazinon
Carbaryl

Fig. 4.10. Short term effect of diazinon and carbaryl applications on Collembola abundance (mean number/m^2 ± se) sampled in 2003, 2004, and 2005 at the municipal and university sites, compared to the untreated control.


2003
2004
2005
Municipal site
University site
Treated
Untreated
Collembola per m^2 X 10^3 (x±se)
140
120
100
80
60
40
20
0
45
40
35
30
25
20
15
10
5
160
Before
1 w after
3 w after
Diazinon
Carbaryl

CHAPITRE V

OVERWINTER SURVIVAL AND ESTABLISHMENT OF ENDOPHYTE-INFECTED AND UNINFECTED TALL FESCUE AND PERENNIAL RYEGRASS IN TURFGRASS LAWNS OF NORTH EASTERN NORTH AMERICA*

*This article has been submitted to ***Crop Science*** (May 2006). The authors are Sophie Rochefort (Centre de Recherche en Horticulture, Université Laval), Yves Desjardins (Centre de Recherche en Horticulture, Université Laval), David J. Shetlar (Ohio State University), and Jacques Brodeur (Institut de recherche en biologie végétale, Université de Montréal).

5.1 Résumé

Le sur-ensemencement de fétuque élevée et de ray-grass vivace dans une pelouse établie de pâturin du Kentucky représente une stratégie permettant d'améliorer la qualité et la durabilité des pelouses de graminées. La présente étude, réalisée sur une période de trois ans, avait comme objectif d'évaluer la survie hivernale et le taux d'établissement de la fétuque élevée (Bonsai 2000) infectée ou non avec l'endophyte *Neotyphodium coenophialum*, et du ray-grass vivace (Palmer III), infecté ou non avec l'endophyte *N. lolii*, dans la province de Québec (latitude ~54°N), région caractérisée par des conditions hivernales rigoureuses. Les espèces de graminées à gazon ont été sur semées en juin 2003 à deux taux d'ensemencement [77,4 kg/ha (0,9 kg / 100 m^2) and 155 kg/ha (1,8 kg /100 m^2)] dans des pelouses expérimentales situées dans deux zones bioclimatiques différentes : Ville de Québec et Ville de Boucherville. La survie hivernale et l'établissement des graminées et des endophytes ont été évalués au printemps et à l'automne 2003 et 2004. La fétuque élevée et le ray-grass vivace ont la capacité de survivre aux hivers québécois, mais sont plus performants lorsque le couvert de neige est important et présent durant tout l'hiver. La proportion de plants de fétuque élevée et de ray-grass vivace retrouvés dans les parcelles suite au sur-semis a rarement atteint 30% durant les trois années d'étude. Toutefois, la mortalité hivernale n'a pas compromis la compétitivité de la plante avec le pâturin du Kentucky durant les saisons de croissance subséquentes puisqu'un rétablissement complet des populations de fétuque élevée et de ray-grass vivace a été observé dans les pelouses mixtes. La survie des endophytes a varié selon les espèces, *N. lolii* étant en mesure de survivre aux conditions hivernales froides, ce qui ne fut pas le cas pour *N. coenophialum*. Pour l'association ray-grass et *N. lolii*, la compétition avec le pâturin du Kentucky s'avère probablement le facteur principal limitant l'augmentation dans le temps de la proportion de ray-grass endophytique dans les pelouses mixtes. Le taux d'ensemencement n'a pas influencé les niveaux d'établissement des deux graminées.

5.2 Abstract

Overseeding of tall fescue and perennial ryegrass into preexisting stands of Kentucky bluegrass is viewed as a strategy to enhance the quality and durability of turfgrass lawns. In a three year study, we investigated the winter survival and establishment of tall fescue (Bonsai 2000), infected or not with *Neotyphodium coenophialum*, and perennial ryegrass (Palmer III), infected or not with *N. lolii*, in the province of Québec, Canada (~latitude, 54ºN), a region characterized by rigorous winter conditions. Grass species were overseeded in June 2003 at two different rates [77.4 kg/ha (0.9 kg /100 m^2) and 155 kg/ha (1.8 kg /100 m^2)], in experimental plots from two bioclimatological conditions: Québec City and Boucherville. Turfgrass establishment and endophyte infection were evaluated during the following two spring and fall periods. Both tall fescue and perennial ryegrass had the capacity to survive winter but performed best when snow cover was thick and present throughout the winter. The proportion of overseeded plants in turfgrass stand rarely reached 30% over the years. Overwinter mortality did not impair plant capacity to compete with Kentucky bluegrass during the following growing season as complete recovery of tall

fescue and perennial ryegrass populations was observed in mixed stands. Overwinter endophyte survival was species specific with *N. lolii* being able to survive cold winter but not *N. coenophialum*. For the perennial ryegrass-*N. lolii* association, competition with Kentucky bluegrass is a primary factor limiting the increase over time in the proportion of endophyte-infected plants in a turfgrass mixture. Seeding rates did not influence the establishment of either grass species.

5.3 Introduction

Mixed stands of grass species is increasingly used to enhance the quality and durability of turfgrass lawns. Mixtures of complementary grass species may improve turf quality due to greater tolerance to abiotic (cold, heat, drought) and biotic (arthropod pests, plant diseases, weed invasion) stresses compared with a single species (Beard 1973, Brede and Duich 1984, Coll and Bottrell 1994). Tall fescue (*Festuca arundinacea* Shreb.) and perennial ryegrass (*Lolium perenne* L.) are the most promising species to be used with Kentucky bluegrass (*Poa pratensis* L.), the most extensively planted grass as monostand in north eastern North America (Turgeon 1991).

The aggressive rhizomatous growth pattern of Kentucky bluegrass provides very dense and uniform lawns over the growing season (Beard 1973). However, Kentucky bluegrass is susceptible to many insect pests and diseases (Tashiro 1987). The introduction of “turf-type” perennial ryegrass and tall fescue in an established Kentucky bluegrass lawn could increase plant diversity and likely enhance resistance to environmental stresses. Tall fescue has an excellent wear tolerance and is usually integrated on playgrounds and sport fields. Perennial ryegrass, because of its high rate of establishment and tillering ability, is included in seed mixtures to provide rapid ground cover prior to germination of Kentucky bluegrass seeds (Turgeon 1991).

Turf management may also be improved through the addition of endophytic grasses in grass mixtures (Funk et al. 1993,Hull et al. 1994). *Neotyphodium* spp. endophytes develop non-pathogenic, systemic, and usually intercellular symbiotic associations with several cool-season grasses such as perennial ryegrass and tall fescues (Marshall et al. 1999, Malinowski et al. 2005), but not with Kentucky bluegrass. *Neotyphodium* is an asexual form of grass endophyte which is transmitted vertically and maternally by hyphae growing into seeds (Breen 1994). *Neotyphodium* infected plants may benefit from enhanced growth and vigour (Latch et al. 1985) and from an increased tolerance to climatic factors, such as drought and high temperatures (Bacon 1993, Belesky 1987), and a reduced susceptibility to diseases or insect infestations (Coll and Bottrell 1994, Carrière et al. 1998, Richmond and Shetlar 2000).

Although turfgrass 'mixtures have potential for better overall quality than any one component species' (Dunn et al. 2002), the establishment and survival of each grass species in the sward, together with the association with endophytes, are likely to differ over time. Indeed, the composition of a lawn is determined by the intrinsic competitiveness of the different grass species, as well as their response to several other factors: climatic conditions, cultural practices (fertilization, mowing, and irrigation), diseases, pests, intensity of wear conditions, etc. Of significance, overwinter mortality of cool-season turf grasses could be very important in north eastern North America, and may significantly reduce the aesthetic value, function, and durability of turfgrass mixtures (DiPaola and Beard 1992). The presence of endophyte in turf type grasses may also influence the competitiveness between turfgrass species and modify the dynamic of plant composition.

The capacity of cool-season turf grasses to overwinter varies greatly among species and cultivars (Beard 1973). Creeping bentgrass (*Agrostis palustris* Huds.), a species commonly used for golf green establishment, tolerates the lowest temperature (Gusta et al. 1980). For residential lawns, Kentucky bluegrass *(Poa pratensis* L.) tolerates very low temperatures, perennial ryegrass is the least hardy species, while tall fescue (*Festuca arundinacea* Shreb.) has intermediate susceptibility to freezing stress (Beard 1973, Gusta et al. 1980). This relatively poor cold temperature tolerance of perennial ryegrass and tall fescue may prevent their use in pure stands in areas where winter temperatures are very low (Christian and Engelke 1994). To our knowledge, no study has examined the effect of cold winter temperatures on *Neotyphodium* endophyte survival and on how grass-endophyte associations might affect their winter survival and competitivity in a Kentucky bluegrass sward.

We have recently initiated a research program investigating the potential of over seeding endophytic turf grasses in established lawns to reduce insect pest problems. The objective of the present field study was to determine the capacity of endophyte-infected and uninfected tall fescue and perennial ryegrass to survive winter conditions prevailing in the province of Québec, Canada when plants are overseeded into pre-existing stands of Kentucky bluegrass. In experimental plots from two ecologically different sites, we measured long-term changes (over three years) in the proportion of endophyte-infected and uninfected 'Bonsai 2000' tall fescue infected or not with *N. coenophialum* and 'Palmer III' perennial ryegrass infected or not with *N. lolii*. The overwinter survival of these two endophyte-plant associations was tested for two overseeding rates.

5.4 Materials and Methods

5.4.1 Study sites

The study was conducted during 2003, 2004 and 2005 in Boucherville (45° 30' N; 73° 30' W), a suburb of Montréal, and in Québec City (46° 49' N; 71° 13' W). Study areas lie within the Southern Laurentians ecoregion (Ecoregions Working Group 1989), which is characterized by a mid-boreal ecoclimate with warm summers and cold, snowy winters. Mean summer and winter air temperatures are 14°C and -11°C, respectively. Mean annual precipitation is 800 mm and 1000 mm near the cities of Montréal and Québec, respectively. Snow generally covers the ground from November to April.

The site located at Boucherville consisted of a new Kentucky bluegrass (*Poa pratensis* L.) lawn established in 2002 from turfgrass sod. The soil was a loam with a pH of 6.3. Broadleaf weed cover was less than 1%. The experimental lawn in Québec City was located at Laval University experimental farm, and consisted of a mixture of Kentucky bluegrass (47%), annual bluegrass (*Poa annua* L.; 14%), creeping red fescue (*Festuca rubra* Shreb; 14%) and bentgrass (*Agrostis stolonifera* L.; 7%). The soil was a well-drained shale loam, with a pH of 6.5. In May 2003, weeds were controlled with one application of Dicamba, MCCP and 2,4-D (TRILLION™, Plant Products Co. Ltd., Quebec, Canada), at the labelled rate to reduce broadleaf cover under 5%.

In June 2003, a total of sixteen plots (2.1 by 2.1 m) per site were randomly assigned to one of four different treatments, two grass species and two over seeding rates. Using a commercial over seeder (MATAWAY®), treatments #1 and #2 were over seeded with Bonsai 2000™ tall fescue at 77.4 kg/ha (0.9 kg / 100 m^2) and 155 kg/ha (1.8 kg / 100 m^2), respectively. Bonsai 2000 is a turf-type tall fescue cultivar which provides a more homogeneous lawn when mixed with Kentucky bluegrass than common-type fescues (Gilbert and DiPaola, 1985). Treatments #3 and #4 were over seeded with Palmer III™ ryegrass, a dark-green color turf-type cultivar, at the same seeding rates of tall fescue. High levels of endophyte infection can be obtained with Bonsai 2000 and Palmer III cultivars. Rates of seeding were determined following the work of Richmond et al. (2000), who showed that 38.75 and 77.4 kg of seeds per ha provide 35% of endophyte-infected perennial ryegrass, which is sufficient to reduce pest problems. Because winters in Québec are more rigorous, higher seeding rates were used in the present study to favor the establishment of a significant proportion of endophytic ryegrass and tall fescue. Each treatment was repeated four times at each site into a randomized complete block design. No test was performed on tall fescue and perennial ryegrass seeds prior to the experiment to assess levels of germination and endophyte infection, but according to seed suppliers

(Hortisem Inc. and Gloco Inc., Montréal, Qc, Canada), initial endophyte infection level was around 50%.

Both sites were exposed to full sun, and received three organic fertilizer (9-2-5, N-P-K) applications per year (0.34 kg N / 100m^2 in spring and summer; 0.57 kg N/ 100m^2 in fall) for an annual rate of 1.25 kg N / 100m^2. The lawns were mowed weekly at 5-8 cm height, and clippings were left on the plots. Experimental plots were not irrigated.

5.4.2 Sampling

5.4.2.1 Turfgrass establishment

In 2003, the first evaluation to determine the establishment of introduced turfgrass species was done in early October, four months and a half after turfgrass overseeding. In 2004 and 2005, turfgrass establishment was assessed twice, in May and September, for a total of five evaluations during the experiment.

The ryegrass and tall fescue composition of turf in each plot was determined using a linear pin quadrant modified from Winkworth and Goodall (1962). The quadrant is an 85 cm width wood frame set on two metal supports, 37.5 cm height, and has 10 fixed points spaced 85 mm apart. Leaves touched by the pin at each point are recorded by species. Two quadrants per plot were randomly placed for a total of 20 points per plot. Data are analysed and presented as the mean percent of grass species per plot for each seeding rate and sampling period.

5.4.2.2 Endophyte infection

As for turfgrass establishment, the percent of endophyte-infected ryegrass and tall fescue in each plot was determined in October in 2003, and in May and September 2004 and 2005.

Twenty tillers per plot were randomly selected and cut at soil surface, brought back to the lab, and tested for endophyte presence. In this instance, a 2-mm cross section of a tiller was analyzed using a commercial tissue print immunoblot test kit (Agrinostics Ltd. Co., Watkinsville, GA). Tissue print immunoblot technique for detection of *N. coenophialum* mycelial proteins was first proposed by Gwinn et al. (1991). The technique was validated by Hiatt et al. (1999) who demonstrated the accuracy of a commercially available, monoclonal antibody-based immunoblot assay (Agrinostic's kit) for the detection of *Neotyphodium* sp.

5.4.3 Data analysis

Differences over time in turfgrass establishment and endophyte infection were analyzed through repeated-measures analysis of variance (ANOVA) using the PROC MIXED procedure (SAS Institute, 2002-2003). The following three effects were tested: site, treatment, and site by treatment interaction. *A priori* contrasts were performed to detect differences between grass species and over seeding rates using the PROC GLM procedure. Means were separated using Fisher's protected least significant difference ($P<0.05$).

5.5 Results

5.5.1 Turfgrass establishment

In Québec City, the proportion of tall fescue (range: 11-38%) and perennial ryegrass (21-48%) plants per plot remained relatively stable throughout the study (Fig. 5.1A and 5.1B). For tall fescue the number of over-seeded plants was maximum in October 2003 and then decreased the following spring to remain stable through the end of the experiment in September 2005. For perennial ryegrass the percent of plants per plot for the 0.9 kg rate was stable throughout the study with no difference between all the sampling periods. At

1.8 kg rate, ryegrass plants were more abundant in October 2003 than in May 2004, May 2005, and September 2005. No difference was observed between the four other sampling periods, from May 2004 to September 2005.

More complex patterns were observed over time at Boucherville, with large variations in the proportion of tall fescue (range: 1-19%) and perennial ryegrass (3-39%) in experimental plots (Fig. 5.1C and 5.1D). Variation of tall fescue establishment at 0.9 kg rate was greater between May 2004 (1.25%) and September 2005 (16.9%). For the 1.8 kg rate, no difference was detected over the five sampling periods. For perennial ryegrass, the establishment at Boucherville significantly decreased from September 2004 to May 2005 for the two tested rates. However, for the 0.9 kg rate, the final establishment (in September 2005) was not different from the initial one (in October 2003). At the 1.8 kg rate, the final establishment was significantly lower than the initial one.

In general, no difference between tall fescue and perennial ryegrass establishment was observed in Québec City, except in September when perennial ryegrass was more abundant than tall fescue 2004 (*F=8.70, df=1, P=0.016*). At Boucherville, perennial ryegrass was more abundant than tall fescue for the first three sampling periods (Oct. 2003: *F=29.72, df=1, P=0.0004*; May 2004: *F=7.66, df=1, P=0.02*; Sept. 2004: *F=25.35, df=1, P=0.0007*).

Tall fescue and perennial ryegrass had a better winter survival in Québec City than at Boucherville (site effect: *F=34.99; df=1; P=0.001*). Tested seeding rates did not influence the establishment of both grass species at both site (Québec: *F=0.61; df=1; P=0.44*; Boucherville*: F=3.17; df=1; P=0.08*).

5.5.2 Endophyte infection

Overall, endophyte infection in tall fescue was lower (≤10% at both sites) than expected (ca. 50%) based on information provided by the supplier. The proportion of plants infected with *Neotyphodium* in Québec City was significantly higher (>27%) for perennial ryegrass than for tall fescue (<7%) for all evaluation periods ($P<0.003$; Fig. 5.2A and 5.2B). A similar trend was observed at Boucherville, with significantly ($P<0.001$) higher endophyte infection in ryegrass (>24%) than in tall fescue (<11%; Fig. 5.2C and 5.2D).

Endophyte infection in tall fescue decreased rapidly in Québec City and was no longer detected in September 2004 and May 2005 for the 0.9 and 1.8 kg seeding rate treatments, respectively (Fig. 5.2A). Similar results were observed at Boucherville, as endophytes were not detected in September 2004 for either seeding rate (Fig. 5.2C). Percent of infected perennial ryegrass plants in both sites remained relatively stable at about 40 % infection throughout the study for the two seeding rate treatments (Fig. 5.2B and 5.2D) with, at the end of the study, a similar level of infection as observed in October 2003 (site effect: $F=0.91$; $df=1$; $P=0.38$). No difference between the two seeding rates was detected for endophyte infection at either site.

5.6 Discussion

5.6.1 Turfgrass establishment

Our results revealed two important ecological attributes of perennial ryegrass var. ‘Palmer III’ and ‘Bonsai 2000’ tall fescue in north eastern North America. First, both species are well adapted to the climatic conditions prevailing in the province of Québec, as shown by their persistence over time once established in a lawn. Second, irrespective of the endophyte infection status, tall fescue and perennial ryegrass have the capacity to colonize a mixture of Kentucky bluegrass and remain competitive two years after over-seeding.

In Québec City, the proportion of tall fescue and perennial ryegrass plants in experimental plots remained fairly constant throughout the study, with no significant variations in abundance between spring and fall sampling periods. This suggests that drastic changes and extreme climatic conditions prevailing in the winter and the summer do not significantly modify turfgrass survival. It also means that factors other than recurrent overwinter mortality prevent the long-term increase in the proportion of tall fescue and perennial ryegrass in turfgrass polyculture (see below).

A different pattern was observed in Boucherville, where tall fescue and perennial ryegrass populations typically declined following winter, although Boucherville (Montréal area) is located at more southern latitude than Québec City. Overwintering mortality of grass species can be caused by different factors such as low soil and air temperatures, extreme temperature variations, lack of a natural cover protection, formation of ice, degree of acclimation in fall and deacclimatation in spring, etc. (Beard 1973, Rajashekar et al. 1983, Humphreys 1989, Ross 2000). Differences in turfgrass overwintering survival between the two study sites are likely due to variations in snow cover. Snow provides excellent insulating properties and would protect turfs against winter desiccation and low temperatures by reducing the frequency of freezing and thawing episodes (Beard 1973, Dionne 2001). Snow cover in Québec City was thick and present from mid-November to end of March in the winters of 2003-2004 and 2004-2005 (Fig. 5.3A and 5.3B). In contrast, snow cover in Boucherville was much reduced and lasted for a shorter period of time than in Québec City (Fig. 5.3C and 5.3D). This was more evident in mid-January 2005 when snow cover had been considerably reduced by rainfalls, thereby exposing turfgrass plants to low temperatures for several days.

Remarkably, although the proportion of tall fescue and perennial ryegrass plants in the spring was much reduced by overwintering plant mortality, it did not impair their capacity to compete with Kentucky bluegrass during the following growing season. Sampling conducted in September 2004 and 2005, showed more or less complete recovery of tall fescue and perennial ryegrass populations in mixed stands. The changes in the composition of grass species during the growing season might be due to enhanced competitiveness of tall fescue and perennial ryegrass over Kentucky bluegrass under adverse biotic and abiotic summer conditions, for instance through better ability to compete for moisture in conditions of drought (Hill et al. 1991, Hunt and Dunn 1993).

There is no indication that the proportion of tall fescue and perennial ryegrass in turfgrass mixed Kentucky bluegrass stands would increase notably above 30% over the years under environmental conditions prevailing in north eastern North America. Doubling the initial seeding rate did not modify substantially the abundance of either tall fescue or perennial ryegrass in experimental plots. A similar pattern was reported in Ohio, USA, by Richmond et al. (2000) who observed no difference between different seeding rates of perennial ryegrass over seeded in an established Kentucky bluegrass lawn at the end of their experiment. On the other hand, they demonstrated that at lower rates (0.454 kg and 0.9 kg) than those tested in our study, proportion of perennial ryegrass tillers increased (28-68%) over two seasons. Three factors could explain the inability of tall fescue and perennial ryegrass plants to expand when over seeded in an established lawn. First, perennial ryegrass and tall fescue are bunch type grasses (Beard 1973) that mainly propagate by seed, a mode of colonization that is greatly reduced in a mowed lawn. Second, competition with other plants, mainly Kentucky bluegrass, may prevent tall fescue and perennial ryegrass from expanding when over seeded in an established lawn. At Boucherville, competition for seed germination and newly germinated plants was particularly important because turfgrass density on the 2-year old Kentucky bluegrass lawn was initially higher at this site than at Québec City. Third, as described above, winter mortality as observed in Boucherville also contributed to reduce the establishment of tall fescue and perennial ryegrass.

5.6.2 Endophyte infection and proportion of RG+

To our knowledge, our study represents the first attempt to examine winter survival of endophytes *N. coenophialum* and *N. lolii* under rigorous winter conditions such as those prevailing in the province of Québec. *Neotyphodium coenophialum* associated with 'Bonsai

2000' tall fescue, rapidly disappeared at both sites. However, further evidence is needed to better assess the overwintering potential of *N. coenophialum* as the initial level of infection in tall fescue was very low (<10%) in our treatment. The resurgence of endophyte-infected tall fescue in the 1.8 kg rate treatment in September 2005 at Boucherville may suggest that dormant hyphae of the endophyte have the capacity to survive harsh conditions for prolonged period of time. Alternatively the 'disappearance' of the endophyte in September 2004 and May 2005 may result from a sampling error; detection of *Neotyphodium* infected plants is problematic when infection levels are very low (<5%). *Neotyphodium lolii* associated with perennial ryegrass has the capacity to survive winter in Québec; the initial level of endophyte infection remained relatively stable throughout the experiment at both experimental sites.

The proportion of tall fescue or perennial ryegrass plants per plot was multiplied by the corresponding proportion of plants determined to be infected with *Neotyphodium* to estimate the total proportion of endophytic plants per plot (Fig. 5.4). Seasonal fluctuations in the proportion of endophytic plants in turfgrass mixtures observed at Boucherville (Fig. 5.4B) arose primarily from variations in the survival of the host plant over the season. This pattern is different from what was observed in studies conducted in more temperate zones (Thompson et al. 1989, Shelby and Dalrymple 1993, Saikkonen et al. 1998, Richmond et al. 2000), where the proportion of endophyte-infected grass increased over time.

The present study indicates that perennial ryegrass and tall fescue can be used as complementary grass species to Kentucky bluegrass in lawns located in regions characterized by rigorous winter conditions. Mixed stands maintain their integrity when snow cover is thick and present for a long period. Overwinter endophyte survival appears to be species specific with *N. lolii* being able to survive cold winter but not *N. coenophialum*. Moreover, for the perennial ryegrass - *N. lolii* association, competition with Kentucky bluegrass is a primary factor limiting the increase over time in the proportion of endophyte-infected plants in a turfgrass mixture. This study is intended as a first step to our understanding of the overwinter ecology of cool-season turfgrass in areas corresponding to the northern limits of their distribution. More information is needed on other grass cultivars and grass-endophyte associations commonly used in North America.

5.7 Aknowledgements

We thank Dr. D. Richmond for helpful suggestions on the experimental design; M. Leblond, V. Joly-Séguin, M. Desjardins and P. Deschênes for technical assistance; Gloco and Hortisem Inc. for providing turfgrass seeds. This work was supported by grants from the Fonds québécois de recherche sur la nature et les technologies, and the Fonds de recherche en écologie urbaine.

5.8 References

Bacon, C.W. 1993. Abiotic stress tolerances (moisture, nutrients) and photosynthesis in endophyte-infected tall fescue. Agric. Ecosyst. Environ. 44:123-141.

Beard, J. 1973. Turfgrass: science and culture. Prentice Hall, Englewood Cliffs, NJ. 672p.

Belesky, D.P., O.J. Devine, J.E. Pallas, Jr., and W.C. Stringer. 1987. Photosynthetic activity of tall fescue as influenced by a fungal endophyte. Photosynthetica 21:82-87.

Brede, A.D. and J.M. Duich. 1984. Establishment characteristics of Kentucky bluegrass-perennial ryegrass turf mixtures as affected by seeding rate and ratio. Agron. J. 76:875-879.

Breen, J.P. 1994. *Acremonium* endophyte interactions with enhanced plant resistance to insects. Annu. Rev. Entomol. 39:410-423.

Christians, N.E., and M.C. Engelke. 1994. Choosing the right grass to fit the environment, pp. 99-113. *In:* A.R. Leslie (ed.), Integrated pest management for turf and ornamentals. Lewis, London.

Carrière, Y., A. Bouchard, S. Bourassa, and J. Brodeur. 1998. Effect of endophyte incidence in perennial ryegrass on distribution, host-choice, and performance of the hairy chinch bug (Hemiptera: Lygaeidae). J. Econ. Entomol. 91:324-328.

Coll, M., and D.G. Bottrell. 1994. Effects of non-host plants on an insect herbivore in diverse habitats. Ecology 75:723-731.

Dionne, J. 2001. Protection hivernale et tolérance au froid du pâturin annuel (*Poa annua* var. *reptans*). Faculté des études supérieures, Université Laval, Ph.D. dissertation.

DiPaola, J.m. and J.B. Beard. 1992. Physiological effects of temperature stress. *In*: D.V. Waddington, R.N. Carrow, and R.C. Shearman (eds.). ASA-CSSA-SSSA Turfgrass Agron. Monogr. 32.

Dunn, J.H., E.H. Ervin, and B.S. Fresenburg. 2002. Turf performance of mixtures and blends of tall fescue, Kentucky bluegrass, and perennial ryegrass. HortScience 37:214-217.

EcoRegions Working Group. 1989. Ecoclimatic regions of Canada, first approximation. Ecological Land Classification series, No. 23, Environnement Canadan, Ottawa, Canada.

Funk, C.R., R.H. White, and J.P. Breen. 1993. Importance of *Acremonium* in turf-grass breeding and management. Agric. Ecosyst. Environ. 44:215-232.

Gilbert, W.B. and J.M. DiPaola. 1985. Cool season turfgrass cultivars performance in the shade, pp.265-274. *In*: F. Lemaire (ed.) Proc. 5th Intl. Turfgrass Res. Conf. Avignon, France.

Gusta, L.V., J.D. Butler, C. Rajashekar, and M.J. Burke. 1980. Freezing resistance of perennial turfgrasses. HortScience, 15:494-496.

Gwinn, K.D., M.H. Collins-Shepard, and B.B. Reddick. 1991. Tissue print-immunoblot, an accurate method for the detection of *Acremonium coenophialum* in tall fescue. Phytopathology 81: 747-748.

Hiatt, E.E., N.S. Hill, J.H. Bouton, and J.A. Stuedemann. 1999. Tall fescue endophyte detection: Commercial immunoblot test kit compared with microscopic analysis. Crop Sci. 39: 796-799.

Hill, N.S., D.P. Belesky, and W.C. Stringer. 1991. Competitiveness of tall fescue as influenced by *Acremonium coenophialum*. Crop. Sci. 31:185-190.

Hull, R.J., S.R. Alm, and N. Jackson. 1994. Toward sustained lawn turf, pp.3-15. *In:* A.R. Leslie (ed.), Integrated pest management for turf and ornamentals. Lewis, London.

Humphreys, M.O. 1989. Assessment of perennial ryegrass (*Lolium perenne* L.) for breeding: I. Freezing tolerance. Euphytica 41:99-106.

Hunt, K.L., and J.H. Dunn. 1993. Compatibility of Kentucky bluegrass and perennial ryegrass with tall fescue in transition zone turfgrass mixtures. Agron. J. 85:211-215.

Latch, G.C.M. and M.J.Christensen. 1985. Artificial infection of grasses with endophytes. Ann. Appl. Biol. 107:17-24.

Malinowski, D.P., D.P. Belesky, and G.C. Lewis. 2005. Abiotic stresses in endophytic grasses, pp.187-199. *In:* C.A. Roberts, C.P West, and D.E Spiers (ed.) *Neotyphodium* in cool-season grasses. Blackwell Publishing, Iowa, USA.

Marshall, D., B. Tunali, and L.R. Nelson. 1999. Occurrence of fungal endophytes in species of wild *Triticum*. Crop Sci. 39:1507-1512.

Rajashekar, C., D. Tao, and P.H. Li. 1983. Freezing resistance and cold acclimation in turfgrasses. HortScience 18:91-93.

Richmond, D.S., H.D. Niemczyk, and D.J. Shetlar. 2000. Overseeding endophytic perennial ryegrass into stands of Kentucky bluegrass to manage bluegrass billbug (Coleoptera: Curculionidae). J. Econ. Entomol. 93:1662-1668.

Richmond, D.S., and D.J. Shetlar. 2000. Hairy chinch bug (Hemiptera: Lygaeidae) damage, population density, and movement in relation to the incidence of perennial ryegrass infected *Neotyphodium* endophytes. J. Econ. Enomol. 93:1167-1172.

Ross, J.B. 2000. Evaluation of winter covers for prevention of freezing injury on putting greens. Prairie Turfgrass Research Centre Annual Report :28-32.

Saikkonen, K., S.H. Faeth, M Helander, and T.J. Sullivan. 1998. Fungal endophytes: a continuum of interactions with host plants. Annu. Rev. Ecol. Syst. 29:319-343.

SAS Institute Inc. 2002-2003. SAS/STAT User's Guide, version 9.1. SAS Institute Inc., Cary North Carolina.

Shelby, R.A. and L.W. Dalrymple. 1993. Long-term changes of endophyte infection in tall fescue stands. Grass Forage Sci. 48:356-361.

Tashiro, H. 1987. Turfgrass insects of the United States and Canada. Cornell University Press, Ithaca, NY. 422p.

Turgeon, A.J. 1991. Turfgrass management. Prentice Hall, Englewood Cliffs, NJ. 392p.

Thompson, R.H., H.A. Freiborg, and B.B. Reddick. 1989. Sampling intensity and timing for detecting *Acremonium coenophialum* incidence in tall fescue pastures. Agron. J. 81: 966-971.

Winkworth, R.E. and D.W. Goodall. 1962. A crosswise sighting tube for point quadrat analysis. Ecology 43:342-343.

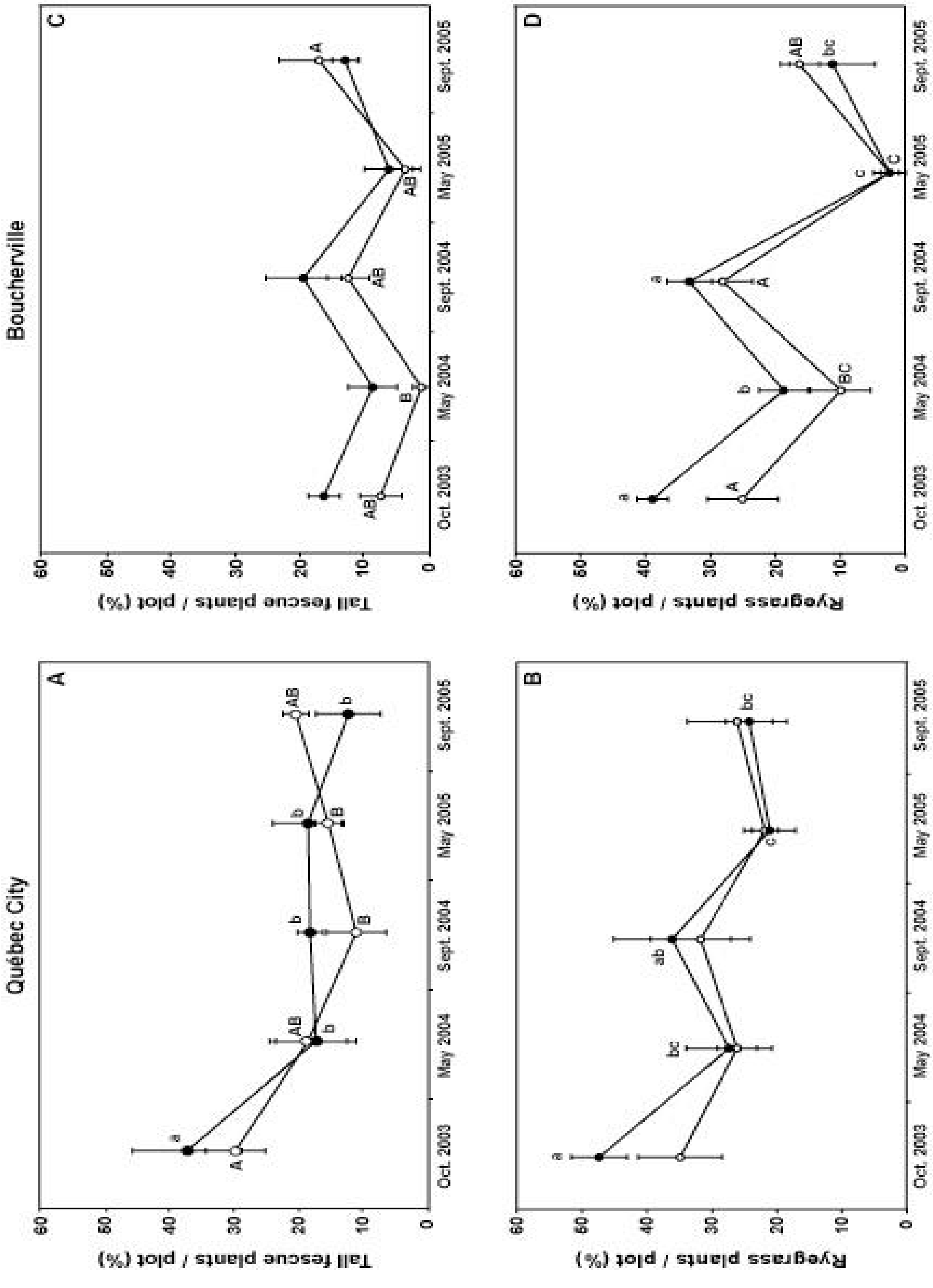


Fig. 5.1. Percent of tall fescue and perennial ryegrass plants (mean ± se) per plot at 0.9 (○) and 1.8 (●) kg seeding rates in Québec City and Boucherville from October 2003 to September 2005. Plots were overseeded in June 2003. Capital letters and lower case above dots indicate differences for 0.9 kg and 1.8 kg seeding rates, respectively. Means followed by different letters are significantly different [ANOVA with repeated-measures (*F=16.85, df=4 P<0.05*)] followed by Fisher procedures, P<0.05.

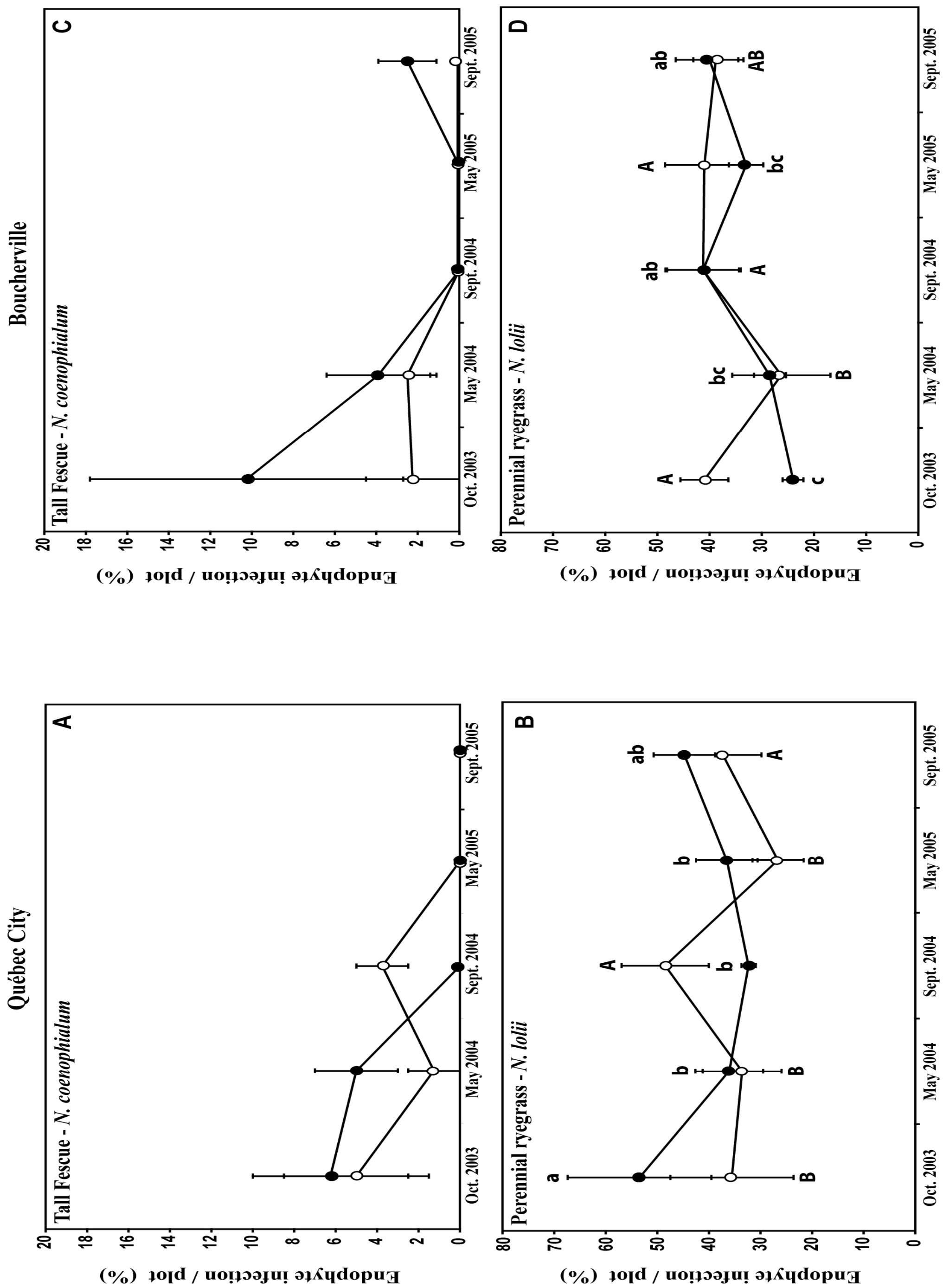


Fig. 5.2. Percent of endophyte infection of tall fescue and perennial ryegrass plants (mean ± se) at 0.9 (○) and 1.8 (●) kg seeding rates in Québec City and Boucherville from October 2003 to September 2005. Plots were overseeded in June 2003. For perennial ryegrass, capital letters and lower case above dots indicate differences for 0.9 kg and 1.8 kg seeding rates, respectively. Means followed by different letters are significantly different [ANOVA with repeated-measures (*F=1.51, df=4, P<0.05*] followed by Fisher procedures, P<0.05. No significant difference was observed for tall fescue (*F=1.51, df=4, P>0.05*).

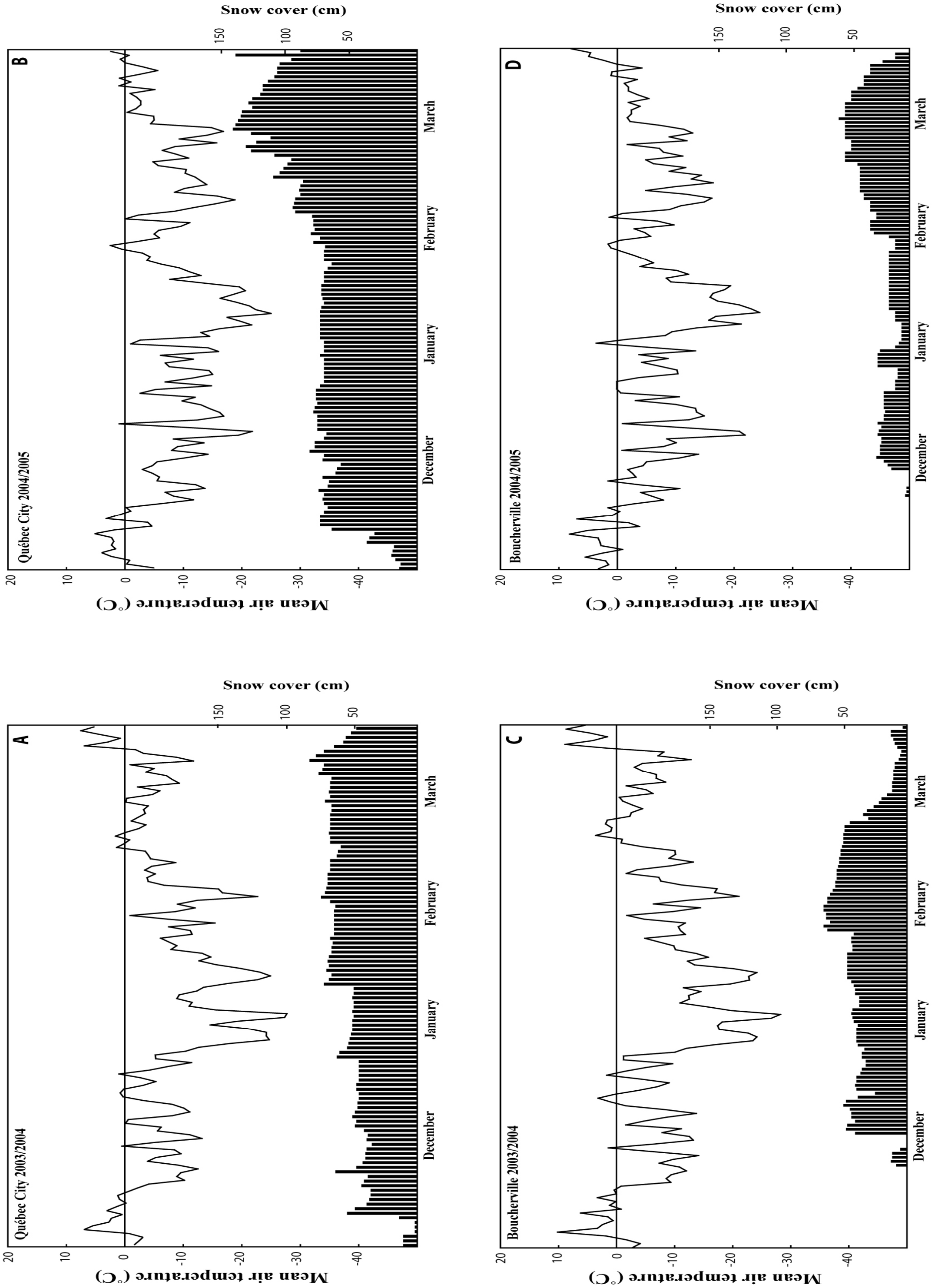


Fig. 5.3. Daily mean air temperature (°Celcius) and snow cover depth (cm) in Québec City and Boucherville for the winters 2003/2004 and 2004/2005. Data from Environment Canada's weather stations.

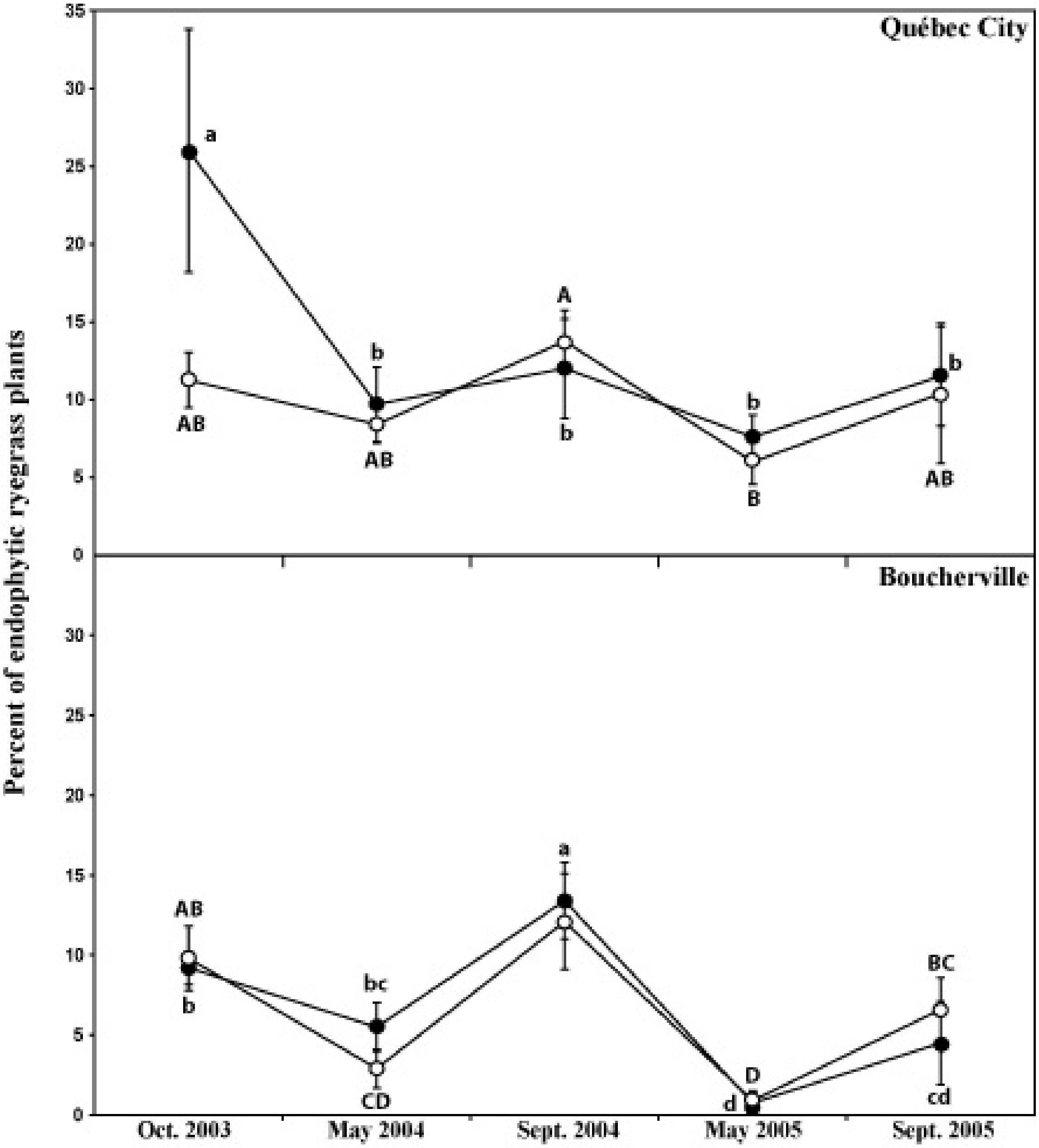


Fig. 5.4. Proportion (mean ± se) of endophytic 'Palmer III' ryegrass per plot in Québec City and Boucherville from October to September 2005 at 0.9 (○) and 1.8 (●) kg seeding rates. Capital letters and lower case above dots indicate differences for 0.9 kg and 1.8 kg seeding rates, respectively. Means followed by different letters are significantly different [ANOVA with repeated-measures (*F=11.70, df=4, P<0.05*)] followed by Fisher procedures,P<0.05.

CHAPITRE VI

EFFECT OF ENDOPHYTIC PERENNIAL RYEGRASS AND KENTUCKY BLUEGRASS MIXTURES ON HAIRY CHINCH BUG, *BLISSUS LEUCOPTERUS HIRTUS* (HEMIPTERA: LYGAEIDAE) SURVIVAL AND DEVELOPMENT

The authors of this chapter are Sophie Rochefort (Centre de Recherche en Horticulture, Université Laval), David J. Shetlar (Ohio State University), and Jacques Brodeur (Université de Montréal).

6.1 Résumé

Des expériences en serres ont été réalisées afin de déterminer l'effet de différentes combinaisons de ray-grass endophytique (RG+), *Lolium perenne* L. et de pâturin du Kentucky (PDK), *Poa pratensis* L. sur la survie et le développement de la punaise velue, *Blissus leucopterus hirtus* Montandon. Cinq combinaisons différentes de ray-grass endophytique et de pâturin du Kentucky ont été testées (100% PDK et 0% RG+, 75% PDK et 25% RG+, 50% PDK et 50% RG+, 25% PDK et 75% RG+, 0% PDK et 100% RG+) et comparées à un traitement avec 100% ray-grass non-endophytique (RG-). Pour chacun des traitements, la survie et le développement de punaises velues de 2^e et 3^e stades larvaires ont été mesurés. La survie des punaises a augmenté en parallèle avec le pourcentage de ray-grass endophytique 'SR 4220' dans les mélanges, tandis que la mortalité maximale a été observée dans le traitement 100% pâturin du Kentucky 'Dragon'. La survie des insectes était la plus élevée avec les traitements 100% RG- et 100% RG+. Le développement de la punaise velue n'a également pas été affecté par la présence d'endophyte car un nombre similaire de larves de 5^e stade a été retrouvé dans les différents traitements. Nos résultats démontrent que la présence de *Neotyphodium* dans la plante n'entraîne pas nécessairement d’effets adverses sur la punaise velue. Le taux de mortalité élevé observé avec le pâturin du Kentucky ‘Dragon’ suggère que chez cette espèce la sélection de cultivars moins sensibles aux insectes ravageurs devrait être prioritaire.

6.2 Abstract

We conducted studies under greenhouse conditions to assess the effect of different proportions of endophyte-infected perennial ryegrass (RG+), *Lolium perenne* L., and Kentucky bluegrass, *Poa pratensis* L. on survival and development of the hairy chinch bug, *Blissus leucopterus hirtus* Montandon. The first five treatments contained 0, 25, 50, 75 and 100% RG+ and a sixth treatment contained 100% non-infected perennial ryegrass. Second and third instar hairy chinch bugs were introduced in the experimental arenas for 18 days. Endophytic perennial ryegrass ‘SR 4220’ did not affect hairy chinch bug survival and development. Survival increased with the proportion of RG+ and was the highest for treatments containing 100% RG, infected or not with the endophyte. The least suitable treatment was Kentucky bluegrass ‘Dragon.’ Our results indicate that the association perennial ryegrass ‘SR 4220’-*L. perenne* does not have adverse affects on the hairy chinch bug survival. In contrast, Kentucky bluegrass ‘Dragon’ is not a suitable host for hairy chinch bug survival and development.

6.3 Introduction

Fungal endophytes from the genus *Neotyphodium* form associations with several turfgrass species (Breen 1994). The fungus develops systemic, and usually intercellular symbiotic associations with several cool-season grasses such as perennial ryegrass (*Lolium perenne* L; Marshall et al. 1999, Malinowski et al. 2005), but not with Kentucky bluegrass (*Poa pratensis* L.), another commonly used species in cool-season lawns. The fungus benefits mainly through access to nutriments provided by plant photosynthesis, while alkaloid compounds produced by the endophyte may reduce insect herbivory (Clay 1988, Breen

1994). Prestidge et al. (1982) first reported a positive association between *Neotyphodium* fungal endophyte in perennial ryegrass and resistance to Argentine stem weevil, *Listronotus bonariensis* Kuschel (Coleoptera: Curculionidae) in a New Zealand pasture. Now, more than 40 species of insects from several different orders are known to be adversely affected by endophytes (Breen 1994), including many major pests of turf grasses. On the other hand, variable responses of insect herbivores to endophytes have been reported, depending on genotypes of endophyte-infected grasses (Funk et al. 1984, Ahmed et al. 1986, Breen 1993). Variation of endophyte-infected plant resistance to insect herbivory has also been explained by the ability of the insect to avoid infected plants. Carrière et al. (1998) not only showed that some endophytic grasses are resistant to the hairy chinch bug, *Blissus leucopterus hirtus* Montandon, an important pest of cool-season turf grasses in northeastern America (Vittum et al. 1999), but also that some cultivars were avoided by the insects. Furthermore, Richmond and Shetlar (2000) have demonstrated that avoidance by hairy chinch bug nymphs of endophytic plants has the potential to reduce insect damages and population densities by altering movement and foraging behavior of nymphs when turf grass mixtures contained moderate levels (~35%) of infected plants. The use of endophytic grasses for turfgrass management is considered as an alternative method to chemical insecticides (Funk et al. 1993).

Mixtures of complementary grass species are increasingly used to enhance the quality and durability of turfgrass lawns because they provide greater tolerance to abiotic (cold, heat, drought) and biotic (arthropod pests, plant diseases, weed invasion) stresses compared with a single species (Beard 1973, Brede and Duich 1984, Coll and Bottrell 1994). Perennial ryegrass is a promising species to be used with Kentucky bluegrass, the most extensively planted grass as monostand in northeastern North America (Turgeon 1991). The aggressive rhizomatous growth pattern of Kentucky bluegrass produces very dense and uniform lawns over the growing season (Beard 1973), but the species is susceptible to insect pests and diseases (Tashiro 1987). Although perennial ryegrass has a high rate of establishment and tillering ability, it has a lower tolerance to cold temperatures than Kentucky bluegrass (Gusta et al. 1980) which prevents its use in pure stands in areas where temperatures are very low in winter (Christian and Engelke 1994, Waldron et al. 1998). The introduction of endophyte-infected "turf-type" perennial ryegrass in an established Kentucky bluegrass lawn would increase plant diversity and likely enhance resistance to herbivorous insects.

Determination of the right combinations of endophyte-infected plants mixed with Kentucky bluegrass is essential to assess their potential for reduction of insect pest density in turfgrass mixtures. The objectives of this study were to examine, under greenhouse conditions, the effect of different proportions of Kentucky bluegrass and endophytic perennial ryegrass on hairy chinch bug survival and development.

6.4 Materials and Methods

6.4.1 Plant material

The plants used in the experiment were perennial ryegrass 'SR 4220' and Kentucky bluegrass 'Dragon.' Perennial ryegrass 'SR 4220' is a turf-type cultivar, resistant to gray leaf spot (*Pyricularia grisea*) disease characterized by a green dark color and a high level (95%) of *Neotyphodium lolii* infection (Seed Research of Oregon, Oregon, USA). Kentucky bluegrass 'Dragon' is a common cultivar used in the province of Québec for sod production. Seeds of perennial ryegrass and Kentucky bluegrass were provided by Seed Research of Oregon, OR, USA, and Gloco Seed cie, Québec, Canada, respectively. Prior to the experiment, perennial ryegrass seeds were tested for endophyte infection using a tissue print immunoblot test kit (Agrinostics Ltd. Co., GA). Level of infection was ca. 85%. Infected and non-infected seeds of perennial ryegrass and Kentucky bluegrass seeds were planted individually in 72 cell flats (Landmark Plastic Co., OH, USA) and placed for eight weeks in a greenhouse under a photoperiod of 16:8 (L:D) h, and with day/night temperatures around 20/15°C. Plants were irrigated daily, fertilized (20:20:20, N:P:K) and clipped weekly to a height of 6 cm.

6.4.2 Insect survival test

Eight weeks after germination, cell flats bearing two tillers were selected to test for endophyte presence, using commercial immunoblot test kits (Agrinostics Ltd. Co., GA). Endophytic and endophyte-free plants were removed from cell flats and transferred to a pot containing a commercial potting soil (PROMIX^{TM}). Six treatments consisting of different proportions of Kentucky bluegrass and endophytic ryegrass are described in Table 1. For each experimental unit, 12 plants were planted in a 6-inch pot. Treatments were repeated six times into a completely randomized design. Throughout the experiment, pots were enclosed in tubular, Plexiglass cages (12.5 cm in diameter by 26 cm in height) to confine the chinch bugs to the plants. Tubular cages were perforated to create three air flow openings (each 4 by 4 cm) on the side of the cages and one on the top. Each opening was covered with nylon mesh. Bioassays were conducted under the same rearing conditions as described above. Second and third instar chinch bugs were collected from an infested lawn located at Laval University (Québec, Canada) with a leaf vacuum (model VacAttack™ Homelite). Chinch bugs were kept intermingled with soil and plant material for less than 24 h and starved 2-3 h before transfer to the cages. One hundred chinch bug nymphs were introduced in each cage. Eighteen days after introduction, the content of each pots (soil and plants) were visually inspected and the number of live chinch bugs was determined.

Data were analyzed using the PROC GLM procedure (SAS Institute 2002-2003), and means were compared with protected Fisher LSD multiple comparison tests ($P<0.05$). Linear effects of KBG and RG+ proportions on hairy chinch bug survival and development were analyzed using polynomial contrasts. *A priori* contrasts were used to detect differences between the different combinations of RG+ and KBG, between KBG and all the treatments with KBG and RG+, and between RG- and all the treatments with RG+.

6.5 Results

We did not detect an endophyte effect on chinch bug survival and development, as similar numbers of chinch bug were recovered from 100% RG+ (52.7± 8.0) and 100% RG- (65.3± 8.7) treatments (Table 6.1). Similar numbers of third, fourth and fifth instars and adult were collected from each treatment (Table 6.1).

A significant effect was detected between the two grass species. Chinch bugs were more abundant on 'SR 4220' ryegrass with and without endophyte than on 'Dragon' Kentucky bluegrass (Table 6.1). When all instars (total) are considered, only 26.5± 4.6 chinch bugs were recovered from KBG after 18 days. Chinch bug abundance (26.2± 6.5) was also very low with the combination level of 50% KBG and 50% RG+, which was not significantly different from the 100% KBG.

Chinch bug abundance increased linearly with the percentage of RG+ (Table 6.2). For all instars, contrast analyses revealed lower survival of hairy chinch bug reared on 100% KBG than on other treatments combining KBG and RG+ (Table 6.2). Chinch bug abundance in RG- treatment was significantly higher from the other treatments with perennial ryegrass.

Finally, development of hairy chinch bugs was not affected by the endophyte used in this study, as fifth instars were more abundant than third instars, the stage at which chinch bugs were introduced at the beginning of the experiment.

6.6 Discussion

Several studies have demonstrated the potential of infected perennial ryegrass and tall fescue to reduce populations of turfgrass insect pests such as sod webworms (Pyralidae spp.), bluegrass billbugs (*Sphenophorus parvulus*), and southern armyworm (*Spodoptera eridania*) (Funk et al. 1984, Ahmed et al. 1986 and 1987). A few studies have also shown the detrimental effect of turfgrass infected by endophytes on hairy chinch bug survival and/or development (Saha et al. 1987, Mathias et al. 1990, Richmond and Shetlar 2000). Our results showed an opposite pattern as endophyte-infected 'SR 4220' perennial ryegrass did not alter hairy chinch bug survival and development. Hairy chinch bug survival was positively correlated with an increase in the proportion of RG+ when in combination with Kentucky bluegrass, indicating that cultivar 'SR 4220' did not cause antibiosis or antixenosis to hairy chinch bugs under greenhouse conditions. Similarly, Lopez et al. (1995) showed that food assimilation rates of the redlegged grasshopper, *Melanoplus fermur-rubrum*, increased with increased levels of *N. starii* endophyte. Frit fly (*Oscinella frit*) and leatherjackets (*Tipula* spp.) are other examples of grass pests that are not affected by endophytes (Lewis and Clements 1986, Lewis and Vaughan 1997).

Detrimental effects of endophyte-infected plants on herbivorous insects depend on alkaloids production (Seigel et al. 1990). In perennial ryegrass, peramine is the major alkaloid causing insect antibiosis (Rowan and Gaynor 1986). Although the presence of *N. lolii* was detected using tissue immunoblot tests, we did not identify nor quantify alkaloid compounds, so we can not state whether insect-active components were present or absent. Survival of hairy chinch bugs on endophytic ryegrass can also be possibly explained by their feeding habits. Mathias et al. (1990) observed that hairy chinch bugs avoid feeding on the leaf sheath, where *N. lolii* mycelium is concentrated, and prefer the leaf blades of infected perennial ryegrass. In a choice test, Carrière et al. (1998) showed that hairy chinch bug nymphs avoid endophytic perennial ryegrass and feed on non-infected plants.

'Dragon' Kentucky bluegrass is a dark green color grass showing an excellent resistance to some of the major turfgrass diseases (NTEP 1997). This cultivar has a strong wear tolerance and is used on sport fields and other high traffic areas. In our experiment, Kentucky bluegrass was less susceptible to chinch bugs than 'SR 4220' perennial ryegrass. This is consistent with the study of Majeau et al. (2000), who observed that hairy chinch bug population densities were positively associated with perennial ryegrass abundance on residential lawn. The treatment 100% RG- provided the highest hairy chinch bug suvival among all treatments, confirming the positive association between perennial ryegrass and hairy chinch bug. 'SR 4220' perennial ryegrass is a cultivar used on home lawns, institutional grounds, school play areas, parks, sport fields, and golf courses, usually in combination with Kentucky bluegrass (Robinson et al. 2001). Tolerance mechanisms of Kentucky bluegrass to hairy chinch bug remain unknown. Other cultivars ('Baron' and 'Newport') of Kentucky bluegrass are known to be less suceptible to this insect pest (Tashiro, 1987). Leaf-surface chemicals, tissue toughness and constitutive chemical defenses (repellents and deterrents) are potential plant defense mechanisms of Kentucky bluegrass resistance (Panda and Kush, 1995).

As mentioned by Popaye and Bonos (2005), the presence of endophyte in a plant does not guarantee resistance to herbivory. Although our data demonstrated that 'SR 4220' perennial ryegrass infected with *N. lolii* has no significant effect on hairy chinch bug survival and development, under greenhouse conditions, fungal endophytes still have roles to play in plant-herbivore interactions**.** Recent studies by Parwinder Grewal (personal communication, Ohio State University) have shown significant changes in alkaloid production due to mowing, fertilization and irrigation regimes. Further laboratory studies are needed to determine the spectrum of insect-active compounds produced by new endophyte-infected perennial ryegrass cultivars and determine which may have potential for the control of hairy chinch bugs.

6.7 Aknowledgements

We thank Dr. D. Richmond for helpful suggestions on the experimental design, M. Desjardins and P. Deschênes for technical assistance, and Seed Research of Oregon and Gloco Inc. for providing turfgrass seeds. This work was supported by grants from the Fonds québécois de recherche sur la nature et les technologies and the Fonds de Recherche en écologie urbaine.

6.8 References

Ahmed, S., J.M. Johnson-Cicalese, W.K. Dickson, and C.R. Funk. 1986. Endophyte-enhanced resistance in perennial ryegrass to the bluegrass billbug, *Sphenophorus parvulus*. Entomol. Exp. Appl. 41:3-10.

Ahmed, S., S. Govindaraian, J.M. Johnson-Cicalese, and C.R. Funk. 1987. Association of a fungal endophyte in perennial ryegrass with antibiosis to larvae of the southern armyworm, *Spodoptera eridania*. Entomol. Exp. Appl. 43:287-294.

Beard, J. 1973. Turfgrass: science and culture. Prentice Hall, Englewood Cliffs, NJ**.** 672p.

Brede, A.D. and J.M. Duich. 1984. Establishment characteristics of Kentucky bluegrass-perennial ryegrass turf mixtures as affected by seeding rate and ratio. Agron. J. 76:875-879.

Breen, J.P. 1993. Enhanced resistance to fall armyworm (Lepidoptera : Noctudiae) in *Acremonium* endophyte-infected turfgrass. J. Econ. Entomol. 86:621-629.

Breen, J.P. 1994. *Acremonium* endophyte interactions with enhanced plant resistance to insects. Annu. Rev. Entomol. 39:410-423.

Carrière, Y., A. Bouchard, S. Bourassa, and J. Brodeur. 1998. Effect of endophyte incidence in perennial ryegrass on distribution, host-choice, and performance of the hairy chinch bug (Hemiptera : Lygaeidae). J. Econ. Entomol. 91: 324-328.

Clay, K. 1988. Clavicipitaceous fungal endophytes of grasses: coevolution and the change from parasitism to mutualism, pp.79-105. *In:* K.A. Pirozynski and D.L. Hawksworth (eds.), Coevolution of fungi with plants and animals. Academic Press, London, UK.

Coll, M., and D.G. Bottrell. 1994. Effects of non-host plants on an insect herbivore in diverse habitats. Ecology 75:723-731.

Christians, N.E., and M.C. Engelke. 1994. Choosing the right grass to fit the environment, pp. 99-113. *In:* A.R. Leslie (ed.), Integrated pest management for turf and ornamentals. Lewis, London.

Funk, C.R., D.C. Saha, and J.M. Johnson-Cicalese. 1984. Association of endophytic fungi with increased persistence and improved performance of perennial ryegrass and tall fescue in low maintenance turfs seeded in 1976. Rutgers Turfgrass Proc. 15:134-146.

Funk, C.R., R.H. White, and J.P. Breen. 1993. Importance of *Acremonium* in turf-grass breeding and management. Agric. Ecosyst. Environ. 44:215-232.

Gusta, L.V., J.D. Butler, C. Rajashekar, and M.J. Burke. 1980. Freezing resistance of perennial turfgrasses. HortScience 15:494-496.

Lewis, G.C. and R.O. Clements. 1986. A survey of ryegrass endophyte (*Acremonium loliae*) in the U.K. and its apparent ineffectuality on a seedling pest. J. Agric. Sci. 107: 633-638.

Lewis, G.C., and B. Vaughan. 1997. Evaluation of a fungal endophyte (*Neotyphodium lolii*) for control of leatherjackets (*Tipula* spp.) in perennial ryegrass. Tests Agrochem. Cult. 18:34-35.

Lopez, J.E., S.H. Faeth, and M. Miller. 1995. Effect of endophytic fungi on herbivory by redlegged grasshoppers (Orthoptera: Acrididae) on Arizona fescue. Environ. Entomol. 24:1576-1580.

Majeau, G., J. Brodeur, and Y. Carrière. 2000. Lawn parameters influencing abundance and distribution of the hairy chinch bug (Hemiptera: Lygaeidae). J. Econ. Entomol. 93:368-373.

Malinowski, D.P., D.P. Belesky, and G.C. Lewis. 2005. Abiotic stresses in endophytic grasses, pp.187-199. *In:* C.A. Roberts, C.P West, and D.E Spiers (eds.) *Neotyphodium* in cool-season grasses. Blackwell Publishing, Iowa, USA.

Marshall, D., B. Tunali, and L.R. Nelson. 1999. Occurrence of fungal endophytes in species of wild *Triticum*. Crop Sci. 39:1507-1512.

Mathias, J.K., R.H. Ratcliffe, and J.L. Hellman. 1990. Association of an endophytic fungus in perennial ryegrass and resistance to the hairy chinch bug (Hemiptera: Lygaeidae). J. Econ. Entomol. 83: 1640-1646.

National Turfgrass Evaluation Program. 1997. 1995 National Kentucky Bluegrass Test (Medium-High Input), Progress Report NTEP No. 98-5. 137p.

Panda, N., and G.S. Khush. 1995. Mechanisms of resistance, pp. 151-206. *In*:. International Rice Research Institute (Manila, The Philippines) (ed.) Host plant resistance to insects. Oxford University Press, Oxford, UK.

Popay, A.J., and S.A. Bonos. 2005. Biotic responses in endophytic grasses, pp.163-199. *In*: *Neotyphodium* in cool-season grasses. C.A. Roberts, C.P. West, and D.E. Spiers (eds.), Blackwell Publishing, Oxford, UK.

Prestidge, R.J., R.P. Pottinger, and G.M. Barker. 1982. An association of *Lolium* endophyte with ryegrass resistance to Argentine stem weevil. Proc. N. Z. Weed Pest Control Conf. 35:119-122.

Richmond, D.S., and D.J. Shetlar. 2000. Hairy chinch bug (Hemiptera: Lygaeidae) damage, population, density, and movement in relation to the incidence of perennial ryegrass infected by *Neotyphodium* endophytes. J. Econ. Entomol. 93: 1167-1172.

Robinson, M.F., L.A. Brilman, B.A. Adams, and C.R. Funk. 2001. Registration of ‘SR 4200’ perennial ryegrass. Crop Sci. 41: 269.

Rowan, D.D., and D.L. Gaynor. 1986. Isolation of feeding deterrents against Argentine stem weevil from ryegrass infected with the endophyte *Acremonium loliae*. J. Chem. Ecol. 12: 647-658.

Saha, D.C., J.M. Johnson-Cicalese, P.M. Halisky, M.I. Van Heemstra, and C.R. Funk. 1987. Occurrence and signifiance of endophytic fungi in the fine fescue. Plant Dis. 71: 1021-1024.

Seigel, M.R., G.C.M. Latch, L.P. Bush, N.F. Fannin, D.D. Rowan, B.A. Tapper, C.W. Bacon, and M.C. Johnson. 1990. Fungal endophyte-infected grasses: alkaloid accumulation and aphid response. J. Chem. Ecol. 16:3301-3315.

SAS Institute Inc. 2002-2003. SAS/STAT User's Guide, version 9.1. SAS Institute Inc., Cary North Carolina.

Tashiro, H. 1987. Turfgrass insects of the United States and Canada. Cornell University Press, Ithaca, NY. 392p.

Turgeon, A.J. 1991. Turfgrass management. Prentice Hall, Englewood Cliffs, NJ. 672p.

Vittum, P.J., M.G. Villani, and H. Tashiro. 1999. Turfgrass insects of the United States and Canada, 2nd ed. Cornell Univ. Press. 422p.

Waldron, B.L., N.J. Ehlke, D.J. Vellekson, and D.B. White. 1998. Controlled freezing as an indirect selection method for field winterhardiness in turf-type perennial ryegrass. Crop. Sci. 38:811-816.

Table 6.1. Mean number of chinch bug instars per pot (±se) 18 days after their introduction in different combination levels of 'Dragon' Kentucky bluegrass and 'SR 4220' ryegrass under greenhouse conditions.

Treatement	**Chinch bug instar**				
	3rd	**4th**	**5th**	**Adult**	**Total**
100% KBG	5.5 ± 2.7 **b**	6.8 ± 1.6 **a**	11.7 ± 2.8 **b**	2.5 ± 1.3 **a**	26.5 ± 4.6 **c**
75% KBG + 25%RG$^+$	13.3 ± 5.2 **ab**	9.0 ± 3.3 **a**	20.0 ± 6.8 **ab**	1.3 ± 0.9 **a**	44.0 ± 6.5 **b**
50% KBG + 50%RG$^+$	6.2 ± 1.6 **b**	6.2 ± 1.9 **a**	12.5 ± 4.2 **b**	1.3 ± 0.9 **a**	26.2 ± 6.5 **c**
25% KBG + 75% RG$^+$	14.0 ± 3.1 **ab**	16.5 ± 4.5 **a**	25.3 ± 6.1 **ab**	1.0 ± 0.4 **a**	56.8 ± 4.8 **ab**
100% RG$^+$	17.3 ± 5.0 **ab**	10.0 ± 5.4 **a**	24.2 ± 3.1 **ab**	1.2 ± 0.3 **a**	52.7 ± 8.0 **ab**
100% RG$^-$	19.5 ± 5.2 **a**	12.7 ± 4.8 **a**	32.7 ± 5.8 **a**	0.5 ± 0.2 **a**	65.3 ± 8.7 **a**

Table 6.2. *F* and *P* values after contrast analyses for the effects of endophytic and non-endophytic perennial ryegrass, Kentucky bluegrass, and different combinations of endophytic ryegrass and Kentucky bluegrass on hairy chinch bug survival.

	Hairy chinch bug instars									
	3rd		***4th***		***5th***		***Adult***		***All instars***	
Contrast	***F***	***P***	***F***	***P***	***F***	***P***	***F***	***P***	***F***	***P***
Linear effect KBG	0.59	0.45	1.81	0.19	1.54	0.22	1.7	0.2	4.11	0.05*
Linear effect RG$^+$	1.52	0.23	1.01	0.32	1.76	0.19	0.08	0.77	5.16	0.03*
T2 vs T3T4	0.43	0.52	0.24	0.63	0.03	0.86	0.04	0.85	0.09	0.76
T1 vs T2T3T4T5	2.52	0.12	0.68	0.41	2.45	0.13	2.54	0.12	6.08	0.02*
T6 VS T2T3T4T5	2.23	0.14	0.27	0.61	4.64	0.04*	0.76	0.39	7.47	0.01*

* $P<0.05$

CHAPITRE VII

CONCLUSION GENERALE

7.1 Conclusion

Ce projet de doctorat a, dans un premier temps, permis de caractériser les populations d'arthropodes retrouvés dans les surfaces gazonnées et ainsi, d'accroître nos connaissances sur la faune de cet écosystème jusqu'àlors déficiente au Québec et même au Canada. Une fois cette caractérisation établie, le deuxième aspect portait sur l'impact de différentes régies de pelouses sur ces populations d'arthropodes. L'effet à court terme (1 et 3 semaines après les applications) de deux insecticides sur les populations d'arthropodes a été évalué ainsi que l'effet à moyen terme (après trois années) des différents types d'entretien de pelouses. Le volet sur les graminées endophytiques s'inscrivait également dans cet aspect de l'effet du type de régie sur les arthropodes. En effet, l'utilisation de graminées endophytiques dans une pelouse affecte plusieurs insectes ravageurs (Richmond et Shetlar 2000) dont la punaise velue, *Blissus leucopterus hirtus* Montandon, un insecte ravageur important au Québec. Avec l'adoption de réglements municipaux et provinciaux de plus en plus restrictifs quant à l'utilisation des pesticides de synthèse, l'utilisation des graminées endophytiques comme méthode alternative à ces produits, devenait donc une avenue intéressante à explorer dans le cadre de ce projet.

Le premier volet du projet a tout d'abord permis de caractériser à l'espèce les populations de deux groupes d'arthropodes importants de cet écosystème soit les collemboles et les carabes. Vingt et une espèces de collemboles ont été identifiées aux deux sites expérimentaux avec les mêmes espèces dominantes de la famille des Isotomidae soit : *Parisotoma notabilis*, *Isotoma viridis* et *Cryptopygus thermophilus*. L'écosystème 'gazon' offre un habitat adéquat pour ces espèces épi et hémi édaphiques en apportant un apport constant en matière organique par les résidus de la tonte et par la présence du feutre. La diversité des espèces de collemboles des pelouses est similaire à celle rencontrée dans les prairies et en milieu agricole, mais moins diversifiée que celle rencontrée en milieu forestier. Tel qu'observé dans d'autres écosystèmes, l'abondance saisonnière des collemboles n'a démontré aucune tendance générale au cours des trois années d'étude avec une très grande variabilité entre les années d'échantillonnage ainsi qu'entre les sites expérimentaux. Au site municipal, soit la pelouse plus âgée, l'abondance des collemboles était moindre que dans la nouvelle pelouse, au site de l'Université Laval. Pour les carabes, la diversité des espèces était également similaire entre les deux sites avec un total de 17 espèces identifiées. Toutefois, les espèces dominantes étaient différentes entre les sites. L'abondance saisonnière des carabes échantillonnés aux deux sites était similaire avec une densité plus importante au mois de juin et juillet, et une baisse des populations de carabes à partir d'août, indiquant que les espèces de carabes qui colonisent les pelouses sont des espèces à reproduction printanière. L'abondance totale des carabes était six fois plus élevée dans la pelouse âgée que dans la nouvelle pelouse. L'abondance de plants de pissenlits au site municipal a favorisé la présence d'espèces granivores tel que *A. aenea,* une espèce de carabe particulièrement abondante dans la pelouse âgée. Les résultats obtenus suite aux expériences avec les collemboles et les carabes suggèrent qu'une composition végétale plus complexe d'une pelouse (tel qu'observé au site municipal), ne se traduit pas nécessairement en un assemblage plus diversifié d'arthropodes, mais semble influencer l'abondance de certaines espèces.

Dans un deuxième volet, l'effet de quatre types d'entretien de pelouses sur les communautés d'arthropodes a été mesuré durant trois saisons (Chapitre IV). Les pelouses, souvent qualifiées de milieu simple et peu diversifié, abritent une entomofaune abondante et diversifié. Tout d'abord, l'échantillonnage à l'aide des pièges-fosses a révélé un nombre moyen par année de captures totales de plus de 34 000 arthropodes aux deux sites expérimentaux avec deux groupes dominants soit les Formicidae et les Araneae. Contrairement à l'hypothèse de départ, les résultats ont clairement démontré que le type d'entretien de pelouse n'a pas d'effet sur les populations d'arthropodes bénéfiques et que les pesticides de synthèse n'ont pas entraîné la résurgence des insectes ravageurs à moyen terme. L'abondance de certains groupes d'arthropodes fut parfois moindre suite à l'application de l'insecticide diazinon et/ou carbaryl, mais cet effet fut de courte durée. En effet, le diazinon et le carbaryl ont entraîné des baisses significatives des populations de carabes et de collemboles, mais ces baisses ont été observées qu'une et/ou trois semaines après l'application du pesticide. De plus, ces baisses ne se sont pas manifestées à chaque année de l’étude. Les résultats suggèrent que la faune de la pelouse a une capacité de récupération suite aux interventions avec des insecticides. Cette capacité de récupération peut s’expliquer par le fait que les arthropodes sont en mesure de re-coloniser les parcelles expérimentales suite à une intervention. Ces résultats suggèrent également que l’usage de pesticides de manière localisé sur une surface gazonnée n’a pas d’impact sur la biodiversité de la pelouse à moyen terme. Les résultats ont également démontré que des facteurs abiotiques tel que la température et l’humidité ont autant d’effet sinon plus, que le type d’entretien de pelouse car dans les parcelles témoin, une importante variabilité saisonnière a parfois été observée. Les pelouses sont en effet des milieux dans lesquels les températures estivales peuvent être parfois très élevées et le taux d’humidité très faible, soumettant les arthropodes à des stress importants. Il serait alors intéressant de mesurer l’impact de ces deux facteurs sur les populations d’arthropodes de cet écosystème, et plus particulièrement sur les populations de collemboles, lesquels sont extrêmement sensibles aux variations de température et d’humidité. De plus, il serait pertinent de vérifier à plus long terme (une dizaine d’années) l’effet de ces interventions sur l’écosystème ‘gazon’. Également, les deux sites expérimentaux représentaient des surfaces gazonnées de grandes dimensions comparativement à ce qui est observé en milieu résidentiel où les pelouses sont davantage fragmentées, entrecoupées de zones non engazonnées (plates-bandes, routes asphaltées, etc.). Une étude réalisée sur des terrains résidentiels serait nécessaire afin de déterminer si l’abondance des arthropodes est similaire à celle obtenue dans notre étude, et si la capacité de re-colonisation est également possible dans ces milieux.

Le troisième volet de mon projet de doctorat s’inscrivait également dans l’évaluation de l’effet du type d’entretien de pelouse sur les arthropodes, mais cette fois avec l’utilisation des graminées endophytiques pour la réduction des populations d’insectes ravageurs des pelouses. Dans un premier temps, puisque les données sur la survie à l’hiver des endophytes au Québec et au Canada étaient inexistantes, j’ai voulu suivre dans le temps le niveau d’infection de *Neotyphodium coenophialum* et *Neotyphodium lolii* (Chapitre V). Les résultats ont démontré que l’association *N. coenophialum* - fétuque élevée ne persiste pas sous nos conditions hivernales alors que l’endophyte *N. lolii* demeurent à un même niveau d'infection dans le ray-grass vivace. De plus, nous avons démontré que la fétuque élevée et le ray-grass vivace survivent aux hivers québécois, mais que la survie est meilleure dans la région de Québec due au couvert de neige plus important que dans la région de Montréal. La proportion de ray-grass endophytique présent dans les parcelles après deux hivers était inférieure à 15%, ce qui n'est pas suffisant pour réduire de façon significative les populations de punaises velues. Afin d'augmenter cette proportion à 30-35% (proportion qui a démontré une réduction des populations de punaises velues; Richmond et Shetlar 2000), un sur-ensemencement annuel devra être envisagé comme pratique culturale par les gestionnaires d'espaces verts désireux d'utiliser les graminées endophytiques dans leur programme d'entretien de pelouses.

Suite à ces résultats, j'ai entrepris des essais en serre afin de déterminer le potentiel de différentes combinaisons de ray-grass endophytique (RG+) et de pâturin du Kentucky pour le contrôle de la punaise velue (Chapitre VI). Les résultats ont démontré que l'association *N. lolii* - RG+ cultivar 'SR 4220' n'affecte pas négativement la survie de la punaise velue, mais plutôt positivement. En effet, les résultats ont démontré un effet linéaire positif du pourcentage de RG+ dans les mélanges sur la survie de la punaise velue. Ces résultats sont assez surprenants étant donné que des études antérieures ont démontré l'effet négatif de l'endophyte *N. lolii* sur la survie de cet insecte (Saha et al. 1987, Mathias et al. 1990). Deux hypothèses peuvent expliquer les résultats obtenus lors de mon étude: i-la production d'alcaloïdes, substances responsables de l'effet d'antibiose et d'antixenose chez les insectes herbivores, produits par l'endophyte était trop faible pour engendrer un effet négatif ou ii-la punaise velue était en mesure de s'alimenter au niveau de certaines parties de la plante où la concentration en hyphes et en alcaloïdes est moindre. Dans mon étude, j'ai évalué la présence de l'endophyte dans la plante, mais je n'ai pas évalué la concentration d'hyphes dans les tissus végétaux et ni quantifier la production d'alcaloïdes. Il aurait également été intéressant d'observer le comportement alimentaire des punaises velues dans les différents mélanges afin de vérifier si effectivement elles s'alimentent davantage dans une zone particulière de la plante, et par la suite quantifier la concentration d'hyphes et d'alcaloïdes dans ces parties végétatives. Enfin, d'autres essais seront nécessaires sur les graminées endophytiques afin de cibler les cultivars les plus performants tant au niveau de la survie à l'hiver qu'au niveau de la phytoprotection, et ainsi être en mesure de faire des recommandations aux gestionnaires d'espaces verts quant à leur utilisation.

Ce projet de doctorat fut un projet innovateur tant par son aspect descriptif des populations d'arthropodes que par son aspect sur l'effet des types d'entretien de pelouses sur ces derniers. Il a démontré une toute autre image de nos pelouses québécoises soit celle d'un environnement diversifié, abritant une abondance étonnante d'arthropodes. Malgré l'absence d'effets du type d'entretien de pelouse évalués dans ce projet, l'utilisation de pratiques de gestion permettant de conserver cette biodiversité sera essentielle afin de maintenir la qualité et la vitalité de nos espaces verts urbains. L'absence d'effet des traitements insecticides sur les arthropodes observée dans cette étude suggèrent qu'en présence de problèmes d'insectes ravageurs, l'application localisés de pesticides soit acceptable sur le plan de la diversité et de la quantité d'arhropodes que l'on dénombre dans une pelouse.

Dans un avenir rapproché, la composition végétale de nos pelouses québécoises sera appelée à changer pour se diriger davantage vers des pelouses mixtes, composées de plusieurs graminées à gazon. L'incorporation de graminées endophytiques sera une avenue intéressante pour augmenter la diversité végétale de nos pelouses car en plus d'apporter une protection à la plante contre les insectes ravageurs, elles permettront une meilleure tolérance aux températures élevées, à la sécheresse et à certaines maladies fongiques (Bacon 1993, Belesky 1987, Malinowski et al. 2005).

7.2 Références

Bacon, C.W. 1993. Abiotic stress tolerances (moisture, nutrients) and photosynthesis in endophyte-infected tall fescue. Agric. Ecosyst. Environ. 44:123-141.

Belesky, D.P., O.J. Devine, J.E. Pallas, Jr., and W.C. Stringer. 1987. Photosynthetic activity of tall fescue as influenced by a fungal endophyte. Photosynthetica 21:82-87.

Malinowski, D.P., D.P. Belesky, and G.C. Lewis. 2005. Abiotic stresses in endophytic grasses, pp.187-199. *In:* C.A. Roberts, C.P West, and D.E Spiers (ed.) *Neotyphodium* in cool-season grasses. Blackwell Publishing, Iowa, USA.

Mathias,. J.K., R.H. Ratcliffe, and J.L. Hellman. 1990. Association of an endophytic fungus in perennial ryegrass and resistance to the hairy chinch bug (Hemiptera: Lygaeidae). J. Econ. Entomol. 83: 1640-1646.

Richmond, D.S., and D.J. Shetlar. 2000. Hairy chinch bug (Hemiptera: Lygaeidae) damage, population density, and movement in relation to the incidence of perennial ryegrass infected *Neotyphodium* endophytes. J. Econ. Enomol. 93:1167-1172.

Saha, D.C., J.M. Johnson-Cicalese, P.M. Halisky, M.I. Van Heemstra, C.R. Funk. 1987. Occurrence and signifiance of endophytic fungi in the fine fescue. Plant Dis. 71: 1021-1024.