Carabid Assemblages (Coleoptera: Carabidae) in a Rotation of Three Different Crops in Southern Alberta, Canada: A Comparison of Sustainable and Conventional Farming

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ABSTRACT Carabids were sampled in 2000 (pretreatment year) and 2003–2005 in experimental plots in southern Alberta, Canada, after a rotation of beans, wheat, and potato under sustainable and conventional farming practices. Each phase of the rotation was present in every year. Crop type had a stronger effect than sustainable treatment on carabid-expected species richness, diversity, and species composition. However, carabid activity density was consistently higher in plots under sustainable treatments than those maintained conventionally. Potato plots, which were sprayed with insecticide for pest control, showed a significantly lower carabid activity density than the other crops. These results support other studies showing the beneficial effect of sustainable farming on activity density of carabid beetles.

KEY WORDS conventional versus sustainable agronomic practices, epigeic predators, ground beetles

Agricultural intensification, especially pesticide use and monoculture cultivation, has been shown repeatedly to negatively affect the structure of faunal and floral landscapes. These effects include soil erosion and contamination, ground water pollution, and biodiversity reduction (Edwards 1987, Pfiffner and Niggli 1996, Hole et al. 2005). In many, if not most, cases, these changes in soil, water, and biodiversity have been linked to conventional farming systems with high chemical input and a predominant focus on high yield production. Not surprisingly, concerns about environmental and food quality have fueled increasing efforts to develop alternative farming practices. Sustainable or low-input farming practices integrate crop rotation, economic injury level (EIL), strip cropping, intercropping, and other practices that can conserve predators of pest arthropods and minimize reliance on synthetic chemicals (Edwards 1987). For example, carabid beetles (Coleoptera: Carabidae) can play an important role in reducing populations of potential insect pests (Menalled et al. 1999, Holland 2002) and weeds (Menalled et al. 2007). The question is how can we maximize the extent and efficiency of this inexpensive, naturally provided pest management force?

Several studies have reported increased diversity and activity density of carabids under organic or sustainable farming (Dritschilo and Wanner 1980, Hokkanen and Holopainen 1986, Kromp 1989, Fan et al. 1993, Pfiffner and Niggli 1996), whereas others have reported no significant effects (Holopainen 1983, Armstrong 1995). Application of manure, a common organic fertilizer used in organic and sustainable farming, has been associated with increases in carabid activity density and diversity (Hance and Gregoire-Wibo 1987, Humphreys and Mowat 1994, Raworth et al. 2004). Moreover, manure application can be the single most important factor influencing farmland carabid community composition and can decrease the negative effects of the use of insecticides (Hance and Gregoire-Wibo 1987). Minimum or zero tillage, as recommended in sustainable agriculture, has been shown to benefit carabid assemblages (House and Stinner 1983, House and Alzugaray 1989, Tonhasca 1993, Andersen 1999). However, some studies have found no significant effects of tillage on the overall carabid abundance (Cárcamo et al. 1995, Hummel et al. 2002, Clark et al. 2006). Responses of some carabid species have also been inconsistent between different tillage intensities (Ferguson and McPherson 1985, Brust et al. 1986, Cárcamo 1995), which may be consequences of carabid life histories and timing of tillage operations.

In this paper, we studied the responses of carabid beetles to three different crops under rotation, wheat (*Triticum aestivus* L.), potato (*Solanum tuberosum* L.), and bean (*Phaseolus vulgaris* L.), and two different levels of agronomic input (conventional and sustainable farming). Our "sustainable" system was not an organic farming system because insecticides were used to manage potato pests; however, this system uses less input in the form of reduced tillage and alternative

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Table 1. Sustainable and conventional treatments and crop types with respective agronomic operations used to study ground beetles near Vauxhall, Alberta, from 2000 and 2003–2005

Rotation	Input	Crop	Variety	Fertilizer	Plant density (plant/m^2)
1	Conventional	Potato	Russet Burbank	134 N, 67 P, 67 K kg/ha, fall	3.6
2	Conventional	Bean	AC Red Bond (2003 UI906)	90 kg/ha, N spring	26
3	Conventional	Wheat	Soft White Spring Wheat AC Reed	90 kg/ha N spring	322
1	Sustainable	Potato	Russet Burbank	62 N, 28 P, 67 K (28 t/ha compost fall)	3.6
2	Sustainable	Bean	AC Red Bond (2003 UI906)	90 kg/ha N spring	43
3	Sustainable	Wheat	Soft White Spring Wheat AC Reed	90 kg/ha N spring	322

nutrient inputs in the form of manure. We analyzed ground beetle responses to these farming systems in terms of diversity, species composition, and activity density.

Materials and Methods

Site Description and Agronomic Treatments. This study was conducted near Vauxhall (50°03′19 N; 112°07′51 W), a region with brown chernozemic soil in the dry grassland of southern Alberta, Canada. The study site was made up of four replicates of 26 plots (10.1 by 18.3 m; interplot distances, 2.0 m) separated by 18-m pathways. Interplots and pathways were seeded with fall cereal that was regularly mowed. Rotations, varying in length for 3–6 yr, were established in 2000, which served as a baseline year where no agronomic inputs were applied. Barley was grown over the whole experimental area in 1999 (the year before project initiation). Each phase of each rotation was present in each year. This study used a subset of these plots to sample carabid assemblages in four replicate plots in wheat, bean, and potato plots of the 3-yr rotation in both sustainable and conventional treatments for a total of 24 plots/yr (in 2000 and 2003–2005; Table 1).

The following practices differentiate the sustainable treatment from the conventional: (1) direct seeding or reduced tillage where possible, (2) fall-seeded cover crops in bean plots, (3) composted cattle manure as a substitute for inorganic fertilizer after potato crop, and (4) straight cutting of solid seeded rather than undercutting of wide-row seeded bean plots. The latter practice may lead to soil erosion risk because it requires subsoil disturbance to uproot the plants in contrast to standard harvesting of straight cutting in one operation with a combine, which leaves some stubble without disturbing the soil. Compost (derived from beef cattle feedlot manure) was applied in the preceding fall to sustainable potato plots. The compost was sourced from the same feedlot each year and had an average (n = 3 yr) total nitrogen content of 12.5 g/kg, total phosphorus content of 4.3 g/kg, and a carbon/nitrogen ratio of 10.9. Fall cultivation involved one pass of a disc and harrow with the exception of the conventional potato treatment that was moldboard plowed. The sustainable bean and wheat plots were preceded by a fall-seeded cover crop cereal (oats or winter-hardy fall rye). Potato and wheat were seeded in late April to early May, and bean plots were seeded in mid-May. Only potato plots, of both treatments, were treated with insecticides (organophosphorous, pyrethroid, or chloronicotinyl) three times a year to control Colorado potato beetles [*Leptinotarsa decemlineata* (Say)] and aphids in this crop. This application was necessary to prevent yield losses from these insect pests that would confound the other "sustainable" treatments such as manure application. Fungicide was applied on beans and potatoes only while herbicides were applied to all crops. Glyphosate was applied once to terminate cover crops before seeding the beans in the sustainable treatment plots. Irrigation was applied to all plots as needed throughout the season. In July 2005, two potato plots (one sustainable and one conventional) were terminated after flooding problems caused by extreme rainfall in June.

Arthropod Sampling. Sampling was done with a 1-liter plastic container buried flush with the soil surface and fitted with another 0.5-liter plastic insert (11 cm diameter) half filled with undiluted plumbing grade propylene glycol (Spence and Niemelä 1994). A rain cover, made of tenplast (standard plastic greenhouse roofing), was suspended, using two 10-cm nails, ≈2 cm above each trap. Pitfall traps were collected every 7–10 d in 2000 (pretreatment year) and 2003–2005. The latter 3 yr constituted the second cycle of the crop rotation; thus, compost had been used at least once on each selected rotation. Sampling periods were as follows: (1) 1 July to 25 August 2000, (2) 12 June to 27 August 2003, (3) 18 May to 1 September 2004, and (4) 3 May to 29 August 2005. Two pitfall traps were placed in opposite corners of each study plot, 2 m from the plot edge and 5 m into the plot. Carabid beetles were stored in 70% ethanol and later identified to species using keys of Lindroth (1961–1969) and the reference collection at the Strickland Entomological Museum of the University of Alberta. Voucher collections were deposited at the Spence Laboratory Insect Collection of the University of Alberta, Edmonton and at the Lethbridge Research Centre.

Weed Survey. Number and frequency of weed species were surveyed using 15 quadrats (0.5 by 0.5 m) placed to form the shape of an inverted "w" on each plot before and after herbicide application (31 May and 24 July 2000; 3 June and 24 July, 2003; 25 May and 9 July 2004; and 4 June and 21 July 2005). Data were expressed in terms of mean plant density (plants/m^2) per plot. Herbicide applications followed the recommendation for chemical and rates as per the crop protection guide of the province of Alberta (Brook

2007). Chemicals used in beans included Ethalfluralin as a seed amendment before planting and sethoxydin and bentazon after emergence. In potatoes, eptam was applied preseeding and metribuzin postemergence. Herbicides used in wheat varied depending on weed presence and included trifluralin preseeding and tralkoxydim-bromoxynil-MCPA and fenoxaprop-p-ethyl, 2–4-D after emergence and glyphosate after harvest.

Analysis. Species that could not be distinguished morphologically were pooled for analysis so that all specimens were retained for at least general analyses. The taxon *Amara carinata* (LeConte, 1848) also included *Amara lacustris* (LeConte, 1855) and *Amara torrida* (Panzer, 1797), and *Harpalus funerarius* (Csiki, 1932) also included *Harpalus fraternus* (LeConte, 1852). Carabid catch from each pitfall trap was standardized for trapping effort (beetle per trap per day) by dividing the number of beetles per trapping days for each trap for each sampling date. Because of the occasional losses of samples of both traps from the same plot for a given period, an average standardized catch was obtained by dividing the standardized catch per sampling date by the number of collection dates.

Rarefaction analysis was applied to the data before standardization using the Vegan package (Jari et al. 2005) available for R software (R Development Core Team 2005). Individual-based rarefaction curves were obtained using 1,000 permutations for each treatment. Rarefaction standardization based on individuals is recommended for standardizing species richness for trapping effort (McCune and Grace 2002). Species diversity was also quantified with the standard Shannon-Wiener function (H') (Krebs 1989). Potential cumulative effects of conventional versus sustainable treatment on H' were tested using repeated-measures analysis of variance (ANOVA) within each of the crop types from 2003 to 2005 (SAS Institute 2005).

Nonmetric multidimensional scaling (NMDS) analysis with Sorensen (Bray-Curtis) distances was performed using PCOrd (McCune and Mefford 1999) to compare the species composition among treatments. NMDS was chosen because it performs well with ecological data that do not meet the assumption of normality (McCune and Grace 2002). A Monte Carlo probability was calculated to evaluate whether the final stress associated with the ordinations differed from random. In NMDS, the stress is a measure of distortion between the positions of real data points from the graphical representation. Thus, low stress represents few distortions from the real position of the data points and is associated with a graph that more accurately represents the dissimilarities in species composition. A preferred number of dimensions is suggested when adding an axis does not reduce stress by more than five.

The number of dimensions of the final ordination was automatically selected when the stress was not lowered by >5 and was near or below 20 with a Monte Carlo test inferior than 0.05. The similarity in species composition among the crop and agronomic input within each crop was tested using multiresponse permutation procedures (MRPP). The procedure uses Sorensen (Bray-Curtis) distances to calculate the variation within (A value) and between groups (T value) and evaluates the probability of these groups to be similar (McCune and Grace 2002). Additionally, species vectors were calculated with a minimum r^2 of 0.3. The angle of the vector indicates the direction of the relationship with the ordination while the length indicates the strength (McCune and Grace 2002).

Beetle catch rates and weed density were log(x + 1) transformed before analysis of variance to reduce heterogeneous variances typical of pitfall data. Weed abundance from both surveys (before and after herbicide use) were summed before transformation. Year-specific sums of carabid catches and weed abundance were analyzed using repeated-measures ANOVA with the catch from each year as the dependent variable and rotation, input, and interaction between these two as model factors. The samples from the year 2000 were used as a model covariate to account for pretreatment heterogeneity. Rotation was used as a model factor instead of crop type, because location of the crop changed every year and consequently the investigation of temporal effects would have been difficult. Although rotation is the model factor, it is feasible to study the effect of crop type every year by determining which crop was present in each rotation in a specific year.

To study the effect of crop type and agronomic input on the catches of the numerically dominant carabid species, we performed a complete factorial multivariate ANOVA (MANOVA) on the catch rate of the five most abundant species each year using crop type and agronomic input as independent factors for each year the treatments were applied (i.e., from 2003 to 2005). Only the five most abundant species were selected, because in certain years, the low catch rate of certain species would have resulted in poor analysis power and unreliable conclusions. In 2005, despite the fact that *Poecilus lucublandus* (Say, 1823) was slightly more abundant than *Bembidion quadrimaculatum* (Linné, 1769), we used the latter in the analysis for the sake of consistency among years. The responses of individual species were tested using ANOVA after significant MANOVA (Wilk's lambda, $P < 0.05$). In each analysis, Tukey's honestly significant difference (HSD) post hoc ($P < 0.05$) test was used to find groupings. We also tested for relationships between each of the five dominant species and weed density through linear regression. Unless otherwise noted, statistical analyses were performed using SPSS 11.0 software (SPSS 1999).

Results

Carabid Fauna. A total of 12,813 carabids, representing 62 species from 22 genera, were collected during the 4 yr of this study (1 pretreatment yr and 3 yr of applied treatments). The highest total catch and number of species were found in 2005 (3,705 individuals) and 2004 (49 species), whereas the lowest were found in 2000 (2,608 individuals and 41 species; Table

Table 2. Count (C) and frequency (F) of carabid species caught near Vauxhall, Alberta, in each study year and pooled total numbers

Carabid species	2000		2003		2004		2005		Total	
	C	F	C	F	C	F	C	F	C	F
Pterostichus melanarius (Illiger, 1798)	1158	44.4	928	30.89	1178	33.7	2257	60.92	5521	43.09
Amara carinata (LeConte, 1848)	30	1.15	655	21.8	267	7.64	271	7.31	1223	9.54
Amara farcta LeConte, 1855	14	0.54	365	12.15	361	10.33		6.15	968	7.55
Poecilus corvus (LeConte, 1873)	230	8.82	27	0.9	288	8.24	246	6.64	791	6.17
Stenolophus comma (F., 1775)	195	7.48	305	10.15	176	5.03	50	1.35	726	5.67
Bembidion quadrimaculatum (Linn 1769)	145	5.56	182	6.06	262	7.49	82	2.21	671	5.24
Poecilus lucublandus (Say, 1823)	293	11.23	22	0.73	122	3.49	97	2.62	534	4.17
Agonum placidum (Say, 1823)	285	10.93	30	1	64	1.83	55	1.48	434	3.39
Harpalus funerarius Mannerheim, 1853	7	0.27	76	2.53	157	4.49	21	0.57	261	2.04
Bembidion timidum (LeConte, 1848)	32	1.23	77	2.56	90	2.57	28	0.76	227	1.77
Harpalus herbivagus Say, 1823	22	0.84	16	0.53	110	3.15	68	1.84	216	1.69
Bembidion obscurellum (Motschulsky, 1845)	9	0.35	52	1.73	68	1.95	54	1.46	183	1.43
Amara apricaria (Paykull, 1790)	5	0.19	47	1.56	23	0.66	37	1.00	112	0.87
Microlestes linearis (LeConte, 1851)	7	0.27	9	0.3	86	2.46	4	0.11	106	0.83
Agonum cupreum Dejean, 1831	51	1.96	1	0.03	21	0.60	17	0.46	90	0.70
Harpalus amputatus Say, 1830	13	0.5	21	0.7	31	0.89	20	0.54	85	0.66
Bembidion rupicola (Kirby, 1837)	17	0.65	24	0.8	22	0.63	19	0.51	82	0.64
Amara torrida (Panzer, 1797)	21	0.81	26	0.87	12	0.34	2	0.05	61	0.48
Bembidion nitidum (Kirby, 1837)	2	0.08	9	0.3	14	0.40	31	0.84	56	0.44
Amara quenseli (Schönherr, 1806)	—	—	29	0.97	15	0.43	10	0.27	54	0.42
Agonum corvus (LeConte, 1860)	1	0.04	17	0.57	16	0.46	12	0.32	46	0.36
Pterostichus femoralis (Kirby, 1837)	35	1.34	5	0.17	3	0.09	1	0.03	44	0.34
Amara latior (Kirby, 1837)	1	0.04	17	0.57	8	0.23	3	0.08	29	0.23
Harpalus fraternus LeConte, 1852	1	0.04	1	0.03	4	0.11	19	0.51	25	0.20
Harpalus paratus Casey, 1924	5	0.19	5	0.17	11	0.31	4	0.11	25	0.20
Calosoma obsoletum Say, 1823	—	—	4	0.13	5	0.14	15	0.40	24	0.19
Pterostichus adstrictus Eschscholtz, 1823	4	0.15	2	0.07	10	0.29	4	0.11	20	0.16
Amara littoralis Mannerheim, 1843	2	0.08	8	0.27	2	0.06	7	0.19	19	0.15
Amara lacustris LeConte, 1855	5	0.19	6	0.2	5	0.14	—	—	16	0.12
Harpalus ventralis LeConte, 1848	1	0.04	—	—	13	0.37	2	0.05	16	0.12
Bembidion bimaculatum (Kirby, 1837)	2	0.08	9	0.3	1	0.03	3	0.08	15	0.12
Bradycellus congener (LeConte, 1848)	2	0.08	5	0.17	5	0.14	2	0.05	14	0.11
Amara obesa (Say, 1823)	1	0.04	2	0.07	5	0.14	6	0.16	14	0.11
Harpalus fuscipalpis Sturm, 1818	—	—	6	0.2	6	0.17	—	—	12	0.09
Poecilus scitulus LeConte, 1848	2	0.08	2	0.07	2	0.06	5	0.13	11	0.09
Bembidion castor Lindroth, 1963	—	—	6	0.2	—	—	3	0.08	9	0.07
Calathus ingratus Dejean, 1828	2	0.08	—	—	6	0.17	1	0.03	9	0.07
Chlaenius sericeus (Forster, 1771)	1	0.04	2	0.07	—	—	4	0.11	7	0.05
Bembidion coloradense Hayward, 1897	—	—	—	—	5	0.14	—	—	5	0.04
Amara confusa LeConte, 1848	—	—	1	0.03	2	0.06	2	0.05	5	0.04
Clivina fossor (Linn, 1758)	—	—	1	0.03	3	0.09	1	0.03	5	0.04
Bembidion rapidum (LeConte, 1848)	—	—	1	0.03	—	—	4	0.11	5	0.04
Harpalus somnulentus Dejean, 1829	—	—	—	—	3	0.09	2	0.05	5	0.04
Amara ellipsis (Casey, 1918)	—	—	1	0.03	3	0.09	—	—	4	0.03
Bembidion scudderi LeConte, 1878	—	—	—	—	1	0.03	3	0.08	4	0.03
Axinopalpus biplagiatus (Dejean, 1825)	—	—	—	—	3	0.09	—	—	3	0.02
Piosoma setosum LeConte, 1848	—	—	—	—	1	0.03	2	0.05	3	0.02
Bembidion acutifrons LeConte, 1879	—	—	1	0.03	1	0.03	—	—	2	0.02
Cymindis cribricollis Dejean, 1831	1	0.04	—	—	—	—	1	0.03	2	0.02
Harpalus nigritarsis Sahlberg, 1827	—	—	—	—	2	0.06	—	—	2	0.02
Cymindis borealis LeConte, 1863	1	0.04	—	—	—	0.00	—	—	1	0.01
Bembidion concolor (Kirby, 1837)	—	—	—	—	1	0.03	—	—	1	0.01
Amara convexa LeConte, 1848	—	—	—	—	—	—	1	0.03	1	0.01
Amara cupreolata Putzeys, 1866	—	—	—	—	—	—	1	0.03	1	0.01
Amara discors Kirby, 1837	1	0.04	—	—	—	—	—	—	1	0.01
Passimachus elongatus LeConte, 1846	—	—	—	—	1	0.03	—	—	1	0.01
Elaphrus lecontei Crotch, 1876	1	0.04	—	—	—	—	—	—	1	0.01
Badister neopulchellus Lindroth, 1954	1	0.04	—	—	—	—	—	—	1	0.01
Bembidion nudipenne Lindroth, 1963	1	0.04	—	—	—	—	—	—	1	0.01
Diplocheila oregona (Hatch, 1951)	—	—	—	—	1	0.03	—	—	1	0.01
Loricera pilicornis (F., 1775)	—	—	1	0.03	—	—	—	—	1	0.01
Lebia vittata (F., 1777)	1	0.04	—	—	—	—	—	—	1	0.01
Total Carabids	2608		3004		3496		3705		12813	

2). The catch frequency varied between years for most species. *Pterostichus melanarius* (Illiger, 1798), a European introduction to North America, was the most abundant species, with 43.1% of the total catch, but in 2005, this species alone represented 60.9% of the total catch (Table 2).

Diversity. Rarefaction curves were prepared for each year of the study and suggested high variability with respect to crops and agronomic inputs from year to year (Fig. 1). In 2000, before the sustainable treatments were applied, beans had the highest expected species richness, although the plots in wheat had the

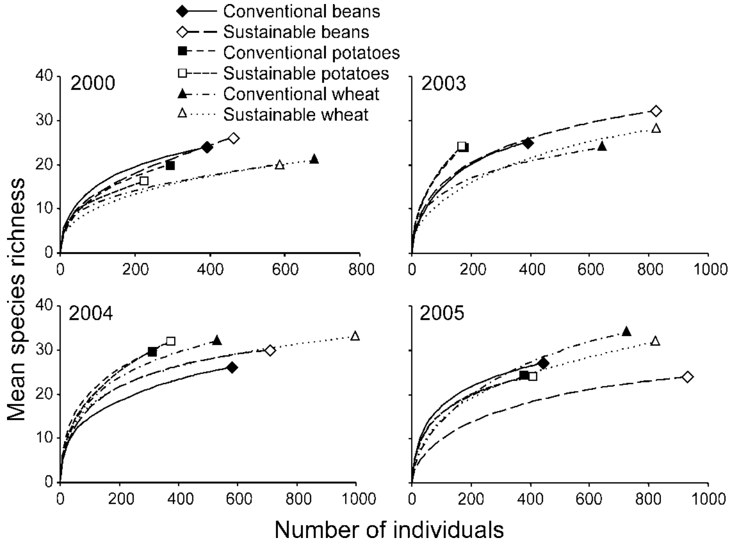

Fig. 1. Individual-based rarefaction curves for each treatment every year. Selection of subsamples of individuals was done randomly and reached the maximum of individuals caught.

highest total number of individuals caught. In general, plots allocated to the conventional or sustainable treatments within crops had similar expected species richness. In most years, and particularly in 2005, one or more of the crops under sustainable management had a higher total number of individuals (longer curves) and often slightly lower expected species richness than those crops under conventional management. The complementary, repeated-measures ANOVA of the Shannon-Wiener diversity index (year 2000 excluded; data not shown) within crops suggested a highly significant effect of year for all crops ($F_{2,12}$ values > 7.30, $P < 0.01$) but no treatment effects. Bean was the only crop where year interacted significantly with treatment ($F_{2,12} = 13.36$, $P < 0.01$); bean plots under the sustainable regimen had lower diversity (0.95 versus 1.88) than those managed conventionally but only in 2005 (least significant difference [LSD], $P < 0.05$). For the other two crops, the same significant trend of decreasing diversity by 2005 relative to 2003 and 2004 was observed. In 2004 and 2005, sustainable wheat and potatoes also had slightly lower diversity (LSD, $P > 0.05$) than their conventional counterparts.

Species Composition. Crop type consistently influenced species composition each year (Fig. 2). The carabid assemblages in bean and wheat plots differed from those in potato each year, whereas the carabid assemblages in wheat significantly differed from those in bean plots only in 2000 and again in 2003 (MRPP, $P < 0.05$). Species composition of sustainable and conventional potato plots was similar every year. However, sustainable bean plots harbored a different carabid assemblage than plots under conventional bean in 2003 and in 2005, whereas the species assemblages of plots under sustainable and conventional wheat differed from each other in 2004 (MRPP, $P < 0.05$). Species vectors associated with the ordination varied from year to year (Fig. 2; Table 3), except for *P. melanarius*, which was present each year and consistently pointed in the opposite direction of the potato plots. Vectors of *Agonum placidum* and *Harpalus amputatus* were associated mostly with wheat. The only species vector that showed strong association with potato plots was *Bembidion timidum* in 2003. No other species vectors were associated with that crop in any other year.

Activity Density. Because two plots were not operational for more than one half of the collecting season in 2005, they were excluded from this analysis. There was an overall effect of agronomic input on the total carabid catch when all the years were analyzed using a repeated-measures design ($F = 5.53$; df = 1,15; $P = 0.03$) but no significant effects were found when years were analyzed separately despite a constant higher carabid catch rate mean in the sustainable treatments each year. Overall, the sustainable input plots had a higher carabid activity density than conventionally managed plots (Table 4). Additionally, potato plots accumulated lower catches than bean or wheat plots each year (2003: $F = 7.63$, df = 2,15, $P = 0.005$; 2004: $F = 7.21$, df = 2,15, $P = 0.006$; 2005: $F = 4.65$, df = 2,15, $P = 0.027$; Table 4). From 2003 to 2005, input and crop type interacted to influence the activity density of the five most abundant species (2003: $F = 2.439$, df = 10,30, $P = 0.031$; 2004: $F = 2.935$, df = 10,30, $P = 0.012$; 2005: $F = 4.431$, df = 10,30, $P = 0.001$; Table 4; Fig. 3). For 2 yr, the activity density of *Amara farcta* was enhanced by the sustainable wheat (2003: $F = 8.27$, df = 2,18, $P = 0.003$; 2004: $F = 5.78$, df = 2,18, $P = 0.011$), whereas treatments in other crops had no influence on its activity density. In 2004, the activity density of *Bembidion quadrimaculatum* was increased by conventional beans and wheat as well as by sustainable potatoes ($F = 7.82$, df = 2,18, $P = 0.004$). However, in 2005, only conventional beans increased

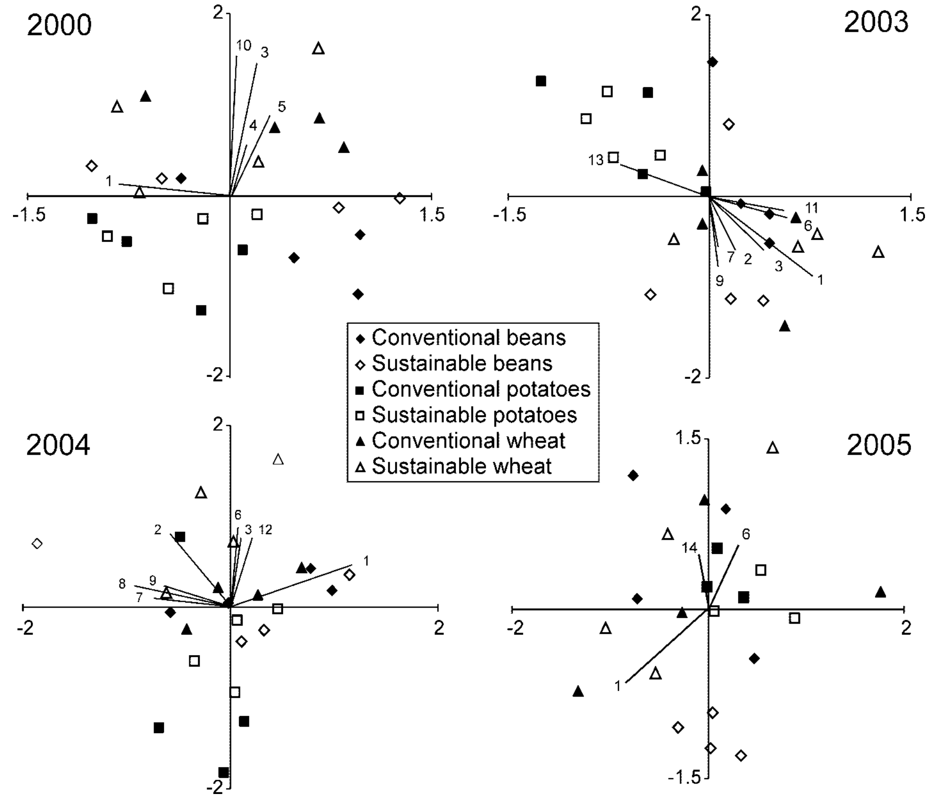

Fig. 2. Nonmetric multidimensional scaling (NMDS) ordination calculated with Sorensen distances done separately for each year to show systematic variations in the species composition of carabids among treatments. Each symbol represents the position of the carabid species composition of an experimental plot relative to the others. Note that input treatments were not applied in 2000. Vectors (minimum r^2 of 0.3) show the NMDS scores for different species as follows: 1, *Pt. melanarius*; 2, *H. amputatus*; 3, *A. placidum*; 4, *A. cupreum*; 5, *P. corvus*; 6, *Am. farcta*; 7, *Am. quenseli*; 8, *H. funerarius*; 9, *Am. carinata*; 10, *P. lucublandus*; 11, *S. comma*; 12, *Am. littoralis*; 13, *B. timidum*; 14, *B. quadrimaculatum*.

it activity density ($F = 10.93$, df = 2,16, $P = 0.001$). Other species such as *Stenolophus comma* and *Poecilus corvus* were also affected by the interaction between crop and input treatment (Fig. 3).

Weed Density and Carabid Activity Density. There was an overall treatment ($F = 22.77$, df = 1,15, $P < 0.001$) and rotation effect ($F = 5.085$, df = 2,15, $P = 0.021$) on weed density (Fig. 4). Sustainable agronomic practices significantly increased weed density every year (2003: $F = 22.16$, df = 1,15, $P = 0.001$; 2004: $F = 9.58$, df = 1,15, $P < 0.001$; and 2005: $F = 4.57$, df = 1,15, $P = 0.050$), whereas wheat and potatoes had higher weed density than beans in 2003 ($F = 12.01$, df = 2,15, $P = 0.001$) and 2004 ($F_{2,15} = 18.81, P < 0.001$; Fig. 4). No significant differences in weed density between crops were found in 2005. There was no significant relationship between the total activity density of carabid beetles and the total weed density for any year. However, in 2003, *A. farcta* and *S. comma* showed a positive significant relationship with weed density ($F_{1,22}$, $R^2 > 0.89$, both $P < 0.001$).

Discussion

This study provides a synthesis of carabid responses to an alternative cropping system that includes less tillage and replacement of synthetic fertilizers with manure, as is characteristic of sustainable regimens. Relative to normal farm scales, the size of the experimental plots were small, but

Table 3. Parameters associated with NMDS ordination for the carabid community for each year at the study site near Vauxhall, Alberta

Year	Iterations	Stress	Monte Carlo P	Axis 1 R^2	Axis 2 R^2	R^2 cumulative
2000	33	18.174	0.0392	0.306	0.409	0.735
2003	71	10.517	0.0196	0.304	0.463	0.767
2004	146	12.526	0.0392	0.258	0.624	0.882
2005	68	20.002	0.0196	0.240	0.462	0.702

Refer to text for methodological details.

Table 4. Mean activity density (specimens/trap days) of the five most abundant carabid species and total carabid abundance in three crops (n = 8, ±1 SE, except potato in 2005 where n = 6) and two input levels (n = 12, ±1 SE, except in sustainable in 2005 where n = 10)

Carabid species	Crop			Input	
	Bean	Potato	Wheat	Conventional	Sustainable
2003					
Amara carinata	0.359 ± 0.138	0.021 ± 0.006	0.200 ± 0.152	0.152 ± 0.102	0.234 ± 0.103
Stenolophus comma	0.007 ± 0.003	0.003 ± 0.002	0.194 ± 0.072	0.017 ± 0.012	0.120 ± 0.055
Amara farcta	0.049 ± 0.014	0.016 ± 0.004	0.230 ± 0.082	0.033 ± 0.010	0.164 ± 0.061
Pterostichus melanarius	0.360 ± 0.114	0.075 ± 0.030	0.372 ± 0.074	0.299 ± 0.074	0.239 ± 0.077
Bembidion quadrimaculatum	0.054 ± 0.011	0.048 ± 0.010	0.032 ± 0.006	0.039 ± 0.007	0.051 ± 0.007
Total carabids	1.025 ± 0.265a	0.288 ± 0.053b	1.188 ± 0.272a	0.683 ± 0.199	0.985 ± 0.215
2004					
Amara carinata	0.090 ± 0.055	0.032 ± 0.007	0.041 ± 0.012	0.025 ± 0.006	0.083 ± 0.036
Poecilus corvus	0.039 ± 0.008	0.031 ± 0.010	0.126 ± 0.040	0.056 ± 0.013	0.076 ± 0.030
Amara farcta	0.044 ± 0.017	0.029 ± 0.009	0.199 ± 0.094	0.049 ± 0.012	0.132 ± 0.067
Pterostichus melanarius	0.320 ± 0.084	0.122 ± 0.031	0.257 ± 0.046	0.221 ± 0.048	0.245 ± 0.056
Bembidion quadrimaculatum	0.071 ± 0.014	0.041 ± 0.009	0.083 ± 0.012	0.077 ± 0.013	0.054 ± 0.006
Total carabids	0.817 ± 0.116ab	0.466 ± 0.103b	1.018 ± 0.183a	0.640 ± 0.082	0.895 ± 0.156
2005					
Amara carinata	0.045 ± 0.008	0.037 ± 0.009	0.089 ± 0.038	0.044 ± 0.008	0.070 ± 0.026
Poecilus corvus	0.094 ± 0.019	0.059 ± 0.012	0.050 ± 0.011	0.064 ± 0.009	0.070 ± 0.015
Amara farcta	0.026 ± 0.011	0.070 ± 0.027	0.100 ± 0.035	0.073 ± 0.023	0.057 ± 0.023
Pterostichus melanarius	0.660 ± 0.127	0.206 ± 0.045	0.671 ± 0.228	0.430 ± 0.149	0.595 ± 0.122
Bembidion quadrimaculatum	0.037 ± 0.014	0.026 ± 0.009	0.018 ± 0.004	0.040 ± 0.010	0.015 ± 0.003
Total carabids	1.046 ± 0.106a	0.531 ± 0.048b	1.099 ± 0.196a	0.835 ± 0.141	0.949 ± 0.116

Letters indicate results from pairwise comparisons (Tukey's $P < 0.05$) after a significant result in ANOVA.

relative to most published experiments (Butts et al. 2003) of this nature, our plots are above average in size. Although pitfall catches in small plots (<10 m wide) may partly reflect interplot carabid movement, many studies have used relatively small plots to study successfully the effects of farming practices on carabids (Clark et al. 1993, 2006, Honek 1997, Raworth et al. 2004). We thus believe that despite this possible effect, the catches reliably reflect carabid habitat association.

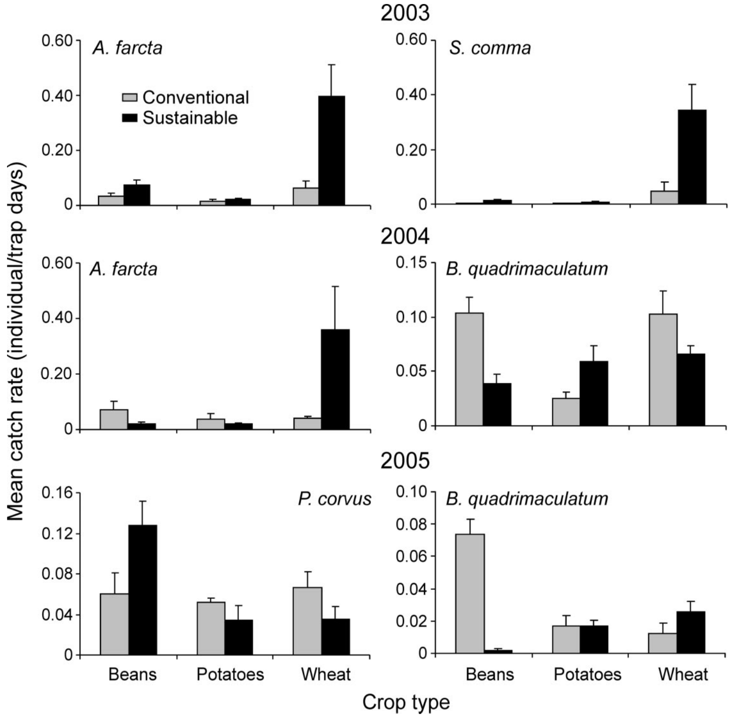

Fig. 3. Mean activity density of carabid species showing a significant response to the interaction between crop and input after a significant MANOVA (n = 4; ±1 SE except potatoes in 2005 where n = 3).

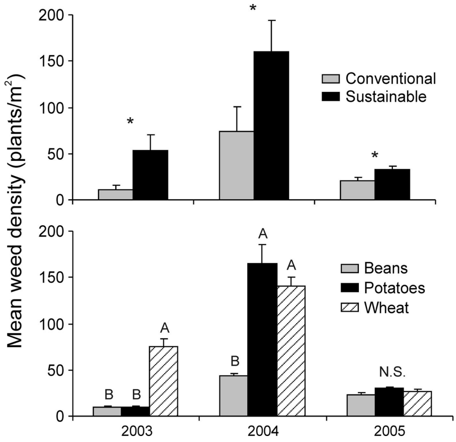

Fig. 4. Average weed density in plots with different inputs ($n = 12$; ±1 SE) and crop types ($n = 8$; ±1 SE) for the 3 posttreatment yr obtained by combining two surveys per year. *Significant difference ($P < 0.05$) was detected each year between sustainable and conventional inputs (left). Letters represent differences among the crop species, within respective years, after a significant ANOVA result (Tukey's test, $P < 0.05$).

Sustainable Versus Conventional Inputs. Contrary to our hypothesis and some past results (Dritschilo and Erwin 1982, Cárcamo et al. 1995, Pfiffner and Niggli 1996, Bengtsson et al. 2005), the sustainable agronomic input treatment did not consistently increase carabid diversity and had a minor role in producing a distinctive species composition. Thus, our results are more similar with those of Holopainen (1983), Clark (1999), and Melnychuk et al. (2003). The higher activity density of common carabids in sustainable wheat plots found in this study changed the structure of the community by reducing its evenness compared with conventional wheat. However, the expected or observed average number of species did not differ markedly between the two treatments. Thus, sustainably or conventionally grown crops such as wheat may not differ in ability to support different carabid species, but sustainable wheat increases the activity density of more common species such as *A. farcta.* Similarity in carabid diversity between sustainably and conventionally grown potato has also been reported by Armstrong (1995), whereas Kromp (1990) reported higher diversity in potato plots managed biologically than in those managed conventionally. Despite the use of the mold board plow in the conventional potatoes, we did not detect a difference in the activity density of carabid beetles in these two types of plots. This suggests that at this site, in contrast to others (Dubrovskaya 1970), the local community is resilient to this type of disturbance; effect of tillage was highly variable and results were site dependent. For example, recent work by Clark et al. (2006) in Maryland suggested little differences between no till and chisel-tilled plots. Menalled et al. (2007) found significantly higher overall carabid diversity and higher activity density of seed predators in plots that were managed under no tillage compared with those managed conventionally. More detailed population studies, in addition to community description, are needed to get a grip of the mechanisms at work in a given site.

In beans, the presence of cover crop and narrower planting rows may have provided different microhabitat structure throughout the season in the sustainable plots, which may have favored some species over others. For example, the absence of cover crop in conventional beans at the beginning of the year likely enhanced the activity density of *B. quadrimaculatum* (in 2004 and 2005), whereas later in the season, *A. carinata* was higher in plots under sustainable bean cultivation (in 2003 and 2004).

Consistently higher carabid catch in plots subjected to various sustainable practices has been reported in earlier studies (Dritschilo and Wanner 1980, Cárcamo et al. 1995, Clark 1999, Clark et al. 2006). A possible explanation for this finding may be the augmentation of potential prey items after manure application, which may also be responsible in the observed increased weed density. Vegetation structure under organic or sustainable agriculture, as observed in our study because of the greater weediness, is more complex than under conventional agriculture, and this, in turn, may support richer carabid assemblages (Andersen and Eltun 2000, Menalled et al. 2007). Hence, sustainable inputs may provide more prey items—arthropods or weeds, depending on species—to carabids. Also, soils in plots under tillage are often characterized by lower moisture and higher temperature. Humidity and temperature are important factors explaining distribution and abundance of carabids (Rivard 1966, Honek 1997).

Some numerically dominant carabid species showed a response to the interaction between crop type and input, which shows their sensitivity to variation in environmental conditions. Many species were also consistently most abundant in plots of a particular crop. The higher abundance of *A. farcta* in sustainable wheat for 2 consecutive yr (2003 and 2004) is probably because of higher weed abundance in both the sustainable treatment and wheat. Indeed, *A. farcta* is often found among weeds (Lindroth 1961–1969). Menalled et al. (2007) showed experimentally through the use of vertebrate exclosures that weed seed removal was correlated with carabid activity density. For some species, however, the combination of lower crop and weed density may enhance their activity density; in our study, *B. quadrimaculatum* was more abundant in conventional bean plots. Because crops were rotated each year on the study site, the location of a specific crop varied among the study years. Thus, in many of these fields, carabids probably recolonized the more suitable habitats that better explains variation in carabid catches than the possible effect of overwintering of individuals within the experimental plots.

Effect of Crop Type. Plots with potato had consistently fewer carabids but not lower diversity than plots with wheat or bean plots. For example, the catches of

P. melanarius, an introduced species, were lower in potato plots than in those planted to beans or wheat. These results can be explained mostly by the heavy application of insecticides, which likely lowered both the abundance of carabids and their available prey. Insecticide application has been shown to reduce carabid activity density (Sekulic et al. 1987; Floate et al. 1989).

Although bean and wheat plots generally had a similar overall carabid abundance, species composition differed between these two crops in 2 of the 4 yr. Differences in microhabitat structure may explain most of this separation. Mature broadleaf plants, such as bean and potato, produce a dense canopy compared with the canopy of wheat that remains more open throughout the season. Canopy structure can be important for thermoregulation of many species. Generally, open canopy provides a drier and warmer environment that may favor xerophilous species. However, wheat and beans are also grown at different plant densities. Plant density was lower in bean than wheat plots, which potentially facilitated carabid movements among plants. It is possible that species associated with open habitat would be enhanced under low plant density. In fact, only small open-habitat species (such as *B. quadrimaculatum* and *B. timidum*) seemed to associate with potato and bean plots.

We conclude that, after 6 yr of subjecting our plots to conventional and sustainable management, the carabid activity density was higher under the regimen that incorporated alternative, more environmentally friendly practices such as the use of manure in combination with reduce soil disturbance before seeding or during bean harvest. Expected species richness, diversity, and community structure were not impacted significantly by cropping systems and seemed to respond more to the type of crop planted. Future studies focusing on populations of carabid beetles are needed to elucidate the mechanisms responsible for the patterns observed.

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