Influence of hedgerow and grassy field borders on ground beetle (Coleoptera: Carabidae) activity in fields of corn

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Abstract

Agricultural landscapes may be manipulated in ways that benefit predatory invertebrates by providing alternate food sources, overwintering sites, and refuge from farming activities. Ecological theory predicts that complex plant communities should support a richer community of natural enemies of pest insects than a simple plant community. A study was conducted in Iowa, USA to investigate the influence of the vegetative diversity of field border types on the activity, species richness, and community similarities of predatory beetles occurring in corn fields.

Ground beetle (Coleoptera: Carabidae) populations were compared among corn fields bounded by either complex hedges or simple grass edges. Directional pitfall traps were used to investigate activity patterns of beetles between border types and their adjacent corn fields. Beetles were trapped during four seasonal periods, based on the growth stage of corn. During corn emergence (May–June) when fields are barren, carabids were more active and species richness was higher in the corn fields bordered by woody hedges. The carabid species Scarites quadriceps, Scarites subterraneus, and Harpalus pensylvanicus, were more dominant in hedge sites as compared to grass sites at this time. Following corn–canopy closure, carabids were now more active in fields bordered by grassy edges, but beetle activity also remained high in the fields adjacent to woody hedges. Further analysis of the carabid communities by Bray–Curtis Similarity Index showed no difference among field edge types at any time of the season. Results indicate that both complex and simple field border habitats support abundant and diverse populations of carabids during most of the growing season. However, during the early growing season hedges appear to be more important than grass edges in supplying carabid beetles to corn fields. Woody hedges may serve as very important overwintering sites and as an early season refuge for predatory beetles in corn. © 2001 Elsevier Science B.V. All rights reserved.

Keywords: Ground beetles; Field borders; Agroecosystem diversity; Landscape diversity; Biological control; Iowa (USA)

1. Introduction

Agricultural landscapes may be managed in ways that sustain invertebrate predator populations, which can result in reduced crop damage by pest insects (Risch et al., 1983; Marino and Landis, 1996). Root’s (1973) classic enemies hypothesis predicts that her-
et al., 1994). Considering that farmland in temperate zones is covered with vegetation for only a few months of the year, seasonally active carabids may need to move between agricultural fields and adjacent landscape habitats for alternate sources of prey and refuge (Bedford and Usher, 1994; Kajak and Lukasiewicz, 1994). One important reservoir for carabids may be the vegetation that borders an agricultural field. Field borders may benefit carabid populations by providing refuge from agricultural practices such as tillage and pesticide use (Asteraki et al., 1992; 1995) and a stable microhabitat for overwintering (Desender and Alderweireldt, 1988; Dennis and Fry, 1992). Field borders with a well-established, thick vegetative cover and a stable microhabitat such as hedgerow (or shelterbelt) have been shown to increase overwintering success compared with the bare, open ground of an agricultural field (Dennis and Fry, 1992; Dennis et al., 1994). Moreover, dense hedges which consist of a thick overstory of woody plants and an understory of woody plants and herbaceous plants, may offer more refuge for overwintering than simple grass borders (Forman and Baudry, 1984; Sotherton, 1985).

Many European studies have demonstrated the benefits of hedgerows for carabid populations in agricultural fields (Nazzi et al., 1989; Bedford and Usher, 1994). In the Midwestern USA, most woody field margins have been removed because they occupied valuable farmland and are thought to be a supply of weed seeds (Forman and Baudry, 1984; Burel, 1996).

The objective of this study was to determine if corn fields bound by complex hedge borders would support a greater abundance and species richness of Carabidae beetles in comparison with farms bound by simple grassy borders. In addition, abundance and species richness of adult carabids within corn fields was measured to determine the activity patterns that occur between field border and crop-field throughout the growing season.

2. Methods

2.1. Experimental design

Ten independent corn fields with field borders in south-central Iowa, USA (Lucas and Wayne Counties) were selected for sampling adult Carabidae populations. Borders consisted of five complex woody hedges and five simple grass edges which bounded agricultural fields planted in dent corn. Selection criteria for borders used in this study was that they had to be bounded by two agricultural fields that were farmed by similar techniques such as minimal tillage and no insecticide use. Broadleaf herbicides were applied by the growers to soils in early May, as is protocol in Iowa.

Beetles were captured in modified pitfalls traps with propylene glycol used as a preservative. Trap design consisted of galvanized steel strips (5 m long × 10 cm high) bordered by six pitfall traps (ca. 1000 ml in volume, 10 cm in diameter) placed with three on each side. Placement of the pitfall traps included two at 10 cm from each of the outer edges and one at the middle (Fig. 1). The strip-trap was placed parallel to the field edge, 5 m into the agricultural field in the bare ground between rows of corn. Pitfall catches depend on the activity and density of insect populations present, and it is generally accepted that traps measure activity rate. Catches may also be influenced by the habits and size of individual species (Mitchell, 1963; Greenslade, 1964; Luff, 1975). Despite these limitations, pitfall traps are the most common method for sampling carabids.

Within each border, one plot of 325 m in length, that occupied the center-most part of a longer field edge was used for sampling carabids. Abundance and species richness were used as measures of Carabidae activity. Abundance and species richness of carabids

![Fig. 1. Experimental design for the Summer of 1997. At each border, 325 m plots were selected. Three modified pitfall traps were placed at 65 m intervals, 5 m into corn fields. Traps were placed between corn rows, parallel to borders. Modified pitfall traps were used to observe for activity patterns between field borders and adjacent corn fields. Carabids trapped on border side of strip-traps indicated beetle activity in border habitat and carabids trapped on corn field side of strip-traps indicated beetle activity in corn fields.](image-url)
Table 1
Dominant vegetation in hedge borders (n = 5) in decreasing order of importance

<table>
<thead>
<tr>
<th>Common name</th>
<th>Species name</th>
<th>Coverage (%)</th>
<th>Frequency</th>
<th>Importance value</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Overstory</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Osage Orange</td>
<td>Maclura pomifera (Raf. ex Sarg.) Schneider</td>
<td>52.20</td>
<td>0.64</td>
<td>0.98</td>
</tr>
<tr>
<td>American Elm</td>
<td>Ulmus americana L.</td>
<td>12.40</td>
<td>0.24</td>
<td>0.27</td>
</tr>
<tr>
<td>Grape Vine</td>
<td>Vitis spp. Adanson</td>
<td>2.40</td>
<td>0.36</td>
<td>0.20</td>
</tr>
<tr>
<td>Slippery Elm</td>
<td>Ulmus rubra Muhl.</td>
<td>1.60</td>
<td>0.24</td>
<td>0.13</td>
</tr>
<tr>
<td>Wild Plum</td>
<td>Prunus americana Marsh.</td>
<td>1.00</td>
<td>0.20</td>
<td>0.10</td>
</tr>
<tr>
<td>White Mulberry</td>
<td>Morus alba L.</td>
<td>2.20</td>
<td>0.12</td>
<td>0.08</td>
</tr>
<tr>
<td>Choke Cherry</td>
<td>Prunus virginiana L.</td>
<td>1.30</td>
<td>0.12</td>
<td>0.07</td>
</tr>
<tr>
<td>Black Walnut</td>
<td>Juglans nigra L.</td>
<td>2.10</td>
<td>0.08</td>
<td>0.06</td>
</tr>
<tr>
<td>Honey Locust</td>
<td>Gleditsia triacanthes L.</td>
<td>0.60</td>
<td>0.04</td>
<td>0.03</td>
</tr>
<tr>
<td><strong>Understory</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Giant Ragweed</td>
<td>Ambrosia tridida L.</td>
<td>17.58</td>
<td>0.67</td>
<td>0.32</td>
</tr>
<tr>
<td>Avens</td>
<td>Geum spp. L.</td>
<td>11.33</td>
<td>0.20</td>
<td>0.20</td>
</tr>
<tr>
<td>Wild Oats</td>
<td>Avena fatua L.</td>
<td>13.08</td>
<td>0.47</td>
<td>0.24</td>
</tr>
<tr>
<td>Smooth Brome</td>
<td>Bromus inermis Leysser</td>
<td>15.42</td>
<td>0.20</td>
<td>0.20</td>
</tr>
<tr>
<td>Sedge</td>
<td>Carex spp. L.</td>
<td>11.17</td>
<td>0.33</td>
<td>0.19</td>
</tr>
<tr>
<td>Squirrel-tail Barley</td>
<td>Hordeum jubatum L.</td>
<td>2.83</td>
<td>0.17</td>
<td>0.06</td>
</tr>
<tr>
<td>Poison Ivy</td>
<td>Toxicodendron radicans (L.) Kuntze ssp.</td>
<td>2.33</td>
<td>0.13</td>
<td>0.05</td>
</tr>
<tr>
<td>Goldenrod</td>
<td>Solidago spp. L.</td>
<td>2.17</td>
<td>0.07</td>
<td>0.04</td>
</tr>
<tr>
<td>Heath Aster</td>
<td>Aster ericoidea L.</td>
<td>1.17</td>
<td>0.13</td>
<td>0.04</td>
</tr>
<tr>
<td>Virginia Creeper</td>
<td>Parthenocissus quinquefolia (L.) Planchon</td>
<td>1.83</td>
<td>0.10</td>
<td>0.04</td>
</tr>
<tr>
<td>Foxtail</td>
<td>Setaria spp. Beauv.</td>
<td>1.42</td>
<td>0.10</td>
<td>0.04</td>
</tr>
</tbody>
</table>

* Only species with a mean basal coverage of 0.2% or greater were considered to be important. The percent coverage of each species was estimated, and was used to determine the average percent coverage, frequency and importance value for dominant species.

Ground beetles were sampled during four specific growth stages of corn (Ritchie et al., 1986). Traps were in place for a 7-day period and samples were collected weekly. The first sampling period occurred when corn was emerging but fields were dominated by bare ground for the weeks ending on 28 May and 6 June 1997. The second sampling period occurred during rapid vegetative growth when corn plants

Table 2
Dominant vegetation in grass borders (n = 5) in decreasing order of importance

<table>
<thead>
<tr>
<th>Common name</th>
<th>Species name</th>
<th>Coverage (%)</th>
<th>Frequency</th>
<th>Importance value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Smooth Brome</td>
<td>Bromus inermis Leysser</td>
<td>49.90</td>
<td>0.88</td>
<td>0.69</td>
</tr>
<tr>
<td>Sedge</td>
<td>Carex spp. L.</td>
<td>18.90</td>
<td>0.36</td>
<td>0.27</td>
</tr>
<tr>
<td>Sunflower</td>
<td>Heliantus spp. L.</td>
<td>2.40</td>
<td>0.36</td>
<td>0.11</td>
</tr>
<tr>
<td>Foxtail</td>
<td>Setaria spp. Beauv.</td>
<td>3.60</td>
<td>0.28</td>
<td>0.10</td>
</tr>
<tr>
<td>Giant Ragweed</td>
<td>Ambrosia tridida L.</td>
<td>1.80</td>
<td>0.32</td>
<td>0.09</td>
</tr>
<tr>
<td>Heath Aster</td>
<td>Aster ericoidea L.</td>
<td>2.20</td>
<td>0.12</td>
<td>0.05</td>
</tr>
<tr>
<td>Common Ragweed</td>
<td>Ambrosia coronopifolia L.</td>
<td>1.90</td>
<td>0.16</td>
<td>0.05</td>
</tr>
<tr>
<td>Goldenrod</td>
<td>Solidago spp. L.</td>
<td>1.90</td>
<td>0.16</td>
<td>0.05</td>
</tr>
<tr>
<td>Reed Canary Grass</td>
<td>Phalaris arundinacea L.</td>
<td>3.40</td>
<td>0.04</td>
<td>0.04</td>
</tr>
<tr>
<td>Prickley Lettuce</td>
<td>Lactuca serriola L.</td>
<td>0.70</td>
<td>0.08</td>
<td>0.02</td>
</tr>
</tbody>
</table>

* Only species with a mean basal coverage of 0.2% or greater were considered to be important. The percent coverage of each species was estimated, and was used to determine the average percent coverage, frequency and importance value for dominant species.
Fig. 2. Seasonal comparison of total Carabidae (A) abundance and (B) species richness between corn fields bordered by hedge and grass. During corn emergence, carabid abundance \((P = 0.002, F = 10.06)\) and species richness \((P = 0.001, F = 12.37)\) were significantly greater in corn fields bordered by hedge. During rapid corn growth, abundance and species richness between corn fields bordered by hedge and grass did not significantly differ. Following corn canopy closure, carabid abundance \((P = 0.001, F = 10.77)\) was significantly greater in corn fields bordered by grass. During physiological maturity of the corn, carabid abundance and species richness between corn fields bordered by hedge and grass did not differ significantly.

were in the six to nine leaf stage but canopies were still open for the weeks ending on 17 and 24 June 1997. The third sampling period occurred just following canopy closure but before corn tasseling for the weeks ending on 22 and 30 July 1997. The forth sampling period occurred when the crop had reached physiological maturity (fruit mature) and the canopy was brown and drying out for the weeks ending on 20 and 27 September 1997. The second and fourth sampling periods concurred during estimated peaks in adult carabid activity (Thiele, 1977). During the four sampling periods traps were in place for 2 weeks, but samples were collected weekly in order to reduce trap odor from decaying insects. Samples were averaged over the 2-week collection period for data analysis.

2.2. Data analysis

Ground beetles were identified to species using published keys (Lindroth, 1961–1969). Identifications were verified by G.E. Ball and D. Shepley, University of Manitoba, Canada. Carabid populations were analyzed for both abundance and species richness.

Table 3
Total number of each carabid species trapped throughout the Summer of 1997\(^a\)

<table>
<thead>
<tr>
<th>Species</th>
<th>Total Hedge</th>
<th>Grass</th>
</tr>
</thead>
<tbody>
<tr>
<td>Harpalus pensylvanicus DeGeer</td>
<td>6750</td>
<td>3349</td>
</tr>
<tr>
<td>Pterostichus permundus Say</td>
<td>6639</td>
<td>3469</td>
</tr>
<tr>
<td>Pterostichus chalcites Say</td>
<td>3436</td>
<td>1240</td>
</tr>
<tr>
<td>Anisodactylus sanctaecrucis Fabricius</td>
<td>2802</td>
<td>856</td>
</tr>
<tr>
<td>Elaphropus anceps LeConte</td>
<td>2524</td>
<td>322</td>
</tr>
<tr>
<td>Scarites quadriceps Chaudoir</td>
<td>1459</td>
<td>825</td>
</tr>
<tr>
<td>Scarites subterranus Fabricius</td>
<td>1307</td>
<td>867</td>
</tr>
<tr>
<td>Stenolophus commun Fabricius</td>
<td>345</td>
<td>86</td>
</tr>
<tr>
<td>Clivina bipustulata Fabricius</td>
<td>431</td>
<td>196</td>
</tr>
<tr>
<td>Anisodactylus spp. Dejean</td>
<td>411</td>
<td>219</td>
</tr>
<tr>
<td>Cyclotrichelus sodalis sodalis LeConte</td>
<td>441</td>
<td>250</td>
</tr>
<tr>
<td>Pterostichus lucublandus Say</td>
<td>344</td>
<td>143</td>
</tr>
<tr>
<td>Agonum spp. Bonelli</td>
<td>270</td>
<td>192</td>
</tr>
<tr>
<td>Harpalus caliginosus Fabricius</td>
<td>189</td>
<td>91</td>
</tr>
<tr>
<td>Bembidion rapidum LeConte</td>
<td>191</td>
<td>73</td>
</tr>
<tr>
<td>Clivina impressifrons LeConte</td>
<td>106</td>
<td>47</td>
</tr>
<tr>
<td>Pterostichus femoralis Kirby</td>
<td>94</td>
<td>50</td>
</tr>
<tr>
<td>Harpalus herbivagus Say</td>
<td>88</td>
<td>26</td>
</tr>
<tr>
<td>Clivina spp. Latreille</td>
<td>61</td>
<td>61</td>
</tr>
<tr>
<td>Agonum cupripenne Say</td>
<td>62</td>
<td>46</td>
</tr>
<tr>
<td>Calathus gregarius Say</td>
<td>74</td>
<td>30</td>
</tr>
<tr>
<td>Chlaenis platyderus Chaudoir</td>
<td>58</td>
<td>24</td>
</tr>
<tr>
<td>Pterostichus stygicus Say</td>
<td>57</td>
<td>40</td>
</tr>
<tr>
<td>Bembidion quadrimaculatum oppositum Say</td>
<td>6</td>
<td>2</td>
</tr>
<tr>
<td>Pterobus longicornis Say</td>
<td>37</td>
<td>32</td>
</tr>
<tr>
<td>Bembidion spp. Latreille</td>
<td>39</td>
<td>22</td>
</tr>
<tr>
<td>Amara spp. Bonelli</td>
<td>29</td>
<td>13</td>
</tr>
<tr>
<td>Dyschirius globulosus Say</td>
<td>21</td>
<td>10</td>
</tr>
<tr>
<td>Galerita janus Fabricius</td>
<td>27</td>
<td>14</td>
</tr>
<tr>
<td>Badister notatus Haldeman</td>
<td>18</td>
<td>4</td>
</tr>
<tr>
<td>Chlaenius pusillus Say</td>
<td>7</td>
<td>6</td>
</tr>
<tr>
<td>Anisodactylus merula Germar</td>
<td>15</td>
<td>12</td>
</tr>
</tbody>
</table>

\( ^a\) Total counts are divided into those trapped solely at shelterbelt and at grass agricultural systems. Carabid species are in decreasing order of total abundance.
Firstly, the number of beetles trapped on both the border side and on the corn field side of strip-traps were combined to compare total carabid communities occurring in corn fields bordered by complex hedge or simple grass. Abundance was a measure of the number of beetles per agricultural system (hedge or grass edge plus their attached corn field) per corn growth stage. Species richness was a measure of the number of species per agricultural system per corn growth stage.

Beetles trapped on the border side of strip-traps and beetles trapped on the corn field side of strip-traps were analyzed separately to compare distribution of beetles between the two habitat types. Abundance was a measure of the number of beetles per habitat type (border or corn field) per corn growth stage. Species richness was a measure of the number of species per habitat type per corn growth stage. Analysis of variance procedures were used to analyze carabid abundance and species richness between agricultural systems and between habitat types. The four periods of corn growth were analyzed separately as four distinct ecological time periods.

Field border vegetation was identified from 8 to 19 September 1997 according to methods described by Noblet et al. (1994). The percent coverage of each overstory and understory species was estimated, and used to determine the average percent coverage, frequency and importance value for major species. Analysis of variance procedures were used to compare plant species richness between border type (Statistix, 1994).

The Bray–Curtis Similarity Index was used to compare Carabidae communities and border vegetation communities. This index measures both abundance and species richness (Bray and Curtis, 1957). The formula is

\[
1 - BC = 1 - \frac{\sum |n_{1i} - n_{2i}|}{\sum (n_{1i} + n_{2i})}
\]

where \(n_{1i}\) is the abundance of species \(i\) from complex woody treatments and \(n_{2i}\) the abundance of species \(i\) from simple grass treatments.

A value between 0 and 1 is derived. When the formula of 1–BC is used, a value close to 0 indicates that communities are different and a value close to 1 indicates that communities are similar.

### Table 4
Seasonal distribution of ground beetles (Coleoptera: Carabidae) captured by pitfall traps in woody hedgerows and grassy strips that border corn fields in Iowa, USA

<table>
<thead>
<tr>
<th>Growth stage of corn</th>
<th>Woody sites (mean ± S.E.)</th>
<th>Grass sites (mean ± S.E.)</th>
<th>(F)-value</th>
<th>(P)-value</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Harpalus pensylvanicus</em> DeGeer</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Corn emergence</td>
<td>0.42 ± 0.10</td>
<td>0.17 ± 0.07</td>
<td>4.52</td>
<td>0.038</td>
</tr>
<tr>
<td>Vegetative growth</td>
<td>2.40 ± 0.27</td>
<td>1.26 ± 0.18</td>
<td>11.6</td>
<td>0.001</td>
</tr>
<tr>
<td>Canopy closure</td>
<td>3.71 ± 0.54</td>
<td>14.34 ± 4.29</td>
<td>5.74</td>
<td>0.018</td>
</tr>
<tr>
<td>Physiological maturity</td>
<td>52.07 ± 7.70</td>
<td>41.73 ± 5.09</td>
<td>1.27</td>
<td>0.262</td>
</tr>
<tr>
<td><em>Pterostichus chalcites</em> Say</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Corn emergence</td>
<td>8.92 ± 1.41</td>
<td>8.43 ± 1.24</td>
<td>0.07</td>
<td>0.798</td>
</tr>
<tr>
<td>Vegetative growth</td>
<td>12.07 ± 1.96</td>
<td>21.17 ± 2.51</td>
<td>8.39</td>
<td>0.005</td>
</tr>
<tr>
<td>Canopy closure</td>
<td>3.69 ± 0.46</td>
<td>13.42 ± 1.98</td>
<td>21.2</td>
<td>0.000</td>
</tr>
<tr>
<td>Physiological maturity</td>
<td>2.50 ± 0.36</td>
<td>2.05 ± 0.27</td>
<td>1.01</td>
<td>0.316</td>
</tr>
<tr>
<td><em>Scarites quadriceps</em> Chaudoir</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Corn emergence</td>
<td>6.04 ± 0.94</td>
<td>2.14 ± 0.38</td>
<td>18.7</td>
<td>0.000</td>
</tr>
<tr>
<td>Vegetative growth</td>
<td>9.88 ± 1.04</td>
<td>9.40 ± 1.10</td>
<td>0.10</td>
<td>0.757</td>
</tr>
<tr>
<td>Canopy closure</td>
<td>0.85 ± 0.17</td>
<td>0.86 ± 0.17</td>
<td>0.00</td>
<td>0.959</td>
</tr>
<tr>
<td>Physiological maturity</td>
<td>1.19 ± 0.21</td>
<td>1.08 ± 0.17</td>
<td>0.16</td>
<td>0.691</td>
</tr>
<tr>
<td><em>Scarites subterraneus</em> Fabricius</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Corn emergence</td>
<td>5.29 ± 0.76</td>
<td>1.86 ± 0.37</td>
<td>19.8</td>
<td>0.000</td>
</tr>
<tr>
<td>Vegetative growth</td>
<td>12.09 ± 1.26</td>
<td>7.02 ± 0.86</td>
<td>10.1</td>
<td>0.002</td>
</tr>
<tr>
<td>Canopy closure</td>
<td>0.11 ± 0.05</td>
<td>0.25 ± 0.08</td>
<td>2.25</td>
<td>0.140</td>
</tr>
<tr>
<td>Physiological maturity</td>
<td>0.69 ± 0.18</td>
<td>0.50 ± 0.10</td>
<td>0.88</td>
<td>0.350</td>
</tr>
</tbody>
</table>
3. Results

3.1. Complex and simple vegetation communities

Plant species richness was significantly greater ($P = 0.015, F = 9.57$) in hedge than in grass borders. Osage orange (*Maclura pomifera* (Raf. ex Sarg.) Schneider) and American elm (*Ulmus americana* L.) were the dominant overstory vegetation species in hedge borders (Table 1).

Giant ragweed (*Ambrosia tridida* L.) and avens (*Geum* spp. L.) were among the dominant understory vegetation species in hedge borders (Table 1). Smooth brome (*Bromus inermis* Leysser) and sedge (*Carex* spp. L.) were among the dominant species in grass borders (Table 2).

Plant community composition between hedge and grass borders was measured by the Bray–Curtis Index (Bray and Curtis, 1957). A value of 0.27 was derived, suggesting that the plant communities were greatly different between hedge and grass borders.

3.2. Carabid community responses to hedge and grass agricultural systems

Total carabid abundance was compared between corn fields bordered by hedge or grassy edges. During corn emergence, carabid abundance was significantly greater ($P = 0.002, F = 10.06$) in corn fields bordered by hedge than by grass (Fig. 2(A)). During rapid vegetative growth, carabid abundance did not significantly differ between corn fields bordered by hedge or grass. Once the corn canopy had closed, carabid abundance was significantly greater ($P = 0.001, F = 10.77$) in corn fields bordered by grass than by hedge. Once fields reached physiological maturity, carabid abundance did not significantly differ between corn fields bordered by hedge or grass (Fig. 2(A)). However, beetle captures remained high within the corn fields.

Total carabid species richness was compared between corn fields bordered by hedge or grass. During corn emergence, carabid species richness was significantly greater ($P = 0.001, F = 12.37$) in corn fields bordered by hedge than by grass. Throughout the remainder of the growing season, carabid species richness did not significantly differ between corn fields bordered by hedge or grass (Fig. 2(B)).

The total number of each Carabidae species trapped at hedge and grass agricultural sites were tabulated (Table 3). *Harpalus pensylvanicus* DeGeer, *Pterostichus permundus* Say, *P. chalcites* Say, *Anisodactylus sanctae crucis* Fabricius, *Elaphropus anceps* LeConte, *Scarites quadriceps* Chaudoir, and *S. subterraneus* Fabricius were the dominant species. Only *Clivina postica* LeConte was trapped solely in hedge agricultural systems, but total counts were low. Of the dominant species, *S. quadriceps*, *S. subterraneus*, and *P. chalcites* are beneficial predators, and *H. pensylvanicus* DeGeer are beneficial reducers of weed seeds in this region (Best and Beegle, 1977). These species will be considered for further analysis.
The dominant species abundances were compared between corn fields bordered by hedge and grass (Table 4). During corn emergence, *S. quadriceps* (*P* = 0.005, *F* = 8.39) abundance was significantly greater in corn fields bordered by hedge than by grass. *S. subterraneus* (*P* = 0.002, *F* = 10.07) and *H. pensylvanicus* (*P* = 0.001, *F* = 11.15) abundances were significantly greater in corn fields bordered by grass than by hedge. Once the corn canopy had closed, *H. pensylvanicus* (*P* = 0.018, *F* = 5.74) and *P. chalcites* (*P* = 0.000, *F* = 21.23), abundances were significantly greater in corn fields bordered by grass than by hedge. Once fields reached physiological maturity, the dominant species abundances did not significantly differ between corn fields bordered by hedge or grass (Table 4).

Carabid community compositions, measured by the Bray–Curtis Index, were similar both during corn emergence (1 − BC = 0.72) and rapid vegetative growth (1 − BC = 0.81) between hedge and grass agricultural systems. Following canopy closure, however, carabid communities less similar (1 − BC = 0.43). During physiological maturity carabid communities were, again, similar (1 − BC = 0.89).

### 3.3. Carabid distribution between borders and their adjacent corn fields

A comparison of the distribution of the total carabid captures between the hedge border side and the corn field side of strip-traps was done to detect activity patterns of beetles in hedge agricultural systems. During corn emergence, carabid abundance was significantly greater (*P* = 0.006, *F* = 9.23) on the hedge border side than on the corn field side of strip-traps. Throughout the remainder of the growing season, total carabid abundance did not significantly differ between the hedge border side and corn field side of strip-traps (Fig. 3(A)). Throughout the growing season, carabid species richness did not significantly differ between the hedge border side and the corn field side of strip-traps (Fig. 3(B)).

### Table 5

Seasonal distribution of ground beetles (Coleoptera: Carabidae) captured on the woody hedgerow side or corn field side of strip-traps placed in corn fields in Iowa, USA

<table>
<thead>
<tr>
<th>Growth stage of corn</th>
<th>Woody border (mean ± S.E.)</th>
<th>Corn field (mean ± S.E.)</th>
<th>F-value</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Harpalus pensylvanicus</em> DeGeer</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Corn emergence</td>
<td>0.67 ± 0.23</td>
<td>0.42 ± 0.15</td>
<td>0.86</td>
<td>0.364</td>
</tr>
<tr>
<td>Vegetative growth</td>
<td>2.89 ± 0.37</td>
<td>2.62 ± 0.43</td>
<td>0.23</td>
<td>0.633</td>
</tr>
<tr>
<td>Canopy closure</td>
<td>3.96 ± 0.84</td>
<td>4.04 ± 0.83</td>
<td>0.00</td>
<td>0.952</td>
</tr>
<tr>
<td>Physiological maturity</td>
<td>58.45 ± 12.3</td>
<td>52.55 ± 11.1</td>
<td>0.13</td>
<td>0.723</td>
</tr>
<tr>
<td><em>Pterostichus chalcites</em> Say</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Corn emergence</td>
<td>11.83 ± 2.23</td>
<td>6.00 ± 1.20</td>
<td>5.07</td>
<td>0.035</td>
</tr>
<tr>
<td>Vegetative growth</td>
<td>16.32 ± 3.69</td>
<td>7.97 ± 1.10</td>
<td>4.85</td>
<td>0.032</td>
</tr>
<tr>
<td>Canopy closure</td>
<td>4.41 ± 0.71</td>
<td>2.96 ± 0.57</td>
<td>2.55</td>
<td>0.473</td>
</tr>
<tr>
<td>Physiological maturity</td>
<td>2.41 ± 0.51</td>
<td>2.59 ± 0.51</td>
<td>0.06</td>
<td>0.813</td>
</tr>
<tr>
<td><em>Scartes quadriceps</em> Chaudoir</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Corn emergence</td>
<td>7.83 ± 1.05</td>
<td>4.25 ± 1.42</td>
<td>4.13</td>
<td>0.054</td>
</tr>
<tr>
<td>Vegetative growth</td>
<td>10.79 ± 1.60</td>
<td>9.00 ± 1.34</td>
<td>0.74</td>
<td>0.393</td>
</tr>
<tr>
<td>Canopy closure</td>
<td>0.89 ± 0.25</td>
<td>0.81 ± 0.23</td>
<td>0.05</td>
<td>0.830</td>
</tr>
<tr>
<td>Physiological maturity</td>
<td>0.97 ± 0.23</td>
<td>1.41 ± 0.36</td>
<td>1.13</td>
<td>0.292</td>
</tr>
<tr>
<td><em>Scartes subterraneus</em> Fabricius</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Corn emergence</td>
<td>6.58 ± 1.03</td>
<td>4.00 ± 1.03</td>
<td>3.16</td>
<td>0.089</td>
</tr>
<tr>
<td>Vegetative growth</td>
<td>12.75 ± 1.95</td>
<td>11.45 ± 1.57</td>
<td>0.26</td>
<td>0.611</td>
</tr>
<tr>
<td>Canopy closure</td>
<td>0.15 ± 0.09</td>
<td>0.07 ± 0.05</td>
<td>0.53</td>
<td>0.470</td>
</tr>
<tr>
<td>Physiological maturity</td>
<td>0.62 ± 0.25</td>
<td>0.76 ± 0.25</td>
<td>0.15</td>
<td>0.702</td>
</tr>
</tbody>
</table>

* See Fig. 1 for trap arrangement.
Fig. 4. Seasonal comparison of the activity patterns in Carabidae (A) abundance and (B) species richness for grass sites between the border side and corn field side of strip-traps. Throughout the growing season of the corn, carabid abundance and species richness between grass borders and their adjacent corn fields did not differ significantly.

The distribution of dominant species were compared between the hedge border side and the corn field side of strip-traps (Table 5). During corn emergence, *P. chalcites* (*P* = 0.035, *F* = 5.07) and *S. quadriceps* (*P* = 0.054, *F* = 4.13) abundances were significantly greater on the hedge border than on the corn field side of strip-traps. During rapid vegetative growth, *P. chalcites* (*P* = 0.032, *F* = 4.85) abundance was significantly greater on the hedge border side than on the corn field side of strip-traps (Table 5). Throughout the remainder of the growing season, abundances of dominant species did not significantly differ between the hedge border side and the corn field side of strip-traps.

Carabid distribution was also compared between the grass border side and the corn field side of strip-trap to detect activity patterns of beetles in grass agricultural systems. Throughout the sampling periods, carabid abundance and species richness did not significantly differ between the grass border side and corn field side of strip-traps (Fig. 4(A) and (B)). Dominant species abundances did not significantly differ between the grass border side and corn field side of strip-traps (Table 6).

Throughout the sampling periods, carabid community compositions, measured by the Bray–Curtis Index, were similar between the hedge border side and corn field side of strip-traps (Table 7). Carabid community compositions were also similar between the grass border side and corn field side of strip-trap (Table 7).

4. Discussion

Agricultural fields bordered by complex hedges were expected to contain more species and numbers of carabids than fields bordered by simple grass edges because the increased architectural layers of hedges have been shown to support a higher abundance of prey and enhanced overwintering protection for carabids (Sotherton, 1985; Nazzi et al., 1989; Letourneau, 1990). In this study, at least during corn emergence (early June), carabids were more active and had a higher species richness in the corn fields bordered by complex hedge than in corn fields bordered by simple grass edges (Fig. 2(A) and (B)). These results may reflect enhanced overwintering success in hedge habitat compared with the simple grass habitat which would not provide as much buffer against winter weather (Sotherton, 1985). Following canopy closure of corn (July), carabids were more active in corn fields bordered by grass. It was also observed that carabid abundance and species richness were greater in simple grass roadside habitats and their adjacent corn fields than in complex prairie habitat later in the corn growing season (Varchola and Dunn, 1999). Following the spring peak in carabid populations, competition for prey may increase which may cause beetles to spread out from corn fields bordered by hedge into other fields with less competition. Canopy closure may aid in this process because as the corn
canopy closes in, the amount of suitable habitat for carabids also increases, making it easier for them to move between habitat types.

No evidence was found that carabid communities differed between hedge and grass border habitats as measured by Bray–Curtis Index. Hence, both hedge and grass border habitats appear to be beneficial for carabids in corn fields.

Research suggests that carabids exhibit seasonal movement between agricultural fields and adjacent borders (Desender and Alderweireldt, 1988; Dennis and Fry, 1992). In this study, carabids were more active on the hedge border side of strip-traps early in the growing season of the corn indicating that they may be using hedges for alternate sources of prey or protection until field conditions become favorable. However, throughout the remainder of the corn growing season, carabid activity between the hedges border and adjacent corn field habitats, and also the grass border and adjacent corn field habitats did not differ. Kromp and Steinberger (1992) observed a high similarity in carabid populations between grass margins and wheat fields in eastern Austria. Duelli et al. (1990) observed high carabid population exchanges

### Table 6
Seasonal distribution of ground beetles (Coleoptera: Carabidae) captured on grassy border side or corn field side of strip traps placed in corn fields in Iowa, USA

<table>
<thead>
<tr>
<th>Growth stage of corn</th>
<th>Grass border (mean ± S.E.)</th>
<th>Corn field (mean ± S.E.)</th>
<th>F-value</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Harpalus pensylvanicus DeGeer</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Corn emergence</td>
<td>0.17 ± 0.09</td>
<td>0.18 ± 0.09</td>
<td>0.01</td>
<td>0.941</td>
</tr>
<tr>
<td>Vegetative growth</td>
<td>1.42 ± 0.22</td>
<td>1.30 ± 0.35</td>
<td>0.08</td>
<td>0.783</td>
</tr>
<tr>
<td>Canopy closure</td>
<td>20.37 ± 8.57</td>
<td>10.83 ± 3.22</td>
<td>1.06</td>
<td>0.308</td>
</tr>
<tr>
<td>Physiological maturity</td>
<td>46.10 ± 7.47</td>
<td>42.57 ± 8.16</td>
<td>0.10</td>
<td>0.751</td>
</tr>
<tr>
<td>Pterostichus chalcites Say</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Corn emergence</td>
<td>9.78 ± 2.10</td>
<td>7.00 ± 1.21</td>
<td>1.27</td>
<td>0.268</td>
</tr>
<tr>
<td>Vegetative growth</td>
<td>23.67 ± 3.81</td>
<td>18.57 ± 3.25</td>
<td>1.03</td>
<td>0.316</td>
</tr>
<tr>
<td>Canopy closure</td>
<td>14.23 ± 2.73</td>
<td>12.59 ± 2.91</td>
<td>0.17</td>
<td>0.681</td>
</tr>
<tr>
<td>Physiological maturity</td>
<td>2.03 ± 0.40</td>
<td>2.07 ± 0.37</td>
<td>0.00</td>
<td>0.951</td>
</tr>
<tr>
<td>Scarites quadriceps Chaudoir</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Corn emergence</td>
<td>2.50 ± 0.55</td>
<td>1.76 ± 0.53</td>
<td>0.92</td>
<td>0.344</td>
</tr>
<tr>
<td>Vegetative growth</td>
<td>10.21 ± 1.46</td>
<td>8.56 ± 1.69</td>
<td>0.54</td>
<td>0.465</td>
</tr>
<tr>
<td>Canopy closure</td>
<td>0.80 ± 0.25</td>
<td>0.93 ± 0.24</td>
<td>0.14</td>
<td>0.709</td>
</tr>
<tr>
<td>Physiological maturity</td>
<td>1.10 ± 0.27</td>
<td>1.07 ± 0.20</td>
<td>0.01</td>
<td>0.921</td>
</tr>
<tr>
<td>Scarites subterraneus Fabricius</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Corn emergence</td>
<td>2.28 ± 0.61</td>
<td>1.41 ± 0.40</td>
<td>1.37</td>
<td>0.250</td>
</tr>
<tr>
<td>Vegetative growth</td>
<td>7.46 ± 1.06</td>
<td>6.57 ± 1.38</td>
<td>0.27</td>
<td>0.608</td>
</tr>
<tr>
<td>Canopy closure</td>
<td>0.23 ± 0.10</td>
<td>0.28 ± 0.12</td>
<td>0.07</td>
<td>0.790</td>
</tr>
<tr>
<td>Physiological maturity</td>
<td>0.37 ± 0.07</td>
<td>0.63 ± 0.12</td>
<td>1.82</td>
<td>0.182</td>
</tr>
</tbody>
</table>

*See Fig. 1 for trap arrangement.

### Table 7
Bray–Curtis Index values for the comparison of Carabidae communities between the border side and corn field side of strip-traps for the Summer of 1997

<table>
<thead>
<tr>
<th>Border</th>
<th>Corn emergence</th>
<th>Vegetative growth</th>
<th>Canopy closure</th>
<th>Physiological maturity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hedge borders</td>
<td>0.70</td>
<td>0.80</td>
<td>0.78</td>
<td>0.91</td>
</tr>
<tr>
<td>Grass borders</td>
<td>0.74</td>
<td>0.81</td>
<td>0.89</td>
<td>0.94</td>
</tr>
</tbody>
</table>

* A value between 0 and 1 is derived. A value close to 0 indicates that communities are greatly different. A value close to 1 indicates that communities are greatly similar.
between field borders and cultivated land in Northwestern Switzerland from April through October 1985. Carabids may actively move between border habitats and their adjacent corn fields throughout the summer.

The results from this study indicates that both hedge and grass borders support similar carabid communities in cultivated fields. Although hedges may be beneficial early in the corn growing season, generally it does not appear that carabids are dependent on border habitats during periods of unfavorable field conditions. Mader (1984) studied the effects of isolation of natural habitat by agricultural fields on carabid populations. He found that small islands of natural habitats in an agricultural field supported a high carabid species richness of low abundance (Mader, 1984). He suggested that small islands of natural habitat were not large enough to sustain most populations indefinitely and the species present will most likely be adapted to agricultural fields, occupying the island only temporarily (Mader, 1984). In addition, there is evidence that some carabids are colonizing species and are better adapted to living in disturbed habitats (Erye et al., 1990; Burel and Baudry, 1994; Dunleavy et al., 1995). Kirk (1971) observed carabids digging into the soil or finding refuge within cracks in cultivated fields in South Dakota, USA. During periods of unfavorable field conditions, carabids may simply dig into the soil during the day for protection from the sun and predators instead of moving into border habitats.

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References


