

Ground beetle (Coleoptera: Carabidae) diversity across three forest communities differing in land use history and successional stage in eastern Cape Breton.

By

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Table of Contents

Acknowledgements -----	iii
List of Tables -----	iv
List of Figures -----	v
Abstract -----	vi
Introduction -----	1
Methods -----	4
Results -----	8
Discussion	
Carabid Diversity -----	12
Diversity and Richness -----	16
Carabids as Indicators -----	17
Future Research -----	20
Conclusions -----	22
Literature Cited -----	23
Appendix -----	26

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List of Tables

<u>Table</u>	<u>Description</u>	<u>Page</u>
1	Total carabids trapped by species from each forest site, including abundance, species richness, number of species found only at an individual site and species richness of canopy tree species on each site	26
2	Total carabids trapped in pitfall and pan traps on each forest site	26
3	Carabid diversity analysis results; Rarefaction, Simpson's Diversity Index and Evenness score and Shannon-Weiner Diversity Index and variance, by trap location	27
4	Natural History information of carabid species trapped from all there forest sites (Larochelle and Larivière, 2003).	28

List of Figures

<u>Figure</u>	<u>Description</u>	<u>Page</u>
1	Map of Cape Breton Island showing the relative locations of the late successional forest plot (Irish Cove EMAN terrestrial monitoring site); the mid-successional forest plot (East Bay) and the early successional forest plot (University College of Cape Breton (UCCB), now Cape Breton University), and Sydney (for reference).	5
2(a)	Trap distribution within 1 ha. research plot in the mid-successional forest (East Bay). Northern edge is A/D line	6
2(b)	Trap distribution within 1 ha. research plots in the early successional forest (UCCB). Northern edge is A/D line	6
3	Pitfall and pan trap placement outside the 1 hectare terrestrial monitoring plot in the late successional forest, Irish Cove, Nova Scotia	6
4	Carabid abundance by species and site. Species were ranked by average abundance, averaged from the three forest sites; early successional (UCCB) forest, mid-successional (East Bay) forest, and late successional (Irish Cove) forest	10
5	Carabid species richness as collected from the early successional forest (UCCB), mid successional forest (East Bay) and the late successional forest (Irish Cove) sample sites and rarefied to 30 individuals.	11
6(a)	Diversity indices of Carabid species trapped at the early successional (UCCB), mid-successional (East Bay) and late successional (Irish Cove) forests - Simpson Diversity Index	11
6(b)	Diversity indices of Carabid species trapped at the early successional (UCCB), mid-successional (East Bay) and late successional (Irish Cove) forests - Shannon-Weiner Diversity Index	11
7	Simpson Equitability scores for Carabid species trapped at the early successional (UCCB), mid-successional (East Bay) and late successional (Irish Cove) forests	12

Abstract

Ecological studies often focus on small suites of species in order to understand the larger system. Using species or groups of species that provide useful data and are logistically feasible to study is key to attaining accurate results. Ground beetles (Coleoptera: Carabidae) may be used as effective bioindicators because; they are relatively easy to identify to species, they are abundant and have representative species in many habitats, they are relatively easy to collect and their life histories are well known. In addition many species are habitat specialists and therefore useful as indicator species. Carabid species diversity assessments are a precursor to determining the use of carabids as bioindicators. Three forests in eastern Cape Breton varying in land use history, stage of succession and vegetation were chosen to explore carabids diversity in early successional versus late successional forests in this region. Beetles were trapped on 1 hectare plots in each forest using randomized pitfall and pan traps between May and October 2004. Specimens were identified and determinations were confirmed by experts. Presence/absence of species associated with specific habitat or feeding needs was analyzed along with species richness, abundance, and diversity indices. Species assemblages, species richness and overall abundances were varied with forest successional stage. Highest diversity was found in the late-successional forest, while highest abundances were found in the mid-successional forest, which was also the least diverse.

Introduction

Ecologists and other ecosystem managers strive to assess the nature of the environments around them. A complete inventory of species within an ecosystem is difficult. Therefore ecologists seek subsets of species to monitor and from which to extrapolate overall system conditions, biotic and/or abiotic. These species subsets, referred to as bioindicators, may be used to follow general energy flow patterns, species assemblages, and habitat types within a system, while observing a small percentage of organisms within it. The small sample size makes monitoring efforts far more cost-effective and efficient (Raino and Niemelä, 2003). Bioindicators are often used to track changes within an ecosystem, monitoring changes in species assemblages, abundance, and diversity, potentially serving as an early warning system of change within the ecosystem (Raino and Niemelä, 2003). Ecologists have employed beetle populations to develop indices of ecological continuity in the course of assessing the degree of ecological disturbance (or conversely integrity) of forested sites (Alexander, 2004). Beetles are an extremely diverse group of insects, covering a broad spectrum of generalization and specializations. As such, there are groups of beetles that may be utilized in indicator analysis. As a precursor to future bioindicator research, biodiversity among ecosystems must be assessed.

Biodiversity within forest ecosystems is often tied to the forest's successional stage (Barbour, 2001). Old growth forests show different species assemblages than younger forests and this applies to the ground beetles found within them (Niemelä, Langor and Spence, 1993, Niemelä, Tukka and Halme, 1994, Bousquet, 1996, Allegro and Sciaky, 2003, Blake, *et al.*, 2003, Pearce, *et al.*, 2003, Alexander, 2004). Forest sites

for this study were chosen based on their successional stage, age, and canopy composition in order to determine how these factors affect ground beetle diversity. Two research plots and one monitoring plot have been established in eastern Cape Breton in differing forest communities. Their canopy tree species, ages, and land use histories are known from previous research (Bouman *et al.* In Press, D'Orsay, 2004). As the three plots differ in age, history, and successional stage; Irish Cove, an undisturbed mature hardwood/hemlock forest; East Bay, a mixed mid-successional forest with some harvesting history; and the UCCB forest, a previously cleared young spruce forest: they lend themselves to comparative biodiversity studies. The stage of natural succession found at each site, as a result of anthropogenic activities, is the base variable identified to explain differences in carabid abundances and diversity found within. Each site exhibits a different land use history (reclaimed farm land, partially harvested, and natural) with differing vegetative qualities. This study characterizes the carabid fauna at these three sites in eastern Cape Breton. The presence or absence of species associated with old growth, or undisturbed habitats, in these forests may have implications on habitat, or biodiversity conservation and forest use practices in eastern Cape Breton, as well as indicate overall community structure in these areas.

Ground beetles (Coleoptera: Carabidae) are a well studied, widely distributed insect group that may be used as bioindicators of forest community structure (Bousquet, 1996, Allegro and Sciaky, 2003, Blake, *et al.*, 2003, Pearce *et al.*, 2003, Raino and Niemelä, 2003). The presence or absence of certain species, which correlate with specific environmental conditions within a forest may provide strong evidence of overall ecosystem health (Allegro and Sciaky, 2003). Carabidae are primarily predaceous

species with a wide range of habitat and feeding requirements (Lindroth, 1961, 1963, 1966, 1968, 1969a, 1969b; Larochelle and Larivière, 2003). It contains many generalist and specialist species which may correlate strongly, or not at all, with particular habitats and other ecological factors. Generalist species, such as many of those within the genus *Pterostichus*, which occur across a wide range of habitats (Larochelle and Larivière, 2003), are rarely of high indicator value. More specialized species may indicate specific habitat types, or ecosystem ages and integrities due to specific needs that cannot be met in other environments. The genera *Scaphinotus* and *Sphaeroderus*, for example, are generally only found in stable, mature forests (Larochelle and Larivière, 2003). They are predators of terrestrial gastropods, primarily snails, which thrive in stable environments, such as mature forests (Larochelle and Larivière, 2003). Because of this, specialist species that point towards ecological relationships must be sought; requiring species level identifications, which are relatively easy within this family compared to other insect groups (Bousquet, 1996).

The three forest sites, varying in age and successional stage, were investigated to determine if carabid species assemblages differed in forests differing in successional stage. Carabids were inventoried in each forest successional stage. The null hypothesis is that carabid species richness and abundance will not significantly vary between forests differing in successional stage, therefore yielding no species indicative of forest stage. Species presence/absence from each forest sampled may be used, with known natural history information, to determine whether species have indicator value.

Methods

Three forests, varying in successional stage, have been studied in eastern Cape Breton (Bouman *et al.*, in press, D'Orsay, 2004; Fig. 1). Here I compare beetle abundance and diversity in an early successional, conifer dominated site on UCCB campus (*Picea glauca* (Moench) Voss, *Abies balsamea* (L.) Mill, *Betula papyrifera* Marshall); a mid-successional mixed forest in East Bay (*Betula papyrifera*, *Betula alleghaniensis* Britt., *Acer rubrum* L., *Acer saccharum* Marsh., *Picea glauca*) and a late successional hardwood-hemlock forest in Irish Cove (*Acer saccharum*, *Tsuga canadensis* (L.) Carr, *Betula alleghaniensis*, *Fagus grandifolia* Ehrh.) (Figure 1). The three sites differed primarily in stand age and overstory composition, as a result of land use history, with the UCCB site being a former field, abandoned ~60 years ago, East Bay being partially cleared and logged to 60-80 years ago, and Irish Cove being undisturbed for over one hundred years. Each site contains a one hectare research or monitoring plot around which sampling was conducted. Sampling was conducted within the one hectare research plots in East Bay and UCCB forests, while it was conducted outside the plot in Irish Cove, as the plot is a non-invasive, long-term EMAN terrestrial monitoring plot and cannot be disturbed (Roberts-Pichette and Gillespie, 1999).



Figure 1 – Map of Cape Breton Island showing the relative locations of the late successional forest plot (Irish Cove EMAN terrestrial monitoring site); the mid-successional forest plot (East Bay) and the early successional forest plot (University College of Cape Breton (UCCB), now Cape Breton University), and Sydney (for reference).

Carabid sampling took place through the summer of 2004, biweekly from late May until mid-August, and in mid-September and mid-October. Twelve traps were deployed for 2-4 days at each site, consisting of two trap types; pitfall traps, composed of plastic cups with a board cover, and pan traps, yellow plastic bowls, which were buried to their rims and contained a soapy, saline solution. Traps were deployed randomly within the one hectare research plots, which were subdivided into 25 20m x 20m subplots, using a random number generator (Figure 2). In Irish Cove, traps were deployed in paired parallel lines 15m and 25m from the east and south borders of the plot. The east and south borders were chosen to minimize land form heterogeneity, as the north and west borders entered ravines, which are not present at the other two sites. Traps were placed in alternating pitfall/pan trap arrangements in lines of three along the two chosen sides, with the first line 15m out from the plot edge, starting 20m in from the outside corners

and 30m from either outside trap to the center trap. The second parallel line of traps was placed 10m further out from the plot from the first line, with a reversed pan/pitfall pattern (Figure 3). Trapping effort was 636 trap nights in the early and late successional forests and 633 trap nights for the late successional forest, totaling an effort of 1905 trap nights across the three sites.

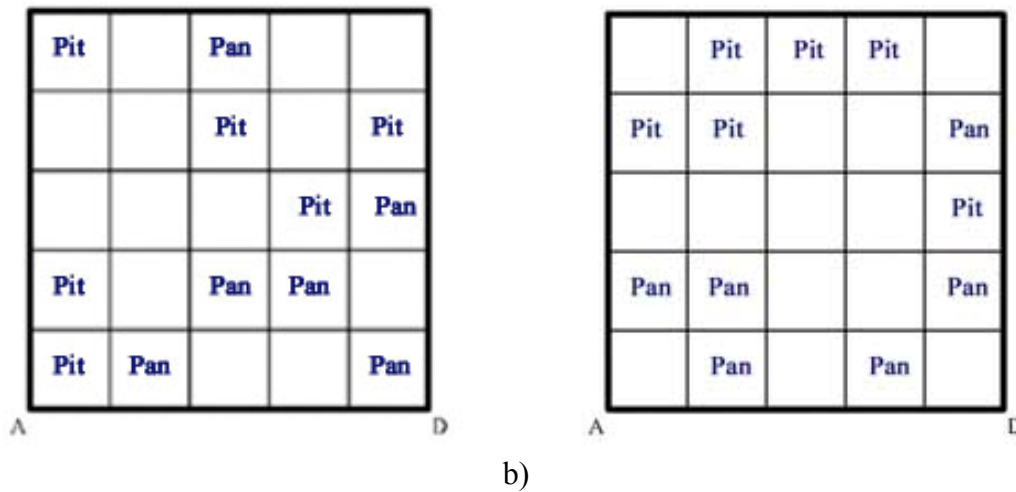


Figure 2 – Trap distribution within 1 ha. research plots in a) the mid-successional forest (East Bay) and b) the early successional forest (UCCB). Northern edge is A/D line.

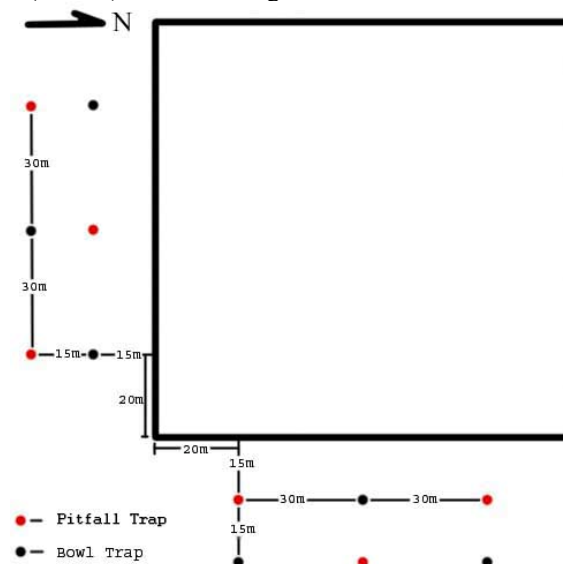


Figure 3 – Pitfall and pan trap placement outside the 1 hectare terrestrial monitoring plot in the late successional forest, Irish Cove, Nova Scotia.

All carabids were labeled and pinned or stored in 70% ethanol and non-carabids were labeled and stored separately in 70% ethanol. Carabids were identified using Downie and Arnett's *The beetles of Northeastern North America* (1996), Lindroth's *The ground-beetles (Carabidae, excl. Cicindelinae) of Canada and Alaska* (1961, 1963, 1966, 1968, 1969a, 1969b) and with reference specimens in the UCCB collection. Identifications were verified by C. Majka (Nova Scotia Museum of Natural History). Voucher specimens are deposited in the collections at UCCB, the Nova Scotia Museum of Natural History, Halifax, and the Canadian National Collection of Insects, Agriculture Canada, Ottawa.

Species assemblages, abundances, and species richness within the three sample sites were compiled. Rarefaction was used to compare species richness between the forests to account for variation in carabid abundance and its effects upon species richness. Rarefaction sub-samples along species accumulation curves, random sampling a set abundance taken from the total sample (Gotelli and Entsminger, 2001, Buddle, *et al.*, 2005). Sub-sampling was run through 1000 iterations, at an abundance of 30 individuals (five less than the smallest sample), providing mean species richness and variance for each site. Rarefaction analysis was conducted using Ecosim Version 7.0 (Gotelli and Entsminger, 2001). The Shannon-Weiner Diversity Index and Simpson Diversity Index were used to compare carabid diversity in each forest based on their total species richness and abundances (Magurran, 2004). Both of these indices assume that species are equally important within an ecosystem and that individuals within a species are equally fit (Gotelli and Entsminger, 2001, Magurran, 2004) and cannot be used to address

differences in species composition, nor indicator value of species. In both equations, p_i is the proportion of individuals represented by species i and S is species richness.

Shannon-Weiner Diversity Index:

$$H' = -\sum_{i=1}^s p_i \ln p_i$$

Simpson Diversity Index:

$$D = \frac{1}{\sum_{i=1}^s p_i^2}$$

Equitability, or evenness, was calculated for each site with the Simpson Equitability algorithm (Magurran, 2004). Evenness measures the distribution of individuals among represented species and may help elucidate ecologically important species; a value between 0 and 1 is produced, with 1 representing completely even distribution among species (Gotelli and Entsminger, 2001). Within the equation, D is the Simpson Diversity Index score, D_{max} is the potential Simpson Diversity Index maximum, p_i is the proportion of individuals represented by species i and S is species richness

Simpson Equitability/Evenness:

$$E_p = \frac{D}{D_{max}} = \frac{1}{\sum_{i=1}^s p_i^2} \times \frac{1}{S}$$

Results

Species assemblages varied across the three study sites (Figure 4, Table 1). A total of 14 species were collected, representing 10 genera. Among the species collected there were species found across all three forests, found in two forests, or found in only one forest (Table 1). A suite of five species were found at all three sites; *Agonum retractum* LeConte, *Calathus ingratus* DeJean, *Pterostichus coracinus* (Newman),

Pterostichus adstrictus Eschscholtz and *Pterostichus pensylvanicus* LeConte. Of the 14 species, seven were collected from one plot only; *Notiophilus aeneus* Herbst from the early successional forest; *Calosoma frigidum* Kirby, *Cymindis cribicollis* DeJean and *Dromius piceus* DeJean from the mid-successional forest; and *Agonum thoreyi* Mannerheim, *Loricera pilicornus* (Fabricus) and *Platynus decentis* (Say) from the late successional forest. *Pterostichus tristis* DeJean was collected from the mid- and late successional forests and *Sphaeroderus c. canadensis* Chaudoir was collected in the early and late successional forests; both species were more numerous in the late successional forest.

Total abundance varied greatly between the sites (Figure 4, Table 1). The early successional forest had the lowest abundance, followed by Irish Cove with almost four times that of the early successional site, with the mid-successional site exhibiting the greatest carabid abundance, almost five times that of the early successional site.

Calathus ingratus was most the most abundant species from each site; it was in the highest proportion in the mid-successional forest at 50% of individuals collected.

Trapping effort was approximately equal for each site, with the loss of a single trap in one trapping period from the late successional forest. Trapping effort yielded 0.055 individuals per trap night in the early successional forest, 0.266 individuals per trap night in the mid-successional forest and 0.215 individuals per trap night in the late successional forest; totaling 0.178 individuals per trap night for all 36 traps on the 3 test sites (Table 1).

Total species richness was greatest in the late successional forest, and lowest in the early successional forest (Figure 5, Table 1). Pitfall traps and pan traps produced

comparable yields; 52% of carabids were collected from pitfall traps and 48% from pan traps (Table 2).

Carabid diversity was greatest in the late successional forest and least in the mid-successional forest. Rarefaction (Figure 5, Table 3), Shannon-Weiner diversity index and Simpson diversity index (Figure 6, Table 3) were similar.

Species evenness, as measured by the Simpson Equitability index, was greatest in the early successional forest and least in mid-successional forest (Figure 7, Table 3).

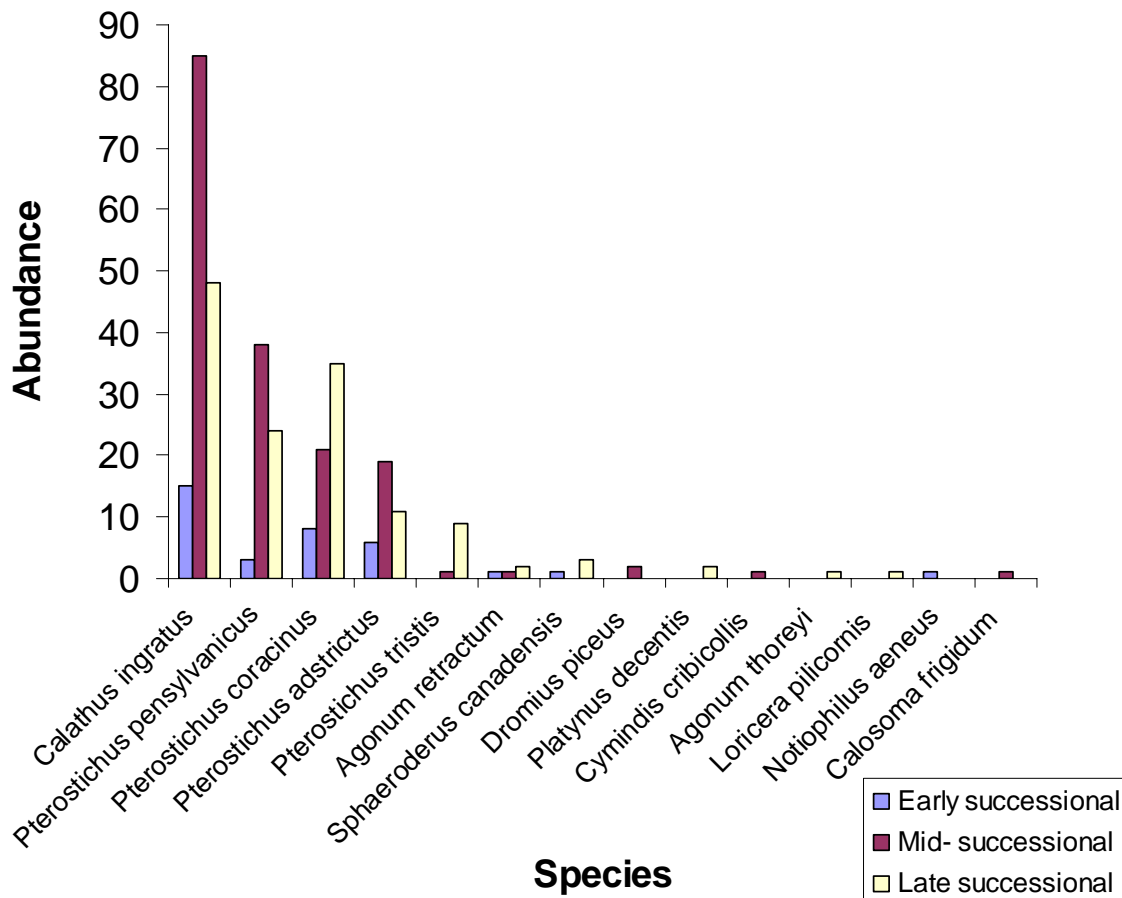


Figure 4: Carabid abundance (individuals captured through 2004 trapping period) by species and site. Species were ranked by average abundance, averaged from the three forest sites; early successional (UCCB) forest, mid-successional (East Bay) forest, and late successional (Irish Cove) forest.

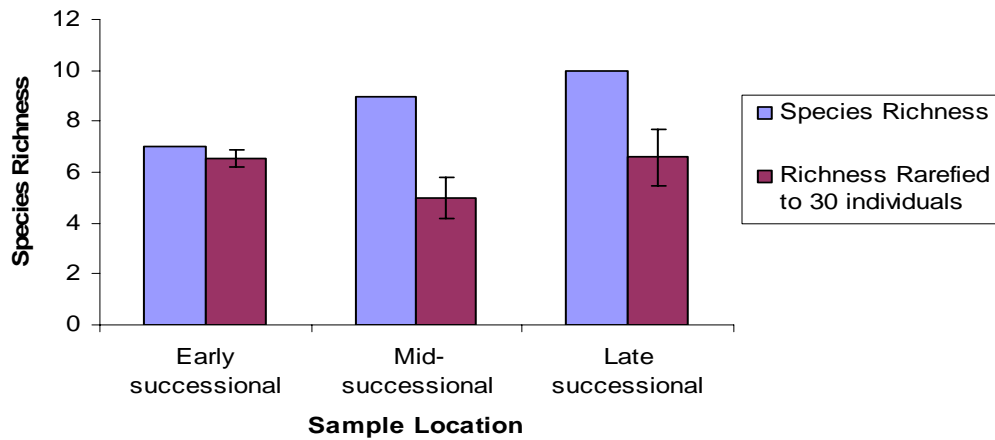
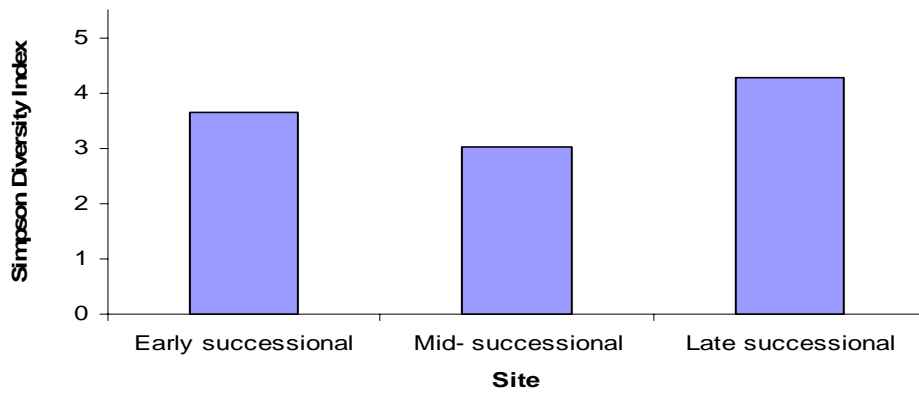


Figure 5: Carabid species richness as collected from the early successional forest (UCCB), mid successional forest (East Bay) and the late successional forest (Irish Cove) sample sites and rarefied to 30 individuals. Error bars represent standard deviation.

a)



b)

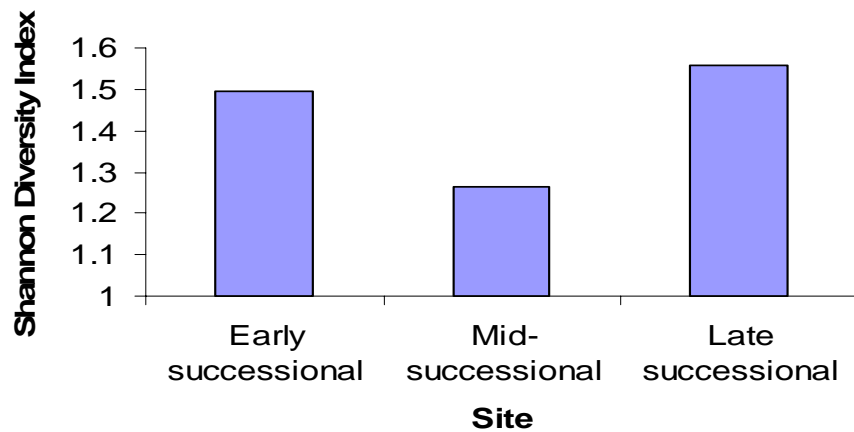


Figure 6: Diversity indices of Carabid species trapped at the early successional (UCCB), mid-successional (East Bay) and late successional (Irish Cove) forests. Diversity indices used were: a) Simpson Diversity Index, b) Shannon Diversity Index.

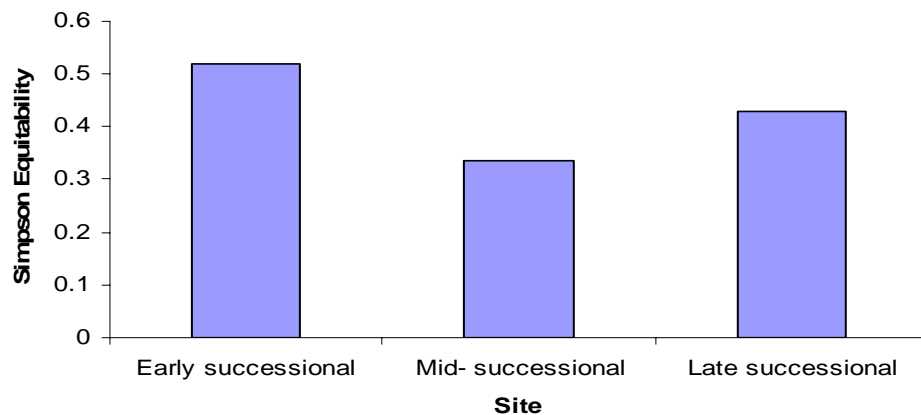


Figure 7: Simpson Equitability scores for Carabid species trapped at the early successional (UCCB), mid-successional (East Bay) and late successional (Irish Cove) forests.

The carabid inventory conducted in this study also increased distributional knowledge of ground beetles on Cape Breton Island. Two species of carabids, *Sphaeroderus c. canadensis* Chaudoir and *Platynus decentis* (Say), were added the distributional and biogeographical checklist of the beetles of Nova Scotia for Richmond County from this study (Majka, 2003, and personal communication).

Discussion

Carabid Diversity

Carabid assemblages and diversity were varied among three forests in eastern Cape Breton differing in successional stage (Figure 4, 5, 6; Table 1, 3). Abundance was the most widely varying aspect of carabid diversity in this study, with abundance peaking in the mid-successional forest. Clear variation between the sites was also seen in species richness and diversity index scores, which showed the late successional forest to have the greatest carabid diversity. The mid successional forest, while having the greatest abundance, was the least diverse. Site evenness, the distribution of individuals between species, was quite low, over half the individuals collected were of a single species

(*Calathus ingratus*), reducing site diversity (Table 1, 3). Diversity scores of the early and late successional forests were greater due to more even distributions of individuals among species and, for the late successional forest, high species richness.

Carabid species assemblages are partially determined by forest composition; carabid species richness trends mirrored the trends of canopy tree species richness between the sites (Table 1). The early successional site was dominated by a few (5) pioneer species (*Picea glauca*, *Larix laricina* (DuRoi) K. Koch, *Acer rubrum*, *Betula papyrifera*, and *Abies balsamea*) (pers. obs., Bouman, pers. comm.), while the mid-successional was composed of more (7) species that are a mixture of early and late successional species (*Betula papyrifera*, *Betula alleghaniensis*, *Acer rubrum*, *Acer saccharum*, *Fagus grandifolia*, *Picea glauca*, and *Abies balsamea*) (Bouman, *et al.*, In Press), and the late successional forest had the greatest (10) tree species richness, lacking dominance of early successional species (*Acer saccharum*, *Acer rubrum*, *Tsuga canadensis*, *Picea rubens* Sarg., *Picea glauca*, *Betula alleghaniensis*, *Fagus grandifolia*, and *Abies balsamea*) (D'Orsay, 2004). Likewise, carabid species richness increased with canopy tree species richness.

Due to its past land use history as agricultural land and the even age of the stand, the understory of early successional forest was qualitatively more homogeneous, with relatively few herbaceous species and little coarse woody debris and surface variation, compared to the other two test sites. Forest floor heterogeneity, such as coarse woody debris, thickness of the leaf litter or understory vegetation may have played a roll in the carabid diversity and abundances found at each site (Niemelä, *et al.*, 1994, Blake, *et al.*, 2003). This homogeneity may have influenced the greater evenness of individual

distribution among species. Mature forests tend to contain greater biodiversity, with richer soils and understory vegetation, than earlier successional forests (Barbour, *et al.*, 1999). It is reasonable to assume that this richness supports the increased carabid diversity represented in the late successional forest in Irish Cove.

The three carabids found only in the mid-successional forest, East Bay, *Dromius piceus*, *Calosoma frigidum* and *Cymindis cribicollis*, share a generalized forest habitat requirement, with *Cymindis cribicollis* often being associated with marginal forests and forest edges (Larochelle and Larivière, 2003, Table 4). All three share a primary diet of lepidopterous caterpillars (Lindroth, 1961, 1969a; Larochelle and Larivière, 2003). This suggests that prey were more plentiful in this forest than in the other two sampled, or perhaps that other factors limited their prevalence elsewhere (perhaps soil moisture or another abiotic factor). All three species are capable of flight and wide dispersal and *Calosoma frigidum* is frequently well represented in North American forest habitats, especially during lepidopterous caterpillar outbreaks (Larochelle and Larivière, 2003).

Species collected in the late successional forest, Irish Cove, *Agonum thoreyi*, *Loricera pilicornus* and *Platynus decentis*, tend to be associated with deciduous forests and/or eutrophied wet soils. The dominant canopy species at this site are deciduous trees: *Acer saccharum*, *Acer rubrum*, *Betula alleghaniensis*, *Fagus grandifolia*, and a conifer: *Tsuga canadensis*. Also at this site, along the eastern edge of the terrestrial monitoring plot, there is a seeping spring. While *Pterostichus tristis* (DeJean) and *Sphaeroderus c. canadensis* were best represented in Irish Cove, they were collected in forests aside from the late-successional Irish Cove forest (East Bay and UCCB, respectively) (Figure 2, Table 1, 4). Only one specimen of each species was found at another site. With the

exceptions of *Agonum thoreyi* and *Loricera pilicornus*, which fly frequently, these species are incapable of flight and are poor dispersers (Lindroth, 1961, 1966; Larochelle and Larivière, 2003), requiring somewhat mature habitat which is infrequently disturbed. These species may be useful indicators of forest disturbance or age in this region. Overall indicator analyses were found to be ineffective due to small sample size.

Carabid species assemblages in Cape Breton forests were found to differ from those found on the Nova Scotia mainland (Majka, pers. comm.). A recent forest beetle study in ~120+ year old coniferous and deciduous forests in Kejimikujik National Park, by Rossolimo and Majka, found the most abundant species in each forest type was *Synchus impunctatus* (Say) (unpublished data), which was absent from all three sample sites on Cape Breton. The absence of this species from Cape Breton forests may have impact on carabid dynamics within our forests. The most abundant species in Cape Breton forests, *Calathus ingratus*, was only mildly represented in the Kejimikujik samples. *Platynus decentis*, which was only found in the deciduous dominated late successional forest in Cape Breton, was only collected from deciduous forests in Kejimikujik as well. This species may be useful for use as an indicator of mature deciduous forest habitats. Their study also showed highest carabid abundance within coniferous forests, with ~70% greater carabid representation than deciduous (Majka, pers. comm.). This result contrasts the findings of my study, however the comparative age of the coniferous forests studied was great and may have influence on the results found.

The numerically dominant species collected from all three sites sampled were *Pterostichus adstrictus* and *Pterostichus pensylvanicus*, early within the trapping period.

While these are early emerging species that overwinter as adults, it is possible that the trapping method may have influenced catch. Pearce, *et al.* (2003) found that these two species are attracted to the disturbance of trap insertion and may be overrepresented in early sampling. The increased representation of these species may be related to higher movement rates across the disturbed ground, or perhaps simply due to an affinity for open land. If traps are set long enough before collecting is to begin so that the generated disturbance is no longer fresh, trapping results may not exhibit this kind of skew.

Platynus decentis also displays a positive correlation to disturbance generated by trap insertion (Pearce, *et al.*, 2003); as only two specimens were collected with a broad time separation, it is unlikely that this phenomenon was a factor in this study.

Diversity and Richness

Standard species accumulation curves demonstrate that as numbers of individuals collected increase, one expects species richness to also increase at a given rate; species per unit of collecting effort. One would thus expect a site with higher abundance to display higher species richness. As such, raw data are plural so are difficult to compare between sites differing greatly in abundance. Therefore analyses that account for abundance and species accumulation should be used to standardize results to compare sites differing in abundance (Buddle, *et al.*, 2005). Although species accumulation curves and rarefaction curves can provide more useful information of site diversity that may be compared between differing sites, they are often overlooked as an analysis tool (Buddle, *et al.*, 2005). Rarefaction, which, through several iterations, accounts for variation and the single-index indices utilized, indicated that the late successional forest, Irish Cove, was the most diverse site, while the mid-successional forest, East Bay, was

the least diverse. Comparative analyses between sites provided a distinctly different interpretation of the data than was intuitively visible in the raw data.

Two single-index diversity measures of α -diversity (Shannon-Weiner Diversity and Simpson Diversity) were used in concert with individual-based rarefaction to compare species richness and diversity across the three sites. Buddle, *et al.* (2005), in a comprehensive literature review found that the most common measures of α -diversity, raw species richness and Shannon-Weiner diversity index often produced contradictory results. Raw species richness does not account for differences in abundance, while Shannon-Weiner diversity scores are difficult to interpret/compare without supporting data; one cannot ascertain whether differences in score are due to variations in abundance, richness, or both (Magurran, 2004, Buddle, *et al.*, 2005). While comparing diversity index scores between sites and rarefied species richness between sites will both illustrate general trends in diversity, rarefaction provides more robust information; standardizing abundance to identify differences in richness.

Carabids as Indicators

The use and quality of carabids as potential indicator species has been a topic explored in several studies (Niemelä and Spence, 1991, Niemelä, Langor and Spence, 1993, Niemelä, *et al.*, 1993, Raino and Niemelä, 2003, Pearce, *et al.*, 2003, Moore, *et al.*, 2004). Habitat generalists with generalized diets and strong dispersing capabilities make poor indicators. The numerically dominant species in all three sites, *Calathus ingratus* DeJean, *Pterostichus adstrictus*, and *P. pensylvanicus* fit this description. *Pterostichus coracinus* (Newman), while a widely distributed generalist, is brachypterous and incapable of flight. These species show little to no correlation to specific forest habitats

and feed on a varied diet, including insect larvae, springtails (Collembola), and plant matter (Larochelle and Larivière, 2003).

Good indicator species do occur within family Carabidae. Strict habitat and/or feeding requirements have been determined for several carabid species, such as *Pterostichus castor* Goulet & Bousquet, which shows obligate association with beaver lodges (Bousquet, 1996, Larochelle and Larivière, 2003). Many habitat specialist species tend to be larger ones or species with poor dispersal powers (poor fliers or those incapable of flight and/or moderate runners), such as many of those in the genera *Scaphinotus* and *Sphaeroderus* (Larochelle and Larivière, 2003). *Sphaeroderus c. canadensis* was mostly collected in Irish Cove, the late successional forest. This species is flightless and associated with stable, relatively mature habitats; feeding largely upon terrestrial gastropods; snails and slugs (Lindroth, 1961, Larochelle and Larivière, 2003), which require stable, older habitats. An association of this species with old growth habitat can be inferred by its presence in only Irish Cove and its bionomics. In the last trapping period (mid-October), a single specimen was collected from the early-successional site, UCCB forest. Being a non-flier with poor dispersal powers and poorly dispersing prey, its presence in the young forest came as surprising. Traps within the UCCB test site did produce some snails, so their food source was available, if less common than in the other sites (pers. obs.).

The most recently disturbed site, the UCCB forest, produced the fewest species and individuals. Other studies that have explored forest carabid diversity (Niemelä, Langor and Spence, 1993, Niemelä, *et al.*, 1993, Niemelä, Tukia and Halme, 1994, Pearce, *et al.*, 2003) often produce results in which the disturbed sites generate the

greatest carabid species richness and abundances. Such studies often take place on sites which have experienced recent disturbance, such as clear cutting, partial logging or other large scale disruption (Pearce, *et al.*, 2003, Niemelä, Langor and Spence, 1993, Niemelä, *et al.*, 1993, Moore, *et al.*, 2004). As a result, they often find an influx of invasive or open habitat species as well as remnants of the natural forest species that have not dispersed or been driven out (Niemelä, *et al.*, 1993). The UCCB site has not been disturbed for approximately 60 years; this temporal distance from the last disturbance may have allowed that effect to dissipate; hence only forest carabid species were trapped. Further studies of carabid assemblages in forests of similar age and land use history may help elucidate the factors affecting their faunal composition.

All species collected were native ones (~10-12% of Nova Scotian carabid species are introductions (Bousquet, 1991, Majka, pers. comm.)); however several species, such as *Pterostichus adstrictus* and *Loricera pilicornis*, are not restricted to North America and are holarctic (Bousquet and Larochelle, 1993). The lack of invasive species suggests that the three forests investigated are relatively natural or indigenous in structure, with few niches for which introduced species are better suited than native species, maintaining niches in which native species may out-compete invasive species (Niemelä and Spence, 1991). Invasive species of vascular plants within the province also tend to be associated with disturbed habitats, with few species established in natural forests (Roland, 1998, Blaney, 2004). Degree of disturbance is often associated with invader success. The common belief is that increased disturbance relaxes competitive pressures allowing invaders to establish (Niemelä and Spence, 1991).

Raino and Niemelä (2003) found that if carabid richness was corrected for overall taxa richness, carabid diversity reflects overall diversity as well as the diversity of other groups. They also found that carabid response to environmental disturbance, such as fragmentation, closely mirrors that of groups, such as spiders. Also, as previously mentioned, raw carabid species richness did mirror raw species richness trends of canopy tree species found through the test sites of this study (Table 1). This similarity in diversity, along with specialist species habitat requirements, supports the use of carabids as potential indicators.

Some species with extremely wide distributions show different habitat associations depending on geographic location (Niemelä and Spence, 1991, Niemelä, *et al.*, 1993, Blake, *et al.*, 2003, Pearce, *et al.*, 2003). *Pterostichus adstrictus*, for example, is often associated with forested habitats in North America, but in Finland is associated with open habitat and clear cuts (Pearce, *et al.*, 2003). Regionally appropriate information on natural history traits should be sought to ensure that interpretations are appropriate to prevalent conditions.

Future Research

Increased trapping effort might have yielded more comprehensive and informative results. Future research in this area may be conducted using more intensive trapping regimes, including more trapping methods (sweep netting, trunk traps, and litter sifting) and an increased in trap nights, as carabid biodiversity is often not independent of sample size (Raino and Niemelä, 2003). At the onset of this project, there was a concern about the possibility of over-trapping, thus depleting local arthropod populations, however, the results of this study indicate that more intensive trapping may be required.

Trap yields did not seem to fluctuate through the trapping period, inferring that more intensive trapping may not greatly influence arthropod abundances. The inclusion of more sample sites within each of the represented successional stages might allow for some additional analytic methods, such as some multivariate techniques. Without replication of sample sites, sample size of forests/forest types was only three in this study, far too small to analyze effectively. Also, replication of sample sites may help elucidate actual carabid biodiversity, accounting for the patchy distribution of carabids, and hence increasing the reliability of results (Raino and Niemelä, 2003). Additional sampling techniques, such as litter sampling, trunk trapping, and even sweep netting (Raino and Niemelä, 2003) may provide a more robust and representative sample of carabid species. The temporal scope of this project may also have a bearing on its results. Günter and Assmann (2004), in a recent long-term study of carabid populations in ancient woodland in northern Germany found that the abundance of some carabid species fluctuated greatly from year to year while others fluctuated only subtly. This agrees with data fluctuations found by Raino and Niemelä (2003). Sampling in successive years may help elucidate annual variations in species abundances and representation within each forest; factors which may impact overall carabid diversity.

The characterization of site features as well as overstory species composition may help to fine-tune carabid presence/absence based on factors such as understory heterogeneity, coarse woody debris, and soil moisture. This study utilized forest canopy tree species composition to characterize the successional stage of each site. While this level of characterization provides useful compositional information, the resolution of habitat characterization may have been too coarse for adequately describing the ground

beetle habitat present. Blake *et al.* (2003) and Raino and Niemelä (2003) pointed out that many carabid species are affected to a greater degree by soil moisture than are plant communities, as many predatory species possess soil-living larval stages. The trapping area within Irish Cove included a moist spring area, which may have influenced the carabid assemblage found to a greater degree than the forest's stage of succession. The UCCB and East Bay forests did not possess similar features near the trapping area.

Conclusions

While carabids have proven to be useful environmental indicators in previous studies, this study was unable to establish the value of carabids as indicator species. Species assemblages and diversity, however, were found to vary with forest successional stage and land use history. Whether this difference in carabid assemblages is directly related to forest successional stages or due to other factors, such as understory heterogeneity, soil moisture or other factors is unknown. Further characterization of the test sites with respect to these factors may help to better establish species/habitat associations. Also further sampling may reveal longer-term temporal trends in Cape Breton's carabid populations.

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Appendix

Table 1 – Total carabids trapped by species from each forest site, including abundance, species richness, number of species found only at an individual site and species richness of canopy tree species on each site.

Species	Plot Location		
	Early successional	Mid-successional	Late successional
<i>Calathus ingratus</i>	15	85	48
<i>Pterostichus pennsylvanicus</i>	3	38	24
<i>Pterostichus coracinus</i>	8	21	35
<i>Pterostichus adstrictus</i>	6	19	11
<i>Pterostichus tristis</i>	0	1	9
<i>Agonum retractum</i>	1	1	2
<i>Sphaeroderus canadensis</i>	1	0	3
<i>Dromius piceus</i>	0	2	0
<i>Platynus decentis</i>	0	0	2
<i>Cymindis cribicollis</i>	0	1	0
<i>Agonum thoreyi</i>	0	0	1
<i>Loricera pilicornis</i>	0	0	1
<i>Notiophilus aeneus</i>	1	0	0
<i>Calosoma frigidum</i>	0	1	0
Total Abundance	35	169	136
Trap Nights	636	636	633
Carabids per Trap Night	0.055	0.266	0.215
Species Richness	7	9	10
Unique Species	1	3	3
Canopy Tree Species Richness	5	7	10

Table 2: Total carabids trapped in pitfall and pan traps on each forest site.

Trap Type	Plot Location			Total
	Early successional	Mid-successional	Late-successional	
Pitfall	20	102	56	178
Pan	15	67	80	162

Table 3: Carabid diversity analysis results; Rarefaction, Simpson's Diversity Index and Evenness score and Shannon-Weiner Diversity Index and variance, by trap location.

	Early successional	Mid- successional	Late- successional
Rarefaction			
<i>Richness</i>	6.555	4.976	6.585
<i>Variance</i>	0.349	0.804	1.102
Simpson Diversity Index	3.635	3.013	4.276
Simpson Evenness Score	0.519	0.334	0.427
Shannon Diversity Index	1.497	1.263	1.558
<i>Variance</i>	0.005	0.020	0.019

Table 4 – Natural History information of carabid species trapped from all there forest sites (Larochele and Larivière, 2003).

Species	Site	Diet	Habitat	Dispersal
<i>Pterostichus coracinus</i>	All	generalist feeder	generalist, mostly forest; Nocturnal	brachypterous
<i>Pterostichus adstrictus</i>	All	generalist feeder	generalist (primarily conifer and mixed, occasional deciduous); Mostly Nocturnal	macropterous
<i>Pterostichus pensylvanicus</i>	All	generalist feeder	generalist, mostly forest, deciduous plus mixed & conifer; Nocturnal	macropterous
<i>Agonum retractum</i>	All	generalist feeder	deciduous w/ deciduous ground cover, other forest types; nocturnal	wing dimorphism, some fly
<i>Calathus ingratus</i>	All	generalist feeder	generalist, mostly forests; Mostly Nocturnal	wing dimorphism, some fly
<i>Calosoma frigidum</i>	Mid-successional	caterpillars, cicadas and locusts	forest association; Diurnal and Nocturnal	macropterous, frequent flier
<i>Dromius piceus</i>	Mid-successional	ant eggs (captivity)	forest w/ shaded ground; Nocturnal	macropterous, frequent flier
<i>Cymindis cribicollis</i>	Mid-successional	caterpillars	marginal habitat, forest edges; Nocturnal	wing dimorphism, some fly
<i>Agonum thoreyi</i>	Late successional	shrimp and seeds (captivity)	eutrophied wetlands; Nocturnal	macropterous; frequent flier
<i>Loricera pilicornis</i>	Late successional	springtail specialist, insect larvae and mites	low forests and eutrophic wet areas; Diurnal and Nocturnal	macropterous; frequent flier
<i>Platynus decentis</i>	Late successional	caterpillars	low forests w/ eutrophied wet regions; Mostly nocturnal	submacropterous, probably incapable of flight
<i>Pterostichus tristis</i>	Mid- and Late successional	generalist feeder	deciduous, plus mixed & coniferous; Nocturnal	brachypterous
<i>Sphaeroderus c. canadensis</i>	Early and Late successional	snail specialist, caterpillars.	forests, mostly deciduous/mixed w/ shaded undergrowth; Mostly Nocturnal	brachypterous; incapable of flight
<i>Notiophilus aeneus</i>	Early successional	caterpillars	forest w/ shaded undergrowth; Mostly Diurnal	macropterous; occasional flier