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Ground beetle diversity and abundance in Quebec vineyards

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Introduction

The family Carabidae, commonly known as ground beetles, is very diverse. In southern Quebec, Canada, about 300 carabid species have been recorded (Lindroth 1961, 1963, 1966, 1968, 1969a; Larochelle 1975). In southern Canada one could find about 250 species over a small surface of 25 to 36 km^2 rich in habitat variety. Among these species, 60 to 70 are expected to breed in cultivated agricultural sites with annual crops (Rivard 1966; Frank 1971; Levesque and Levesque 1994; Raworth *et al.* 1997). Ground beetles are also potentially good indicators of healthy environmental condition and quality because many species seem to maintain quite stable population levels over the years (Lindroth 1945, Rainio and Niemela 2003). Adults and larvae of most species predate or scavenge on various insects while those of a few species feed on a narrow range of insect preys (Kromp 1999). A few species are omnivorous (Balduf 1935; Lund and Turpin 1977a; Larochelle 1990) and some others feed on weed seeds (Alcock 1976; Lund and Turpin 1977b, Thiele 1977). This is the first study of ground beetles associated with vineyards. Our goals were to: 1) compare the abundance of and variation in captures of ground beetles species in two vineyards, 2) characterize the species diversity of each vineyard in relation to soil types, 3) rank the most prevalent species at each vineyard, and 4) compare the species diversity of each vineyard over a three-year period.

Materials and Methods

The three-year study (Table 1) was done in two commercial vineyards: "Le vignoble de L'Orpailleur", Dunham, characterized by an organic sand and gravel loam soil type, and "Le vignoble Dietrich-Jooss", Iberville, characterized by a clay loam soil type. The study plot at the Dietrich-Jooss vineyard was bordered by the vineyard on three sides, and by a 15 m wide herbaceous fallow band with a creek in the middle on the fourth side. The study plot at the L'Orpailleur vineyard was adjacent to a large fallow field and a small bushy site with leaf litter on the West side, an apple orchard on the North side, and by vineyards on the East and South sides. In both vineyards topsoil was cultivated twice a year, once in the spring to uncover the short vines, and once in the fall to cover them. During spring and summer, the soil had a light weed cover. Before 1997 these sites were treated with pesticides against mites, insects, weeds and fungi. During our study, only fungicides were applied at the two sites. The pitfall traps (Fig. 1) used to collect adult ground beetles, were placed 4 to 6 m apart to prevent an excessive sampling of specimens. Shannon index of diversity (H') (Belaoussoff et al. 2003) was used: H'= ∑ ni / N Ln (ni / N), where "ni" is the number of specimens for a species, and "N" is the total number of ground beetles captured at a site. At each site, the evenness index (J') was calculated as follows: J' = H' / Ln S. It is derived from the Shannon index, "H", described the level of evenness in the number of captures for each species included in the diversity study. "S" represented the total number of species recorded. Despite the wide variety of accidental species in the vineyards, the total number of captures from other habitats was low. We used the expression "expected species" for species breeding or normally expected to breed in the vineyard ecosystem; only those species were considered in our study.

Results and Discussion

1) Abundance of and variation in capture rates of ground beetles in two vineyards.

Abundance of captures and diversity of species. In the two vineyards 11,435 specimens representing 124 species were captured from 1997 to 1999 inclusive. Among these, 7,659 specimens representing 81 species were captured at the Dietrich-Jooss vineyard, and 3,776 specimens representing 89 species at the L'Orpailleur vineyard. Many species were atypical of these two sites. Based on habitat preferences of the species (Lindroth 1961, 1963, 1966, 1968, 1969a; Larochelle 1975), 53 species were unlikely to breed in the two vineyards. Though these unexpected species represented 42% of the total diversity of species captured at both sites, they amounted for only 1.7% of total captures (192 specimens). These species were not used in the analyses. The expected species are listed on Table 2. At the Dietrich-Jooss and at the L'Orpailleur vineyards, respectively 7,535 specimens (51 expected species) and 3,685 specimens (54 expected species) were captured (Table 3).

Capture rates for the three-year period. Comparing the captures of one site for a three-year period was difficult as the total number of captures and species varied each year. The variation in sample size may have been caused by variations in population size or by climatic conditions. Rain and prolonged dry and hot conditions curtailed activity markedly (Goulet, H, unpubl. information). The most appropriate way to evaluate the trapping efficiency was to express it as number of specimens per trap per week. At both sites, the 1997 season had the least and 1999 the highest number of captures per trap per week. The range in the number of specimens per trap per week was smaller at the Dietrich-Jooss vineyard with 3.5 to 5.7 specimens than at the L'Orpailleur vineyard with 2.0 to 6.1 specimens. At the Dietrich-Jooss vineyard, the capture rate for 1998 was very similar to that of the 1999 season, but at the L'Orpailleur vineyard, it was a little closer to that of the 1997 season. The adult mobility rate of ground beetles adapted to well-drained habitats was usually high. However, adult mobility of dry adapted species was more reduced during rainy periods (as in 1997) than that of more mesic adapted species of drained habitats that retained moisture.

2) Similarities in species diversity between the two vineyards.

With a good bio-indicator group, one assumes that a stable site will show each year a similar species composition and rank of captures, and that sites with similar physical conditions in a region will have a similar diversity (Rainio and Niemela 2003). Thus, the diversity between two sites with similar numbers of species but with different ecological variables showed some differences in species composition and rank of captures. Based on species data for each site (Table 2), from 62 to 72% of species were shared by both vineyards (Table 3).

3) Ranking of the more commonly captured species at each vineyard.

The large size of our annual samples allowed the evaluation of the relative ranking position of commonly trapped species at each vineyard (Tables 4 and 5). *Pterostichus melanarius* was consistently the most commonly captured species. Most (10 species in Table 4) of the commonly captured species showed a moderate range in ranking positions. For example, the capture rank of *Anisodactylus sanctaecrucis* placed this species between the second and fourth position over the three-year period. This rather consistent ranking among more commonly trapped species supported our hypothesis that ground beetles were likely good biological indicators of the environmental quality of agricultural sites. Some commonly captured species showed a much wider range of position over the years. *Pterostichus vernalis* is an unusual species. The near simultaneous discoveries in 1997 of the species south of Montreal at the Dietrich-Jooss vineyard and in Vermont 3 km south of the Canadian border (Byers et al. 2000) suggest that it had recently become established. Many more specimens were found in 1998 and 1999. We assume that the species is in the process of establishing its rank position among species of ground beetles in both vineyards. The rank position for many species ranks at the L'Orpailleur vineyard (Table 5) was similar to that of Dietrich-Jooss. However some of the most commonly captured species such as *Amara latior*, were peculiar to this site and other species were less commonly seen at the Dietrich-Jooss vineyard (Table 4). Soil with organic matter, sand and gravel is more appealing to ground beetles requiring very well drained habitats. Thus L'Orpailleur vineyard was diverse in species of *Amara* and *Harpalus*. Four species showed a greater rank range of position. The variation of the *Pterostichus melanarius* capture rates was unexpected. Captures of this species fell drastically in 1999. Perhaps the hot and dry conditions prevalent may have caused this species to become less active and to enter an aestivation period. *Agonum placidum* and *Harpalus rufipes* were more commonly captured after 1997. *Harpalus rufipes* was the more interesting of the two species. In 1997 at both sites, we captured the first specimens of this European species in southern Quebec. L'Orpailleur was the vineyard where the species became markedly common. In 1998, *H. rufipes* was often captured (position 9), and by 1999, it had become the sixth most commonly captured species of ground beetle at this site while remaining rare at the Dietrich-Jooss site. The L'Orpailleur site had a rank order that was quite consistent for at least nine species. Among the more commonly trapped species, *Chlaenius sericeus* and *Clivina fossor* best characterized the Dietrich-Jooss vineyard, and *Amara latior* and *Harpalus herbivagus* best characterized the L'Orpailleur vineyard.

4) Species diversity of each vineyard for a three-year period.

The Shannon index of diversity and evenness indexes showed consistently higher values at the L'Orpailleur vineyard (Table 6). The higher evenness value at the L'Orpailleur vineyard was due to a lower number of specimens of the few dominant and mostly adventive species than at the Dietrich-Jooss vineyard. At the Dietrich-Jooss vineyard adults of *P. melanarius* were dominant as this species represented 34 to 43% of all captures whereas in the L'Orpailleur vineyard there were no species with more than 20% of the total captures. Though we have no hard evidence, the marked dominance of a few adventive species may have displaced native species, leading to lower diversity and evenness indexes. Possibly, adults of some species became on average less mobile at both sites because the weather in 1999 was exceptionally hot and dry. Species with mesic adaptations may have been more affected at the L'Orpailleur vineyard because the sand and gravel loam dried even earlier. This is supported by samples from Wakefield, Quebec, where a very unusual shift in mobility rates occurred in 2001 (Goulet, unpubl. information). After many years of pesticides use, there was no increase in species diversity from 1997 to 1999 at each vineyard. The slight decrease in diversity observed at both sites in 1999 was more likely the result of a hot and dry period during the summer on the mobility rate of adults of some of the species.

Conclusions

Fifty-one species (7,535 specimens) and 54 species (3,685 specimens) were found respectively at the Dietrich-Jooss and the L'Orpailleur vineyards in southern Quebec between 1997 and 1999. There was 61 to 65% of species shared between both sites. The ranking position of commonly trapped species was similar for most species over the three-year study, but the species involved and the ranking order was partly different between the sites. Many of the trapped species were peculiar to each site, but among the most commonly trapped species, *Chlaenius sericeus* and *Clivina fossor* were much more common at the Dietrich-Jooss vineyard, and *Amara latior* and *Harpalus herbivagus* at the L'Orpailleur vineyard. These last differences between sites were likely due to different soil types. The Shannon and the evenness indexes though high in both sites were consistently higher at the L'Orpailleur site. The higher index values at the last site may have been due to the reduced dominance of a few weed species able to displace native species.

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Figures and Tables

Table 1. Sampling period and number of pitfall traps used in two commercial vineyards in southern Quebec.

		1997	1998 and 1999
Dietrich-Jooss	Sampling period	June 3 – Sept. 17	May 6 – Sept. 2
	Number of pitfalls/year	23	34
L'Orpailleur	Sampling period	June 10 – Sept. 17	May 6 – Sept. 2
	Number of pitfalls/year	16	20

Figure 1: Pitfall trap

Vineyard	Year	Number of specimens	Number of species	Percent species shared between the vineyards	Number of weeks	Mean number of adults/trap/week
Dietrich-Jooss	1997	1220	29	69	15	3.5
	1998	3034	41	68	17	5.3
	1999	3281	40	65	17	5.7
	Total	7535	51	65		
L'Orpailleur	1997	451	30	67	14	2.0
	1998	1176	39	72	17	3.5
	1999	2058	42	62	17	6.1
	Total	3685	54	61		

Table 3. Number of carabid specimens and species captured at each vineyard yearly, and yearly mean number of adults captured per trap weekly at each vineyard.

Carabid species	Year 1997	1998	1999	Average rank	Range in rank
Species with quite consistent rank					
Pterostichus melanarius (Illiger) !	1	1	1	1.0	1 - 1 (1)
Anysodactylus sanctaecrucis (Fabricius)	3	2	4	3.0	2 - 4 (3)
Harpalus pensylvanicus (DeGeer)	4	4	2	3.3	2 - 4 (3)
Bembidion quadrimaculatum oppositum Say	5	5	3	4.3	3 - 5 (3)
Clivina fossor (Linné) !	6	3	5	4.6	3 - 6 (4)
Stenolophus comma (Fabricius)	2	6	7	5.0	2 - 7 (6)
Harpalus affinis (Shrank) !	8	8	6	7.3	6 - 8 (3)
Poecilus lucublandus (Say)	10	7	8	8.3	7 - 10 (4)
Chlaenius sericeus sericeus (Forster)	11	11	9	10.3	9 - 11 (3)
Agonum placidum (Say)	12	9	10	10.3	9 - 12 (4)
Species with marked changes in rank					
Amara littoralis Mannerheim	9	15	14	12.6	9 - 15 (7)
Pterostichus vernalis (Panzer) !	21	13	17	17	13 - 21 (9)
Harpalus compar LeConte	30	10	11	17	10 - 30 (21)

Table 4. Ranking of carabids captured at the **Dietrich-Jooss** vineyard for the most commonly trapped species with a narrow range of relative position, followed by species showing marked range variations in relative position from 1997 to 1999. The "!" mark denotes an accidentally introduced species. The "average rank" is the sum of the rank position each year divided by 3. The "range in rank" is the lowest and highest rank recorded in the three-year period followed by the number of rank positions (in parentheses) within the range.

Carabid species	Year 1997	1998	1999	Average rank	Range in rank
Species with quite consistent rank					
Amara latior (Kirby)	1	2	4	2.3	1 - 4 (4)
Harpalus pensylvanicus (DeGeer)	4	3	1	2.6	1 - 4 (4)
Stenolophus comma (Fabricius)	3	4	5	4.0	3 - 5 (3)
Anisodactlus sanctaecrucis (Fabricius)	5	5	2	4.0	2 - 5 (4)
Bembidion quadrimaculatum oppositum Say	6	8	3	5.6	3 - 8 (6)
Harpalus affinis (Shrank) !	10	7	7	8.0	7 - 10 (4)
Poecilus lucublandus (Say)	8	10	10	8.6	8 - 10 (3)
Clivina fossor (Linné) !	9	12	12	11.0	9 - 12 (4)
Harpalus herbivagus Say	14	13	11	12.6	11 - 14 (4)
Species with marked changes in rank					
Pterostichus melanarius (Illiger) !	2	1	9	4.0	1 - 9 (9)
Agonum placidum (Say)	19	6	8	11.0	6 - 19 (14)
Harpalus rufipes (DeGeer) !	21	9	6	12.0	6 - 21 (16)
Amara aulica (Panzer) !	7	11	20	12.6	7 - 20 (14)

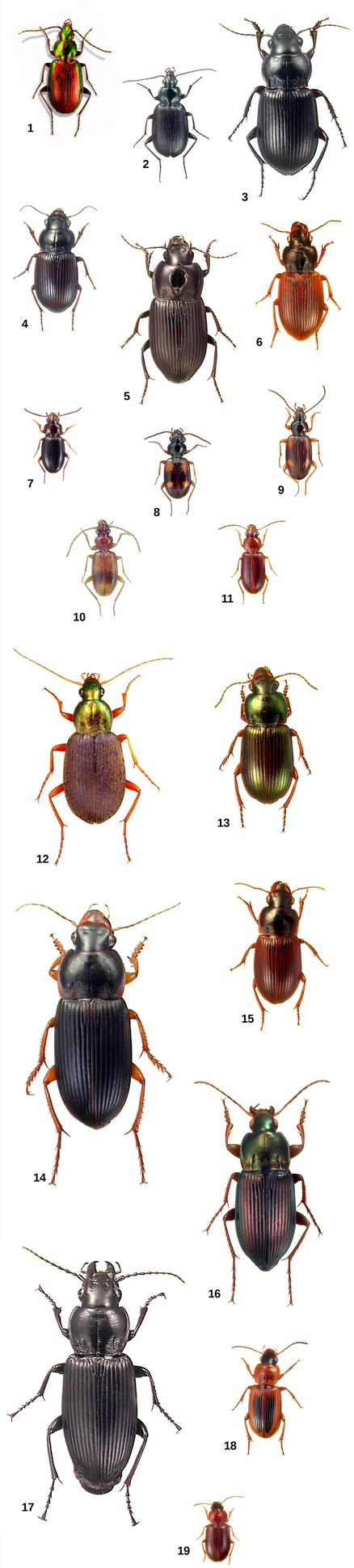
Table 5. Ranking of carabids captured at the **L'Orpailleur** vineyard for the most commonly trapped species with a narrow range of relative rank positions, followed by species showing marked range variations in relative rank from 1997 to 1999. The "!" mark denotes an accidentally introduced species. The "average rank" is the sum of the rank position each year divided by 3. The "range in rank" is the lowest and highest rank positions recorded in the three-year period followed by the number of rank positions (in parentheses) within the range.

Vineyard	Year	Shannon index (H')	Evenness index (J')
Dietrich-Jooss	1997	2.20	0.59
	1998	2.07	0.51
	1999	2.21	0.56
	1997-1999	2.22	0.51
L'Orpailleur	1997	2.69	0.77
	1998	2.87	0.71
	1999	2.65	0.63
	1997-1999	2.84	0.63

Table 6. Shannon index (H') and evenness index (J') for each site and year of each sample.

Table 2. Number of carabids captured over a three-year period and expected to breed in each vineyard. The "!" mark denotes an introduced species. Numbers preceding species refer to photographs on right.

Carabid species	Dietrich-Jooss 1997	1998	1999	L'Orpailleur 1997	1998	1999
[1]*Agonum cupripenne* (Say)		1			2	
Agonum muelleri (Herbst) !		3				
Agonum nutans (Say)		1				
[2]*Agonum placidum* (Say)	8	32	41	3	65	75
Amara aenea (DeGeer) !	5	9	20		19	15
Amara angustata (Say)				5	1	7
Amara apricaria (Paykull) !		1	3	1	2	3
[3]*Amara aulica* (Panzer) !	2	5	3	22	29	13
[4]*Amara avida* (Say)	3	6	9			2
Amara bifrons Gyllenhal !						1
Amara convexa LeConte				2		
Amara cupreolata Putzeys					1	
Amara familiaris (Duftschmid) !		2	5		2	4
Amara impuncticollis (Say)				9	13	
Amara latior (Kirby)	38			87	165	188
Amara littoralis Mannerheim	20	8	17	3	10	24
Amara musculis (Say)						1
Amara patruelis Dejean				1		
Amara rubrica Haldeman			3			
[5]*Anisodactylus harrisii* LeConte	4	6	1	9	11	18
Anisodactylus nigerrimus (Dejean)					2	
[6]*Anisodactylus sanctaecrucis* (Fabricius)	181	343	342	28	92	321
Bembidion nitidum (Kirby)					1	1
Bembidion obscurellum (Motschulsky) !		3	3			
[7]*Bembidion obtusum* Audinet-Serville !		1				1
[8]*Bembidion quadrimaculatum oppositum* Say	80	175	360	27	50	205
[9]*Bembidion tetracolum* Say !		2	2			
[10]*Blemus discus* (Fabricius) !		3	6			
Bradycellus neglectus (LeConte)	1		2	1		
Bradycellus nigriceps LeConte		3	4			2
[11]*Bradycellus rupestris* (Say)		3	5	5	18	23
Calathus opaculus LeConte					1	
Carabus granulatus granulatus Linné !			1			
Chlaenius sericeus sericeus (Forster)	15	30	44			
[12]*Chlaenius tricolor* Dejean	6	27	14	6	18	15
Cicindela punctulata punctulata Olivier			3			
Cicindela sexguttata sexguttata Fabricius	7	4	4	1	2	
Clivina fossor (Linné) !	49	270	249	15	24	33
Cymindis americanus Dejean				1	1	
Diplocheila obtusa (LeConte)	1	5			9	16
Dyschirius globulosus (Say)		4	1		7	1
Elaphropus anceps (LeConte)					6	27
Elaphropus incurvus (Say)	2	7	22	8	13	10
[13]*Harpalus affinis* (Schrank) !	36	89	199	13	59	106
Harpalus compar LeConte		31	25	1		4
Harpalus erythropus Dejean		1	4	1	2	4
Harpalus fallax LeConte	1			4	3	5
Harpalus faunus Say		2	4	1	3	
Harpalus herbivagus Say	3	7	4	8	22	38
Harpalus indigens Casey					5	
Harpalus longicollis LeConte		1				1
[14]*Harpalus pensylvanicus* (DeGeer)	125	268	652	36	164	525
Harpalus plenalis Casey						2
Harpalus reversus Casey	1					
Harpalus rubripes (Duftschmid) !						1
Harpalus rufipes (DeGeer) !	1	1	2	2	34	124
[15]*Harpalus somnulentus* Dejean						1
Lebia fuscata Dejean						1
Lebia grandis Hentz						1
Lebia solea Hentz		1				
Patrobus longicornis (Say)	1	2	1			
Poecilus chalcites (Say)		8	5			
[16]*Poecilus lucublandus* (Say)	17	98	53	16	32	43
[17]*Pterostichus melanarius* (Illiger) !	422	1401	1069	82	192	54
Pterostichus vernalis (Panzer) !	1	16	8		1	3
Selenophorus gagatinus Dejean						1
[18]*Stenolophus comma* (Fabricius)	188	152	87	53	94	138
[19]*Stenolophus conjunctus* (Say)	1		3			
Stenolophus lineola (Fabricius)	1					
Syntomus americanus (Dejean)				1		
Trechus rubens (Fabricius) !			1			
Total of specimens	**1220**	**3034**	**3281**	**451**	**1176**	**2058**
Grand total of specimens (3 yrs)			**7535**			**3685**
Total number of species	**29**	**43**	**42**	**30**	**39**	**42**
Grand total of species (3 yrs)			**51**			**54**
Number of trapping weeks	**15**	**17**	**17**	**14**	**17**	**17**
Mean number of adults/trap/week	**3.5**	**5.3**	**5.7**	**2.0**	**3.5**	**6.1**
Number of species shared between the two vineyards	**20**	**28**	**26**	**20**	**28**	**26**
Percentage of species shared	**69**	**68**	**65**	**67**	**72**	**62**
Total of species shared			**65**			**61**
Shannon index of diversity (H')	**2.20**	**2.07**	**2.21**	**2.69**	**2.87**	**2.65**
Shannon index of diversity (H') (3 yrs)			**2.22**			**2.84**
Evenness index (J')	**0.59**	**0.51**	**0.56**	**0.77**	**0.71**	**0.63**
Evenness index (J') (3 yrs)			**0.51**			**0.63**



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