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Temporal dynamic of a ground beetle community of Eastern Alps (Coleoptera Carabidae)

Vittoria GNETTI[1,2], Pierluigi BOMBI[1], Augusto VIGNA TAGLIANTI[3], Marco Alberto BOLOGNA[1,2], Ettore D'ANDREA[1], Mario CAMMARANO[1], Marco BASCIETTO[1,4], Bruno DE CINTI[1], Giorgio MATTEUCCI[1,5]
[1]*National Research Council - Institute of Agro-environmental and Forest Biology, Monterotondo, Rome, Italy*
[2]*Dipartimento di Scienze, Università Roma Tre, Rome, Italy*
[3]*Dipartimento di Biologia e Biotecnologie, Università di Roma "Sapienza", Rome, Italy*
[4]*Council for Agricultural Research and Economics - Research unit for Climatology and Meteorology applied to Agriculture, Rome, Italy*
[5]*National Research Council - Institute of Agriculture and Forestry Systems in the Mediterranean, Rende, Cosenza, Italy*

Abstract

Ground-beetles are often used in biodiversity assessment and conservation plans as they are easily captured, are taxonomically well known, and respond to changes in habitat structure. An investigation of carabid beetle communities of a managed spruce forest in eastern Alps (Cadore, Veneto region, Italy) was carried out. Samples were collected by pitfall traps from May to September (2013). We positioned the pitfall traps across different sample units (i.e. forest stands), at an elevation between 800 and 1500 m a.s.l. We sampled 22 species of Carabidae and 7,420 individuals. We investigated the phenology appearance of adult Carabidae to understand the temporal variation in species richness, diversity, and community composition. The study of the variation of species composition along time and the ecological structure of carabids assemblages during sample sessions allow to understand temporal dynamics of each structural parameters of communities and to analyse in detail how the ground beetle communities arrange across time. We observed a great species replacement during the season, with different species showing different temporal patterns of activity. This temporal information could be useful for management plans and for further studies on ecological communities of beetles to plan sampling programme because allow understanding how local communities arrange along season.

Key words: mountain ecosystems, Carabidae, species richness, temporal dynamic, phenology.

Introduction

Eastern Alps have great conservation importance. The Italian Dolomites have recently been included among the Unesco Heritages sites (UNESCO 2009, Report of decisions of the 33rd session of the World Heritage Committee). Alpine sites are of great interest for ecological and biogeographic research since harsh abiotic conditions, along with high spatial heterogeneity, dominate these mountain ecosystems, in stark contrast to the surrounding landscapes (Lomolino, 2001; Brandmayr *et al.*, 2003b). In recent years, many activities linked to the pastoralism in the Alps have stopped. The abandonment of traditional pastoral practices, and the consequent absence of grazing domestic animals, lead to shrubs and bushes encroachment, with a modification of the wild fauna and negative consequences for animal diversity including birds (Laiolo *et al.*, 2004), grasshoppers and butterflies (Marini *et al.*, 2009). The Alps has numerous species with restricted ranges (endemic species), which are often ancient lineages that survived in Pleistocene alpine refugees (Brandmayr *et al.*, 2003a).

Carabid beetles (Coleoptera Carabidae), with more than 35,000 species, represent a non-negligible component of biodiversity (Lorenz, 2005), with about 700-800 species in central Europe (Vigna Taglianti, 2004). Italy has 1381 species, in 192 genera (Vigna Taglianti, 2005, with unpublished revision). Carabids are used as indicators species of environmental and ecological aspects because they are diverse, abundant, well known taxonomically, and sensitive to environmental variables (Lövei and Sunderland, 1996; Brandmayr *et al.*, 2005; Pearce and Venier, 2006; Koivula, 2011). Furthermore, they are particularly linked to the soil, with a specific ecology and a tendency to the endemism (Thiele, 1977; Casale *et al.*, 1982).

In habitat with extreme seasonal changes of environmental conditions (e.g. temperature, snow cover, vegetation structure), like on the Alps, invertebrate species have a short period of time available for reproduction and the structure of communities changes across time in response to the specific phenologies (Brandmayr *et al.*, 2005). In mountain ecosystems, during winter, only few invertebrate species is active because of the extreme weather conditions (Vanin and Turchetto, 2007). In general, the carabid activity is restricted to a rather short summer period and is divided into early and late-breeders species (Harry *et al.*, 2011).

There exist many quantitative studies on the distribution of carabid beetles in various habitats in Europe. More in detail, associations of particular species with broad habitat categories related to a different type of forest management, have been established generally for carabids in the context of taxonomic and faunal work (Magura *et al.*, 2000; Paillet *et al.*, 2010; Baini *et al.*, 2012). However, recent studies on the temporal dynamic and on the phenology assemblages of forest carabids are particularly rare (Brandmayr *et al.*, 2005).

The main aim of this research is the description of the temporal dynamic of a carabid beetle community in the Eastern Alps. More in detail, we focused on the seasonal activity and phenology of carabids species. The temporal analysis of the carabids community structure aims to point out the changes in the diversity of species as well as in the species composition (Cartellieri and

Lövei, 2003). We investigated some aspects of the species community structure (observed and estimated species richness and diversity) and we observed as these parameters change along sampling session. In particular, our study conducted in the Dolomites (Eastern Alps), used a qualitative and quantitative ecological approach, aimed to analyze the variation in the structure of the species assemblages across time. We focused also on the species ecological characteristics (wing morphology, food adaptation and microhabitat) and we investigated the temporal dynamics of these parameters.

Methods

Sampling was carried out in the woodlands (1082 ha) of the main valleys (Val de Cridola, Val Frison, Val del Piova and Val Mauria) around the village of Lorenzago di Cadore (Veneto Region, Italy, figure 1), characterized by forests of Norway spruce (*Picea abies*) and European silver fir (*Abies alba*) with sporadic Larch (*Larix decidua*) and Beech (*Fagus sylvatica*) trees. We installed 92 pitfall traps, placed randomly by mean of a GIS (Geographic Information System). We positioned the pitfall traps across eleven sample units (i.e. forest stands) with an average dimension of 28.16 ha (figure 1) at an elevation between 800 and 1500 m a.s.l. Nevertheless, the stands were not distributed along a homogeneous elevation gradient because only one stand was positioned at high elevation (1500 a.s.l.) and all the remaining stands at medium elevations. The total number of pitfall traps, corresponding to eight traps per sample unit, represents the minimum unit to obtain a sufficient level of saturation of the local communities, according to literature (Ward *et al*., 2001; Pearce *et al*., 2005; Baini *et al*., 2012). Traps were located at more than 50 m from each other and from the forest edge in order to ensure data independence and to avoid edge effect (Digweed *et al*., 1995; Magura *et al*., 2000; Baker and Barmuta, 2006). Pitfall traps were active for about three months and half, from 17 May to 6 September 2013 and were emptied every second week. Months before May and after September are characterized by frozen soil or snow, and no ground beetle activity. We obtained a measure of the total sampling activity of 1656 trap-weeks. During the sample session, we lost 6 pitfall traps (2 due to flood and 4 damaged by animals and human). Trapped Carabidae were identified to species level using keys to European Carabidae in Trautner and Geigenmüller (1987). The voucher specimens became part of the private collection of the specialist Augusto Vigna Taglianti.

We measured the total sampling effort computing the angular coefficient (slope) of a line intersecting the last 10% of the total species accumulation curves (Colwell and Coddington, 1994; Gotelli and Colwell, 2001).

We analysed the temporal variations of activity density for individual species as well as dynamic of species richness and community diversity in the different stands. We used the number of observed species per sampling unit as a measurement of community and it underlies many ecological models and conservation strategies (Cornell, 1999; Gotelli and Colwell, 2001). We tested the significance of temporal trends of observed species richness and diversity using the analysis of variance, by computing the ANOVA F-ratio tests for analysing variation in a continuous response variable (Quinn and Keough, 2002). We tested the significance of the different patterns of the temporal dynamic of the species ecological preferences using Spearman rank correlation coefficient (ρ). We used Spearman non-parametric correlation analysis in order to detect monotonic relationships between variables (Quinn and Keough, 2002).

We computed Bray-Curtis measure of ecological distance in order to obtain a quantitative measure of compositional species dissimilarity over time (Bray and Curtis, 1957; Quinn and Keough, 2002). We used the Bray-Curtis equation as:

$$BC = \sum_{j=1}^{p} \left| y_{1j} - y_{2j} \right| \Big/ \sum_{j=1}^{p} \left(y_{1j} + y_{2j} \right)$$

y_{1j} and y_{2j} are the abundances of species j in sampling session 1 and 2, $\sum_{j=1}^{p} \left(y_{1j} + y_{2j} \right)$ is the sum of the abundance of species j in both sampling sessions.

We calculated the Shannon diversity index (Shannon and Weaver, 1949; McCarthy, 2004) to detect changes in species relative abundance in the different stands.

The observed species richness is an underestimation of the total number of species actually present (Colwell and Coddington, 1994). Therefore, we used the first order Jackknife estimator (Burnham and Overton, 1979), calculating the expected species richness in each unit as:

$$S_p = S_O + \left[a_1 \left(N - {}^{1}\!/_{N} \right) \right]$$

Where S_0 is the observed number of species in the unit, a_1 is the number of species occurring only in one trap of the unit (singletons), and *N* is the number of traps in the unit. According to literature, we chose the first order Jackknife because it is particularly effective in highly intensity sampled communities (Colwell and Coddington, 1994; Brose and Martinez, 2004).

Additionally, we analysed the ecological characteristics of the most common species of our sample, especially their phenology. We classified species in different

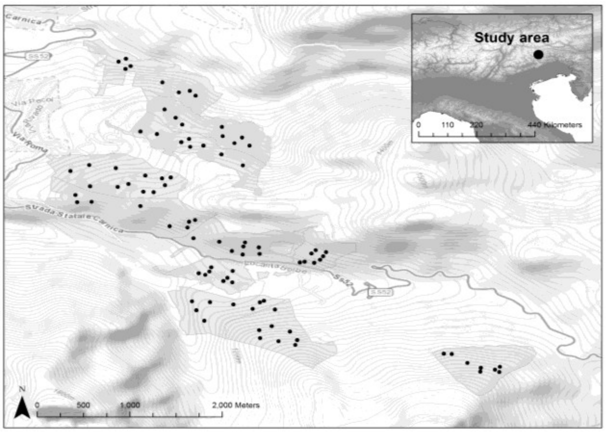

Figure 1. Sample units in the municipality of Lorenzago di Cadore, district of Belluno, Veneto (Italy). Black dots indicate trap positions. Sample units are delimited by grey lines.

Table 1. List of species (with subspecies) collected in the study area with indication of food adaptation, micro-habitat and wing morphology.

Species	Food adaptation	Micro-habitat	Wing morphology
Carabus (*Eucarabus*) *arcensis venetiatus* Bernau 1914	oligophagous	forest	brachypterus
Carabus (*Tachypus*) *cancellatus emarginatus* Duftschmid 1812	polyphagous	forest	brachypterus
Carabus (*Tomocarabus*) *convexus dilatatus* Dejean 1826	polyphagous	forest	brachypterus
Carabus (*Platycarabus*) *creutzeri creutzeri* F. 1801	oligophagous	forest	brachypterus
Carabus (*Megodontus*) *germarii germarii* Sturm 1815	oligophagous	forest/prairie	brachypterus
Cychrus angustatus Hoppe et Hornschuch 1825	oligophagous	forest	brachypterus
Cychrus attenuatus attenuatus (F. 1792)	oligophagous	forest	brachypterus
Leistus nitidus (Duftschmid 1812)	oligophagous	forest	macropterus
Notiophilus biguttatus (F. 1779)	oligophagous	forest	macropterus
Ocydromus deletus deletus (Audinet-Serville 1821)	polyphagous	forest/prairie	macropterus
Pterostichus (*Bothriopterus*) *oblongopunctatus* (F. 1787)	polyphagous	forest	macropterus
Pterostichus (*Haptoderus*) *unctulatus* (Duftschmid 1812)	polyphagous	forest	brachypterus
Pterostichus (*Cheporus*) *burmeisteri burmeisteri* Heer 1838	polyphagous	forest	brachypterus
Pterostichus (*Pterostichus*) *fasciatopunctatus* (Creutzer 1799)	polyphagous	forest	brachypterus
Molops piceus austriacus Ganglbauer 1889	oligophagous	forest	brachypterus
Abax (*Abax*) *parallelepipedus inferior* (Seidlitz 1887)	oligophagous	forest	brachypterus
Abax (*Abax*) *pilleri* Csiki 1916	oligophagous	forest	brachypterus
Harpalus laevipes Zetterstedt, 1828	polyphagous	forest/prairie	macropterus
Trichotichnus (*Trichotichnus*) *laevicollis* (Duftschmid 1812)	polyphagous	forest/prairie	macropterus
Synuchus vivalis vivalis (Illiger 1798)	polyphagous	forest/prairie	macropterus
Laemostenus (*Actenipus*) *elegans* (Dejean 1828)	oligophagous	forest	brachypterus
Lymodromus assimilis (Paykull 1790)	polyphagous	forest/prairie	macropterus

categories choosing their trophic habit, their wings morphology (brachypterous: species lacking wings; macropterous: species with wings) and their microhabitat preferences (open habitat, indicated as open forest and prairie species; forest specialist species). Then, we analysed the temporal dynamic of every ecological characteristics and we described in detail the climate condition (thermophilic or mesic) requested by forest specialist species.

Finally, we analysed the level of activity of the community along the season and the peak of activity for each species in different sample sessions (eight sample sessions from May to September every second week) to understand the phenology of the single species. We used the quartile method proposed by Fazekas *et al.* (1997). More in details, the period of species activity was divided into four quartiles (25, 50, 75 and 100%), based on the total number of individuals. The maximum peak of activity measures the date when 50% of the total number of individuals was caught.

Results

We collected 7,420 individuals belonging to 22 different species of Carabidae. We reported the species names and their ecological characteristics (wing morphologies, food specialization and microhabitat) (table 1).

Concerning the total sampling effort, the slope of the final interval of the species accumulation curves is in a range between 0.01 and 0.06, depending on the stands.

The measure of compositional species dissimilarity along sessions shows a high temporal turnover of species at the beginning and at the end of the season. On the contrary, the temporal turnover of species shows low values of dissimilarity in the central part of the season (figure 2).

The temporal trend of observed species richness was highly heterogeneous among stands (figure 3A). Species richness reached the maximum value in the third sample sessions (June/July) and then decreased to a similar value of the beginning in the last session (September). Overall, the number of species in each unit changes across sampling sessions (F = 7.559, p < 0.001): it started from 5-12 in the first session, raised up to 9-14 in the second one, and then gradually fell back to 5-10 in the final session (figure 3).

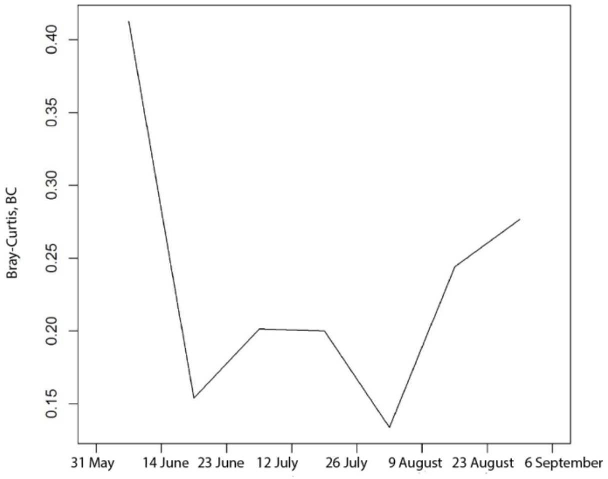

Figure 2. Compositional species dissimilarity over time (Bray-Curtis measure). The single line represents the measured temporal trend of the total species dissimilarity.

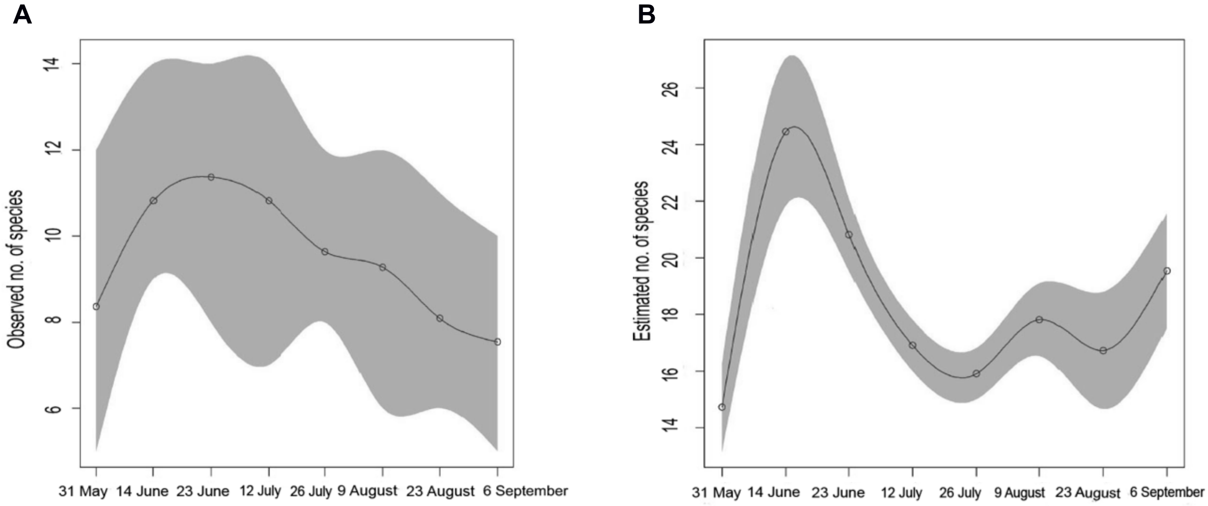

Figure 3. Temporal trend of observed species richness for ground beetles across the activity season. Sampling sessions span from mid-May to early-September. The lines represent the mean estimated richness value. (A) The number of species is calculated as the average richness among all the considered forest stands. The grey band indicates the range of variation across stands. (B) The number of species is calculated by jackknife method (see text for the details). The grey band indicate the standard error in the calculation.

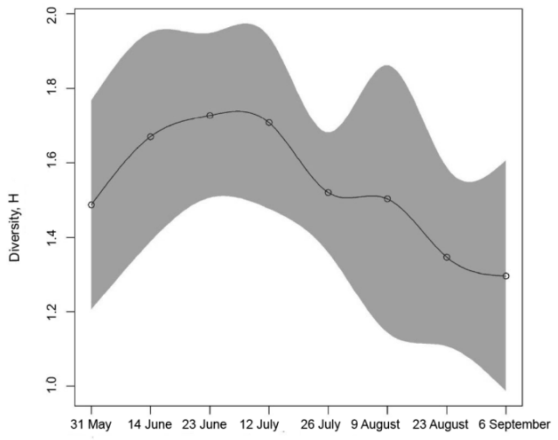

Figure 4. Temporal trend of species diversity for ground beetles across the activity season. The species diversity (Shannon index) is calculated as the average diversity among all the considered forest stands. The grey band indicates the standard deviation across stands.

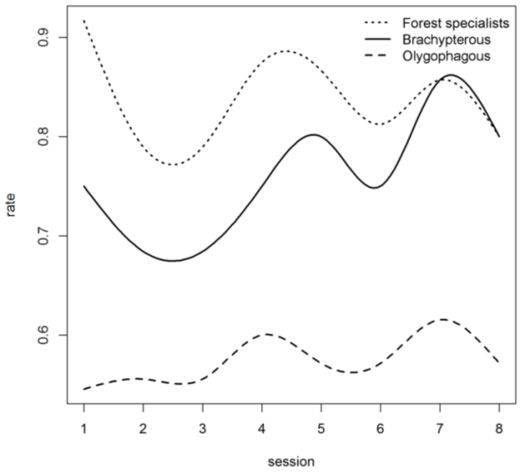

Figure 5. Temporal trend of the ecological characteristics of the species. Wing morphology (brachypterous), food adaptation (olygophagous) and microhabitat (forest specialists).

The temporal dynamic of observed and estimated species richness were similar (figure 3). The highest values of estimated as well as observed species richness occurred in the second sampling session (early June). Some differences between the two curves included the main peak being earlier for the estimated value, and the reduction stopped after the fourth session. The community diversity result shows statistical differences along periods ($F = 7.559$, $p < 0.001$).

Similarly to species richness, diversity reached a maximum in the first half of the season, in the second, third, and fourth sampling sessions. After this period, the diversity gradually decreased (figure 4). The total species diversity calculated for the entire sampling period and for the ensemble of all units was a Shannon index of 2.09.

The temporal dynamic of the species ecological preferences show different patterns (figure 5). Species microhabitat preferences do not change during the season. In fact, the rate of forest specialists does not show any clear temporal pattern (figure 5; Spearman: $\rho = -0.131$, $p = 0.755$). On the contrary, species food adaptations and wing morphologies become different across the season. Both the rates of olygophagous and brachypterous species grow along time (figure 3; Spearman: $\rho = 0.749$, $p = 0.03$; $\rho = 0.741$, $p = 0.03$ respectively).

Concerning the temporal dynamic of each species, we represented the activity peak of the total community (figure 6) and that of the single species (figure 7). The total temporal activity graphic shows that we reached the 25% of the community activity before the third sampling session (at the end of June). Then, we measured the maximum community activity peak before the fourth session,

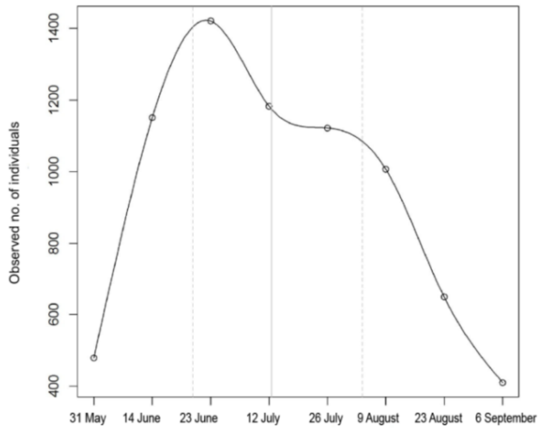

Figure 6. Temporal trend of observed community activity. The three lines represent the period of the total species activity (25%, 50%, and 75%), based on the total number of observed individuals.

in the middle of our sample (12 July). Finally, we obtained the 75% of the total activity peak before the sixth session, at the beginning of August (figure 6). The results of the single species activity peak show a high level of heterogeneity (figure 7). More in detail, five species (*C. arcensis*, *M. piceus*, *N. biguttatus*, *O. deletus*, *P. fasciatopunctatus*) had the main peak of activity on the first third of the sampling season and can be defined as early-breeders. Seven species (*A. parallelepipedus*, *A. pilleri*, *C. cancellatus*, *C. creutzeri*, *L. assimilis*, *P. oblungopunctatus*, *P. unctulatus*) were more abundant in the central third of the season, and five species (*C. germarii*, *C. attenuatus*, *L. elegans*, *L. nitidus*, *S. vivalis*) were late-breeders, being more abundant in the third part of the season. Four species (*C. convexus*, *C. angustatus*, *H. laevipes*, *T. laevicollis*) had long periods of activity, being similarly abundant for most of the season. *P. burmeisteri* had a bimodal pattern of activity, with the highest number of individuals during June and the beginning of August.

The most abundant species was *P. burmeisteri*, with about 400 individuals in four sampling sessions. Four of the seven species mainly active in the central part of the season were rather abundant (> 100 individuals in at least one session). Only one early-breeder and one late-breeder species were abundant (> 100 individuals in at least one session). All the species with long-spanning activities were very rare (< 10 individuals per session).

Discussion

The measure of the slope of the species accumulation curves was very low and almost completely horizontal, indicating that our sampling provided a near-complete representation of the carabid assemblages present in the study area by installing 92 traps.

The low value of compositional species dissimilarity in the central part of the sampling show that the community reach the stability in the summer period (June and July). On the contrary, the high value of community dissimilarity between sessions at the beginning and at the end of the sample highlights the sporadic presence of different species.

The majority of the assemblage was active in the springtime and at the beginning of the summer period (June and July). The high species richness value obtained in the first part of the sampling period is confirmed by the trends of the Shannon index. The values indicated high diversity in the second, third and fourth sessions, indicating heterogeneity and a high replacement of species. The estimated number of species reached his peak earlier than the observed one. This is due to two factors: first because common species in the central part of the season are present in the first phase only in small number, second because of the higher proportion of rare species present in the first part of the season (*C. arcensis*, *N. biguttatus*, *O. deletus*). For the same reasons, the reduction of the observed species richness occurring at the end of the season is less evident for the estimated number of species. The rare species occur with few individuals along the entire sampling season (*H. laevipes*, *L. elegans*, *S. vivalis*) but appear especially at the beginning and at the end of the season, rather than in the central one, increasing the probability of non-detection. In the central part of the season, observed and estimated species richness were more similar. The late-breeder species (*C. attenuatus* and *C. angustatus*) show a very high activity density in the later sample session (figure 7). In fact, highest activity is recorded in September for males and in November for females (Loreau, 1985). According to this attitude, the trapping period for these two species was not exhaustive.

The most abundant in our samples were forest specialist species; there were few generalist and eurytopic species such as *H. laevipes*, *L. assimilis*, *O. deletus*, *C. germarii* and *S. vivalis*, none of which were abundant. Concerning the temporal dynamics of the species ecological preferences, we hypothesized that the increase of carabids diversity, characterized by a greater number of olygophagous species along sampling sessions, might indicate a response to an increase in prey supply. More in detail, the change of the carabids ecology could be determined by the structural diversity of the habitat along session (the ground flora conditions) and consequently by the densities of other soil surface macro-invertebrates (Butterfield, 1997).

The majority of sampled species were brachypterous, with reduced or absent wings. Flightlessness and flight dimorphism, as anatomical condition (some individuals in a given species have wings, others do not) has repeatedly evolved in ground beetles. The high number of flightless individuals usually reflect increasing habitat persistency and time since colonization in stable habitats (Brandmayr, 1991). In addition, the alpine habitats hold high rates of brachypterous species as result of evolutionary processes (Schoville *et al*, 2012). In accordance with these hypotheses, all species collected in high numbers were flightless, including *A. parallelepipedus*, *A. pilleri*, *P. burmeisteri*, *M. piceus*, *P. unctulatus* and *C. attenuatus*.

Regarding the ecological preferences of the more abundant species, it is possible to identify four main groups from the more to the less specialized:

(a) Thermophilic forest species. (a1) *P. burmeisteri*: it is conditioned by microclimate conditions of his niche, with a particular preference for humid site. It is more

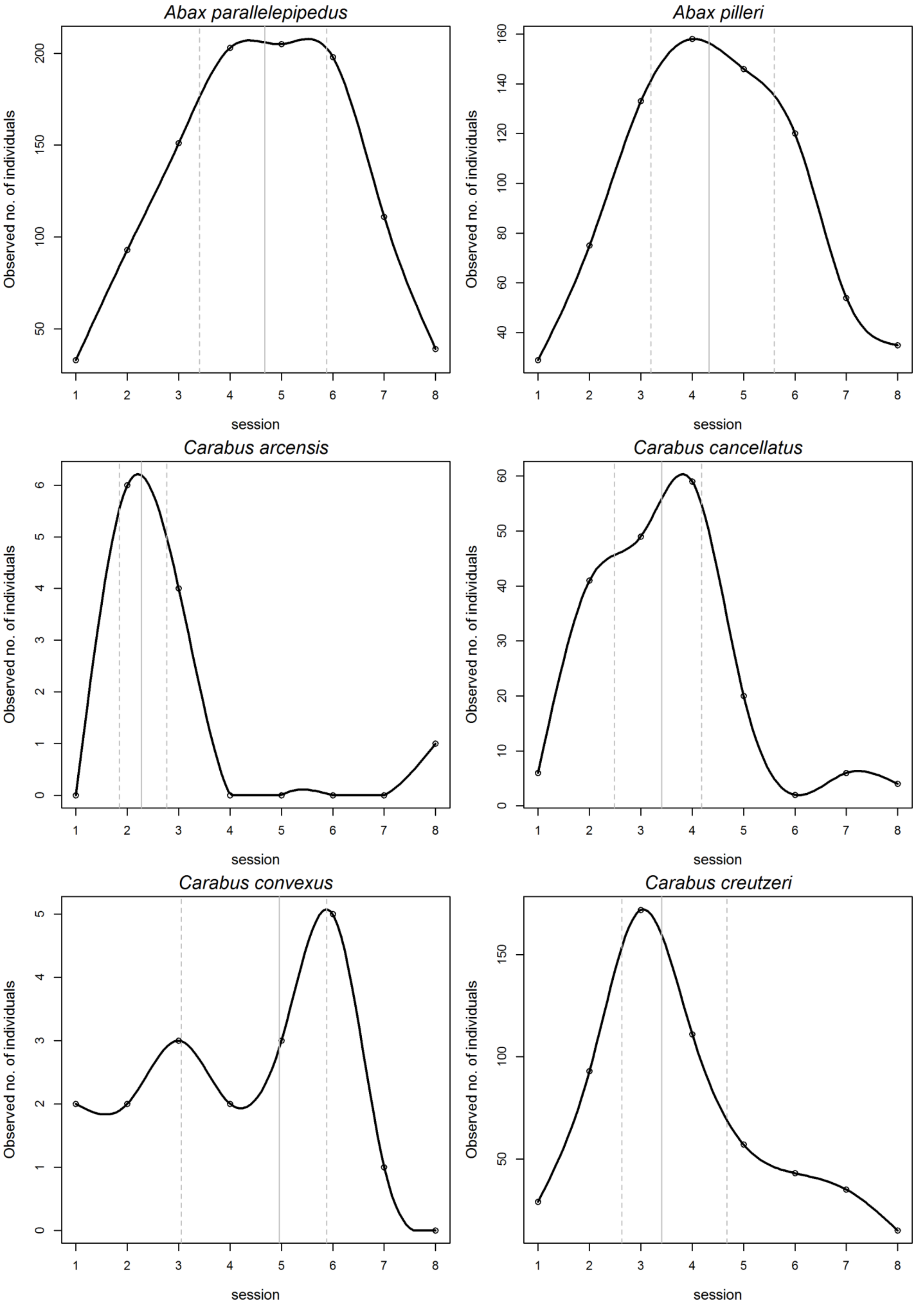

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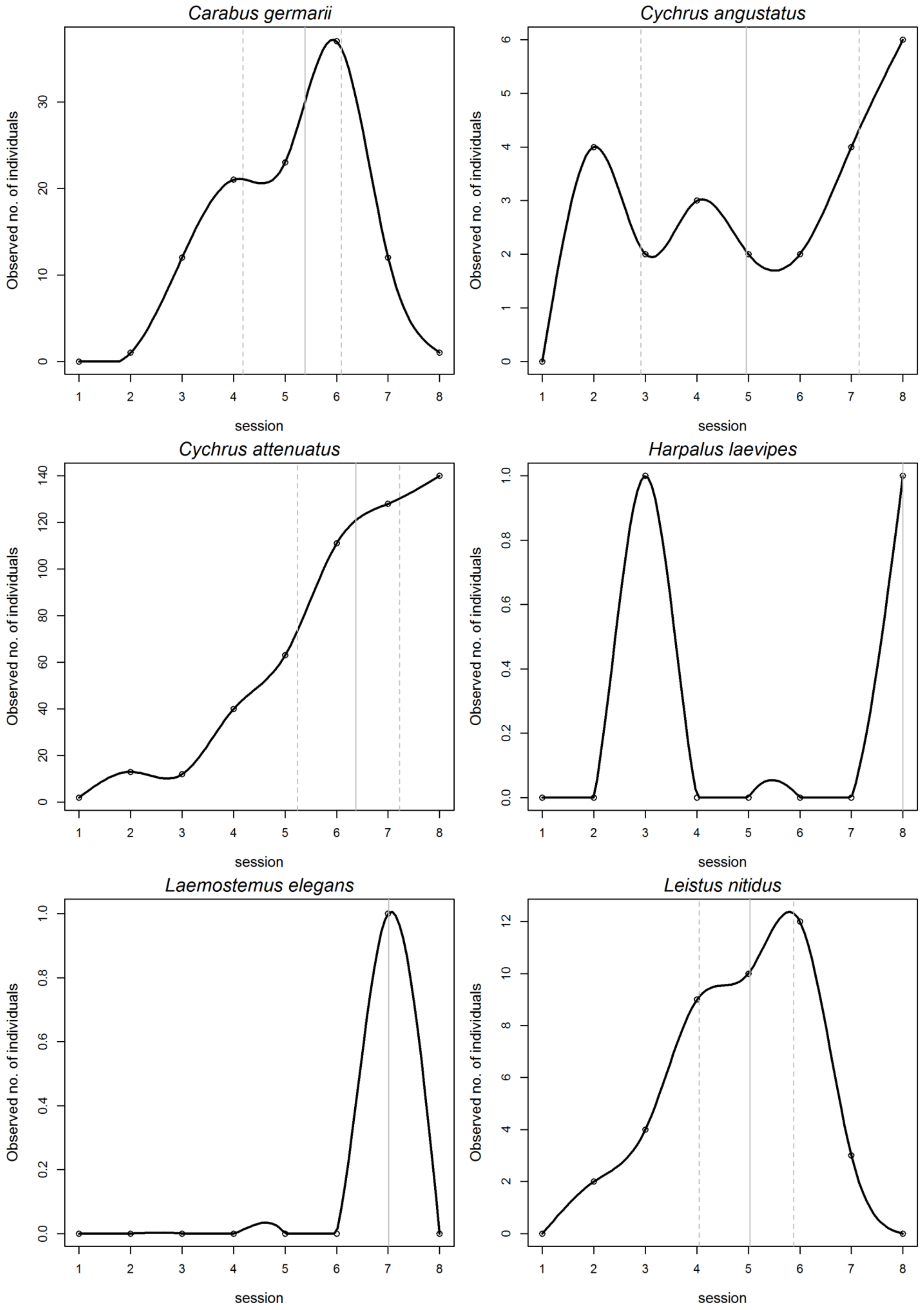
Figure 7. Temporal trend of observed species activity. The three lines represent the period of the single species activity (25, 50 and 75%), based on the total number of observed individuals.

(Figure 7 continued)



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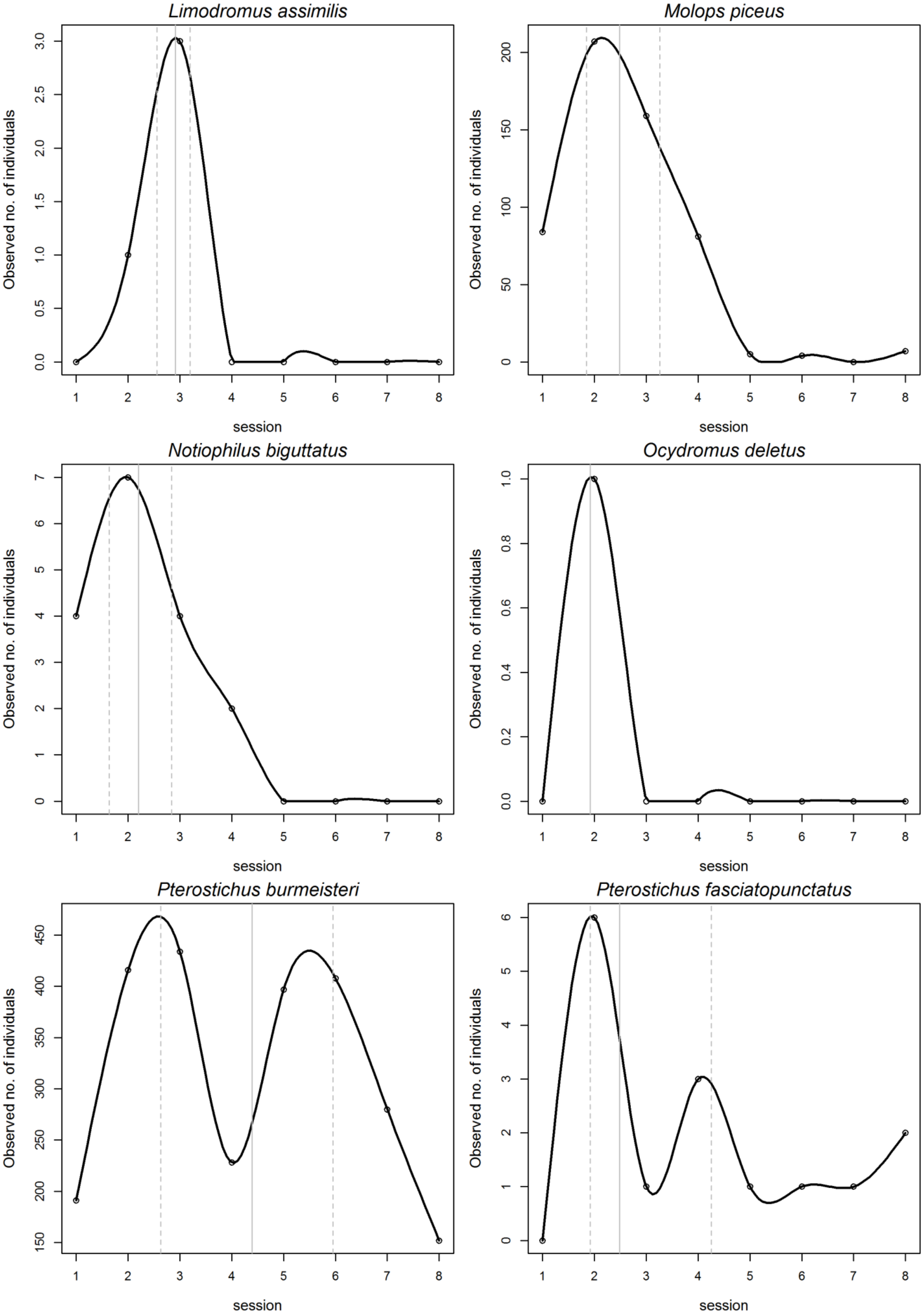

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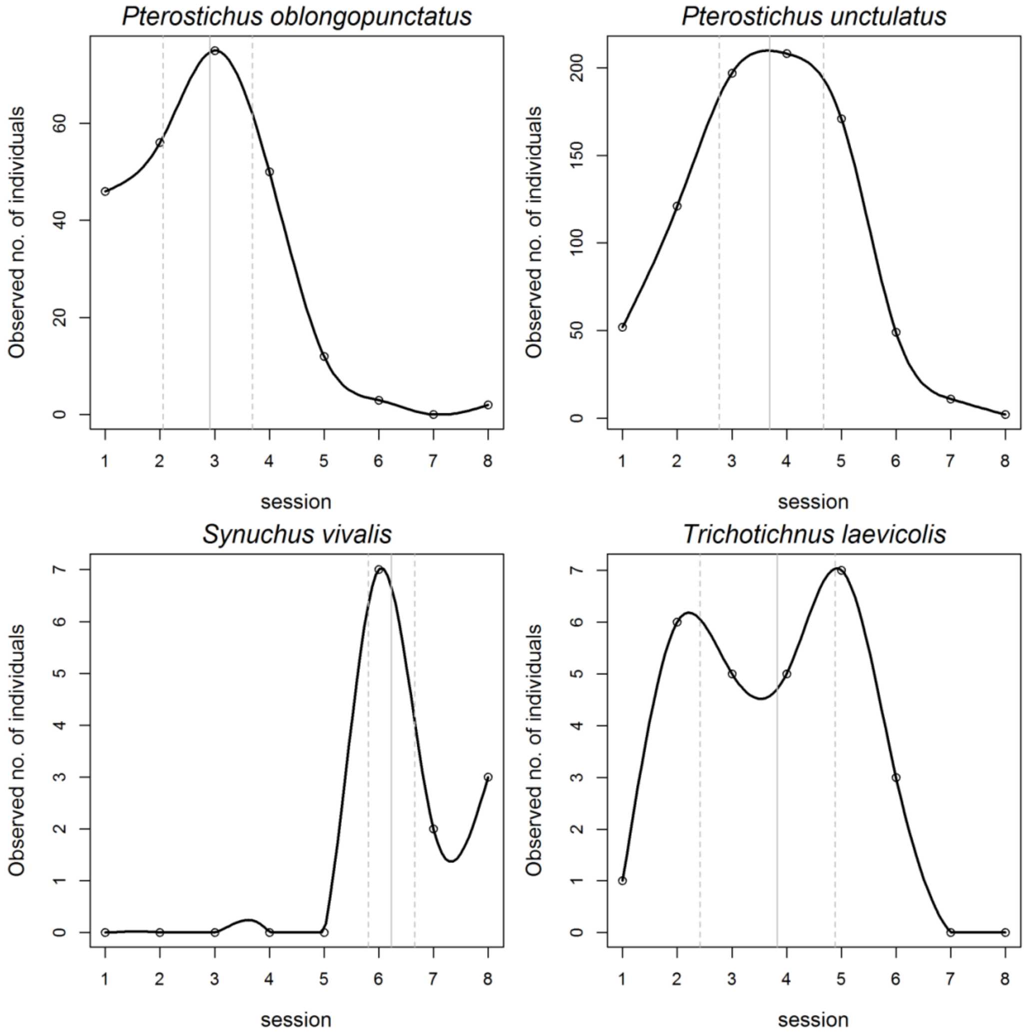

Figure 7. Temporal trend of observed species activity. The three lines represent the period of the single species activity (25, 50 and 75%), based on the total number of observed individuals.

abundant in sample units with the average monthly minimum temperature of −1.6 °C (Brandmayr and Zetto Brandmayr, 1987). (a2) *M. piceus:* it is endemic to Eastern Alps. In particular, this species prefers humid and cold sites and in the Alps is frequent from the subatlantic to the boreal forest biome (Brandmayr *et al.*, 2005). It is linked to mature and poor soils, and the larvae are specialized to feed on earthworms (Brandmayr and Zetto Brandmayr, 1987).

(b) Mesic forest species. (b1) *C. attenuatus*: it is typical of spruce forests. We found the majority of individuals in sites with an average monthly minimum temperature of −1.6 °C. This species prefers young soils for the trophic attitude of the adult individuals to eat snails (Brandmayr and Zetto Brandmayr, 1987).

(c) Generalist forest species. (c1) *A. parallelepipedus*: is one of the most common species in our sample, especially distributed in thermophilic or mesophilic forests, more related to mature calcium-rich soil. At larval stage, it feeds on earthworms, but adults are oligophagous on all arthropods (Brandmayr *et al.*, 2005). (c2) *P. unctulatus*: common polyphagous species, endemic to Alps (Magistretti, 1965).

(d) Forest and prairie (grassland/meadow) species. (d1) *C. creutzeri*: it is endemic to Alps, more abundant in woodland and open habitats with calcium-rich soil because of the larval trophic specialization to feed on snails (Brandmayr *et al.*, 2005).

According to literature, we observed that the quartile method could not be applied to species that show continuous activity, two maxima, or an abundant number of individuals (*C. convexus*, *C. angustatus*, *H. laevipes*, *T. laevicollis*, *P. burmeisteri*) (Cartellieri and Lövei, 2003).

The temporal dynamic of the carabid assemblage in the Eastern Alps, showed a seasonal activity that began immediately after snowmelt. The species activity peak in the springtime after snowmelt is common in mountain regions, especially in subalpine and alpine ecosystems (Ottesen 1996; Brandmayr *et al.*, 2003b). Harry *et al.* (2011) attribute this specialization to food availability, mainly Diptera and Hymenoptera, and the advantage of starting to reproduce early to avoid the cool season. The high heterogeneity of species in the first phase of the activity season is mostly made by rare species coming from surrounding open habitats with low numbers of individuals.

Later in the season, in the central part, the community species richness decreases but the remaining species are more abundant and a higher number of species has its activity peak in this moment. Similarly to the first phase, at the end of the season the total number of species increases but these species are almost all very rare.

The great temporal change of species community structure has important consequences for the conservation of Carabidae beetles (Niemelä, 2001). No specific short period can be identified that were particularly important for community persistence. Each period, between May and September, had its specific assemblage of species. Consequently, no period for forest management or extraction activities can be identified that would avoid harming the carabid community. As a consequence, the entire vegetative season should be considered a sensitive period for carabids and particular care should be paid in carrying out activities with a high potential impact in forest habitats in these alpine regions.

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Authors' addresses: Pierluigi BOMBI (corresponding author, pierluigi.bombi@ibaf.cnr.it), Vittoria GNETTI, Ettore D'ANDREA, Mario CAMMARANO, Marco BASCIETTO, Bruno DE CINTI, Giorgio MATTEUCCI, National Research Council - Institute of Agro-environmental and Forest Biology, via Salaria km 29.300, 00015 Monterotondo, Rome, Italy; Augusto VIGNA TAGLIANTI, Dipartimento di Biologia e Biotecnologie, Università di Roma "Sapienza", piazzale Aldo Moro 5, 00185 Rome, Italy; Marco Alberto BOLOGNA, Dipartimento di Scienze, Università di Roma Tre, viale Guglielmo Marconi 446, 00146 Rome, Italy.

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