Research Article

On the seasonal abundance of two coexisting species of *Ceroglossus* ground beetle (Coleoptera: Carabidae) from the Katalapi park, south Chile

Sobre la abundancia estacional de dos especies coexistentes de *Ceroglossus* (Coleoptera: Carabidae) del parque Katalapi, sur de Chile

Pablo Fuentes-Olivares[1] and Carlos P. Muñoz-Ramírez[*2,3]

[1] *Departamento de Botánica, Facultad de Ciencias Naturales y Oceanográficas. Universidad de Concepción, Casilla 160-C, Concepción, Chile. E-mail: fuentesolivares90@gmail.com*
[2] *Facultad de Ciencias, Universidad Católica de la Santísima Concepción, Chile.*
[3] *Centro de Investigación en Biodiversidad y Ambientes Sustentables (CIBAS), Universidad Católica de la Santísima Concepción, Chile. *E-mail: cpmunoz@ucsc.cl*

Abstract. Species abundance is an important ecological parameter that can provide insights on ecological and evolutionary processes. Here, we report patterns of abundance for two coexisting *Ceroglossus* ground beetle species (*C. buqueti* and *C. darwini*) from a Valdivian temperate rainforest area in South Chile, sampled at four time periods within a year. Results show similar overall species abundances, although they varied differently along the year for each species. The abundance of the species *C. darwini* peaked earlier than the species *C. buqueti* and it was absent during fall and winter, while *C. buqueti* was detected at all seasons. Abundances also varied spatially, but they were positively correlated between species suggesting no spatial segregation.

Key words: Carabidae, Chile, species abundance, Valdivian temperate rainforest.

Resumen. La abundancia de una especie es un parámetro importante que entrega información valiosa sobre procesos ecológicos y evolutivos. En este trabajo reportamos patrones de abundancia de dos especies de *Ceroglossus* (*C. buqueti* y *C. darwini*) que coexisten en el bosque templado Valdiviano de Chile, que resultaron de cuatro muestreos a lo largo de un año. Los resultados muestran valores de abundancia total similares para las dos especies, aunque con diferencias a lo largo del año. La abundancia de *C. darwini* alcanza su máximo antes que la especie *C. buqueti* y estuvo ausente durante el otoño e invierno, mientras que la especie *C. buqueti* fue detectada en todas las estaciones a lo largo del año. Las abundancias de cada especie también variaron espacialmente, pero mostraron un patrón similar entre especies con una correlación positiva y significativa de sus abundancias sugiriendo la ausencia de segregación espacial.

Palabras clave: Abundancia de especies, bosque templado Valdiviano, Carabidae, Chile.

Introduction

Gathering and analyzing data on species abundance is a fundamental step to understand not only population and community ecology processes, but also important evolutionary dynamics. For example, the analysis of the relative abundance of two or more coexisting and ecologically similar species can provide valuable insights on the nature of potential

competition. Similarly, having detailed data on species/populations abundances can also help understanding the consequences of important evolutionary processes such as positive or negative frequency dependent selection, in which the fitness of a particular phenotype may depend on its relative abundance (Chouteau *et al.* 2016). Unfortunately, data on species abundance is usually rare for most species, particularly for economically non important taxa, limiting our understanding of potentially important processes driving their ecological and evolutionary dynamics.

The ground beetle genus *Ceroglossus* Solier (Coleoptera: Carabidae) contains beautifully colored and flightless species that distribute across temperate forests of South America between 30° S and 54° S. As with many other Neotropical insects, data on ecological aspects of these species are scarce despite their conspicuousness and the interest these beetles generate among entomologists and collectors. Recent studies have shown their potential for studying interesting ecological and evolutionary questions. For example, they have been recently used as model organisms to understand the role of forest fragmentation and plantation's understory on several aspects of its ecology (Henríquez *et al.* 2009; Cerda *et al.* 2015), showing that these aspects are relevant for their abundance and movement across environments. They have also been studied in relation to habitat isolation and its consequences for body proportions (e.g., Henríquez *et al.* 2009; Benítez *et al.* 2008) suggesting that habitats differences, including the age of the plantation (Benítez *et al.* 2008) or type of forest (Henríquez *et al.* 2009; Benítez *et al.* 2011), can have an effect on different body measurements that may reflect a response to perturbations. Recently, Muñoz-Ramírez *et al.* (2016) showed that the color of *Ceroglossus* species co-vary across space, suggesting Müllerian mimicry may have played a role in *Ceroglossus'* color evolution. Despite these studies highlight the suitability of these beetles to study a wide range of ecological and evolutionary questions, basic ecological data (such as abundance over time) of coexisting species is still scarce (but see Fierro *et al.* 2011) and preclude our understanding of important ecological traits such as their phenology.

In this article, we report abundance data across four seasons for two *Ceroglossus* species from an area in South Chile to increase our body of knowledge on their patterns of abundance and to start understanding their phenology.

Material and Methods

Sampling

We collected abundance data from two *Ceroglossus* species, *Ceroglossus buqueti* Laporte de Castelnau and *Ceroglossus darwini* Hope, in the Katalapi Park, south Chile (Fig. 1). The park—a 28 ha private area—is located at 18.5 kilometers southeast from the city of Puerto Montt in an area dominated by Valdivian temperate rainforest. Some common tree species within the park are *Nothofagus nitida* (Phil.) Krasser, *Luma apiculata* (DC.) Burret, *Embothrium coccineum* J.R. Forst. & G. Forst., and *Drimys winteri* J.R. Forst. & G. Forst. Other vegetational types including prairies and wetlands are also present in the park in a lower proportion. Precipitations are present during the entire year, although they are higher during the winter, with the annual mean varying between 1800 and 2000 mm. The mean annual temperature is 14° C. To collect the beetles, we set pitfall traps (7.5 cm depth x 11 cm wide) in 10 sites across the entire park (table 1), placing 8 traps per site (5 m apart from each other) to maximize captures (pseudoreplicates). Ethanol was used as the fixative liquid within the traps. Sites were located at minimum distances that ranged between 50 m and 200 m from one another. Pitfall traps were collected after 72 hours. Material was pooled by sites and stored in 95% ethanol. We repeated the same procedure four times, one time per season during the year 2014 (table 1). The species of *Ceroglossus* from this locality can be easily identified by their body coloration, with *C. buqueti* being brown-red and *C. darwini*

being blue (Fig. 2). *Ceroglossus chilensis*, another common species from South Chile, was not found in the park. All analyses and plots for seasonal and spatial patterns of species abundance were conducted in R (R Development Core Team 2013).
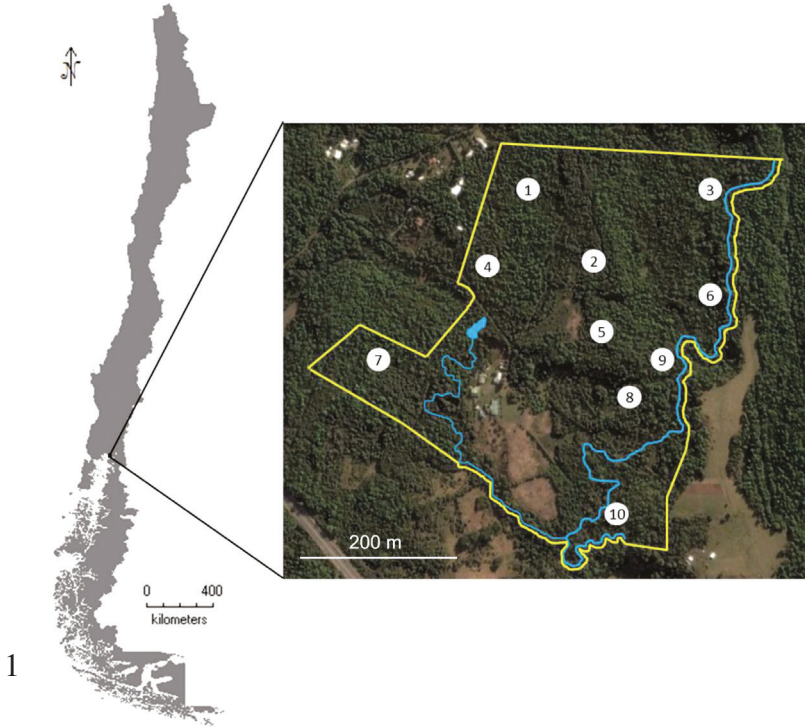

Figure 1-2. 1. Map and sample sites in the Katalapi Park, south Chile, where two species of *Ceroglossus*, *C. buqueti* and *C. darwini* were collected. 2. *Ceroglossus darwini* (upper left) and *Ceroglossus buqueti* (lower right) in their natural habitat.

Results

Total (annual) abundances for the park (which corresponded to the sum of all sites and their pseudo-replicates across the four time periods) were very similar between species. A total of 120 individuals were collected for the species *C. buqueti* and 116 for the species *C. darwini*. However, both species presented clear differences in abundance across seasons and the pattern was different between species (Fig. 3). *Ceroglossus darwini* presented the highest abundances during spring (69) and summer (47), whereas *C. buqueti* presented the highest abundances during summer (52) and fall (46). *Ceroglossus darwini* was not collected during winter and fall, while *C. buqueti* was collected in all seasons, although at much lower densities during the winter and the spring seasons (6 and 16, respectively). Abundances were relatively similar during the summer season (the season with the greater overlap in abundances), with 52 and 47 individuals collected for *C. buqueti* and *C. darwini*, respectively.

Species abundances also varied across sites for both species. Considering only the summer season (in which both species were similarly abundant) and all 10 sampling sites, *C. buqueti* had a minimum of 0 individuals, a maximum of 18 individuals, a mean of 5.2 individuals, and a standard deviation of 6.44 individuals. Similarly, *Ceroglossus darwini* had a minimum of 0 individuals, a maximum of 18 individuals, a mean of 4.7 individuals, and a standard deviation of 5.5 individuals. For this season, abundances were highly correlated between the species (r= 0.73, p= 0.017), indicating that both species showed a similar pattern of abundance across sites (Fig. 4). That is, sites that had low captures had similarly low captures for both species, whereas sites with high captures had similarly high captures for both species.

Table 1. Geographic and abundance data for each sampling site.

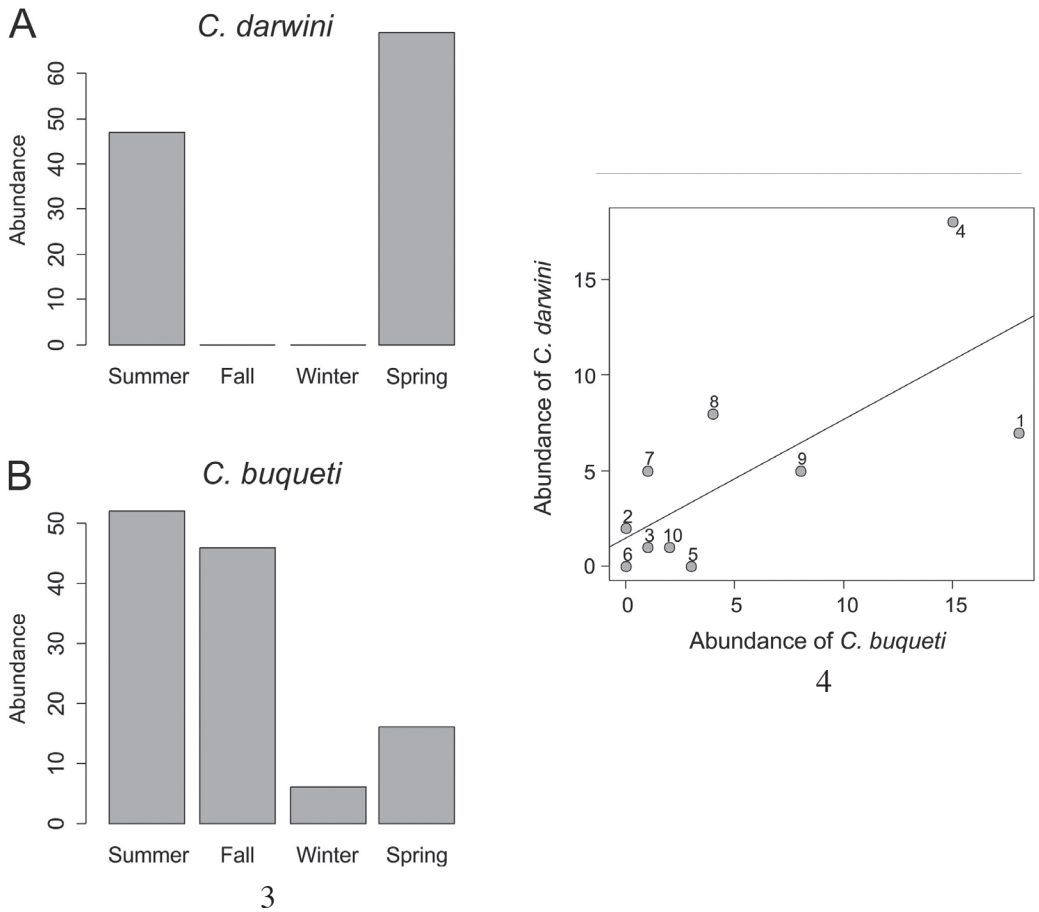| Site N°	Latitude	Longitude	Summer (Jan. 8, 2014)		Fall (Apr. 8, 2014)		Winter (Jun. 30, 2014)		Spring (Oct. 15, 2014)	
			buq	dar	buq	dar	buq	dar	buq	dar
1	41.5184	-72.7521	18	7	10	0	0	0	1	16
2	41.5199	-72.7511	0	2	0	0	0	0	0	0
3	41.5184	-72.7488	1	1	1	0	0	0	0	2
4	41.5199	-72.7533	15	18	5	0	6	0	12	16
5	41.5210	-72.7510	3	0	3	0	0	0	1	2
6	41.5201	-72.7488	0	0	0	0	0	0	0	8
7	41.5213	-72.7548	1	5	0	0	0	0	0	1
8	41.5217	-72.7503	4	8	2	0	0	0	0	12
9	41.5211	-72.7496	8	5	25	0	0	0	2	12
10	41.5235	-72.7505	2	1	0	0	0	0	0	0
Total			52	47	46	0	6	0	16	69

Figure 3-4. 3. Seasonal captures for A) *Ceroglossus darwini* and B) *Ceroglossus buqueti*. These are total captures resulting from the sum of all sites. 4. Relationship between the abundances of *C. darwini* and *C. buqueti* during the summer season (highest overlap of species abundances). Each dot represents the abundance at an individual site, while the numbers refer to the site ID (see table 1 and figure 1). The line corresponds to the best-fit line from a linear regression model. The correlation was statistically significant (R = 0.73; p = 0.017).

Discussion

The results show wide spatial and seasonal variation in species abundances for *C. buqueti* and *C. darwini*. The seasonal variation in species abundance found for *Ceroglossus* mirrors a widespread pattern found in many other carabids from temperate regions of the world (Sota 1985; Kotze *et al.* 2011), in which temperature and rainfall are the most important environmental variables explaining this variation. Optimal temperatures during spring and summer favor reproductive activities and also provide enough resources for foraging. Seasonal variation in temperature and rainfall in South Chile is, therefore, a likely explanation for seasonal changes in abundance in *Ceroglossus*. However, we are far yet from knowing the exact role of these environmental variables on the *Ceroglossus* beetles' life cycle. Potential mechanisms may include physiological restrictions of temperature on activity of larvae or adults and gonad maturation (Kotze *et al.* 2011). Analysis to estimate periods of larval and adult activity may help to understand reproductive strategies and provide hints on the role of temperature and rainfall on shaping *Ceroglossus*' life cycles.

The seasonal abundance pattern was different between species. *Ceroglossus darwini* seemed to initiate its period of (adult) highest activity earlier than *C. buqueti*, reaching the highest abundances during spring-summer. *Ceroglossus buqueti*, on the other hand, were collected in higher numbers during the summer-fall period. This difference in temporal abundance between species needs to be confirmed statistically with more data, such as inter-annual sampling and sampling in other geographic areas. However, assuming the pattern is not driven by chance, it may suggest a role for competition. Differences in seasonal activity between coexisting carabid beetles have been found in other regions (e.g., Sota 1985; Lovei and Sunderland 1996) and they have been largely explained as a mechanism to avoid competition (e.g., Sota 1985). This is plausible in *Ceroglossus* species because they are considered generalist predators of small invertebrates and have similar body size (Jiroux 2006)—body size is commonly used as a proxy for trophic niche (e.g., Erikstad *et al*. 1989; see also Niemela 1993 for a review)—suggesting high trophic niche overlap and a potential for strong competition. However, until more data on the niche of these beetles is collected (e.g., diet, microhabitat, period of activity), the hypothesis of competition and its relation to patterns of abundance will remain unsupported.

Alternatively, seasonal segregation could be a strategy to avoid high predation rates. These beetles have been recently hypothesized as aposematic (Muñoz-Ramírez *et al*. 2016), so they rely on their conspicuous coloration and distastefulness to avoid experienced predators (predators that have learnt to avoid the aposematic pattern). However, aposematic patterns are optimal when they are unique, like in Müllerian mimicry systems in which multiple aposematic species share the same coloration (Ruxton *et al*. 2004). *Ceroglossus* from the Katalapi park are not mimetic (they have a different body coloration; see Fig. 2), which suggests that their defense against predators is not optimal and even detrimental as the variety of colors may disrupt predator learning. Perhaps, the differences in seasonal abundance of the beetles may help them to avoid the same predator assemblages if we assume predator communities are also structured seasonally. However, this mechanism seems unlikely because a similar temporal segregation has also been reported for *Ceroglossus* in a region where species are mimetic (Fierro *et al*. 2011), suggesting that temporal segregation might reflect competition rather than a strategy to allow the local survival of different aposematic colors. Although highly speculative, these hypotheses could be tested in future studies by collecting data on potential predators (seasonal abundance, prey preferences) and conducting field experiments that assess predation rates.

The precense of *C. buqueti* across all seasons may suggest that *C. buqueti* can overwinter and/or keep activity in adult stage during the coldest season, whereas *C. darwini* may cease activities in the adult stage during fall and winter. However, sampling needs to be conducted to support this hypothesis.

Our study contributes to the knowledge of *Ceroglossus* ecology by documenting capture data of two coexisting species (*C. buqueti* and *C. darwini*). This data suggest striking patterns of abundance that may shed light on ecological and evolutionary processes like interspecific competition and mimicry. However, whether any of these mechanisms (or others) play a role in *Ceroglossus'* patterns of abundance is a question that needs to be further investigated. We hope this work encourages new research on these beetles and helps providing potential questions that may deserve consideration in future studies.

Acknowledgments

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