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Short communication

Indicating assemblage vulnerability and resilience in the face of climate change by means of adult ground beetle length–weight allometry over elevation strata in Tenerife (Canary Islands)

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ABSTRACT

Adaptive trade-offs in length–weight allometry might reduce vulnerability under climate change of adult ground beetle (Col., Carabidae) assemblages in their original elevation stratum on Tenerife. In particular this study shows that the predictive values for simple log-linear regression parameters were high in all strata and also the *F*-tests were statistically significant ($p < 0.0001$). Ground beetle assemblage on upper stratum had smaller coefficients and higher intercepts than did lower ones, indicating that the ground-beetle assemblages may be trading off higher powers for higher resilience via water and thermal efficiency in the face of environmental warming, in opposition to strategies adopted in cool and wet climates. Adults of ground beetle assemblages from warm and dry lower strata might have to be heftier, with encapsulation of bodies and heavily sclerotized exoskeleton, than those from cloudy, cool and wet strata; the latter group, freed from this constraint, would thus be characterized by more elongated, thinner and softer-bodied species. The outlined methodology could become a useful tool for the vulnerability and resilience assessment of natural assemblages, and could theoretically be applied to any latitudinal and altitudinal assemblage.

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1. Introduction

Adaptive trade-offs are important in determining assemblage vulnerability and resilience in the face of climate change (Bennett and Lenski, 2007; Calosi et al., 2008; Lyle and Ostendorf, 2011; Parmesan, 2006). Size of specimens, including length and weight, is a central factor to key ecological processes (Jia and Chen, 2013). Based on this criterion one might expect indications concerning the effects on the body allometry trade-off and particularly how their mathematical functions can suggest changes in metabolic rate on body size and temperature (Gillooly et al., 2001). Márquez et al. (2011) suggests that the geometric morphometrics could be of great utility in order to detect the effect of environmental pollution variables on gastropod shell shape and structure. Fundamental relationships between body length–weight allometry and the environment have been shown in insect's assemblages (Schoener, 1980; Smock, 1980). Interestingly, the carabids or ground beetles (Coleoptera, Carabidae) exhibit conspicuous adaptive responses and they occur in a wide variety of habitats (Larsen et al., 2003; Luff et al., 1992; Thiele, 1977), being therefore an ecological indicator sensitive to temperature and moisture gradients, stages of ecological succession and disturbance (Butterfield et al., 1995; Pearce and Venier, 2006).

The environmental constraint assemblage trade-offs may be emphasized in Tenerife by contrasting situations up (cool) and down (warm) on elevation gradients analogous to the contrast between the situation in early and late development of global climate change. Based on this premise, this research hypothesizes that body length–weight allometric trade-offs are important in determining if an assemblage can adaptively track a changing climate across the elevation range. Firstly, it would be possible to establish changes in the simple log-linear regression coefficient values for ground beetle assemblages from different strata. Secondly, it is possible to show allometric changes between the ground beetle assemblages of warm and dry strata and those from cool and wet strata. Moreover, the results obtained on the island of Tenerife can be compared with ground beetle assemblages of geographic areas with different climates to establish adaptive trade-offs indicating the consequences of global change.

2. Materials and methods

2.1. Study area

The ground beetle sampling started at sea level and extended up to 2360 m a.s.l. along the Valley of Güímar in the southeast of the

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Table 1
Species ordered by the population biomass (de los Santos, 2010), listing the 18 species together with their mean characteristics and the strata in which the measured and weighed individuals were caught (a: basal stratum; b: cloudy montane stratum; c: summer-xeric montane; d: summit stratum). Parenthetical number of specimens considered by species and by stratum.

Species	Length (mm)	Dry weight (mg)	Elevation stratum
Carabus (*Nesaeocarabus*) *interruptus* Dejean, 1831	20.89	110.32	b(63), c(54)
Calathus (*Lauricalathus*) *depressus* Brulle, 1838	12.59	26.52	b(49), c(19)
Calathus (*Lauricalathus*) *ascendens* Wollaston, 1862	12.08	22.46	b(15), c(62), d(76)
Calathus (*Lauricalathus*) *auctus* Wollaston, 1862	17.36	57.62	b(29), c(51)
Licinopsis alternans (Dejean, 1828)	18.47	61.41	c(20), d(66)
Zabrus (*Macarozabrus*) *laevigatus* Zimmermann, 1831	16.14	56.37	a(19), b(11), c(6)
Scarites (*Scallophorites*) *buparius* (Forster, 1771)	29.20	285.27	a(3)
Calathus (*Lauricalathus*) *freyi* Colas, 1941	10.43	13.52	a(3), b(45)
Broscus rutilans Wollaston, 1862	15.90	62.35	d(2)
Calathus (*Lauricalathus*) *rectus* Wollaston, 1862	10.31	10.15	a(1), b(32), c(7)
Platyderus alticola alticola Wollaston, 1864	9.40	6.76	a(48), b(20), c(12), d(26)
Dicrodontus brunneus exilis Machado, 1992	8.71	7.57	b(10), c(12), d(7)
Nesarpalus (*Nesacinopus*) *sanctaecrucis* (Wollaston, 1864)	11.46	23.18	a(3), b(6)
Amaroschema gaudini Jeannel, 1943	7.99	7.20	d(22)
Olistophus glabratus glabratus (Brullé, 1838)	4.48	1.60	b(1), c(1)
Trechus flavocintus flavocintus Jeannel, 1922	3.69	0.40	a(1), b(1), c(5)
Philorhizus atlanticus fortunatus Mateu, 1957	2.93	0.34	a(1), b(1), c(4), d(1)
Syntomus inaequalis (Wollaston, 1863)	2.55	0.30	c(1)

island of Tenerife. The elevation gradient shows strong adiabatic declines in temperature, up to ca. 0.7 °C for every 100-m above sea level under humid conditions in the north-facing slopes and 1.5 °C in the slopes most south-facing strata (de Nicolás et al., 2011). The height at which the dew point temperature occurs allows a division between two large types of strata: a warm and dry basal stratum situated between seashore and 600 m a.s.l. (mean annual temperature 16.5–21 °C, with seasonal fluctuations; mean annual precipitation 300 mm) and a wet montane stratum. The latter in turn could be split into cloudy stratum situated between >600 and 1700 m a.s.l. and summit stratum (mean annual temperature 9.5–12.5 °C, on the Cañadas of Teide to 5 °C; mean annual precipitation 200–450 mm) placed between >1700 and 2360 m a.s.l. The seasonal effects of variation in median elevation and elevation range of trade-wind inversion zone (1200 m a.s.l. in summer and 1700 m a.s.l. in winter) further split the cloud belt habitat into a stratum that is cloudy (or humid) almost all the year round (600–1200 m a.s.l.; mean annual temperature 14.5–16.5 °C; mean annual precipitation 700 mm) and one summer-xeric stratum (1200–1700 m. a.s.l.; 12.5–14.5 °C; mean annual precipitation 400–650 mm). For more information on any matter of study area see de los Santos (2009).

2.2. Fieldwork and laboratory processing

Annual catching of ground beetle adults were obtained along altitudinal gradients with pitfall traps between April 12, 1985 and November 1, 1989 over twenty-six study plots. A fraction of the specimens captured weekly was taken to the laboratory within a plastic container labeled according to date and plot. The sample was transferred into formalin-preserved (10% formalin). The use of formalin as a preservation fluid for samples of many aquatic animal taxa has long since been known to affect body dry weights and sometimes also body lengths of animals (e.g., Ahlstrom and Thrailkill, 1963; Shields and Carlson, 1996; Durbin and Durbin, 1978). Recently, the effect has also been documented with a common medium-sized ground beetle by Knapp (2012), showing evidence that suggests that formaldehyde as preservative fluid appears to be an optimal storage method for studies in which the body mass of dead terrestrial insects is considered since it does not alter the estimate of body size and body mass. Normally the specimens in the samples were preserved around two weeks between trapping and dry weight determination. Body lengths were measured under a dissecting microscope to the nearest 0.01 mm from the frons to the tip of elytra. Then, each specimen was dried in an oven at 60 °C for up to 24 h, and afterwards cooling in a desiccator and then was weighed on a top-loading electronic balance to determine dry weights to the nearest 0.01 mg.

2.3. Statistical analyses

The expected pattern is a parabolic or power curve, in the form

$$DW = aL^b \quad (1)$$

where DW is dry weight in mg, L is body length in mm, and b and a are the constants. Body length and weight data are transformed to natural logarithms for analysis using linear regressions:

$$\ln DW = \ln a + b \ln L \quad (2)$$

Logarithmic transformations reduced heteroscedasticity in the data in accordance with statistical assumptions (Huston McCulloch, 1985). The a is the intercept, which SPSS terms the 'Constant', while the b is called variable L's regression coefficient because it determines how the predicted DW_i values change as the value of L_i changes.

Simple log-linear regression coefficients, Pearson's correlation coefficients, Student's t-test and ANOVA F-test were performed using the Statistical Package for the Social Sciences version 18.0 for Windows (SPSS, Inc., Chicago, IL, USA). The applied hypothesis test in this research for the difference between two regression coefficients is Student's t-test–Z values (Clogg et al., 1995). For more information on any topic on this analysis see Sokal and Rohlf (1995).

3. Results

Regressions were found for a total of 816 adult ground beetle specimens including eighteen species from thirteen genera (Table 1). The results of the analysis of the length–weight data (Eq. (2)) are presented stratum by stratum and combined strata (Tables 2 and 3) and the curves derived from Eq. (1) are illustrated in Fig. 1. Graphically, it was evident in all regressions that the variance in weight increased with beetle length and that ground beetle assemblages of lower (Fig. 1a), middle (Fig. 1b and c) and upper (Fig. 1d) stratum were divergent length–dry weight relationships when analyzed as composite samples from each stratum, or the combined strata (Fig. 1e).

As the 'model summary' table (Table 2) shows, relatively high values were obtained for the coefficients of correlation. The "ANOVA table" (Table 2) shows a high regression sum of squares

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