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Natural and anthropogenic alterations of the soil affect body condition of the fossorial amphisbaenian *Trogonophis wiegamnni* in North Africa

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ABSTRACT

Soil alteration is one of the major threats in arid environments, which can have serious consequences for soil biodiversity. However, the ecology of fossorial animals is poorly understood and their low conspicuousness may lead researchers and managers to overlook potential conservation problems. Amphisbaenians are fossorial reptiles and, because of their secretive habits, there is a chronic almost lack of data on their conservation state. Here, we examined the effects of diverse natural (salinization and seagulls influence) and anthropogenic factors (disturbance of the soil physical structure and lead contamination) that affect physical and chemical properties of the soil on body condition of *Trogonophis wiegmanni* amphisbaenians from the Chafarinas Islands, in North Africa. Results indicated that soil salinization and human induced mechanical disturbance and compaction of the soil affected negatively to body condition of amphisbaenians. In contrast, the increase in organic matter and heavy metals pollutants in the soil, either because of the seagull or anthropogenic influence, did not seem to affect body condition of amphisbaenians. We suggest potential management techniques to solve these problems and emphasize the need for periodic surveys of subterranean herpetofauna to prevent future conservation problems.

1. Introduction

Soil alteration is one of the major threats in arid environments (Dregne, 1976; Zeppel et al., 2003), which can have serious consequences for soil biodiversity. However, compared to terrestrial epigeal animals, the fossorial fauna inhabiting underground environments has been little studied and their ecology is little understood (Copley, 2000). Soil biodiversity is considered to be an important factor in regulating the functioning of terrestrial ecosystems, but this importance is often not appreciated (Decaens et al., 2006), and the absence of concern about fossorial animals from conservationists is conspicuous (Wolters, 2001; Böhm et al., 2013). This may have unfortunate consequences for conservation planning, because fossorial species may be at particular risk from anthropogenic disturbance and local extinction of fossorial populations due to landscape and soil alterations may be occurring unnoticed (How and Shine, 1999; McKenzie et al., 2003; Zeppel et al., 2003; Measey, 2006; Measey et al., 2009).

Moreover, most studies deal with soil invertebrate ecology, while fossorial vertebrates are largely overlooked (Measey, 2006; Böhm et al., 2013). Among them, several groups of reptiles and amphibians, as much as 20%, nearly 3000 species of the world's herpetofauna, are fossorial (Measey, 2006), and their ecology and conservation status is much less well understood than that of their epigeal relatives (Böhm et al., 2013). Amphisbaenians are one of the prominent groups of fossorial reptiles with important morphological and functional adaptations to the underground life (e.g. reduced vision, elongated body, and loss of limbs in most species) (Gans, 1978, 2005) and a suite of original responses to ecological demands (e.g. Papenfuss, 1982; Martín et al., 1990, 1991; López et al., 1998; Webb et al., 2000). However, because of the fossorial secretive habits of amphisbaenians, there is very little information on the ecological requirements of most species, and there is a chronic almost lack of data on their potential conservation problems (Böhm et al., 2013). Most amphisbaenians live in tropical wet areas, but also in arid regions there are a few species, such as the Checkerboard Worm Lizard, *Trogonophis wiegmanni*, a representative of the family Trogonophidae inhabiting North Africa (Bons and Geniez, 1996; Gans, 2005). It lives buried in the soil and it is usually

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found thermoregulating or foraging under rocks (López et al., 2002; Civantos et al., 2003; Martín et al., 2011b,c, 2012; 2013a,b). It is listed as of 'Least Concern' by the IUCN in view of its wide distribution and "presumed" large population (Mateo et al., 2009). However, the potential threats to this species have not really been studied and are, therefore, not well known. We predicted that, given the fossorial habits, soil alterations should have a profound impact on health state and conservation of amphisbaenians.

In this paper, we examined diverse natural and anthropogenic factors that affect physical and chemical characteristics of soils used by a population of *T. wiegmanni* amphisbaenians from the Chafarinas Islands, in North Africa. We specifically considered the following potential threats identified in a preliminary survey (Martín et al., 2001a): two of natural origin (salinization and influence of seagulls on soil properties) and two of anthropogenic origin (disturbance of the soil physical structure and contamination by lead).

One of the threats of soil degradation in arid habitats is salinization (Zeppel et al., 2003; Rengasamy, 2006). Salinization can be caused by natural processes, such as mineral weathering or the gradual withdrawal of the sea, but it also may be induced by intense use of groundwater resources. Salts from the groundwater are raised by capillary action to the surface of the soil, decreasing soil water osmotic potential (Bressler et al., 1982). Therefore, water availability is much lower in saline soils, which may affect directly osmoregulation and cause dehydratation of amphisbaenians tissues (Shoemaker and Nagy, 1977). Thus, we predicted that more saline soils may affect negatively to amphisbaenians.

On the other hand, concentration of seagulls in nesting and resting areas also induces profound changes in soil chemical properties including eutrophication, salinization, acidification and nutrient imbalances (García et al., 2002a,b). Moreover, seabirds may be the main vectors moving heavy metals to soils (Headley, 1996; Otero, 1998; García et al., 2002a,b; 2007b), which can be then transferred to plants and soil invertebrates, and go up the food chain to reach high toxicological concentrations in vertebrate tissues (e.g. Márquez-Ferrando et al., 2009). We predicted that if there were actual differences in chemical properties of the soil in sites used by seagulls, these could affect negatively to amphisbaenians.

In addition to natural causes, urbanization by man has induced modifications of physical, chemical and biological properties of soils (Craul, 1992). Anthropic activities have led to profound modifications of the original soil horizons affecting their physical properties and the addition of organic residues and materials of domestic or industrial origin (Craul, 1992; Effland and Pouyat, 1997). These soil alterations may lead to increased compaction, restricted aeration and water drainage and the possible presence of contaminants, especially lead (Markus and McBratney, 2000). Anthropic soils are, however, often used by fossorial animals that live near human settlements. Thus, we predicted that if anthropogenic disturbance resulted in alteration of the physical properties of the soil and lead contamination, these changes may also affect negatively to amphisbaenians.

To assess how these potential threats to soil characteristics may affect amphisbaenians, we measured body condition of individual *T. wiegmanni* amphisbaenians that used these soils. Body condition is an important measure of the fitness of an animal, because it reflects the relative amount of energy stores (Green, 2000; Schulte-Hostedde et al., 2005), which can be allocated to maintenance, growth or reproduction (Perrin and Sibly, 1993; Heino and Kaitala, 1999; Madsen and Shine, 2002). Information on the condition of individuals in a population is necessary to predict potential reproductive output and changes in population size. Thus, a population with many animals in poor condition could indicate that individuals have a low reproductive potential and the population might be declining.

2. Material and methods

2.1. Study area

We conducted field work at the Chafarinas Islands (Spain), a small island archipelago located in the southwestern area of the Mediterranean Sea (35°11′N, 2°25′W), 2.5 nautical miles off the northern Moroccan coast (Ras el Ma, Morocco) and 27 miles to the east of the Spanish city of Melilla. It consists of three islands: Congreso (25.6 ha), Isabel II (15.1 ha) and Rey Francisco (13.9 ha). The islands present a dry, warm, Mediterranean climate, very influenced by dominant winds from the east and west. Vegetation is conditioned by the aridity of the climate (an average annual precipitation of 300 mm), the high soil salinity, and the guano accumulation from numerous seabird colonies (in Congreso and Rey Francisco) (García et al., 2002a,b). Vegetation is dominated by woody bushes (*Salsola*, *Suaeda*, *Lycium* and *Atriplex*) adapted to salinity and drought (García et al., 2002a,b). Natural soils are poorly developed and immature and are characterized by a thin A horizon, rich in organic matter, which is underlain by the original volcanic rock (Clemente et al., 1999; García, 2005; García et al., 2007a). Only Isabel II Island is currently inhabited by a small population (less than 50 people). However, the islands supported a greater population until half of the 20th century, and many buildings (some in ruins) and paved streets cover 34% of the Isabel island surface, and 1% of surface in each of Rey and Congreso (García, 2005).

Two of the islands, Congreso and Rey, support nesting colonies of two species of seagulls; the Audouin's gull (*Larus audouinii*) (897 nests in Rey in 2011), a rare and protected Mediterranean seabird, and the widespread yellow-legged gull (*Larus cachinnans*) (2250 nests in Rey and 3244 nests in Congreso in 2011), a Mediterranean seabird "pest". The population of yellow-legged gull has increased considerably in the last years as in 1976 the figures were 300 nests in Rey and 600 nests in Congreso. There is also an important breeding colony in Congreso of Cory's shearwater (*Calonectris diomedea*) (400–500 nests in burrows or under rocks). The third island (Isabel) is inhabited by man and has had negligible seabird influence since 1848.

2.2. Study animals and body condition

We visited the study area during two weeks in March 2011. We walked haphazardly covering all the habitats and types of soils available in the three islands (Clemente et al., 1999; García, 2005), on days with favorable climatic conditions (warm sunny days) and between 07:00 and 18:00 (GMT), searching for amphisbaenians by lifting all stones found. We captured amphisbaenians by hand, gathered morphological measurements *in situ* and released them at their exact point of capture in less than 5 min. We determined sexes of adult amphisbaenians by examining cloacae (Martín et al., 2011c). For each individual we measured total length (TL; from the tip of the snout to the tip of the tail) with a metallic ruler (to the nearest 1 mm) and body mass with a pesola spring scale (to the nearest 0.01 g). To avoid confounding effects, we measured individuals with empty stomachs. Amphisbaenians usually expulsed most gastrointestinal contents when handled, but we also compressed gently their vents to force the expulsion of feces. The residuals of an ordinary least squares linear regression of log-transformed mass against log-transformed total length ($r = 0.97$, $F_{1,38} = 645.37$, $P < 0.0001$) were used as a body condition index. It has been argued that such residuals provide the cleanest way to separate the effects of condition from the effects of body size (Bonnet and Naulleau, 1994; Jakob et al., 1996; see reviews in Green, 2000; Schulte-Hostedde et al., 2005). Body condition indexes are used as proxies of health state in many animals (e.g. Schulte-