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Original investigation

Food selection and predation risk in the Andean white-eared opossum (*Didelphis pernigra* Allen, 1900) in a suburban area of Bogotá, Colombia

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ABSTRACT

Urbanization is spreading throughout the Andes, and despite it there is still wildlife which survives in these novel environments throughout Colombia and elsewhere. The Andean white-eared opossum (*Didelphis pernigra* Allen, 1900) can tolerate moderate levels of urbanization in the Andes highlands, and we evaluated its food selection based on optimal patch use theory using foraging stations to measure giving-up densities in a suburban area in Bogotá (~2600 m a.s.l.). We offered the opossums equicaloric mixtures of protein-rich and sucrose-rich foods, and they preferred the sucrose mixture. However, the magnitude of this preference was influenced by temporal and spatial effects. We suggest that in environments such as the high Andes, where air temperature regularly drops below 10 °C, the opossums prefer foods that provide energy easily. We also assessed the opossums' perceived risk of predation when domestic dogs (*Canis lupus familiaris*) are present by sprinkling dog urine in cotton swabs next to foraging stations; we expected opossums to forage more when the predator's signal was not present. Dog urine indicated a risk for opossum's at only one of six foraging stations, suggesting a weak predator's signal effect that depends on location. Both food preferences and perception of risk by the opossum were affected by the spatial heterogeneity of the urban environment. Thus, microhabitat management at the study site, which is part of a recently created reserve to preserve Bogotá's natural capital, appears to be key to conserve the opossums and their ecological functions in highly disturbed areas of the Andes.

Introduction

The expansion of urbanizations is associated to the increase in human population, which comes at the expense of natural ecosystems, threatening wild species, fragmenting their habitat and causing population declines (Adams et al., 2006; Babini et al., 2015). In many cities, isolated natural ecosystems remain and this is not an exception in Bogotá, Colombia's capital, in the high Andes. In Bogotá, Andean forests and wetlands are threatened by urbanization, agriculture and pollution (Camargo Ponce De León, 2007), even though there are reserves expected to protect wildlife (Ramírez et al., 2008). Despite the intense perturbations in Bogotá, some of its vertebrate species are tolerant to moderate levels of human encroachment and are able to survive in rural and suburban areas (Mendoza and Sanchez, 2014; Tellez-Farfán et al., 2013). One of those species is the Andean white-eared opossum, *Didelphis pernigra* Allen, 1900, a nocturnal and solitary marsupial (family Didelphidae) that feeds on insects, fruits, and occasionally small vertebrates (Eisenberg, 1989; Pérez-Hernández et al., 1994). As a consequence, this opossum may provide ecosystem services associated with the control of noxious invertebrate populations and seed dispersal that helps recovery of degraded areas, as has been described for other species of the genus *Didelphis* (Cáceres, 2002; Cantor et al., 2010). Therefore, providing information about the ecology of *D. pernigra* may help taking decisions on how to manage urban expansion in relation to its effects on wildlife and the preservation of ecosystem functions (Barrera-Niño and Sánchez, 2014). In the light of the above, we used optimal patch-use theory (Brown, 1988) to study food preferences and foraging decisions of *D. pernigra* when faced with signals of a potential predator, the domestic dog (*Canis lupus familiaris*).

Optimal patch use theory predicts that a forager must leave a food patch when the benefits of foraging are equal to or lower than the costs of using it (Brown, 1988). Costs are associated with the

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energetic costs of exploiting the patch (E), the perceived risk of predation (P), and missed opportunity costs (MOC), whereas benefits are indicated by the harvest rate (H); $H \leq E + P + MOC$. Also, in a food patch where the forager experiences diminishing returns, the forager's harvest rate depends on the amount of food in the patch, and therefore, the quitting harvest rate may be estimated from the food left in the patch, i.e., the giving-up density, GUD (Kotler and Brown, 1990). According to Brown's model, the marginal value of a food patch will increase with the quality of the food in it, provided that other foraging costs remain constant. Patch quality is linked to the nutrients in the patch and for example sucrose is a source of easily metabolized energy, and since Bogotá is ~2600 m a.s.l., opossums are exposed regularly to air temperatures below 10 °C (IDEAM, 2007). Therefore, this sugar should be highly valuable for nocturnal marsupials such as *D. pernigra*. Nevertheless, protein synthesis and degradation are major components of marsupial metabolism (Hume, 1999), and opossums feed on invertebrates, and small vertebrates whenever they can (Eisenberg, 1989; Pérez-Hernández et al., 1994; Sánchez and Alvear, 2003). This suggests that protein-rich food may also be highly valuable to the opossums. Thus, we tested the hypothesis that foraging by opossums is affected by the food type available by offering opossums two types of food, a sugar-rich food and a protein-rich food.

Our second hypothesis is associated with the opossums' perceived risk of predation (cost in the equation). A forager's behavior is influenced by the probability of falling prey to a predator (Lima and Dill, 1990), and predation has been recognized as a powerful selective force that makes individuals adopt strategies to survive and maximize their fitness (Brown and Kotler, 2004). Therefore, prey animals display different anti-predator behaviors, including changes in the use of space or time to improve their chances of survival, and some of these responses are elicited by signals left by predators, including chemical ones (Apfelbach et al., 2005). This should be true even in human-dominated environments characterized by the introduction of novel stimuli (Frid and Dill, 2002). Indeed, urbanization may limit survival of wild species because humans introduce predators exotic to an area, and it should be advantageous for a forager to detect potential predators. For instance, in urban and rural environments, domestic cats and dogs may interact with local fauna as competitors, disease vectors, and/or predators (Adams et al., 2006; Vanak and Gompper, 2009), and they may affect habitat use by small mammals (Baker et al., 2003). Odor cues left by domestic dogs, such as their urine or feces, can reduce foraging in mammalian prey (Arnould and Signoret, 1993; Epple et al., 1993), and in suburban areas of Bogotá we have found white-eared opossums killed by dogs. Therefore, we expected that the foraging behavior of the marsupials would be negatively affected by odor cues related to the presence of the dogs near foraging patches.

Material and methods

Field-site description

We did the study at the University of Environmental and Applied Sciences, located on the north of Bogotá, 4°35′ N, 74°04′ W, 2554 m a.s.l. Bogotá is the socio-economical center of Colombia and has an estimated population of over seven million people (DANE, 2009). According to the meteorological station at the University (IDEAM station, code 2120626), minimum average air temperature at night is ~13 °C, but can reach ~0 °C. The University is divided into two by a road, having a south and a north campus. The south campus is part of the city's urban expansion area, whereas the north campus is part of the recently created Thomas van der Hammen Forest Reserve, which is mainly dominated by rural environments. We did the study on the south campus, since we have previously found opossums there (Sánchez, 2013). At the time of the study, the south campus was surrounded by a metal fence that included a soccer pitch, and there was a flower plantation next to the campus. Surrounding the pitch was a live fence of native trees, including *Sambucus peruviana*, *Alnus acuminata*, *Lafoensia acuminata*, *Smallanthus pyramidalis,* and there was also *Physalis peruviana* (Téllez-Farfán et al., 2013). We placed feeders along the top of a metal fence where we previously had recorded frequent opossum activity. A line of *S. peruviana* trees planted every 1–2 m ran next to the metal fence. These trees are about 4–5 m tall, and are pruned from time to time by campus groundskeepers. In particular, trees were pruned a couple of weeks prior to the beginning of the second sampling period of the food selection experiments. Although the fence allowed us to hang feeders at a uniform height, stations still differed from each other in one important aspect: canopy cover. While each feeding tray was hung on the fence close to a *S. peruviana* tree, trees varied in heights and therefore in the cover that each provided to the adjacent feeder.

Food selection

We offered sugar-rich and protein-rich foods to the opossums at six foraging stations, and each station had two feeders placed next to each other. Stations were separated by at least 30 m and were placed at ~2 m above the ground on the top of the metal fence, which was built of a straight metal frame covered with hexagonal mesh. Prior to the experiments, we regularly observed opossums walking on the metal fence and we detected at least 10 individuals prior to the experiment (F. Sánchez, unpublished results). The artificial food patches traditionally used to measure GUD consist of a container with a food resource mixed with a non-edible substrate, modified to meet the requirements of the species in question (Brown, 1988; Kotler et al., 1994; Sánchez, 2006). As feeders, we used cylindrical-plastic containers (base 5 cm; height 14.5 cm) with an opening big enough for the opossums to feed from (Suárez, 2012). Feeders were placed in a PVC tube (diameter 6.08 cm; height 15 cm) that supported the feeders and prevented the opossums from breaking them with their teeth. Each feeder contained 60 glass spheres (diameter 1.5 cm), all in a nylon-mesh bag to prevent the opossums from removing the non-edible substrate that interfered with their drinking behavior; this arrangement generated diminishing returns on the harvest rate. At the top of the feeder we placed a strip of two-sided sticky tape that trapped hairs as evidence that the opossums used the feeders. During four days we habituated opossums to the use of the feeders, and we attracted them with pieces of banana placed between the feeders. After habituation, we replaced the banana pieces with cotton swabs impregnated with banana essence; these were renewed daily (Suárez, 2012). Each feeder had an equicaloric mixture of water and food, comprising 170 mL of water and 35 g of sucrose for the sugar-rich food, and 170 mL of water and 38.1 g of Bienestarina for the protein-rich food. Bienestarina is a protein-rich supplement given to children in Colombia and it is made of wheat flour, corn starch, powdered milk, vitamins and minerals. At each station the two feeders contained different food types, and the food in a feeder was chosen randomly for every trial. We weighed the feeders with and without food before placing them on the fence around sunset, ~17:00 h. On the following day, around sunrise (~06:30 h), we weighed the food left in the feeders from which we calculated the GUD. We did this for a total of 30 nights, in three different periods of 10 days each. The first sampling period occurred in April 2011, the second in August 2011 and the third in October 2011. We did this to account for possible changes in food selection through time.