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Original investigation

Habitat use and sensitivity to fragmentation in America's smallest wildcat

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ABSTRACT

Fragmentation and human-wildlife conflicts represent severe threats to wildcats such as the kodkod cat (*Leopardus guigna*), endemic to the heavily impacted Chilean temperate rainforest. Here we assess to which extent this vulnerable forest specialist is able to use altered habitat (agricultural matrix, forest edge, human presence) by studying its home ranges, habitat use, and patch selection in privately owned rainforest remnants. We radio-tracked five individuals over 33–376 days. Mean 95% kernel home ranges were 623 ha, with a mean 50% core area of 191 ha. Ecological-niche and Mahalanobis distance factor analysis confirmed forest-dependency and revealed that the individuals made intensive use of forest edges, close to water. They did not avoid houses. Generalized linear mixed models showed that the monitored kodkods selected elongated woodland patches. We conclude that the kodkods compensated the non-forest space by maintaining larger home ranges and making efficient use of forest edges probably due to higher prey availability. Future studies should identify ecological traps, and describe connectivity and source-sink dynamics in the agricultural matrix to develop long-term conservation efforts for the smallest cat of the Americas.
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Introduction

The response by predators to fragmentation of their habitat deserves special interest as they have a crucial role in ecosystem functioning. Mammalian carnivores are sensitive to landscape change due to their large ranges, low numbers, slow population growth rates, and direct persecution by humans (Cardillo et al., 2005; Crooks et al., 2011). Among felids, 44% of the species fall into the top categories of threat of the IUCN Red List (critically endangered, endangered, and vulnerable; Macdonald et al., 2010). They face particular challenges in anthropogenically modified landscapes, even within protected areas (Woodroffe and Ginsberg, 1998). Habitat loss and fragmentation lead to an increase in wildcat mortality due to vehicle collisions (e.g. European wildcat *Felis silvestris*, Klar et al., 2009), loss of prey for food specialists (Iberian lynx *Lynx pardinus*, Ferreras et al., 2010), loss of territory due to the preference for undisturbed habitat (jaguars *Panthera onca*, Colchero et al., 2010) or retaliatory persecution following livestock predation (75% of felids, Inskip and Zimmermann, 2009). While conservation efforts have targeted large and charismatic felids, smaller, more cryptic species have received comparatively little attention. Half of the smaller cat species (8 of 16 species < 10 kg) are classified as vulnerable or endangered by IUCN; among those, six are associated with different degrees with forest habitat (Macdonald et al., 2010).

The 2-kg guiña or kodkod cat (*Leopardus guigna*) is the smallest wildcat of the Americas and one of the rarest and least known cats of the world (Nowell and Jackson, 1996). Kodkods are strongly associated with the heavily fragmented temperate rainforests of Chile and Argentina (Wilson et al., 2005) where they have the most restricted distribution range known for any New World felid (30–48°S, Quintana et al., 2009). The species is considered vulnerable on the IUCN Red List due to habitat destruction and human persecution as a response to poultry depredation (Napolitano et al., 2015).

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According to Dunstone et al. (2002), kodkods are forest specialists, including in human dominated landscapes where they favor large tracts of dense native forest over small fragments (Acosta-Jamett and Simonetti, 2004; Sanderson et al., 2002) or pine plantations (Zúñiga et al., 2009). More recent studies showed that kodkods are able to occupy native forest patches as small as 20–40 ha (Gálvez et al., 2013), plantations with well-developed undergrowth vegetation (Simonetti et al., 2013) and even edge type and moderately sized forest patches (Fleschutz et al., 2016). This indicates a higher tolerance to altered habitats than was suggested earlier.

We predict that the survival of kodkods in anthropogenic landscapes is related to its ability to relax its forest-dwelling behavior and/or make intensive use of the remaining forest, for example through hunting at prey-rich forest edges (e.g. leopard cats *Prionailurus bengalensis*, Azlan and Sharma, 2006; European wildcat, Klar et al., 2008). Exclusive forest-dependent behavior in modified habitats can drive felids to a critically endangered status as has occurred with Sumatran tigers (*Panthera tigris sumatrae*, Sunarto et al., 2012). Tolerance to human presence should facilitate felids' movement in impacted habitats (e.g. jaguars, Foster et al., 2010). Sunde et al. (1998) showed that resting Eurasian lynxes (IUCN status: least concern) tolerated short distances (50 m) towards intruding people. Recent camera-trapping revealed that kodkod occupancy increased near buildings (Fleschutz et al., 2016). Yet, a higher permeability of the landscape through tolerance to human disturbance might be at the cost of greater probability of contact and conflict with humans (Silva-Rodríguez et al., 2007).

Here we study habitat use and sensitivity of kodkods to fragmentation, adding to the small body of literature of fragmentation effects for carnivores in southern hemisphere temperate rainforests. Our aim is to quantify kodkod home ranges, describe habitat preferences in the fragmented landscape, and patch selection in forest remnants in the Andean foothills using radio-telemetry. Our predictions were that (1) cats would show aversion to the agricultural matrix (Dunstone et al., 2002; Sanderson et al., 2002), (2) as rodent consumers (Delibes-Mateos et al., 2014; Freer, 2004) they would make efficient use of the forest edge, and (3) human infrastructure would not be avoided (e.g. male kodkods, Sanderson et al., 2002; Fleschutz et al., 2016). We close the paper with recommendations of habitat preferences for kodkod conservation.

Material and methods

Study area

The study was conducted in the Chilean Araucanía region at the northern limit of the South American temperate rainforest. We worked in lowland forest (<550 m.a.s.l.) at the pre-Andean foothills of the Lake Villarrica catchment (39°16′S, 71°50′W, Fig. 1). The size of the study area was 133 km^2 with a 52% of remaining forest cover. The protected areas are all situated > 800 m.a.s.l. The region has a temperate Mediterranean climate with an annual average temperature of 10 °C and a mean annual precipitation of 2500 mm (DMC, 2001). Lowland vegetation comprises deciduous forests dominated by *Nothofagus obliqua*, *Laurelia sempervirens*, *Aextoxicon punctatum*, *Podocarpus saligna*, and *Eucryphia cordifolia*; the understory is often mixed with bamboo *Chusquea quila* (Luebert and Pliscoff, 2006). Since colonization during the 20th century, the lowland forest areas have been fragmented and internally degraded through logging, cattle grazing, and fires (Rojas et al., 2011).

Animal trapping and tracking

We trapped kodkods in forest remnants on private land, based on local information about recent sightings and camera-trap surveys (capture period 09/2010-02/2012). All sampling procedures and animal manipulations were approved by the Chilean Agriculture and Livestock Service of the Ministry of Agriculture (trapping permit No. 3729). We used custom-built wooden and Tomahawk traps baited with chicken and a menu of attractants (valerian, catnip, Hawbaker's wildcat lure No. 2, sound attractants imitating mice and birds). The traps were preferably placed on animal trails near creeks, rivers, or wetland and checked once a day at dawn. Captured animals were anesthetized with Ketamine + Xylazine (reversed by Yohimbine) or Medetomidine + Ketamine (reversed by Atipamezole) by a team of veterinarians. During anesthesia the cats were tagged with radio-collars with activity sensors and mortality switches (45 g, Wagener Telemetrieanlagen, Germany). Individuals were classified as juveniles or adults by their body mass, tooth wear, and reproductive condition. When possible, we took samples of feces, hair, and blood for further analysis, such as population genetics (Napolitano et al., 2014).

We obtained telemetry locations on foot using a 3-element Yagi antenna and receiver (Sika, Biotrack, UK and R-1000, Communication Specialists, USA). Each individual was located at least 15 days per month for the first three months and thereafter at least eight days per month (telemetry period 09/2010-05/2012). We followed a schedule that aimed to equally cover different times throughout the 24 h and added more intensive sessions up to four hours during the nights (32% of locations). Each individual's fixes were systematically taken at 15 min intervals by triangulation based on three bearings. We assume there was no bias regarding the acquisition of fixes in relation to the landscape. Trails within forest fragments were frequent so as to guarantee tracking also deeper inside the forest. Location errors were minimized by using only azimuths that differed by 60°–120° from the previous one. At each fix, we recorded the cat's activity (active/inactive) and presence of bamboo within approximately 50 m of the animal. We used program LOAS (2012) to process the triangulation data and discarded locations with error ellipse sizes ≥ 1.5 ha and bearing errors > ±50° (21 locations or 1.8% of all fixes). This yielded n = 1132 fixes with a mean error ellipse area of 0.09 ± 0.01 ha and a mean bearing error of 0.81 ± 0.2°.

Statistical analyses

Home range estimates were produced by fixed kernel probability densities. By visual inspection we chose an Epanechnikov kernel (Silverman, 1986) and the reference smoothing parameter (h_{ref}). We calculated 95% and 50% contours; the latter was interpreted as an individual's core area size (Laver and Kelly, 2008). In order to reduce temporal autocorrelation for kernel estimates, we used independent fixes only which we defined as fixes separated by at least 6 h (n = 11–114, assumed time to biological independence). Additionally, we computed the 95% minimum convex polygon areas (MCP) using all fixes (n = 37–456). Home ranges were estimated with package "adehabitatHR" (Calenge, 2006) and site fidelity following Spencer et al. (1990) with package "rhr" (Signer and Balkenhol, 2015) from the R Environment (R Development Core Team, 2013).

To explore the kodkod's habitat preferences within the fragmented landscape, we focused on 11 environmental variables (Table 1). We contrasted the distribution of the locations (used space) versus the distribution of the pixels of the ecological space (available) defined as the minimum bounding rectangle around the 95% kernel areas of all individuals (133 km^2, Fig. 1). For this, we used a statistical approach based on multivariate ordination (Calenge and Basille, 2008). In contrast to more traditional ways of analyzing habitat use (e.g. Aebischer et al., 1993), we chose this method because it is exploratory (we only had five individuals) and allows ecological niches to be quantified and visualized in a

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