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Spatial ecology of pumas in southern Brazil

HOME RANGE AND HABITAT SELECTION OF PUMAS (*PUMA CONCOLOR*) IN THE SERRA DO ITAJAÍ NATIONAL PARK, SOUTHERN BRAZIL

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Abstract: Pumas (*Puma concolor*; Carnivora, Felidae) have experienced population declines in the Atlantic Forest due to habitat loss, fragmentation, and human-related pressures. In southern Brazil, information on their spatial ecology remains limited, constraining conservation planning at regional scales. This study aimed to estimate puma home range size and habitat selection using satellite tracking data in Serra do Itajaí National Park (SINP), state of Santa Catarina, Brazil. Individuals were equipped with Argos Lotek® collars and location data were used to estimate home range and habitat selection. Home range was estimated using the Autocorrelated Kernel Density Estimator (AKDE). Habitat availability was defined using a Minimum Convex Polygon encompassing all locations, and land use was classified into five categories based on MapBiomas data. Habitat selection was assessed using Ivlev's Electivity Index. Due to technical failures, only two individuals provided sufficient data for analysis. One sub-adult male (2.5 years-old) was monitored between July and December 2013 (N = 222 locations; acquisition success of 24%), with a home range size of 202 km² (144.39 – 269.32), 40% located outside SINP limits. The other individual was an adult male (9 years-old) monitored between July and September 2014 (N = 128 locations; acquisition success of 36%), with a home range size of 201 km² (73.87 – 391.71) entirely within SINP limits. Forests comprise 95% of the available habitats and were the only one selected by pumas, whereas anthropized ones were avoided by them. Despite the limited sample size, this study provides the first GPS-based evidence of space use by *P. concolor* in southern Brazil, highlighting the importance of continuous forest cover and landscape connectivity for the species.

Keywords: Atlantic Forest; carnivores; habitat use; protected areas.

INTRODUCTION

The loss and degradation of natural ecosystems are the main causes of global biodiversity decline (Ehrlich 1988, Myers *et al.* 2000, Pereira *et al.* 2010, Rands *et al.* 2010), and these pressures are expected to intensify with climate change, demanding new strategies for conservation (Crooks & Sanjayan 2006, Lawler *et al.* 2013). As habitat is lost, landscapes become increasingly fragmented into smaller, more isolated patches immersed in a human-modified matrix (Crooks *et al.* 2011). Carnivores may be particularly sensitive to changes in the landscape due to their relatively low population density and demand for large areas of habitat (Carroll *et al.* 2001). Consequently, they may not be capable of persisting in human-dominated landscapes, particularly those without functional connections or a permeable matrix among natural areas (Crooks *et al.* 2011).

The Brazilian Atlantic Forest has undergone significant biodiversity loss due to economic development (Mittermeier *et al.* 2020), with less than 23% of its original cover remaining undisturbed (Vancine *et al.* 2024). In the state of Santa Catarina (SC), only 22.7% of the Atlantic Forest persists (Fundação SOS Mata Atlântica/INPE 2025). The Itajaí River Basin (IRB), the largest basin in the state, has lost 44% of its forest cover (Dambrowski & Marenzi 2023). Nevertheless, the best-preserved forests occur in the Itajaí Mountain Ridge (Campanili & Prochnow 2006), protected by the Serra do Itajaí National Park (SINP), the state's second-largest remaining forest remnant (MMA 2009). Although forest formation remains predominant in this basin, agricultural and forestry activities are driving increasing fragmentation, which may compromise landscape connectivity and lead to habitat isolation (Dambrowski & Marenzi 2023).

The puma (*Puma concolor*; Carnivora, Felidae) is the largest carnivore in the SINP and, despite occurring within a protected area, faces several anthropogenic pressures (MMA 2009). In Brazil, populations are increasingly threatened by habitat loss and fragmentation from agriculture, mining, and infrastructure, as well as by direct persecution and road mortality (Azevedo *et al.* 2018). Habitat loss and illegal hunting remain the main threats throughout its range (Logan & Sweanor 2001, Novack *et al.* 2005, Paviolo *et al.* 2009, De Angelo *et al.* 2011, Guerisoli *et al.* 2019).

Although widely distributed in the Atlantic Forest biome, the puma effective population size is estimated to be less than 1,000 individuals (Azevedo *et al.* 2013). Globally classified as "Least Concern", the species is declining in Latin America (Nielsen *et al.* 2017) and is considered "Near Threatened" in Brazil (MMA 2022) and "Vulnerable" in the state of Santa Catarina (CONSEMA 2011). Particularly, southern populations show genetic diversity loss, small effective population sizes, and low densities, highlighting the need to maintain connectivity among protected and unprotected areas (Castilho *et al.* 2011).

Its large body size, carnivorous diet, and behavioral traits make pumas require extensive continuous vegetation to ensure survival (Logan & Sweanor 2001, De Angelo *et al.* 2011, Elbroch & Wittmer 2012), with home range size becoming highly variable and dependent on prey availability, habitat features, and landscape composition (Logan & Sweanor 2001, Dickson & Beier 2002, Beier 2010, De Angelo *et al.* 2011, Dickson *et al.* 2014, de la Torre *et al.* 2017, Almeida 2021, Karelus *et al.* 2021).

Pumas are key ecological actors and potential umbrella and key species, mediating energy flow and biotic interactions and guiding conservation priorities (Beier 2010, Dickman *et al.* 2015, Barry *et al.* 2019, LaBarge *et al.* 2022). Understanding landscape use by puma can support effective strategies to protect not only large carnivores but also other species whose habitat requirements can be largely met (Noon *et al.* 2008, Rodríguez-Soto *et al.* 2011, Smereka *et al.* 2020, Almeida 2021).

Monitoring large mammals is challenging due to their cryptic, nocturnal, solitary habits, large home ranges, and low densities (Pardini *et al.* 2004). Radiotelemetry, especially global positioning system (GPS) tracking, has become essential for studying carnivore ecology without direct contact (Jacob & Rudran 2004, Gitzen *et al.* 2013). In Brazil, such studies on pumas are limited to Minas Gerais and São Paulo states (Penteado 2012, Paula *et al.* 2015, Azevedo *et al.* 2020). In the southern Atlantic Forest, particularly in Santa Catarina, data on puma space use and habitat selection remain scarce, constraining the development of region-specific ecological understanding and conservation strategies.

The fact that puma is a key species for the balance of ecosystems and that a low population density was observed in southern Brazil reveals an extremely worrying situation for the conservation of the species. Therefore, preserving enough habitat to ensure the survival of viable populations in the long term requires conservation planning based on knowledge of the species' use of space. Given this scenario, the objective of this study was to analyze the home range and habitat selection of pumas in the SINP, the results of which may support the definition of priority areas for conservation in the Itajaí River Basin.

MATERIAL AND METHODS

The study was conducted in the SINP (26°59'S to 27°17'S and 49°01'W to 49°22'W), which is located within the Itajaí River Basin, which covers 15,000 km², in the state of Santa Catarina, Brazil. Established in 2004, it has an area of 573,74 km² and encompasses portions of nine municipalities (Figure 1). The SINP has elevations ranging from 80 to 1,039 m and presents irregular relief, with small plains and undulating and elongated hills, creating a rugged landscape that is, from a morphological point of view, unsuitable for human occupation (MMA 2009). The Buffer Zone comprises areas of economic activity, mostly rural, with emphasis on agriculture, pasture and monocultures of exotic tree species, such as *Pinus* spp. and *Eucalyptus* spp. (MMA 2009). The characteristic climate is humid subtropical (Cfa), with precipitation distributed throughout the year (Pandolfo *et al.* 2002). The vegetation belongs to the phytoecological region of the Dense Ombrophilous Forest (MMA 2009).

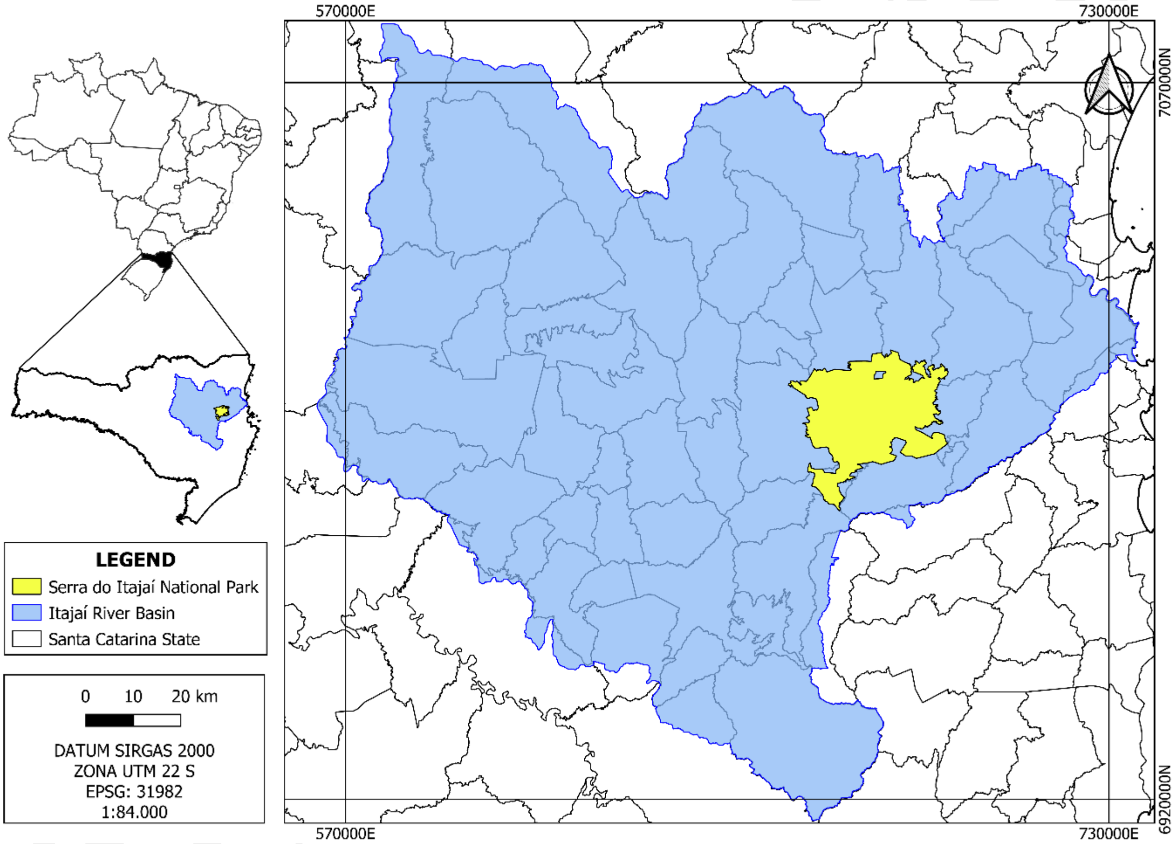

Figure 1: Location of the Serra do Itajaí National Park in the Itajaí River Basin, state of Santa Catarina, Brazil.

Pumas were captured following protocols approved by the Chico Mendes Institute for Biodiversity Conservation/Ministry of the Environment (ICMBio/MMA) through the Biodiversity Authorization and Information System - SISBIO (license number 36038-5). Between December 2012 and July 2018, seven campaigns lasting from 11 to 21 days were carried out by researchers from

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ICMBio. At the time of the study, approval from an Animal Ethics Committee was not required, as such a committee was only established in 2024 under the Internal Regulations of ICMBio's National Committee for Ethics in the Use of Animals (ICMBio 2024). Pumas were captured using foot-hold snares following established protocols (Logan *et al.* 1999). Traps were equipped with VHF transmitters and monitored remotely every hour, with daily field inspections to minimize risks to captured animals.

Captured individuals were chemically immobilized with tiletamine–zolazepam (6–8 mg/kg, intramuscular) using a dart rifle (Distinject®). Biometric measurements, clinical assessments, and age estimation based on tooth wear and physical characteristics were performed (Shaw *et al.* 2007), and physiological parameters were continuously monitored throughout handling. The chemical immobilization of the animals was carried out by a veterinarian and followed current guidelines and regulations for wildlife handling in Brazil (CFBio 2024).

Pumas were classified as sub-adult (12 to 30 months of age) and adult (> 30 months) based on physical characteristics such as tooth wear and fur color (e.g., Shaw *et al.* 2007). Captured individuals were equipped with GPS7000 collars fitted with an Argos transmitter from Lotek® (Canada), powered by batteries with an estimated lifespan of one year and operating 24 hours per day. Locations were programmed to be obtained via satellite at predetermined 4-hour intervals. All collars had a release mechanism (*i.e.*, dropoff), which was programmed to be released 12 months after capture.

During the study, the equipment malfunctioned. Only two of the three captured individuals were monitored and for a shorter period than planned. The number of GPS locations obtained for these two individuals was low, mainly due to damage to the external antenna, which compromised data transmission via the Argos system. The third individual received a collar whose antenna was damaged shortly after deployment, preventing monitoring. The extremely rugged relief and dense forest canopy also affected location acquisition. Because the last locations were not transmitted before activation of the drop-off device, collar recovery was difficult, and the devices could not be located using VHF

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tracking or overflights, making data retrieval impossible. Consequently, analyses of seasonality, displacement, and movement rates could not be performed.

Home range was estimated using the Autocorrelated Kernel Density Estimator (AKDE), implemented in the "ctmm" package (Calabrese *et al.* 2016) through the ctmmweb interface (Dong *et al.* 2018) in R (R Core Team 2021). This method accounts for temporal autocorrelation in telemetry data and provides robust estimates compared to traditional kernel approaches (Fleming *et al.* 2015). Home range sizes were calculated using the 95% utilization distribution (Fleming *et al.* 2015, Calabrese *et al.* 2016).

Habitat availability for each individual was defined based on a Minimum Convex Polygon (MCP) encompassing all recorded locations, representing the accessible area during the monitoring period. Land use and land cover data were obtained from MapBiomas Collection 6, year 2013, based on Landsat imagery with 30 m spatial resolution (Projeto MapBiomas 2021), and geoprocessing was performed using QGIS software. Habitat classes were grouped into five categories: forest, forestry, pasture, agriculture, and agriculture–pasture mosaic.

To compare pumas' locations among different habitat types and determine their habitat selection within their home ranges, the Habitat Selection Index (or Electivity Index) was used (Ivlev 1961), given by the formula: IVLEV = (U - A) / (U + A), where U = Habitat Utilization and A = Habitat Availability. The index value ranges from -1 to 1, with -1 indicating rejection and values close to 1 indicating selection.

RESULTS

Three males with estimated ages of 2.5, 5 and 9 years, weighing 45, 53 and 54 kg were captured. Due to technical failures, only two individuals provided sufficient data for analysis. The sub-adult male (2.5 years-old) was monitored between July and December 2013 (N = 222 locations) and the adult male

(9 years-old) was monitored from July to September 2014 (N = 128 locations), with acquisition success rates of 24% and 36%, respectively.

We estimated similar home ranges for both individuals. The subadult male exhibited a home range of 202 km² (95% CI: 144.39–269.32), with approximately 40% extending beyond park boundaries, whereas the adult male presented a home range of 201 km² (95% CI: 73.87–391.71), entirely within the park (Figure 2).

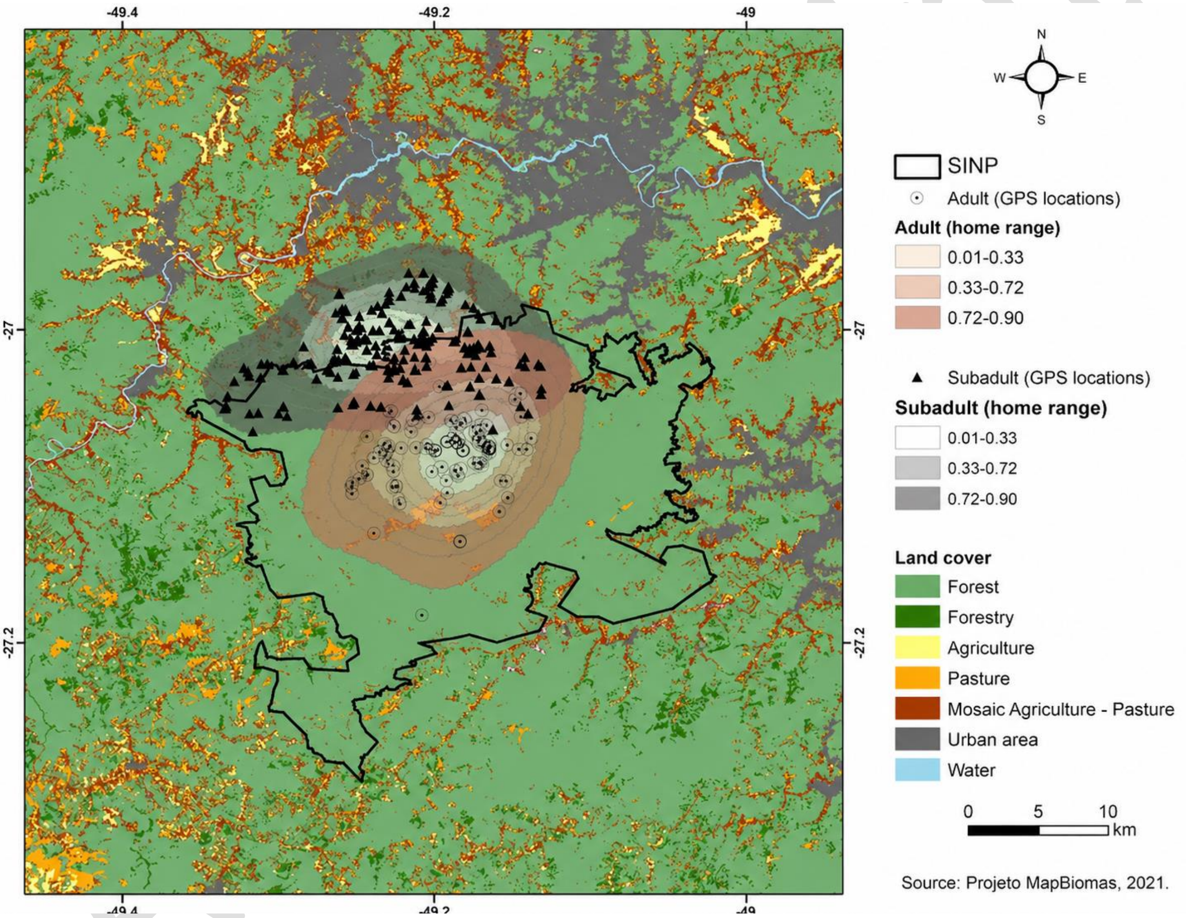

Figure 2: Home range of two pumas, *Puma concolor* (Carnivora, Felidae) monitored with Global Positioning System collars in the Serra do Itajaí National Park region, state of Santa Catarina, Brazil, in relation to land use and cover.

Forest formation represented 95% of the available habitats in the study area and was the only habitat selected by the pumas (E = 0.80–0.92), whereas anthropogenic habitats were avoided (E < 0) (Table 1 and Figure 2).

Table 1: Habitat availability and habitat selection by two male pumas, *Puma concolor* (Carnivora, Felidae), monitored with Global Positioning System collars in the Serra do Itajaí National Park region, state of Santa Catarina, Brazil. The value of the index ranges from -1 to 1, with -1 being rejection and values close to 1 indicate selection. (Adult = 9 Years-old; Sub-adult = 2.5 Years-old).

Habitat class	Proportion of available area	Number of observed GPS locations	Proportion of habitat used	Selection index (IVLEV)	Status
Adult					
Forest	0.9515	123	0.9609	0.92	**selected**
Forestry	0.0041	0	0.0000	-1	avoided
Pasture	0.0290	0	0.0000	-1	avoided
Agriculture and Pasture Mosaic	0.0152	5	0.0391	-0.33	avoided
Agriculture	0.0002	0	0.0000	-1	avoided
Sub-adult					
Forest	0.9462	200	0.9010	0.8	**selected**
Forestry	0.0215	7	0.0315	-0.62	avoided
Pasture	0.0042	1	0.0045	-0.9	avoided
Agriculture and Pasture Mosaic	0.0265	14	0.0630	-0.33	avoided
Agriculture	0.0016	0	0	-1	avoided

DISCUSSION

Limitations related to collar and GPS performance should be considered in the present study, as issues such as data gaps or reduced fix success may have affected the temporal resolution of the dataset. Despite these limitations, the data allowed, for the first time, an understanding of space use patterns by pumas in the southern Atlantic Forest based on telemetry. Although the sample size was small, the monitored individuals likely represent a significant portion of the population in the study area, considering the low density of the species reported for southern Brazil (0.09 and 0.32 pumas/100 km^2) (Castilho *et al.* 2011) and the size of the SINP in the Itajaí River Basin (Dambrowski & Marenzi 2023).

Previous studies found home range estimates for pumas to be very limited and to vary widely, but the home ranges of the two pumas (~200 km²) in the SINP fall within the range reported across the species' distribution, where male home ranges vary from 62 to 763 km² (de la Torre *et al.* 2017). Variation in home range size is driven by multiple ecological and biological factors. Males generally occupy larger areas than females, a pattern associated with territorial behavior and increased access to mates (Logan & Sweanor 2001, De Angelo *et al.* 2011). In contrast, female home range size is more closely related to prey availability (Logan & Sweanor 2001, De Angelo *et al.* 2011). Age and reproductive status also influence space use, as subadults tend to exhibit wider movements during dispersal (Logan & Sweanor 2001, Stoner *et al.* 2013), which is consistent with the partial use of areas outside park boundaries observed for the subadult individual in this study. Prey availability is another key factor affecting home range size in the species (De Angelo *et al.* 2011).

The few studies conducted in Brazil using telemetry on pumas also found substantial variation in home range size, reflecting both landscape context and individual conditions. In a predominantly anthropogenic landscape within the Cerrado–Atlantic Forest ecotone in the state of Minas Gerais, Azevedo *et al.* (2020) analyzed three adult males and two adult females and reported home range sizes similar to those observed in the SINP, despite the lower availability of native vegetation, with male home ranges ranging from 174.2 to 266.5 km². Although the landscape was dominated by agricultural habitats, pumas selected native vegetation over other available habitat classes, even where its availability was limited (Azevedo *et al.* 2020). In the Atlantic Forest of São Paulo, Penteado (2012) monitored a reintroduced adult male for six months, estimating a home range of 114 km²; although the study area was predominantly composed of sugarcane plantations, the individual also preferred forested habitats. In contrast, Paula *et al.* (2015) studied an adult male for one year in the Serra do Brigadeiro State Park and recorded a home range of 610 km², with approximately 80% of records occurring outside the protected area. This extensive use of areas beyond the park boundaries was associated with anthropogenic pressures, including hunting, the presence of domestic dogs (*Canis lupus familiaris*; Carnivora, Canidae), habitat fragmentation, and possible intraspecific competition (Paula *et al.* 2015).

The selection of forest habitats observed in this study reflects a well-established ecological pattern. Pumas consistently use areas with dense vegetation cover (Dickson & Beier 2002, Dickson *et al.* 2005, 2014, LaRue & Nielsen 2008, Onorato *et al.* 2011, Castilho *et al.* 2015, Angelieri *et al.* 2016, Zeller *et al.* 2017, Azevedo *et al.* 2020, Craighead *et al.* 2022), which provides structural conditions required for ambush hunting, movement, and resting (Hornocker 1970, Maehr & Cox 1995, Dickson & Beier 2002). In this context, the predominance of forest habitat in the study area likely explains the strong association observed, and the consistent avoidance of anthropogenic habitats further supports this pattern.

Previous studies have shown that areas with low vegetation cover and high human disturbance are generally unsuitable for pumas (Logan & Irwin 1985, Cox *et al.* 2006, Holmes & Laundré 2006, Land *et al.* 2008, De Angelo *et al.* 2011, Elbroch & Wittmer 2012, Dickson *et al.* 2014, Knopff *et al.* 2014, Gray *et al.* 2016). Although the occasional use of modified environments has been reported in heterogeneous landscapes (Goulart *et al.* 2009, Guerisoli *et al.* 2019, Karelus *et al.* 2021, Ramírez-Álvarez *et al.* 2021, Himmelsbach *et al.* 2025), such behavior was not evident here, where locations were almost exclusively associated with forest habitats.

The spatial pattern observed for the subadult individual, with part of its home range extending beyond the park boundaries, indicates that suitable habitats are not restricted to the protected area and are likely maintained by forest environments in the surrounding matrix. Although only one sub-adult individual was monitored, these results overall can indicate that habitat structure, particularly the availability of continuous forest cover, influences space use by pumas in the region, reinforcing the importance of maintaining forest landscapes on a regional scale. These findings highlight not only the importance of SINP for puma conservation, but also the role of the surrounding forest matrix in providing suitable conditions for the species.

Pumas likely disperse into habitats of similar quality to their original home range (Logan & Sweanor 2001, Thompson & Jenks 2010, Stoner 2013) and recolonize unoccupied habitats when these are geographically linked to source populations (Murphy *et al.* 1999). Thus, the SINP may function as a source of puma dispersal if landscape connectivity is maintained, promoting gene flow between populations and the recolonization of unoccupied areas. This role is supported by the park's importance as a central area for watershed conservation, the predominance of forest cover (56%), and the presence of 28 protected areas within the basin, which may help sustain landscape connectivity (Dombrowski & Marenzi 2023).

Given the difficulty of establishing large protected areas, a network of smaller areas connected by ecological corridors can help maintain puma populations in the long term and facilitate genetic exchange (Beier 1995). The conservation and restoration of corridors are essential strategies to mitigate landscape changes caused by human activity and climate change (Hoegh-Guldberg *et al.* 2008). The results of this study can be used to support distribution and connectivity models for pumas, aiming to identify priority areas for the establishment of ecological corridors, thus contributing to conservation planning in the Itajaí River basin. SINP plays a fundamental role in regional connectivity and, together with smaller protected areas, can enable the implementation of ecological corridors through a mosaic approach.

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