Analyzing the distribution of an endemic páramo lizard, *Stenocercus lache* using GIS technology and knowledge from the field

Abstract

The Andes formation during the Pliocene, created islands of high altitude grasslands known as páramos that harbor a great number of endemic and small ranged species. These species are threatened with climate change as they will start migrating towards the top of the mountains and eventually be driven to extinction. This study analyzes the distribution range of the endemic lizard, *Stenocercus lache* from the páramo region of the eastern mountain range of Colombia. Findings show that over 60% of this lizard's distribution fall within protected areas. The most immediate threat to the lizard's extinction is climate change and not habitat loss by the expansion of the agriculture frontier. *S. lache*'s survival will depend on its ability to adapt to the changing climate, although presumably living in the high altitude tropics this species has a broad thermal tolerance and will be able to cope with a rise in temperature. Nevertheless, changes in precipitation, food availability and species interactions as well as competition from lowland species migrating to higher grounds pose challenges to its survival. Due to its small range, *S. lache* meets the IUCN criteria to be Red listed as an endangered species. Understanding the impact climate change will have on high altitude ecosystems and ectotherms, requires periodic monitoring of the species within the protected areas. Coupling páramo restoration efforts along the border of protected areas with environmental services payment program will reduce the edge effects of agriculture to habitat sensitive organisms and create an incentive for locals to protect the ecosystem.

Introduction

Unlike temperate areas, the tropics have low annual variation in temperature (Ghalambor et al. 2006; Janzen 1967). In the tropics climate is stratified along the elevation gradient where temperature falls 0.5°C every 100 meter increase in altitude (Luteyn 1992). Species have physiologically adapted to tolerate narrow temperature ranges, which limits its distribution range (Ghalambor et al. 2006; Janzen 1967). Although hypothesis to explain tropical diversity abound, there is no doubt that the Andean tropical region is one of the most biodiverse places in the world (Keating 2008; Myers et al. 2000).

High altitude tropical environments that occur above the tree line and below the snow line are unique, and they have produced high levels of diversity and endemism in their flora and fauna (Luteyn 1992). The tropical high-altitude mountain páramo ecosystem is found between 11° north and 8° south latitude, from 3500 – 4700 meters above sea level (Luteyn 1992). In the páramo, daily temperature change surpass annual variations (Navas 2006), where temperature at the soil level fluctuates between below 0°C at night and 23°C during the day (Jaime Vicente Estevez-Varon 2006; Ojeda et al. 2001). True páramo, characterized by the giant rosette plants from the *Espeletia* genus, is distributed along the Colombian, Venezuelan, Ecuadorian and Peruvian Andes (Vuilleumier & Monasterio 1986). There are small patches of páramo-like vegetation in Panama and Costa Rica (Rundel et al. 1994). .

Since the formation of the Andes, the páramo ecosystem has been naturally fragmented by elevation gradients, forming isolated patches across the landscape

(Simpson & Todzia 1990). High levels of endemism are attributed to speciation (Keating 2008; Simpson & Todzia 1990) that occurred in the mid to late Pliocene when the mountain ranges reached elevations greater than 2000 m (Simpson 1975). The biodiversity of the paramo ecosystem is comparably high in contrast to ecosystems with similar temperatures in the temperate zones (Janzen 1967). There is a great number of endemics with restricted geographic ranges (Myers et al. 2000).

High altitude tropical ecosystems have already undergone changes in climate (Rull & Vegas-Vilarrubia 2006; Vuille et al. 2008). Climatic data between 1961 and 1990 from the high Andes of Peru, Bolivia and Ecuador show a 0.1ºC warming per decade and an overall increase of 0.68ºC since 1939 (Vuille et al. 2008). Retreating glaciers in the tropical Andes will have consequences for water used domestically, in agriculture and industry, as there will be abundant water in the rainy season and limited water in the dry season (Vuille et al. 2008). Given that glaciers regulate the amount of water available at lower elevations, an increase in temperature will result in a higher incidence of lowland flooding events (Vuille et al. 2008). Climate change will alter air quality, intensity of ultraviolet radiation, temperature increase and rainfall patterns (Foster 2001; Ron et al. 2003). Unlike lowland tropical species that have shifted their ranges by going to higher elevations (Parmesan 2006), páramo organisms will be driven to extinction with climate change as they will eventually have no places to go (Deutsch et al. 2008; Ghalambor et al. 2006; Parmesan 2006; Rull & Vegas-Vilarrubia 2006; Rundel et al. 1994; Williams et al. 2007).

One high altitude organism is the lizard, *Stenocercus lache. S. lache* is endemic to the páramo ecosystem in the north eastern mountain range of Colombia. *S. lache* was found in 1973 in Cocuy National Park, and described in 1983 (Corredor 1983). *S. lache* has only been found in the páramo ecosystem from 2900 to 4000 meters above sea level (Corredor 1983; Torres-Carvajal 2007b). There is little knowledge of its role in the páramo ecosystem or the health of its populations. The species faces cultural rejection: locals think it is a poisonous animal and kill it on sight.

In this study a species distribution model was created for *Stenocercus lache* using field data and geographic information from the literature. The distribution was refined to include only undisturbed, suitable and viable areas that would support a lizard population. The distribution was then analyzed based on an estimate of its home range in the context of the landscape.

Methods

Focal Species

Within the Order Squamata, the *Stenocercus* genus (Iguania: Tropiduridae) is the largest with 61 species described from Colombia to Argentina (Torres-Carvajal 2007a). Six species of this genus are found in Colombia, fifteen in Ecuador, and one in Venezuela (Torres-Carvajal 2005; Torres-Carvajal & University of Kansas Natural History 2000). These species occur in a variety of habitats ranging from 0 – 4000 m above sea level although there is evidence of the Andean herpetofauna originating *in situ* (Vuilleumier & Monasterio 1986).

Of the six species of *Stenocercus* found in Colombia, *S. lache* inhabits the highest elevations reaching 4300 m on the eastern mountain range (Torres-Carvajal 2007b). The range described in the literature is from 2900 to 4000 meters (Torres-Carvajal 2007b).

According to Omar Torres-Carvajal, a *Stenocercus* expert at the Smithsonian Museum of Natural History, *S. lache* has not been found south of Tunja (5°31' N, 73°22' W) (Pers. Comm. Torres-Carvajal), and to the north, the mountain range slopes down in Chitagá, Colombia (7° 7' N, 72°40'W) to less than 2500 meters (Corredor 1983).

Species distribution

GPS points collected in the field (N = 14) and three geographic locations from the literature of the places that were not sampled, were used to create a species distribution map using the Maximum Entropy Program, Version 3.2.19 (Phillips et al. 2006; Phillips et al. 2004). To reduce redundancy in the predictive variables, a multivariate analysis served to exclude two from a total of eight environmental variables (Table 1). Annual precipitation and mean annual temperature, from the 50-year World Clim database (Hijmans et al. 2005), were rescaled from 1000 m, to 90 m resolution. Slope, radiation, rugosity and aspect were derived from the SRTM 90m elevation layer (Werner 2000). The land cover layer, produced by the Colombian Government's Research Institutes, was derived from satellite images from 1999 and 2002 (IDEAM et al. 2007). Layers were projected in the World Geodetic System (WGS) from 1984, Universe Transverse Mercator (UTM) zone 18 North and ESRI's ArcGIS Version 9.2 was used to manipulate the geographic information.

Refining the distribution

The predicted lizard distribution of MaxEnt was further refined by incorporating knowledge from the field. Unsuitable areas, that included pastures, agricultural fields, and urban areas, were excluded from the predicted lizard distribution (Figure 1) because lizards are presumably sensitive to traveling across transformed ecosystems (Escallón &

Mogollón 2008). Although lizards might use some of these areas to transit between one patch and another, this is not their preferred or ideal habitat as they are more exposed to predators and might be sensitive to agrochemicals from potato cultivations. Since the Maximum Entropy prediction was based on the GPS points, the actual range of use is presumably larger. To take this into account, if more than 50% of the predicted lizard distribution fell within a suitable habitat type, defined as shrubs, high altitude Andean forest, páramo, or rocky places with interspersed vegetation, then the entire zone of that habitat type was included. If less than 50% of the predicted lizard distribution fell within a suitable habitat, then only that portion of the predicted lizard distribution was included (Figure 2). Each patch in the remaining predicted lizard distribution was given its individual identification (Figure 3).

Home Range

Prior knowledge on the space that a species utilizes over its lifetime, its home range, is an important measure to assess the lizard's future survival given the entire landscape. The home range for *S. lache* was calculated based on allometric relationships found in the literature (Table 2). This is a technique used by many other studies (Buckley & Jetz 2007). Snout-vent length for females and males (Corredor 1983) was used to calculate the weight of *S. lache* (Pough 1973). The weight was used to calculate the home range based on an equation developed by Turner et al. (1969). Insufficient information on the lizard's diet, food availability, species territoriality, metabolism rate, physiological constraints of living in the páramo, and density of individuals (McNab 1963; Perry & Garland Jr 2002; Ruby & Dunham 1987), the home range was overestimated to 3 km^2 (Loiselle et al. 2003). The overestimated home range was used to qualify the predicted lizard distribution areas.

Patch Metrics

Going beyond the traditional structural connectivity analysis into the functional connectivity, I constructed a database and gave more importance to the patch characteristic that met the criteria determined by the estimated home range (Theobald 2006). I derived the area, perimeter and thickness for each patch. I calculated the core area of every patch by shrinking each patch by 100 m. I created a surrounding index that took into account the land cover matrix outside of the distribution by buffering the predicted lizard distribution 100 meters from the edge of each patch. The buffer was intersected with the land cover layer to determine the surrounding context for each patch. After determining what percentage surrounding each patch was unsuitable habitat, I created a surrounding index by controlling for the area of the patch. Evaluating the landscape matrix is important to spatially understand the barriers to connectivity or the possible corridors that can be formed with other patches (Fahrig 2001; Ricketts 2001).

To further refine the predicted lizard distribution, from the estimated home range a criterion was developed based on core area, surrounding index, area and thickness to select those patches that are promising for conservation (Table 3). If the size of the habitat is too small to support one or two individuals, then that particular population is more likely to go extinct (Jordan et al. 2003). Once the better patches were identified, a more rigorous criterion, including surrounding index, core area and distance to the nearest patch was included (Table 4). Each patch was then ranked with area weighing the most. The bigger and more connected patches were the better patches (Figure 4). To determine if connectivity between these patches is viable given the rugosity of the terrain, a cost raster layer was developed based on land cover, slope and elevation (Table 5).

Results

The predicted lizard distribution decreased by 10% from its original size ($1400km^2$) when cutting out the unsuitable habitat and including certain areas of the suitable habitat. The predicted lizard distribution further decreased 6%, from 1267 km^2 to 1200 km^2, when filtering out those patches that failed to meet the criteria.

Around 61% (726 km^2) of the predicted lizard distribution fall within protected areas. Furthermore, the patches within protected areas are mostly composed of the biggest and best connected patches. Overlaying the remaining ranked patches on the cost layer, a corridor can be visually seen (Figure 6) that could connect the southeastern patches in Pisba National Park with the northeastern patches in Cocuy National Park.

Discussion

Given that tropical species have physiologically adapted to certain regions, a change in temperature will result in community changes and extinctions of species (Williams et al. 2007). Páramo ecosystems, harboring endemic species that have adapted to the low oxygen and daily fluctuating temperatures are especially vulnerable to rising temperatures. The distribution of *S. lache* is naturally constrained by mountain ranges that were created during the late Pliocene (Corredor 1983), but climate change will fragment the páramo ecosystem and the lizard's distribution even more (Parmesan 2006).

Since the majority, and the biggest and most connected patches of the predicted lizard distribution fall within protected areas, then it can be determined that this species is protected enough so that extinction in the future will not be attributed to direct human encroachment on its habitat. Given the overestimated home range (3 km^2), an individual lizard will never cross from one protected area to the other, but creating a corridor between Pisba and Cocuy National Parks might maintain genetic diversity within populations (Joly et al. 2003). Climate change will decrease the size of the suitable patches and increase the isolation between patches (Fahrig 2003) given that the topography of the area poses physiological constraints and costs to species migrating from one place to another (Figure 7) (Joly et al. 2003).

There is uncertainty whether the 3 km^2 is an overestimation or underestimation of *S. lache*'s home range. Lizards inhabiting more vertically complex habitats (i.e. arboreal species) tend to have smaller home ranges, and in the case of *S. lache* who is not arboreal (Ruby & Dunham 1987), the vertical complexity might be expressed as high elevation. Furthermore, restrictive temperature regimes, such as those in the páramo ecosystem where amount of direct sunlight depend on season and time of day (Escallón & Mogollón 2008), have smaller home range (Ruby & Dunham 1987). At the same time low food availability correlates with a bigger home range (Perry & Garland Jr 2002; Ruby & Dunham 1987), but this is uncertain for *S. lache* because there is no knowledge of diet and food availability. For future studies, this home range estimate can serve to calculate an extinction threshold for the lizard populations (Fahrig 2003).

Unlike tropical lowland species that may be doomed in the face of climate change, *S. lache*'s livelihood could take two different paths. This species might start migrating to the higher parts of the mountains looking for cooler places since temperature is the most important stressor for high-elevation lizards (Huey et al. 2009; Kearney et al. 2009; Navas 2002). The interspersed páramo fragments on the Eastern mountainrange would complicate the migration of these lizards since they would have to cross valleys at a lower elevation which present physiological challenges (Janzen 1967). Eventually this species will be driven to extinction by rising temperatures and disappearing habitat (Parmesan 2006).

This species might also adapt to climate change. *S. lache* shares more physiologic similarities to temperate animals in comparison to tropical lowland animals given the climatic conditions of the páramo. While temperate ectotherms deal with seasonal temperature variation, high Andean organisms cope with extreme daily temperature fluctuations. Research shows that the thermal tolerance of organisms is proportional to the magnitude of temperatures they have experienced (Deutsch et al. 2008; Kearney et al. 2009; Tewksbury et al. 2003). It might follow that an increase in temperature would not be devastating to *S. lache* (Huey et al. 2009), but instead would enhance their thermal performance (Deutsch et al. 2008). If this is the case, expanding the lizard's habitat and de-fragmenting the landscape by páramo restoration might maintain the lizard populations. However, high altitude insectivorous lizards like *S. lache* might be somewhat resilient to a rise in temperature, but they might be susceptible to changes in water resources and food abundance (Buckley 2007). Furthermore, lizard's eggs might be susceptible to higher intensities of UV radiation (Buckley 2007).

Survival of other páramo organisms, with rising temperatures and drastic rain patterns, will depend on their ability to adapt to the new environment and cope with their physiological requirements (Deutsch et al. 2008; Huey et al. 2009). Changing annual rainfall patterns due to global climate change will likely affect frog populations given frogs' permeable skin and requirement of water sources year around (Navas 2006), as was the case with the extinction of the Jambato toad in the Ecuadorian Andes (Ron et al. 2003). Climate change will affect predators and competitors differently (Huey et al. 2009). While some species might adapt to the changing environment, their prey might not. Uncertainty abounds in the impact climate change will have on the trophic cascade of the páramo ecosystem. Although since temperature limits lizard diversity in tropical high elevation mountains (Navas 2006; Vuilleumier & Monasterio 1986), species interactions in the páramo ecosystem might be more closely interconnected that more species rich ecosystems in the lowland tropics. Lowland species might be migrating higher up the mountains, and displacing páramo organisms that have had to deal with very little competition (Ghalambor et al. 2006). There are many uncertainties of the impacts climate change will have on *S. lache*, so constant monitoring can further the understanding of how the changing climate will affect high altitude tropical ecosystems.

Based on the IUCN criteria, *Stenocercus lache* falls within the category of being an endangered species because its distribution (1200 km^2) is less than 5000 km^2 (IUCN 2001). As of May 2009, this lizard does not appear on any Red List. Appearing on the Red List is important so that future studies on the lizard can be compared through time, and an assessment of climate change's impact on organisms across ecosystems can be accomplished (Willis et al. 2007). Furthermore, although organisms are not distributed along political boundaries, the internal political situation of a country can be a barrier to doing research in the field. Internal warfare in Colombia since the 1960s has made field work extremely challenging, although Colombia is one of the most biodiverse places in the world, harboring 15% of the known species in the world (Gast et al. 2003). Listing tropical endemic species in the IUCN Red Lists creates a database to compare the extinction rates and distribution of species from different ecosystems in the face of climate change. Furthermore, this list can add to knowledge of speciation and divergence processes of tropical species.

For the future conservation of the lizard, periodic monitoring of the lizard within protected areas is important to understand how the lizard is behaving towards the changing climate. Sighting a lizard under sunny conditions in Cocuy National Park is easy and since the communities around this park have an aversion towards it (Escallón & Mogollón 2008), making the lizard the flag species of Cocuy National Park would raise its conservation status.

Restoring the páramo areas surrounding the park by setting a payment for ecosystem services program would reduce edge effects while creating an incentive for locals to protect the ecosystem (Fahrig 2001, 2003). Converting pasture for raising cattle or agricultural fields back to natural habitat might serve some species that are sensitive to traveling on transformed habitats (Ricketts 2001).

S. lache is a model organism to study the impact climate change will have on tropical high altitude heliothermic species because as this research shows, its distribution is restricted to a relatively small area and the majority of its distribution is within protected areas which isolates other anthropogenic factors (i.e. habitat lost to agriculture) that in a different scenario could be the main reason for its decline. The impact that global climate change will have on this ecosystem and on *S. lache* is out of our immediate control, although a step forward would be for government institutes and agencies to make climate and geographic data and information free and available to the public (Vuille et al. 2008).

Acknowledgements

I would like to thank Jennifer Swenson for her optimism, patience, suggestions, humor and guidance throughout this project. I would also like to thank Norm Christensen for his recommendations to the written manuscript and for always seeing the big picture. Thanks to John Fay for translating ideas into spatial analysis processes, to Clinton Jenkins for making the programs needed to run these analysis available, German Forero for the ecosystems layer and credibility in Colombia's future, Stuart Pimm for making me part of the Pimm Family, Marion Adeney for looking over my presentation twice and giving constructive comments, and Scott Spillias for constructing and reconstructing a methodology for patch analysis. Thanks to the Link who got my computer and my hard disk formatted correctly to have enough space for the geographic layers and to the Library Staff who helped me find ArcGIS tools during times of crisis. Finally I would like to thank Camilo Escallón for his idea to start a project with this lizard a year ago and for being extremely supportive and patient during this project.

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Tables and Figures

Table 1. A multivariate analysis of the environmental variables helped reduce the number of variables that were included to predict the species distribution.

Environmental Variables	Excluded *
Aspect	
Annual Precipitation	
Annual Mean Temperature	x
Elevation	
Radiation	
Slope	x
Land Cover	
Rugosity	

* $R^2 > 0.7$

Table 2. The home range for *Stenocercus lache* was estimated using Turner et al.'s (1969) equation, by first deriving weight from the allometric relationship between size and weight for lizards.

	Snout-Vent (cm)	Weight (gm)	Estimated Home Range (m2)
Males (N=6)	8.1	15	2245.4
Females (N=10)	6.6	7	1088.6

Table 3. Criteria that patches of the predicted lizard distribution must meet in order to sustain a viable population of *S. lache*. These criteria are based on the estimated home range.

Criteria that Patches must meet
Core Area >= $3km^2$
Surrounding Index <= 1
Thickness > 0.25 km
Area >= $3km^2$

Table 4. A second round of criteria that the remaining patches from the predicted lizard distribution must meet to sustain more than one population of *S. lache*.

Criteria that Patches must meet
Core Area >= 5km^2
Surrounding Index <= 0.4
Distance to the nearest patch >= 5km^2

Table 5. Using ranges with elevation and slope, and categories with land cover a cost layer was developed using the criteria to determine the places of high cost and low cost of traveling across a landscape.

	High Cost	Low Cost
Elevation (m)	2500-3000	3000-4300
	4300-5341	
Land cover	Urban areas	High altitude andean forest
	Open pastures	Paramo
	Agriculture	Rock with interspersed vegetation
	Snow	Shrubs
Slope	>45º	<45º

Figure 1. The unsuitable habitats were clipped out from predicted lizard distribution. Box A shows the predicted lizard distribution in black before taking out the unsuitable habitats, and box B shows the predicted lizard distribution after clipping out the unsuitable habitat. Unsuitable habitat consists of urban areas, open pastures for raising cattle and sheep, and agriculture.

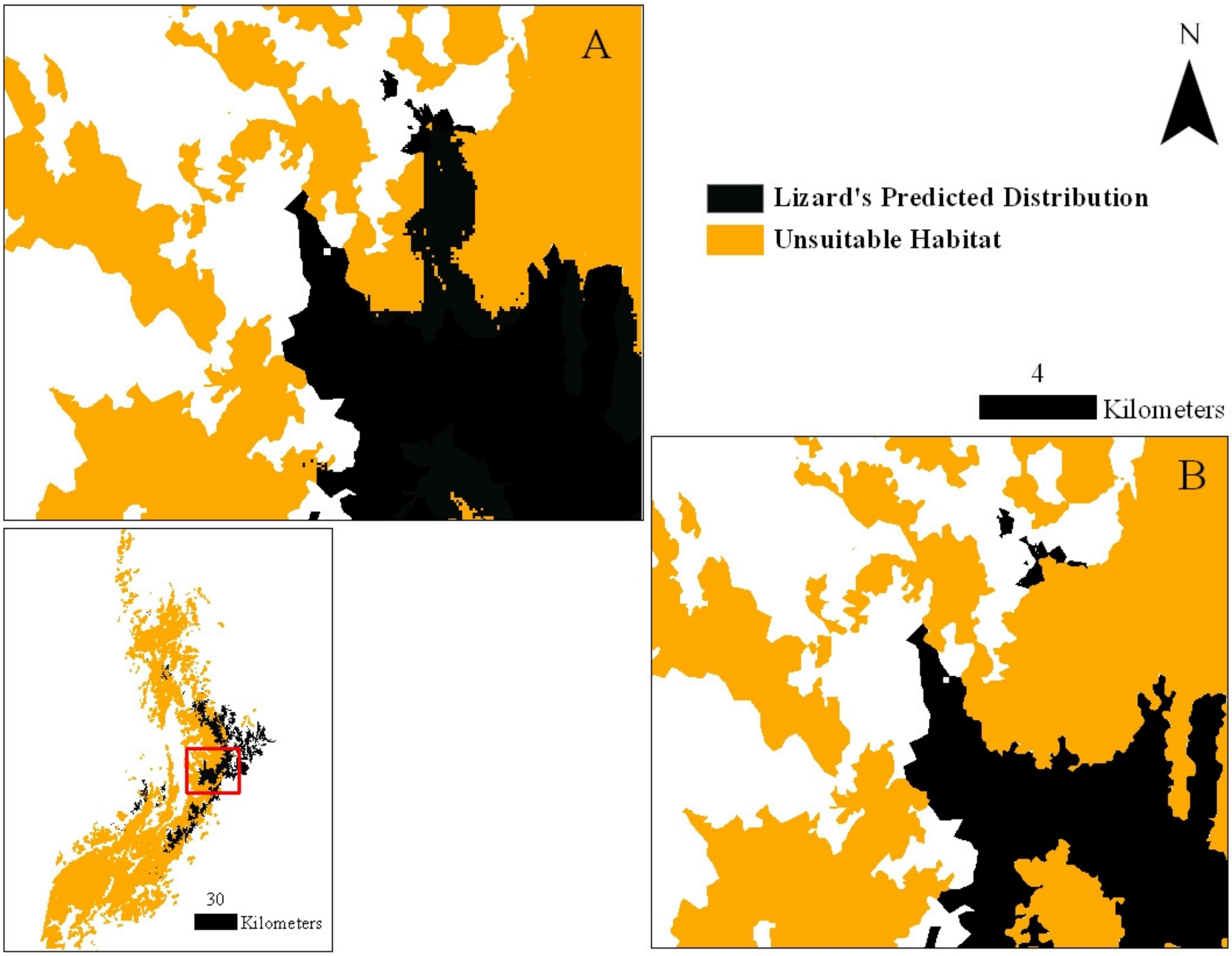

Figure 2. To include potential distribution that the species distribution did not take into account because it was only based on the points used in the model, some of the suitable habitat was included. If 50% or more of the predicted lizard distribution fell within suitable habitat areas, then all those areas were added to the lizard distribution. If not, then only the portion of overlap was included. Box A shows the predicted lizard distribution in black overlaid with each region of suitable habitat, and box B shows the predicted lizard distribution expanded to those areas where the distribution is 50% or more within the suitable habitat areas.

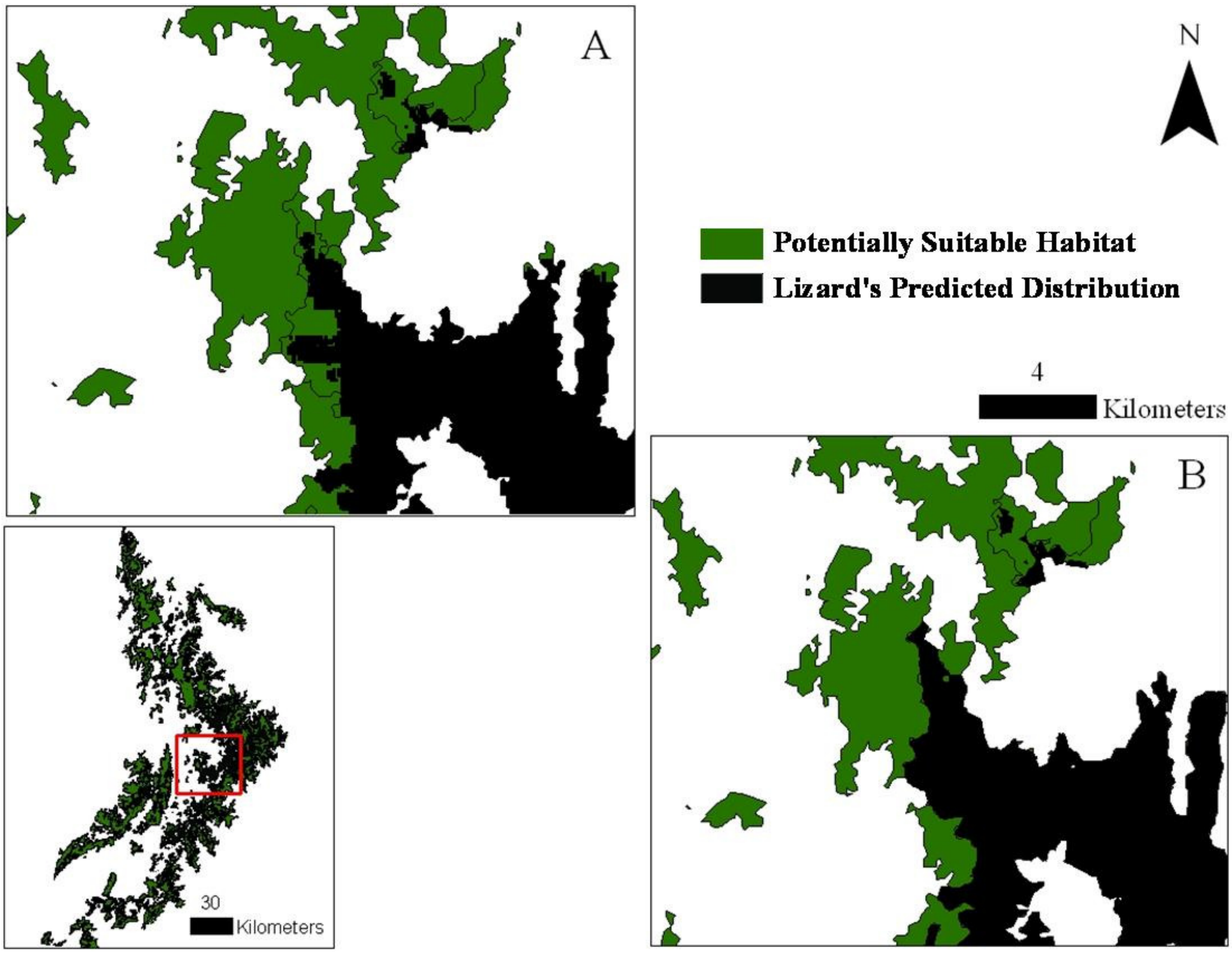

Figure 3. This is the predicted lizard distribution after excluding unsuitable areas and including some of the suitable areas. Each of this patches was given its individual identification.

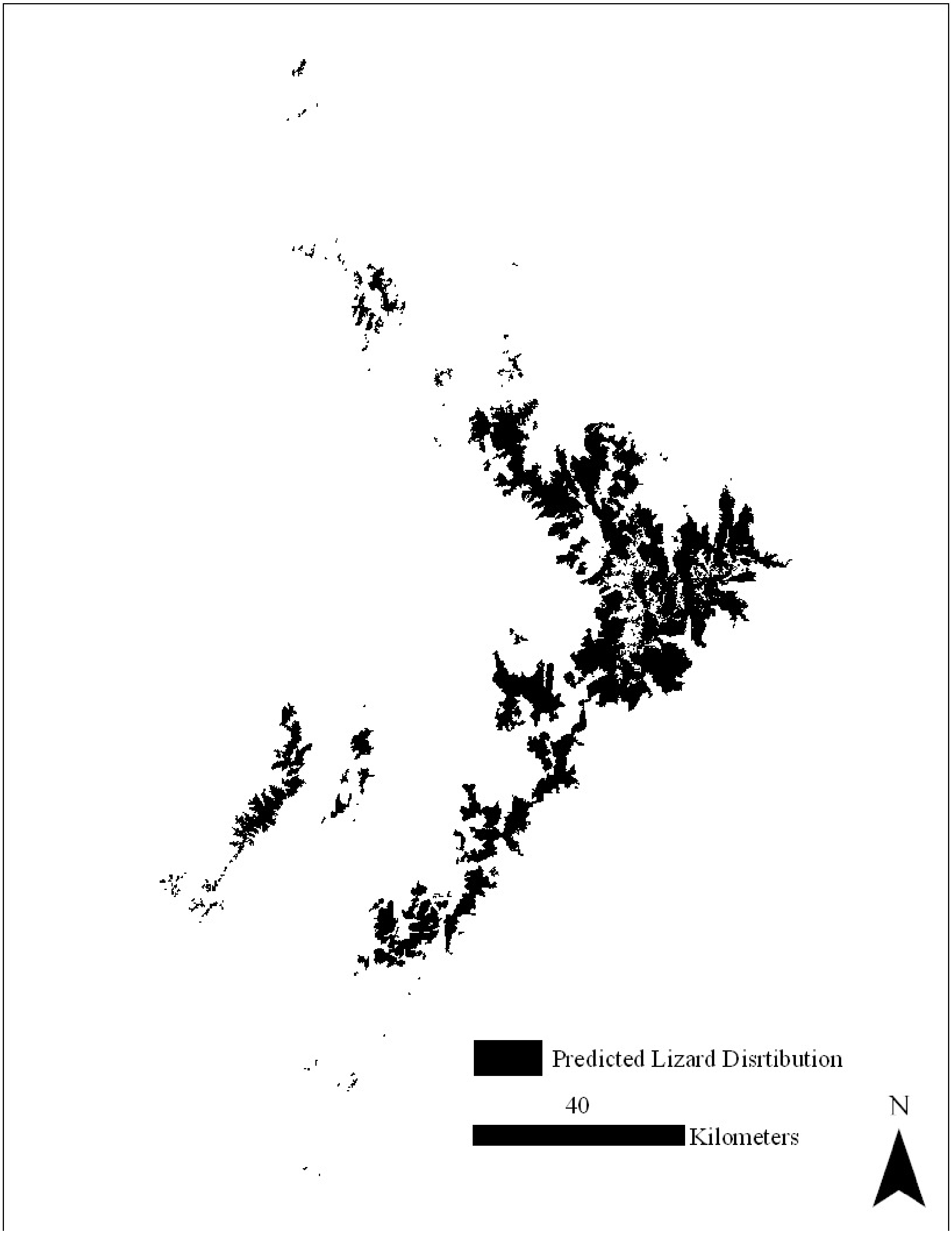

Figure 4. The most suitable patches are those that met the criteria based on core area, proximity to another patch and surrounding index. The redder patches are those that meet these requirements and could possibly harbor the healthiest lizard populations.

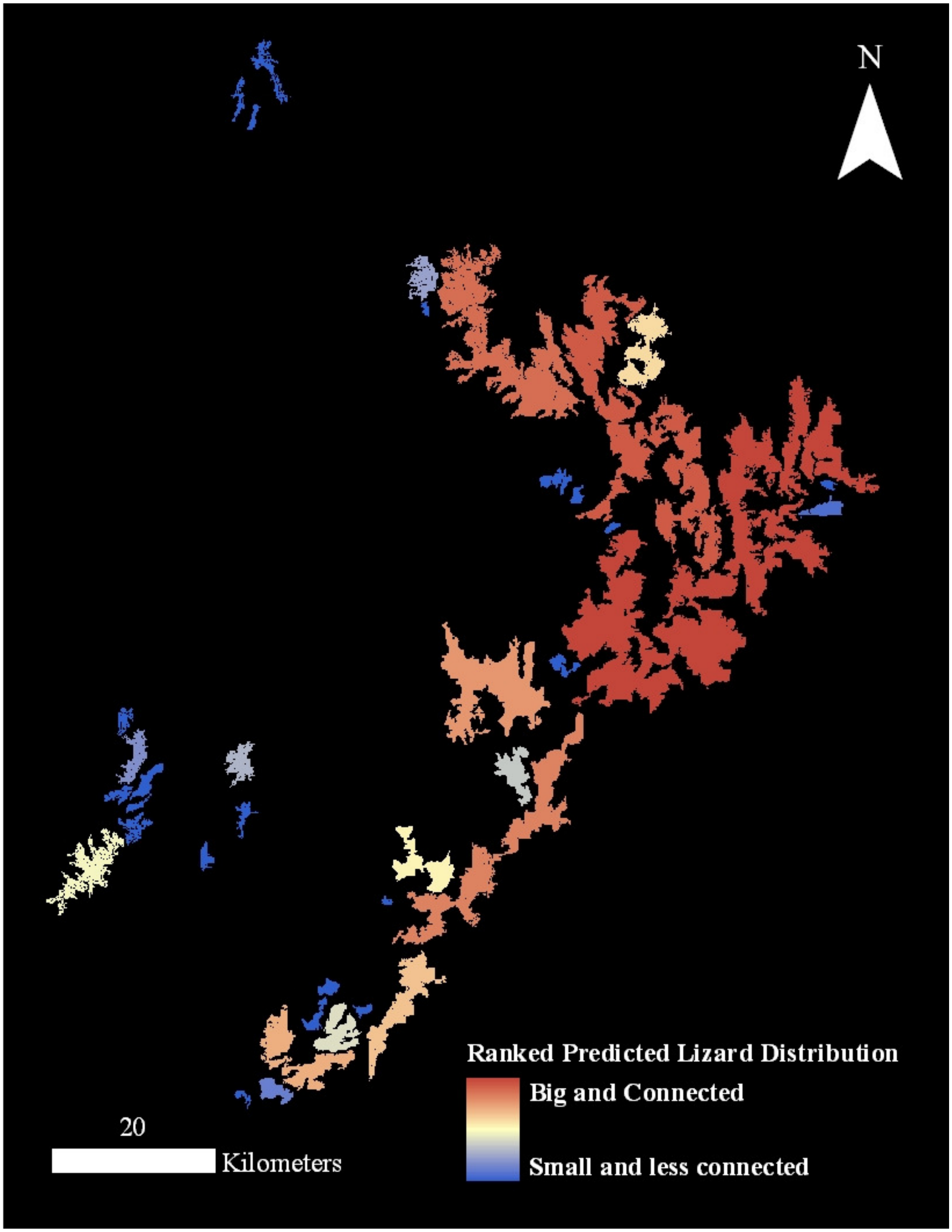

Figure 5. A cost layer derived from slope, land cover and elevation can elucidate the regions where a corridor connecting patches would be beneficial to maintaining genetic diversity between lizard populations as the regions in blue show the lowest cost to travel across the landscape.

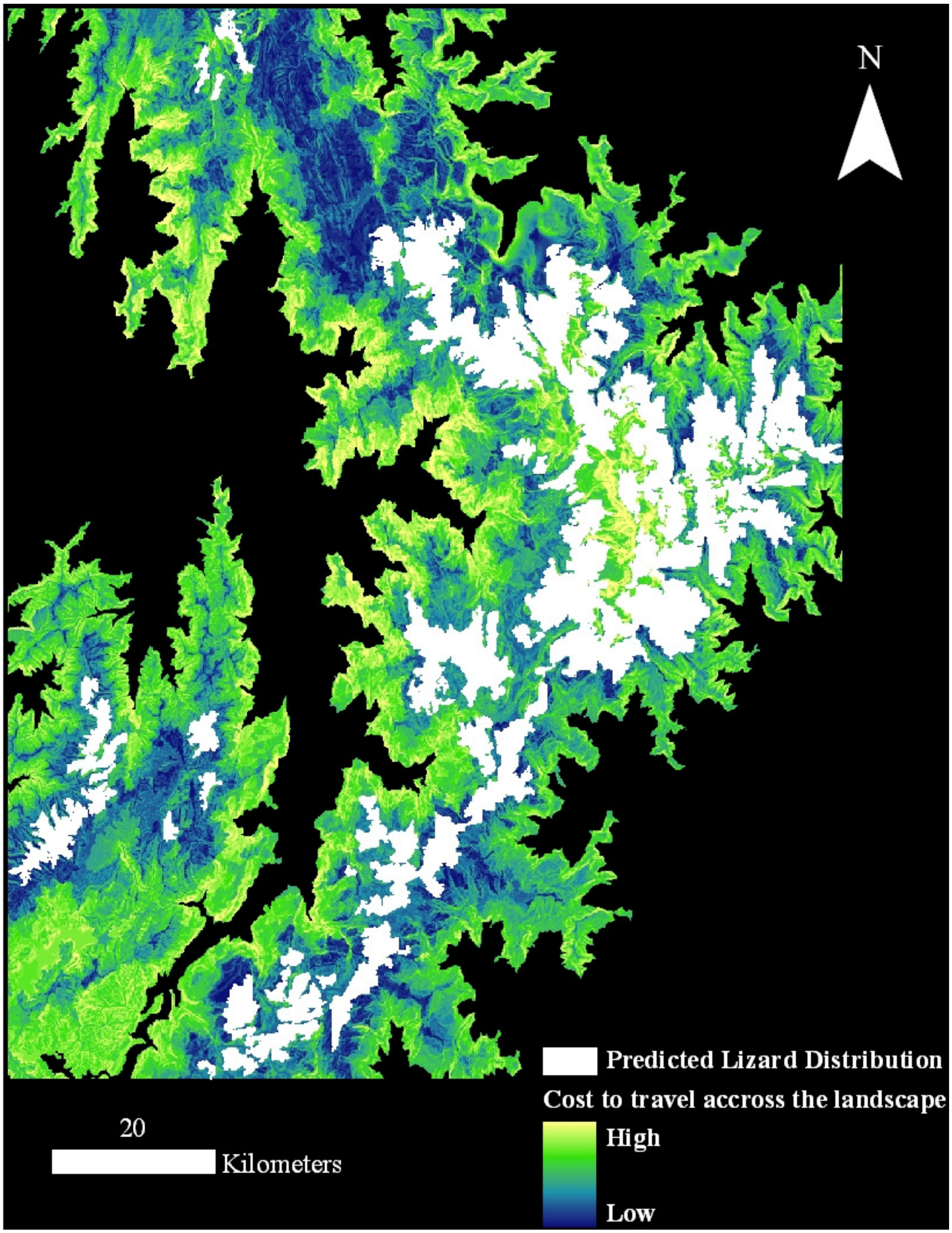

Figure 6. The majority of the biggest and most connected patches are within protected areas. A corridor connecting Cocuy National Park with Pisba National Park would connect the northern patches with the southern patches.

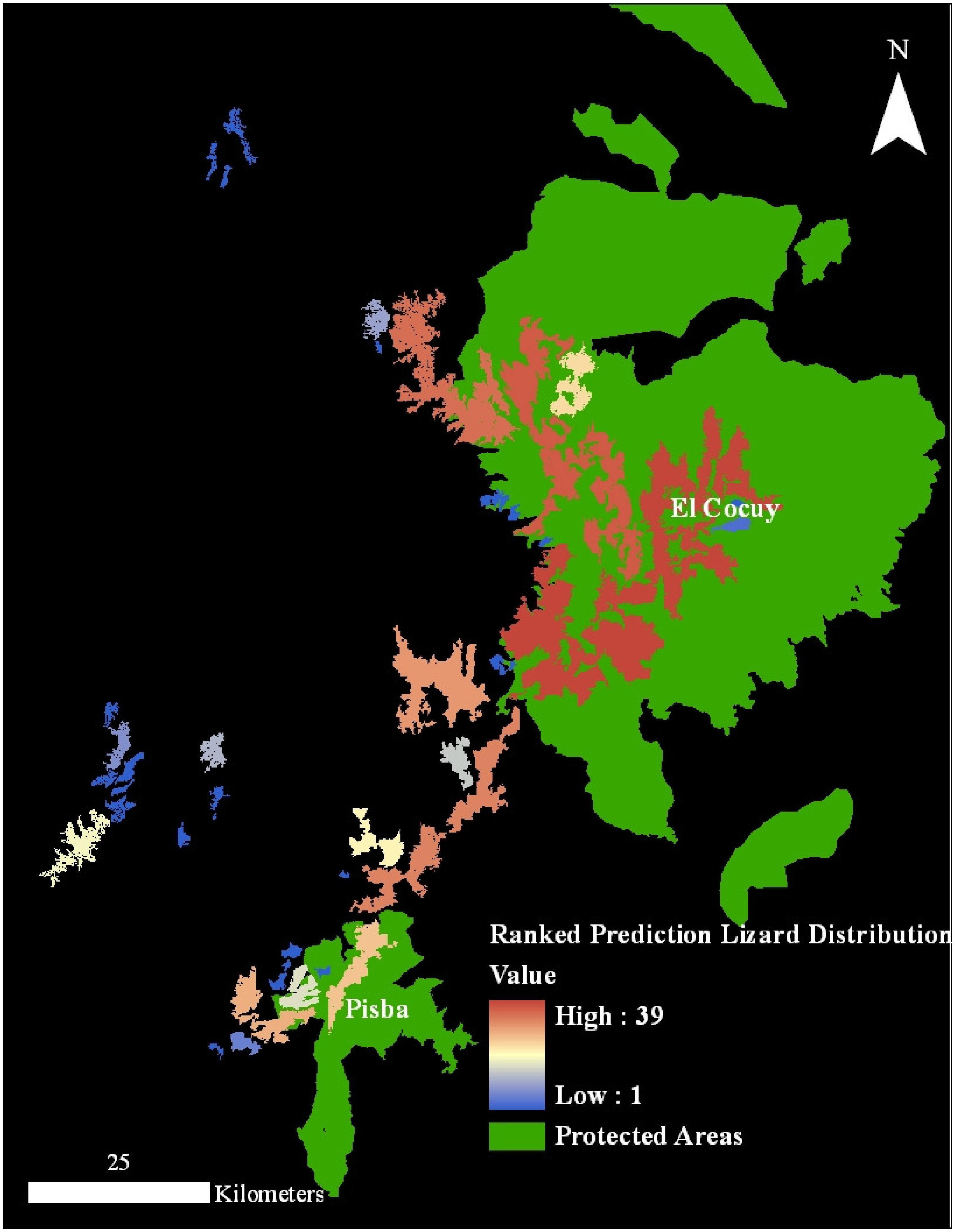

Figure 7. The predicted lizard distribution has not only been reduced by transformation of land, but this part of the Andes