Viability and improvement of constructive wildlife corridors in tropical forests, proposing a new method for evaluating corridors geospatially using MaxEnt

by

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EXECUTIVE SUMMARY

Habitat fragmentation is habitat destruction that occurs in small patches and breaks up a landscape, creating a matrix of modified land cover and making it difficult for populations of species to move, interact, and reproduce (Pimm et al. 2021). The effects of habitat fragmentation are heavier on rare species with small ranges due to the genetic diversity and interaction already lacking among individuals. In addition, this threat to biodiversity is even more concentrated in the forests of the global tropics, as these ecosystems are home to a majority of the Earth's species, many of which are endemic to small and unique areas.

Wildlife corridors are a forestry management tool developed to restore connectivity in human-modified landscapes (Ford et al. 2020). Habitat corridor ecology remains a new and developing field in wildlife and forest management. Although a popular tool in conservation projects, little is known about how corridors statistically work or how they should be established and monitored.

Stuart Pimm and his non-profit, Saving Nature, build constructive habitat corridors in tropical forests. These types of corridors are large landscape-scale projects that can connect several islands of forests. Saving Nature now hopes that the data collected from these corridors can contribute to the growing knowledge in the field of corridor ecology. In this study, I analyzed camera trap data from Saving Nature's corridors in Colombia, Ecuador, and Brazil.

Occupancy models were run to determine general corridor efficiency based on the species detected in the camera traps and species that were expected to appear based on habitat range, elevation, and other environmental variables. Detection and occupancy probabilities from the models were weighted according to IUCN conservation status and averaged together to determine each corridor's overall probabilities. All corridors exceeded 36% occupancy

probability and 17% detection probability, despite the absence of more than half of the target species in each corridor.

I also propose maximum entropy models as an alternative way to achieve an answer to the same question. Variables that were considered in the MaxEnt models included land use land cover, forest habitat, elevation, slope, distance from edge habitat, distance from the nearest stream, and distance from the nearest road. Percent True scores were calculated from the MaxEnt confusion matrices, which were used on the same weighted scale as the occupancy model results to determine the overall score for each corridor. PT scores were significantly lower than the occupancy model results. However, the suitable habitat maps resulting from the MaxEnt models show the connection between habitat fragments.

In addition, jackknife graphs from the MaxEnt models were used to rank variable importance in determining suitable habitat in each corridor. Overall, land use land cover and elevation were the most important variables for the MaxEnt models. Slope, elevation, and distance to edge habitat were slightly less important variables but were still significant contributors. The least important variables were distance to the nearest road and distance to the nearest waterway.

These rankings of environmental variable importance were also used to build the equations of the least cost path models, which identified the areas where animals are most likely to be found in the corridors so that cameras can be repositioned to collect more data. The resulting models show that all corridors would benefit from adjusting the camera trap locations.

Overall, all corridors were determined to be working adequately, but with room for improvement. After repositioning the camera traps according to the least cost path models, it may be so that the corridors are operating at levels higher than this analysis determined.

Finally, MaxEnt models show some potential as a method to evaluate corridor projects, but model refining and further research and development are required. This method should be explored further as Saving Nature collects more data and launches new corridor projects.

This analysis is not only significant to Saving Nature, but to the field of wildlife ecology. These methods can assist other corridor ecologists and foresters when building corridors and managing wildlife around the world. In addition, proposing a new way of geospatially evaluating projects has the potential to change how ecologists and forest managers use habitat corridors.

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INTRODUCTION

Habitat Fragmentation: a threat to tropical biodiversity

Habitat destruction is arguably the dominant factor in terrestrial biodiversity loss (Kuipers et al. 2019) and the leading cause of modern species extinction (Pimm & Raven, 2000). Habitat fragmentation is habitat destruction that occurs in small patches and breaks up a landscape, creating a matrix of modified land cover and making it difficult for populations of species to move, interact, and reproduce (Pimm et al. 2021). Fragmentation often results from a change in land use (e.g. logging or agriculture) and leads to a shift in land cover, therefore causing a change in the average size, shape, and spatial arrangement of the overall landscape (Kuipers et al. 2019). Most species prefer core habitat to edge habitat (Ford et al. 2020), and when an ecosystem is fragmented, the ratio of core-to-edge habitat decreases. This increases the extinction risk of these core-dwelling species (Kuipers et al. 2019). The effects of habitat fragmentation are heavier on rare species with small populations and ranges due to an already present lack of genetic diversity and interaction among individuals. With a small-ranged species, a local extinction can also easily mean a global extinction (Pimm et al. 2021). This threat to biodiversity is even more concentrated in the forests of the global tropics, as they are home to at least two-thirds of the Earth's terrestrial species and contain a majority of the world's biodiversity hotspots (Sarathchandra et al. 2021). Not only does habitat fragmentation have a severe impact on a forest's biodiversity, but these systems provide a plethora of ecosystem services (Felton et al. 2019) and may serve as carbon sinks (Baker et al. 2020), making their conservation critical in the fight against large-scale environmental change.

Habitat Corridors: reconnecting the forest

Wildlife corridors are a forestry management tool developed to maintain or restore connectivity in human-modified landscapes (Ford et al. 2020). This tool has less of an emphasis on economics and more on species conservation, compared to other forestry management techniques. The idea of implementing habitat corridors to connect fragments has been used in the field of ecology for decades, but there is little research available as to if or how these corridors work, what the most effective way to establish and manage them is, or how and which animals are using them (Naidoo et al. 2018). While there are a few studies that suggest that corridors can increase species movement by 50%, the research is limited, and their true effectiveness is still debated in the field, even though their use in conservation planning, land use, and sustainable development remains popular and widespread (Naidoo et al. 2018).

Saving Nature and constructive habitat corridors

Saving Nature (SN), founded by Stuart Pimm in 2019, works toward building constructive habitat corridors – a subtype for which even less research has been done – to connect habitat fragments in countries like Ecuador, Colombia, Brazil, and Sumatra (Pimm 2019). SN works in highly concentrated areas of biodiversity. As a result, most of their efforts exist in the tropics, as these regions hold a majority of Earth's biodiversity and are also under severe threat of deforestation (Pimm 2019). SN has formulated an approach to conservation based on science and research, and they partner with local organizations (Pimm 2019) to identify biodiversity hotspots where there are concentrations of small-ranged species that are under threat of anthropogenic actions and habitat fragmentation (Pimm et al. 2021). After detecting these hotspots and identifying the small-ranged species most at risk in these areas, Saving Nature looks for opportunities to purchase land to connect fragments and preserve the hotspots at low prices and with as little political conflict as possible (Pimm 2019). After establishment, their primary

method of monitoring these corridors is installing camera traps throughout the tract. Camera traps are currently deployed in the Andes Cloud Forest constructive corridor in Colombia, the Lowland Forest constructive corridor in Ecuador, the Atlantic Forest constructive corridor in Brazil, and the Atlantic Forest bridge corridor in Brazil (see Saving Nature's website for more information on each reforestation project).

Now Saving Nature would like to know if these corridors are working to assist target species in moving between fragments, and if they are not working, they want to know why. Answers to these questions will not only help SN's endeavors but will also assist other wildlife corridor ecologists and foresters when building future corridors and managing these tracts of forest for wildlife around the world.

OBJECTIVES

Research Questions

1. What species do we expect to see using SN's habitat corridors, and which are? The answer to this will be used as a proxy to measure corridor viability (i.e. if the corridor works)
    a. Can maximum entropy models be used as an alternative method to answer this question?
2. Are the camera traps currently in the right places to be most efficient at capturing the species of interest? Are there better locations for the camera traps?

Hypotheses

1. I hypothesize that we are not seeing all the species in the camera trap images that should be using the corridors, and therefore the corridors can be improved
    a. I hypothesize that yes, MaxEnt models can be used to determine habitat corridor viability
2. I hypothesize that there are likely better locations for the camera traps that would maximize the likelihood that an animal crosses in front of the camera, therefore resulting in the collection of more data

MATERIALS & METHODS

Study Areas

Please note that exact locations are confidential information among the staff at Saving Nature and their partners, to maximize privacy and protection of wildlife.

Colombia

The Colombia constructive corridor is located in the Western Andes Cloud Forest. This habitat type is currently facing a double threat from climate change impacts and anthropogenic expansion (Spanne, 2012). The cloud forest is home to nearly a sixth of the world's biodiversity, many species of which are found nowhere else in the world (Pimm, 2019).

Reforestation began in 2013 to reconnect forested areas that were fragmented by agriculture and rangeland. The completed corridor is planned to cover 8,478ha, connecting 100,000ha of forest. Camera traps used in this analysis were placed later to aid in monitoring efforts.

Saving Nature has partnered with The Hummingbird Conservancy to reforest, monitor, set up camera traps, and collect data within the corridor, as well as aid in outreach to local communities.

Ecuador

The Ecuador constructive corridor lies in the Pacific Lowland Forest. The corridor connects a coastal reserve to a cloud forest reserve. The region surrounding the two reserves has been heavily impacted by deforestation, which has been detrimental to wildlife and indigenous people.

Ecuador is home to the most bird species per square kilometer of any country. In addition, this area has a suite of endemic species associated with it, including primates, amphibians, and plants (Pimm, 2019).

Reforestation began in 2014 to reconnect the heavily fragmented area between the reserves. The completed corridor will cover 1,000ha. Camera traps used in this analysis were placed later to aid in monitoring efforts.

Saving Nature has partnered with IUCN Netherlands, Third Millennium Alliance, and Grupo Ecologico Jama Coaque on this project.

Brazil

Two corridors in Brazil were analyzed in this project. Both are located in the Atlantic Forest, a habitat type that is home to 60% of Brazil's endangered species (Pimm, 2019).

The first corridor is a constructive corridor that connects forest islands previously fragmented by rangeland. Reforestation began in 2007 and has shown evidence of use by golden lion tamarins (*Leontopithecus rosalia*). Camera traps in this analysis were placed much later in 2018.

The second corridor is a bridge corridor that connects two sides of a major highway, the first of its kind in Brazil. The bridge was constructed by the Brazilian government, but their plan omitted a connection from the bridge to the nearby reserves. It is in these areas that Saving Nature has partnered with DOB Ecology and Associação Mico Leão Dourado to reforest, monitor, set up camera traps, and collect data.

Data Sources

Saving Nature and its partners from the study areas provided all the camera trap data that was used in this analysis in the format of a OneDrive cloud. Data were then organized into Excel spreadsheets to be analyzed. Also provided by SN were the metadata and geopoint data for all camera traps, as well as background information and metadata on the corridors, such as location, area, acquisition, and management plans.

Geospatial data were collected from external sources (Table 1).

Table 1. List of external data sources and GIS layers

Data	Data Type	Source
Shapefiles of habitat fragments	Feature class	User-generated
Species information and range maps		(IUCN, 2022)
Land Use Land Cover	Raster, 10m res	Sentinel-2 (Karra et al., 2021)
Elevation	Raster, 250 res	USGS (Danielson & Gesch, 2011)
Slope	Raster, 10m res	Derived from elevation
Waterways	Feature class	(OpenStreetMaps, 2021)
Roads	Feature class	(OpenStreetMaps, 2021)
South America boundaries	Feature class	(Esri, 2013)
Colombia Municipalities boundaries	Feature class	(Esri, Colombia Municipio Boundaries 2020, 2021)
Ecuador Cantone boundaries	Feature class	(Esri, Ecuador Cantone Boundaries 2020, 2021)
Brazil Subdistrict boundaries	Feature class	(Esri, Brazil Subdistrito Boundaries 2020, 2021)

Methods

Data Prep

Preparing the camera trap database

I received the camera trap data in the form of a OneDrive cloud database for each country. Data were already sorted into folders according to the Sanderson & Harris (2013) protocol (i.e. by camera trap -> species name -> number of individuals in the image).

The metadata for each camera trap image or video was entered into a spreadsheet for each country (Figure A1, Appendix A). The finished spreadsheets included 16,887 entries for

Colombia, 16,825 for Ecuador, and 2,087 for Brazil. These file directories serve as an asset to future researchers, as they can simply add additional data to the existing spreadsheets and not have to repeat this step in the analysis.

The International Union for Conservation of Nature (IUCN) Red List (IUCN, 2022) was utilized to generate a list of target species for each country's site location. In the Red List, there is a tool to draw a polygon around a study area that returns every species within that range. From this list, all species of interest were entered into another Excel spreadsheet. Species that were not considered in the target list included primates, small rodents, reptiles, amphibians, small songbirds, bats, insects, plants, fungi, and marine species. In addition, species were omitted if they fell out of location or habitat type range (see Appendix A for explanation).

This process left 29 species/guilds in Colombia, 32 in Ecuador, and 38 in Brazil (Tables A1-3, Appendix A).

Next, the content of these two spreadsheets was combined to create normalized file directories. Duplicate entries were eliminated (see Appendix A for explanation). This process left 3,651 entries across 16 camera traps in Colombia, 6,936 entries across 7 camera traps in Ecuador, and 1,553 entries across 7 camera traps in Brazil.

From these normalized directories, pivot tables were generated to calculate counts of occurrences for each species at each camera trap for each country. In these pivot tables, undesired species were not selected, such as *Ghost* (i.e. no animal in the image), *Human*, and any unwanted species. These counts were subtracted from the total run times of each camera to get a count of absence days for each species at each camera. These numbers were compared with those that resulted from the occupancy model text files (see below, Stage 1 Analysis Methods – Occupancy

Model), resulting in 277 presences and 39,027 absences in Colombia, 406 presences and 27,448 absences in Ecuador, and 352 presences and 32,318 absences in Brazil. Of the 352 presences in Brazil, 336 occurred in the bridge corridor, therefore it was decided to exclude the constructive corridor in Brazil from Stages 1 and 2 of the analysis.

A final spreadsheet type was created from these counts, with columns for Species, Latitude, Longitude, and Observed (where 1 = presence, 0 = absence). A row was given to each presence and each absence. These spreadsheets were used to create the confusion matrices for the MaxEnt models (see below, Stage 2 Analysis Methods – MaxEnt Model) for each country.

Setting up the ArcGIS Pro Workspace

The primary search tool for acquiring the appropriate geospatial layers needed for the analysis (see Table 1 above) was ArcGIS Pro's Living Atlas. The Sentinel-2 satellite time series land cover map (Karra et al., 2021) was used to extract the appropriate years of land cover data for South America. These years were determined based on when the data for each country were collected: 2018 for Colombia, 2020 for Ecuador, and 2019 for Brazil. This land cover map was developed from data from the Sentinel-2 satellite by a team at Impact Observatory, who used a huge training dataset from the National Geographic Society. The land cover map is at 10m resolution with a global extent, projected in WGS-1984, and predicts 10 land cover classes. These land cover maps were then masked to the extent of the boundaries of South America (Esri, 2013) to make their file sizes more manageable.

Elevation was determined to be a considerable variable due to the large sizes of the corridors. The US Geological Survey's Global Multi-resolution Terrain Elevation Dataset (Danielson & Gesch, 2011) was chosen for the analysis. This raster digital elevation model has a global extent

at 250m resolution. The layer was also cut to the extent of South America and masked to the cell extent of the Sentinel-2 land cover map. Slope datasets were eventually created from this dataset (see below, Stage 2 Analysis Methods – MaxEnt Model). See Appendix C for elevation and slope maps in each country.

The OpenStreetMap project provided up-to-date and delineated feature classes for all waterways (OpenStreetMap Waterways for South America, 2021) and roads (OpenStreetMaps Highways for South America, 2021) in South America (Figures C6, C15, C24, Appendix C). These layers were all rasterized to the same extent and cell size as the South America cut Sentinel-2 land cover maps. Linear transportation is important to consider in research questions regarding animal movement (Ascensao, 2022).

Temperature and precipitation, additional variables that are often included in MaxEnt and least cost path models, were considered but ultimately left out of the analysis. The corridors, although large enough for elevation to play a factor, were determined to be too small for temperature or precipitation to play a significant enough role. It was assumed that temperature and precipitation needs were met for a species if they fell within the spatial and elevation range of the corridor.

All of these layers were processed through an ArcGIS Pro ModelBuilder (Figure B1, Appendix B). Also added to the project were shapefiles of the camera trap locations that were created from the latitude-longitude coordinates. The ArcGIS Pro project workspace was set up with GCS_WGS_1984 as the Environment Coordinate System.

Occupancy Models (Stage 1)

The Sanderson & Harris (2013) protocol for camera trap data processing was used due to the large nature of the datasets. This protocol is extremely user-friendly; it streamlined the process and reduced errors as much as possible. It was developed by Jim Sanderson of the Small Wild Cat Conservation Foundation and the Wildlife Conservation Network and Grant Harris of the US Fish and Wildlife Service, and it aimed to create a way to process camera trap data faster while minimizing data entry errors. All tools that are used in the protocol can be found on Sanderson's website https://smallcats.org/resources/. Traditionally, this method is to be used immediately after camera trap data collection, eliminating the need to produce an Excel spreadsheet of the data. These Excel spreadsheets, however, served as my first product for Saving Nature, and so the method was modified.

First, the normalized directory Excel spreadsheets were saved as .txt files for each country. These files were inputs for the CreateInput tool, which created the Input.txt file necessary to run the OccupancyMatrix tool. These Input.txt files were corrected manually with the start and stop dates of each camera trap (extracted from the original file directory). In addition, all species from each respective country were entered at the end of this file (e.g. all 29 target species/guilds from Colombia were entered into the Input.txt file for Colombia). The camera traps of the Brazil Input.txt file were split into two sites, as there is both a constructive corridor and a bridge corridor that are geographically separate.

These finalized Input.txt files were run through the OccupancyMatrix tool, which creates a file free of error that can be imported to the PRESENCE (Hines, 2012) program. These files included a count for each species for the length of the runtime at each camera trap, with a maximum of

one presence per day. This feature removes any repeats in the data. These numbers were compared to the pivot table values generated in the data prep stage.

Finally, the files were imported to PRESENCE to produce occupancy models (Sanderson & Harris, 2013; Cove et al., 2013). The past decade has shown an initiation and increasing rate of occupancy modeling being used to analyze camera trap data (Sollmann, 2018), and this is especially true for analyzing medium and large mammals and birds in the Neotropics (Cove et al., 2013), thereby making this model appropriate for this analysis. Occupancy models estimate species occurrence and are useful in determining if certain species that should be present in an area are significantly represented in the data (Sollmann, 2018). Occupancy models require spatial independence, which can be achieved by spacing camera traps far enough apart (Sollmann, 2018). This, of course, may not completely prevent the same individual from appearing in two different camera traps, but it reduces the risk. I determined our camera traps to be far enough apart for all the target species in each country (Figures C2, C11, C20, Appendix C), and so an occupancy model remained the ideal method. In addition, an occupancy model was chosen over an abundance model because the former is better suited for larger landscape data while the latter requires much more data (Sollmann, 2018), which the database I was given does not have. In addition, by using camera traps, this project leaves the possibility that a species may be present but not detected, meaning it is not necessarily absent. Due to the nature of the dataset, it is more appropriate to estimate occupancy rather than abundance. These occupancy models that were run should not be interpreted as a measure of abundance.

To import data into the PRESENCE software, the following steps were followed. The OccupancyMatrix.txt files that the Sanderson & Harris protocol generated produced occupancy matrices for each species (i.e. 29 different matrices for Colombia, etc.), accounting for the run

times of each camera trap. A new PRESENCE project was created for each species to analyze the occupancy of each species separately. The matrices generated in the OccupancyMatrix.txt files were directly copied and pasted into PRESENCE to reduce error as much as possible. Pre-defined (1 group, constant P) single-species single-season occupancy models were generated for each species in each project (Hines & MacKenzie, 2019). It was assumed that detection and occupancy probabilities would be constant and not be explained by co-variates such as time of day, temperature, date, or presence of another species.

The AIC, Ψ psi occupancy probability, P detection probability, standard errors of those two values, and naïve occupancy estimate were recorded for each model. Ψ and P were totaled on a weighted average with the IUCN score of the species or summed IUCN score of all species in a guild (Tables A1-3, Appendix A) to determine a total occupancy probability and total detection probability for the corridor. The IUCN conservation status was used to generate these scores, as they are assumed to be a proxy for the relative abundance that the corridor should be seeing (Robert et al., 2015). These scores increase with less threatened statuses (e.g. critically endangered = 2, near threatened = 5), as species with more threatened statuses will have fewer individuals in the wild. An assumption was made to give the lowest score of 1 to species classified as Data Deficient because this status is given to species whose abundance and distribution are not studied enough to classify further, either from lack of studies or because the species is so rare (IUCN, 2022).

Occupancy models were run on the Colombia, Ecuador, and bridge Brazil corridors. Due to a lack of data, the constructive corridor in Brazil could not be analyzed by the occupancy model.

MaxEnt Models (Stage 2)

Maximum Entropy (MaxEnt) models have become one of the most widely used species distribution modeling methods due to their power, accuracy, and simplicity in use (Merow et al., 2013). Sollman (2018) states that camera trap analysis is an ongoing development as new analytical approaches emerge. It is also stated that occupancy models can be considered a type of habitat distribution model due to the concern to describe species occurrence patterns. This supports the idea that MaxEnt models, a type of habitat distribution model, may be useful for analyzing camera trap data. MaxEnt is an appropriate model to use because it is a "presence only model," which is what camera trap surveying is; the absence of an animal from the data doesn't necessarily mean they're absent in the ecosystem, just that they didn't pass in front of the camera (Sollman, 2018). There seems to be no literature on MaxEnt being used for evaluating conservation projects, so I would like to propose it and determine if it is a viable method to evaluate habitat corridors.

A MaxEnt model was run for each country using the preprocessed GIS layers and the presence/absence spreadsheets that were created in the data prep stage of the analysis (see above). Because these preprocessed GIS layers were created using the cell size of the Sentinel-2 land cover map, the entire analysis will have a 10m cell resolution.

First, a small area within each country that still well exceeded the bounds of the camera traps was extracted from the municipality, cantone, and subdistrict feature layers for Colombia, Ecuador, and Brazil, respectively. These layers served as masks to extract smaller subsets of the foundational dataset layers to make geoprocessing faster and easier, as well as to ensure that each variable in the MaxEnt model has the same spatial extent. Both Brazil corridors were ultimately omitted from Stage 2 of analysis – the constructive corridor due to lack of data and the bridge

corridor because it was determined to be too narrow to generate effective results from this type of geospatial analysis. However, this preprocessing step of subsetting the foundational data layers was still performed for Brazil for use in Stage 3 of the analysis.

After the elevation subset was created, it was filled using the Fill tool to erase any holes in the dataset that would affect any tools run afterward. Next, a slope layer was created using the Slope tool, with parameters set to percent rise (output measurement) and planar (method).

The land cover map that was subset was run through the Con tool to extract pixels classified as Trees. These pixels were given a value of 1, while all other pixels were given a value of 0, creating a habitat and non-habitat raster layer.

Similarly, the subset land cover map was run through a second occurrence of the Con tool to define non-habitat (i.e. every other class) as 1 and all Tree pixels as No Data. The Euclidean Distance tool was run on this raster, with a parameter of planar (method), to create a layer with values describing how far away a core habitat pixel is from the nearest edge habitat.

The rasterized waterway and road layers were then subset to the same extent for each site. Each of these rasters was then run through the Euclidean Distance tool, with a parameter of planar (method), to generate distance-to rasters.

The final environmental variables that were saved to separate geodatabases for Colombia and Ecuador are as follows:

- Land use land cover
- Forest habitat (derived from land cover)
- Elevation
- Slope (derived from elevation)
- Distance to edge of forest habitat
- Distance to the nearest waterway
- Distance to the nearest road

All species were extensively searched via literature to see if observations had been made regarding the maximum distance they would prefer to be from a stream or road to determine if any exceptions to a standard had to be made. No such exceptions were discovered, so a base assumption was made for these buffers. In addition, since Saving Nature is interested in conserving the greatest number of species, a range in elevation that is inclusive of all the major species we expect to see in each country was used to generate general maps and run the models. These ranges were conservative so that they wouldn't exclude any target species.

The MaxEnt program version 3.4.4 was downloaded (Phillips et al., n.d.), and models were run using the above list of environmental variable layers. The program generated raster maps of habitat and non-habitat for each species.

After running the MaxEnt models, habitat rasters were imported into ArcGIS Pro to be evaluated by running confusion matrices, using the presence/absence spreadsheets that were created (see above, Data Prep). In these spreadsheets, presence points (observation = 1) are represented by every animal occurrence in every camera on a daily basis. Days where no animal occurred in a certain camera are marked as pseudo absence points (observation = 0). The issue with this method is that these pseudo absence points are not truly random and pseudo, and they may not represent true absences in the data (see Discussion → Caveats).

These presence and absence spreadsheets were imported into ArcGIS Pro as point shapefiles and laid on top of the MaxEnt map for each species. The Extract Values To Points tool was used to extract the value of habitat suitability at each camera trap location site. This information was added to the Arc spreadsheets for each species.

The Calculate Field tool was then used to add another column for predicted habitat to each Arc spreadsheet. The “Balance training omission, predicted area and threshold value” threshold value from the MaxEnt output for each species was used to give each model a threshold for “habitat” and “non-habitat.” Pixels below this value were given a value of 0 in the Predicted column, and those above were given a value of 1.

Finally, the Summary Statistics tool was used to summarize the above information and split them into the four possible categories of a confusion matrix. The Statistics field was set to Count of the ObjectID, and the Case field was set to Observed and Predicted. From this, a Percent True (PT) value was calculated for each species by summing the true positives and true negatives and dividing by the total number of presences and absences

Because MaxEnt models were not generated for species that had no occurrences in the dataset, there was no suitable habitat map to lay presence and absence points on to generate a confusion matrix. Therefore, this method did not work for these species. Instead, a PT score of 0 was given for these species.

The PT scores for all species were multiplied on a weighted score using the same method as the occupancy models (i.e. IUCN conservation status scores). Since I provided the opportunity for each species to pass in front of each camera every day, the weighted PT score was expected to be low due to there being many more absence points than presence points. PT scores are traditionally used to measure how well the MaxEnt model performed, but since I used actual absence instead of pseudo absence points, I am tentatively proposing the score can be used in this way until future research develops a better method.

The results of Stages 1 and 2 will be compared. The Stage 2 MaxEnt models are a proposed alternative method to Stage 1 to see if the results are comparable. If they are comparable, using MaxEnt may be a viable option for geospatial evaluation of wildlife corridor camera trap data. If they are not comparable, using MaxEnt is likely not a viable option and should not be attempted by future researchers.

The workflow for this stage of analysis was constructed in an ArcGIS Pro ModelBuilder (Figures B2-B4, Appendix B).

Least Cost Path Models (Stage 3)

To answer the second core question of this analysis – are the camera traps currently in the right places to be most efficient at capturing the species of interest? – Least Cost Path Corridor models were run for each site. These models use cost distance rasters to generate a path between two sources. This path represents the least ecological cost to a species, thereby making it the most likely path the animal will take between the fragments. Features such as roads, wide waterways, non-habitat, proximity to edge habitat, steep slopes, and low or high elevation are all costs to an animal, as these variables can make movement difficult or expose an individual to predators. Through these models, we can answer if there are better places for the camera traps to be located to maximize the likelihood of capturing an animal.

Many of the environmental variables that were used to create the MaxEnt models were also used to create the Least Cost Path Corridors but underwent additional processing to display them in terms of cost (Table 2).

Table 2. Final environmental variables, in terms of cost, that were saved to separate geodatabases for each site

		Cost				
		0	1	2	3	4
LULC: Land Use Land Cover		Trees	Clouds*	Flooded Veg, Bare Ground	Crops, Rangeland	Water, Built Area
W: Waterways		No Data	Drains, Ditches	Streams	Rivers, Weirs, Farmland	Canals, Dams
R: Roads		No Data, Path	Service, Unclassified, Track, Footway, Bridleway, Pedestrian	Residential, Tertiary, Steps, Roads	Secondary	Primary, Trunk
E: Elevation (m)	Colombia	1200-2000	900-1200 2000-2200	63-900 2200-3735		
	Ecuador	0-500	500-650	650-762		
	Brazil	0-900	900-1150	1150-1500	1500-1767	
S: Slope (degree)	Colombia	0-4.96236	4.96236-9.684009	9.684009-14.868565	14.868565-21.79365	21.79365-75.824127
	Ecuador	0	0-2.968366	2.968366-7.005343	7.005343-13.436802	13.436802-81.036385
	Brazil	0-0.264866	0.264866-1.613278	1.613278-5.09266	5.09266-12.496882	12.496882-49.301285
DE: Distance to edge (m)	Colombia	584.37-3539.67	280.96-584.37	111.47-280.96	0-111.47	0
	Ecuador	11525.23-53876.63	236.84-11525.23	65.79-236.84	0-65.79	0
	Brazil	407.32-4377.54	179.60-407.32	69.46-179.60	0-69.46	0
DW: Distance to nearest waterway (m)	Colombia	0-423.44	423.44-951.68	951.68-1592.96	1592.96-2504.30	2504.30-8256.96
	Ecuador	0-488.34	488.34-1148.18	1148.18-2138.09	2138.09-5569.51	5569.51-54045.90
	Brazil	0-218.17	218.17-725.63	725.63-1460.70	1460.70-2802.81	2802.81-19420.76
DR: Distance to nearest road (m)	Colombia	6865.17-19150.58	3100.56-6865.17	1262.65-3100.56	425.55-1262.65	0-425.55
	Ecuador	5246.43-53980.66	1120.50-5246.43	408.66-1120.50	145.04-408.66	0-145.04
	Brazil	1006.36-17995.63	505.35-1006.36	259.29-505.35	96.69-259.29	0-96.69

*Clouds were given a cost of 1 because it was likely they covered Trees or Rangeland

The elevation layers were reclassified based on the IUCN range of optimal elevation for all target species in each corridor. These ranges were conservative, so as not to exclude any species.

The slope layers were reclassified based on the quantile breaks in the values (Figures C5, C14, C23, Appendix C). Steeper slopes make it more difficult for an animal and traverse.

The subset waterway and road layers were both reclassified on a scale of 0-4 using the Reclassify tool to give costs to different types. Smaller waterways and roads were given scores of 1, as it

would be easier for an animal to cross these obstacles. Conversely, the largest waterways and roads were given scores of 4 because it would be very dangerous for an animal to cross these obstacles. Intermediate waterways and roads were given scores of 2 or 3. The smallest roads (i.e. paths) were given a cost of 0 due to these types of small, rarely used trails being a preference for larger mammals as a means to disperse or quietly stalk prey (Goulart et al., 2009).

The distance to edge habitat layers were reclassified based on the quantile breaks in the values (Figures C3, C12, C21, Appendix C).

The distance to the nearest waterway layers were reclassified in the same manner (Figures C7, C16, C25, Appendix C). Although the waterways themselves serve as potential obstacles or barriers an animal would have to cross, proximity to a water source is vital for survival.

The distance to the nearest road layers were reclassified in the same way as the above two (Figures C8, C17, C26, Appendix C).

These generalized parameters serve to include all target species into one model per site. In this way, Saving Nature can place camera traps as to maximize the likelihood of capturing any species. The models were set up in a way that makes it easy to adjust if later it becomes desirable to focus on a particular species.

All cost layers were added together using the Raster Calculator tool to generate a cost raster where each pixel value represents the total cost to an animal going through that pixel. The equation, inspired by the ranking of environmental variables from the MaxEnt models (Tables 4 and 7), used is as follows:

= LULC*3 + E*3 + S*2 + W*2 + R*2 + DE*2 + DW + DR

This cost raster was run through the Con tool to change any values of 0 to 0.001, a near-zero value that will not cause an error in subsequent tools.

Next, shapefiles of the habitat fragments were created in Google Earth. Only entrances of the fragments were used as the shapefiles to reduce the error that considering the whole fragment would entail. If the whole fragment were considered, it could result in a least cost path venturing out of the corridor, where Saving Nature does not have the authority to set up camera traps.

The Cost Distance tool was run for both habitat fragments in each corridor, using the fragment shapefiles as sources and the cost raster generated from the environmental variables.

The results from the Cost Distance tools and the shapefile of the other fragments were inputs for the Cost Path tool, with a path type of "each cell." The output from this tool created paths of pixels animals are likely to walk through to move between the two habitat fragments. Least Cost Path Corridor models are not the ultimate answer to this question; animals can still potentially use the whole corridor and miss the cameras. However, this method provides the most likely path that an animal is going to take given environmental constraints, so placing cameras within this corridor will give the best chance of capturing an animal on camera.

This type of model is not presence data dependent, meaning that Brazil was included in this stage of analysis. It did not make sense to run this model on the bridge corridor in Brazil, due to the area available for an animal to cross is already quite restricted, but a Least Cost Path Corridor model was run on the constructive corridor in Brazil.

The workflow for this stage of analysis was constructed in an ArcGIS Pro ModelBuilder (Figure B5, Appendix B).

RESULTS

Colombia

Occupancy Model for calculating occupancy and detection probabilities (Stage 1)

The Colombia corridor had a weighted occupancy probability (Ψ) of 0.365792973, with the lowest Ψ for a species being 0.0000 and the highest being 1.0000 (Table 3). The corridor had a weighted detection probability (P) of 0.170455676, with the lowest P for a species being 0.0000 and the highest being 0.3523. This means that the species in the corridor occupy an estimated 36.58% of the sites within the corridor and will be detected at an estimated 17.05% of the sites within the corridor. Interestingly, species with a Ψ of 0.0000 had the highest P of 0.3523.

For species that had zero presences in the database, their standard errors of P were incredibly high, while their standard errors of Ψ were 0.0000.

Table 3. PRESENCE occupancy model results for the species of Colombia

Species	AIC	Ψ (occupancy probability)	Stan. Error Of Psi	P (detection probability)	Stan. Error Of P	Camera Traps Present	IUCN Score
BassaricyonNeblina	4.0000	0.0000	0.0000	0.3523	301961.63	0	5
CaluromysLanatus	4.0000	0.0000	0.0000	0.3523	301961.63	0	6
CerdocyonThous	20.1992	1.0000	-1.#IND	0.0008	0.0008	1	6
Cervidae	167.256	0.3325	0.1221	0.0967	0.0199	5	6
CoendouQuichua	4.0000	0.0000	0.0000	0.3523	301961.63	0	1
CoendouRufescens	4.0000	0.0000	0.0000	0.3523	301961.63	0	6
Columbiformes	576.063	0.4034	0.1285	0.1301	0.0126	6	12
ConepatusSemistriatus	4.0000	0.0000	0.0000	0.3523	301961.63	0	6
CrypturellusObsoletus	350.451	0.5044	0.1386	0.0575	0.0088	9	6
Cuniculus	234.258	1.0000	0.0000	0.0000	0.0000	1	11
DasyproctaPunctata	4.0000	0.0000	0.0000	0.3523	301961.63	0	6
DasypusNovemcinctus	66.1931	0.1540	0.1029	0.0349	0.0154	2	6
Didelphis	68.6143	0.6813	0.4505	0.0064	0.0054	3	12
DinomysBranickii	4.0000	0.0000	0.0000	0.3523	301961.63	0	6
EiraBarbara	182.832	1.0000	-1.#IND	0.0140	0.0034	6	6
Galliformes	174.635	0.2027	0.1054	0.0634	0.0137	3	6
HydrochoerusIsthmius	4.0000	0.0000	0.0000	0.3523	301961.63	0	1
LeopardusPardalis	223.993	1.0000	0.0000	0.0182	0.0038	8	6
LeopardusTigrinus	4.0000	0.0000	0.0000	0.3523	301961.63	0	4
MustelaFelipei	26.6364	0.0727	0.0708	0.0511	0.0388	1	4
NasuaNarica	4.0000	0.0000	0.0000	0.3523	301961.63	0	6
NasuaNasua	74.0951	0.2222	0.1154	0.0461	0.0184	3	6
NasuellaOlivacea	46.0011	1.0000	-1.#IND	0.0025	0.0014	1	5
PantheraOnca	4.0000	0.0000	0.0000	0.3523	301961.63	0	5
PecariTajacu	4.0000	0.0000	0.0000	0.3523	301961.63	0	6
PotosFlavus	4.0000	0.0000	0.0000	0.3523	301961.63	0	6
PumaConcolor	20.1992	1.0000	-1.#IND	0.0008	0.0008	1	6
Sciuridae	194.069	0.2671	0.1149	0.1286	0.0224	4	7
TremarctosOrnatus	46.0011	1.0000	-1.#IND	0.0025	0.0014	2	4
Total Weighted Probability		**0.365792973**		**0.170455676**			

MaxEnt Model for evaluating presence in corridor and ranking environmental variable importance (Stage 2)

MaxEnt models only analyze species individually, and only if there's at least one presence. Since only 16 of the 29 possible species in Colombia were represented in the data, the MaxEnt program produced only 16 models. However, the presence at only one camera trap does not produce a good habitat model (Figure D1, Appendix D), resulting in 5 of those 16 species not being well represented by MaxEnt. These species were CerdocyonThous, Cuniculus, MustelaFelipei, NasuellaOlivacea, and PumaConcolor. In addition, when only one camera trap is represented for a species, the lack of a good habitat model also results in no predicted omission rate (Figure D2, Appendix D), jackknife failure (Figure D5, Appendix D), response curves of all variables stabilizing at 0.5 (Figure D4, Appendix D), and all logistic thresholds to equal 0.5, which results in a low PT score (Table 5).

For the remaining 11 species, the jackknife charts were analyzed for an overall ranking of important variables (Table 4). Elevation is the variable that accounts for the highest gain in most of the models, while slope is often the variable that accounts for the least gain and has the lowest ranking. When elevation did not account for the highest gain in a model, distance to streams did. Forest habitat often mimics land use land cover, both of which rank fairly low but still account for significant portions of some models. Distance to roads never accounts for the highest or lowest gain and often shows a significant contribution to the models. Distance to edge habitat was significant for a couple of species but overall ranked low.

Table 4. Ranking of environmental variables for 11 species in Colombia represented by MaxEnt. Higher ranks (1) show overall higher gain to the MaxEnt model, lower ranks (6) show very little or no gain

	Distance to edge	Distance to roads	Distance to streams	Elevation	Forest Habitat	Land use land cover	Slope
Cervidae	5	2	1	3	6	7	4
Columbiformes	6	2	5	1	3	3	6
CrypturellusObsoletus	6	2	5	1	3	3	7
DasypusNovemcinctus	7	2	1	3	7	7	4
Didelphis	4	2	3	1	5	5	7
EiraBarbara	7	2	3	1	4	4	7
Galliformes	6	3	4	1	5	5	2
LeopardusPardalis	6	2	3	1	4	4	7
NasuaNasua	2	3	7	1	4	4	7
Sciuridae	2	6	6	1	4	4	7
TremarctosOrnatus	7	3	2	1	7	7	7
Average Rank	**5.2**	**2.6**	**3.6**	**1.4**	**4.7**	**4.8**	**5.9**

For these 11 species, the response curves of all variables were also analyzed and generally followed expected trends (e.g. Figure D9, Appendix D). Habitat suitability decreased with increasing distance from streams and increasing slope. Suitability increased in forested habitat (forest = 2 in the land use land cover response curves) compared to non-forested and increased with increasing elevation. Suitability also increased with increased distance from edge habitat, except in the case of Galliformes (Figure D39, Appendix D). Interestingly, however, suitability also decreased with increasing distance from a road, meaning that the models predict more presences to occur nearby roads.

The same weighted IUCN process that was used in the occupancy models was used for the MaxEnt confusion matrix PT scores (PT = (true positive + true negative) / total presences and absences). The weighted PT score for the Colombia corridor is 0.047412433, or 4.74% (Table 5). The MaxEnt model performed quite well for some species, such as DasypusNovemcinctus (50.12%) and Cervidae (32.24%).

To see the MaxEnt models, response curves, jackknife charts, habitat/non-habitat threshold value, and confusion matrix for each present species, they can be found in Appendix D.

Table 5. Percent True (PT) score results for the MaxEnt models of the species of Colombia

Species	PT Score	Camera Traps Present	IUCN Score
BassaricyonNeblina	0.0000	0	5
CaluromysLanatus	0.0000	0	6
CerdocyonThous	0.00083963	1	6
Cervidae	0.32241814	5	6
CoendouQuichua	0.0000	0	1
CoendouRufescens	0.0000	0	6
Columbiformes	0.07808564	6	12
ConepatusSemistriatus	0.0000	0	6
CrypturellusObsoletus	0.03610411	9	6
Cuniculus	0.00083963	1	11
DasyproctaPunctata	0.0000	0	6
DasypusNovemcinctus	0.50125945	2	6
Didelphis	0.13014274	3	12
DinomysBranickii	0.0000	0	6
EiraBarbara	0.01427372	6	6
Galliformes	0.01763224	3	6
HydrochoerusIsthmius	0.0000	0	1
LeopardusPardalis	0.01847187	8	6
LeopardusTigrinus	0.0000	0	4
MustelaFelipei	0.00083963	1	4
NasuaNarica	0.0000	0	6
NasuaNasua	0.00587741	3	6
NasuellaOlivacea	0.00083963	1	5
PantheraOnca	0.0000	0	5
PecariTajacu	0.0000	0	6
PotosFlavus	0.0000	0	6
PumaConcolor	0.00083963	1	6
Sciuridae	0.02434929	4	7
TremarctosOrnatus	0.00251889	2	4
Weighted PT Score	**0.047412433**		

Least Cost Path for adjusting camera trap locations (Stage 3)

The Least Cost Path (LCP) model shows all possible likely paths an animal can take to get from one habitat fragment to the next, no matter where the animal exits (Figure 1).

There are currently no camera traps that fall within the LCP area of this corridor. There are a few cameras that are located within a habitat fragment, however, there are some units (e.g. Camera 8) that are outside of the fragment and LCP model and should therefore be adjusted. In addition, placing more cameras within the LCP area will increase the chances of recording data.

Hopefully, this model can inform Saving Nature on where to better place the camera traps in this corridor so that more data can be collected for future analysis.

There is another fragment of forested area to the southwest of the corridor that has additional camera traps placed within it. This analysis can be repeated for that area to determine the ideal locations for those cameras.

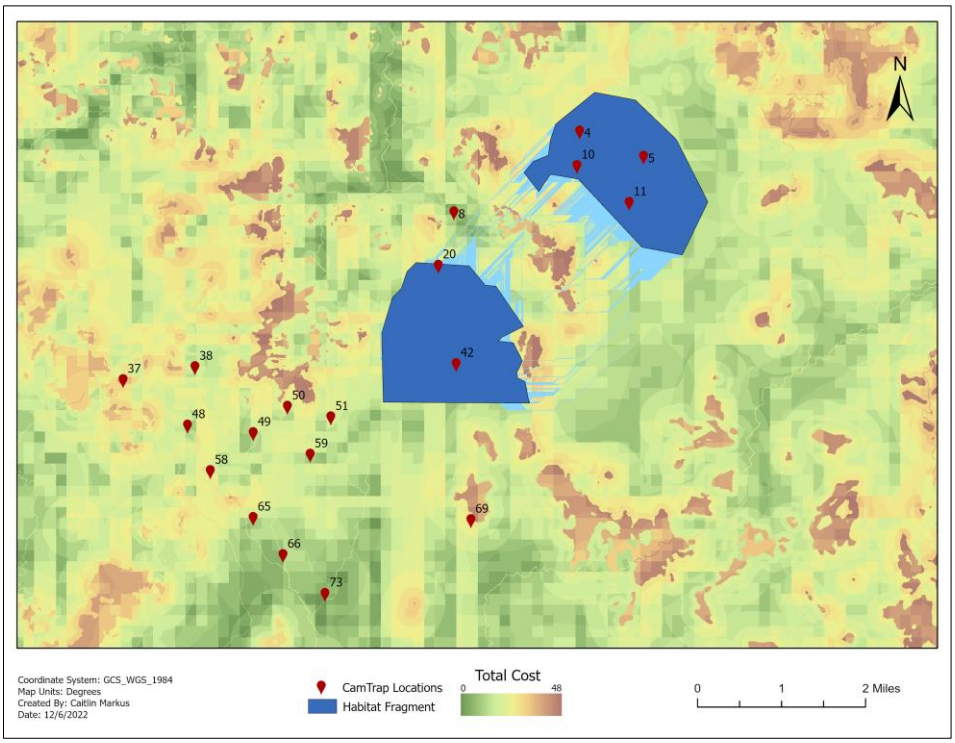

Figure 1. Least Cost Path model between the habitat fragments in the Colombia corridor. Blue pixels show likely paths animals will take when traveling between the fragments

Ecuador

Occupancy Model for calculating occupancy and detection probabilities (Stage 1)

The Ecuador corridor had a weighted Ψ of 0.409580423, with the lowest Ψ for a species being 0.0000 and the highest being 1.0000 (Table 6). The corridor had a weighted P of 0.209902116, with the lowest P for a species being 0.0000 and the highest being 0.3358. This means that the species in the corridor occupy an estimated 40.96% of the sites within the corridor and will be detected at an estimated 20.99% of the sites within the corridor. Interestingly again, species with a Ψ of 0.0000 had the highest P of 0.3358.

Again, for species that had zero presences in the database, their standard errors of P were incredibly high, while their standard errors of Ψ were 0.0000.

Table 6. PRESENCE occupancy model results for the species of Ecuador

Species	AIC	Ψ	Stan. Error Ψ	P	Stan. Error P	Camera Traps Present	IUCN Score
BassaricyonMedius	4.0000	0.0000	0.0000	0.3358	-1.#IND	0	6
CabassousCentralis	4.0000	0.0000	0.0000	0.3358	-1.#IND	0	1
Caluromys	245.1271	0.6299	0.2487	0.0891	0.0145	3	12
CerdocyonThous	4.0000	0.0000	0.0000	0.3358	-1.#IND	0	6
ChironectesMinimus	4.0000	0.0000	0.0000	0.3358	-1.#IND	0	6
CoendouQuichua	4.0000	0.0000	0.0000	0.3358	-1.#IND	0	1
Columbiformes	464.5170	1.0000	0.0000	0.0000	0.0000	1	6
ConepatusSemistriatus	4.0000	0.0000	0.0000	0.3358	-1.#IND	0	6
CuniculusPaca	230.8843	0.6416	0.2488	0.0813	0.0139	3	6
CyclopesDidactylus	4.0000	0.0000	0.0000	0.3358	-1.#IND	0	6
Dasyprocta	937.9329	0.9472	0.1470	0.3244	0.0174	6	12
DasypusNovemcinctus	241.7213	0.7509	0.2041	0.0852	0.0140	4	6
Didelphis	234.2585	1.0000	0.0000	0.0000	0.0000	1	12
EiraBarbara	4.0000	0.0000	0.0000	0.3358	-1.#IND	0	6
HerpailurusYagouaroundi	4.0000	0.0000	0.0000	0.3358	-1.#IND	0	6
LeopardusColocolo	4.0000	0.0000	0.0000	0.3358	-1.#IND	0	5
LeopardusPardalis	83.2219	1.0000	-1.#IND	0.0094	0.0035	3	6
LeopardusWiedii	4.0000	0.0000	0.0000	0.3358	-1.#IND	0	5
LycalopexCulpaeus	4.0000	0.0000	0.0000	0.3358	-1.#IND	0	6
MazamaAmericana	129.7121	0.7091	0.2360	0.0353	0.0093	3	1
MetachirusNudicaudatus	4.0000	0.0000	0.0000	0.3358	-1.#IND	0	6
NasuaNarica	234.2585	1.0000	0.0000	0.0000	-1.#IND	1	6
PantheraOnca	4.0000	0.0000	0.0000	0.3358	-1.#IND	0	5
PecariTajacu	249.7448	0.6260	0.2485	0.0917	0.0147	3	6
PhilanderOpossum	4.0000	0.0000	0.0000	0.3358	-1.#IND	0	6
PotosFlavus	4.0000	0.0000	0.0000	0.3358	-1.#IND	0	6
ProcyonCancrivorus	52.6843	0.6109	0.3374	0.0092	0.0055	1	6
PumaConcolor	4.0000	0.0000	0.0000	0.3358	-1.#IND	0	6
SciurusGranatensis	234.2585	1.0000	0.0000	0.0000	-1.#IND	1	6
SpeothosVenaticus	4.0000	0.0000	0.0000	0.3358	-1.#IND	0	5
TamanduaMexicana	134.9253	1.0000	-1.#IND	0.0175	0.0048	4	6
TayassuPecari	4.0000	0.0000	0.0000	0.3358	-1.#IND	0	4
Total Weighted Probability		**0.409580423**		**0.209902116**			

MaxEnt Model for evaluating presence in corridor and ranking environmental variable importance (Stage 2)

MaxEnt models only analyze species individually, and only if there's at least one presence. Since only 13 of the 32 possible species in Ecuador were represented in the data, the MaxEnt program produced only 13 models. Unlike some of the species in the Colombia corridor, there were no species in the Ecuador corridor that were only present in one camera trap and therefore all species were adequately represented by the MaxEnt models.

For the remaining 13 species, the jackknife charts were analyzed for an overall ranking of important variables (Table 7). Land use land cover and forest habitat are the variables that account for the highest gain in most of the models, while distance to streams is often the variable that accounts for the least gain and has the lowest ranking. Forest habitat did mimic land use land cover in this corridor, similar to the Colombia results. Elevation overall ranks high and often is the variable that accounts for the most gain in models when land use land cover or forest habitat ranks lower. Distance to edge habitat also ranks a little higher and slope ranks much higher in this corridor.

Table 7. Ranking of environmental variables for 13 species in Ecuador represented by MaxEnt. Higher ranks (1) show overall higher gain to the MaxEnt model, lower ranks (6) show very little or no gain

	Distance to edge	**Distance to roads**	**Distance to streams**	**Elevation**	**Forest Habitat**	**Land use land cover**	**Slope**
Caluromys	5	6	7	1	3	3	2
Columbiformes	7	7	7	7	1	1	7
CuniculusPaca	5	6	7	1	3	3	2
Dasyprocta	4	6	7	1	4	3	2
DasypusNovemcinctus	5	7	7	1	3	3	2
Didelphis	7	7	7	7	1	1	7
LeopardusPardalis	2	6	7	4	3	3	1
MazamaAmericana	3	6	7	1	4	4	2
NasuaNarica	7	6	6	6	1	1	6
PecariTajacu	4	6	7	1	3	3	2
ProcyonCancrivorus	1	5	6	4	3	3	2
SciurusGranatensis	7	6	6	6	1	1	6
TamanduaMexicana	4	6	7	2	3	3	1
Average Rank	**4.7**	**6.2**	**6.8**	**3.2**	**2.5**	**2.5**	**3.2**

For these 13 species, the response curves of all variables were also analyzed and generally followed expected trends (e.g. Figure D64, Appendix D). Habitat suitability increased with increasing elevation. Suitability increased in forested habitat (forest = 2 in land use land cover response curve) compared to non-forested. Suitability also increased with increased distance from edge habitat. Interestingly, however, suitability decreased with increasing distance from a road, meaning that the models predict more presences to occur nearby roads. In addition, most species in the Ecuador corridor saw increasing suitable habitat with increasing slope, contrary to the Colombia results. Also contrary to the Colombia results, most of the models were very minimally impacted by the distance to edge variable, and suitability did not change whether this variable increased or decreased.

The same weighted IUCN process that was used in the occupancy models was used for the MaxEnt confusion matrix PT scores (PT = (true positive + true negative) / total presences and absences). The weighted PT score for the Ecuador corridor is 0.030331248, or 3.03% (Table 8). The MaxEnt model performed quite well for some species, such as Dasyprocta (32.74%) and PecariTajacu (4.91%).

To see the MaxEnt models, response curves, jackknife charts, habitat/non-habitat threshold value, and confusion matrix for each present species, they can be found in Appendix D.

Table 8. Percent True (PT) score results for the MaxEnt models of the species of Ecuador

Species	PT Score	Camera Traps Present	IUCN Score
BassaricyonMedius	0.0000	0	6
CabassousCentralis	0.0000	0	1
Caluromys	0.04774898	3	12
CerdocyonThous	0.0000	0	6
ChironectesMinimus	0.0000	0	6
CoendouQuichua	0.0000	0	1
Columbiformes	0.01091405	1	6
ConepatusSemistriatus	0.0000	0	6
CuniculusPaca	0.04365621	3	6
CyclopesDidactylus	0.0000	0	6
Dasyprocta	0.32742156	6	12
DasypusNovemcinctus	0.02728513	4	6
Didelphis	0.0095498	1	12
EiraBarbara	0.0000	0	6
HerpailurusYagouaroundi	0.0000	0	6
LeopardusColocolo	0.0000	0	5
LeopardusPardalis	0.0095498	3	6
LeopardusWiedii	0.0000	0	5
LycalopexCulpaeus	0.0000	0	6
MazamaAmericana	0.01909959	3	1
MetachirusNudicaudatus	0.0000	0	6
NasuaNarica	0.0095498	1	6
PantheraOnca	0.0000	0	5
PecariTajacu	0.04911323	3	6
PhilanderOpossum	0.0000	0	6
PotosFlavus	0.0000	0	6
ProcyonCancrivorus	0.00545703	1	6
PumaConcolor	0.0000	0	6
SciurusGranatensis	0.0095498	1	6
SpeothosVenaticus	0.0000	0	5
TamanduaMexicana	0.01773533	4	6
TayassuPecari	0.0000	0	4
Weighted PT Score	**0.030331248**		

Least Cost Path for adjusting camera trap locations (Stage 3)

The Least Cost Path (LCP) model shows all possible likely paths an animal can take to get from one habitat fragment to the next, no matter where the animal exits (Figure 2).

Only Cameras 4, 6, and Finca 1 fall within the area in the LCP model. There are a few cameras that are located within a habitat fragment, however, there are some units (e.g. Cameras 3 and Del Rio) that are outside of the fragment and LCP model and should therefore be adjusted. In addition, placing more cameras within the LCP area will increase the chances of recording data.

Hopefully, this model can inform Saving Nature on where to better place the camera traps in this corridor so that more data can be collected for future analysis.

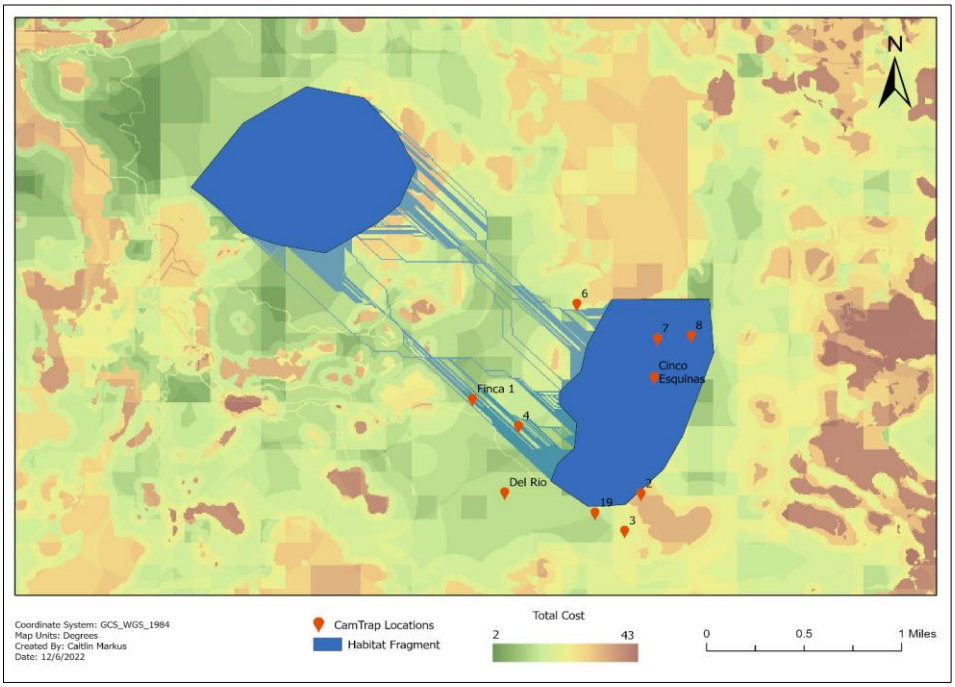

Figure 2. Least Cost Path model between the habitat fragments in the Ecuador corridor. Blue pixels show likely paths animals will take when traveling between the fragments

Brazil

Occupancy Model for calculating occupancy and detection probabilities (Stage 1)

The Brazil bridge corridor had a weighted Ψ of 0.381131349, with the lowest Ψ for a species being 0.0000 and the highest being 1.0000 (Table 9). The corridor had a weighted P of 0.260240873, with the lowest P for a species being 0.0000 and the highest being 0.5000. This means that the species in the corridor occupy an estimated 38.11% of the sites within the corridor and will be detected at an estimated 26.02% of the sites within the corridor. Interestingly again, species with a Ψ of 0.0000 had the highest P of 0.5000.

Again, for species that had zero presences in the database, their standard errors of P were incredibly high, while their standard errors of Ψ were 0.0000.

Table 9. PRESENCE occupancy model results for the species of Brazil bridge corridor

Species	AIC	Psi (occupancy probability)	Stan. Error Of Psi	P (detection probability)	Stan. Error Of P	Camera Traps Present	IUCN Score
CabassousTatouay	52.1577	0.4437	0.3991	0.0086	0.0049	1	6
CaluromysPhilander	46.1325	0.5032	0.2517	0.0272	0.0138	3	6
CerdocyonThous	141.2951	1.0000	0.0000	0.0200	0.0053	5	6
ChironectesMinimus	4.0000	0.0000	0.0000	0.5000	2.4376e12	0	6
ChrysocyonBrachyurus	4.0000	0.0000	0.0000	0.5000	2.4376e12	0	5
Coendou	4.0000	0.0000	0.0000	0.5000	2.4376e12	0	12
Columbiformes	155.8685	0.7500	0.2165	0.0660	0.0143	3	6
CuniculusPaca	527.3704	0.5004	0.2502	0.1762	0.0162	2	6
DasyproctaLeporina	4.0000	0.0000	0.0000	0.5000	2.4376e12	0	6
Dasypus	216.1879	0.2570	0.2225	0.0727	0.0130	1	12
DidelphisAurita	282.0239	1.0000	0.0000	0.0499	0.0082	5	6
EiraBarbara	234.2585	1.0000	0.0000	0.0000	0.0000	2	6
EuphractusSexcinctus	19.1036	1.0000	0.0000	0.0014	0.0014	1	6
GalictisCuja	4.0000	0.0000	0.0000	0.5000	2.4376e12	0	6
Galliformes	75.0847	0.7501	0.2165	0.0231	0.0086	2	5
HerpailurusYagouaroundi	4.0000	0.0000	0.0000	0.5000	2.4376e12	0	6
HydrochoerusHydrochaeris	4.0000	0.0000	0.0000	0.5000	2.4376e12	0	6
LeopardusGuttulus	4.0000	0.0000	0.0000	0.5000	2.4376e12	0	4
LeopardusPardalis	234.2585	1.0000	0.0000	0.0000	0.0000	1	6
LeopardusWiedii	464.5170	1.0000	0.0000	0.0000	0.0000	1	5
LontraLongicaudis	4.0000	0.0000	0.0000	0.5000	2.4376e12	0	5
Marmosa	234.2585	1.0000	0.0000	0.0000	0.0000	1	12
MarmosopsIncanus	78.3732	0.3309	0.2852	0.0167	0.0066	1	6
Mazama	4.0000	0.0000	0.0000	0.5000	2.4376e12	0	10
MetachirusNudicaudatus	268.1222	0.2525	0.2187	0.1004	0.0151	1	6
Monodelphis	4.0000	0.0000	0.0000	0.5000	2.4376e12	0	19
NasuaNasua	464.5170	1.0000	0.0000	0.0000	0.0000	2	6
PecariTajacu	4.0000	0.0000	0.0000	0.5000	2.4376e12	0	6
PhilanderFrenatus	4.0000	0.0000	0.0000	0.5000	2.4376e12	0	6
PotosFlavus	4.0000	0.0000	0.0000	0.5000	2.4376e12	0	6
ProcyonCancrivorus	464.5170	1.0000	0.0000	0.0000	0.0000	4	6
PumaConcolor	4.0000	0.0000	0.0000	0.5000	2.4376e12	0	6
SalvatorMerianae	232.8067	1.0000	0.0000	0.0385	0.0073	4	6
Sciuridae	240.7587	0.2544	0.2203	0.0853	0.0140	1	6
SpeothosVenaticus	4.0000	0.0000	0.0000	0.5000	2.4376e12	0	5
TamanduaTetradactyla	73.0775	1.0000	0.0000	0.0086	0.0035	3	6
TapirusTerrestris	4.0000	0.0000	0.0000	0.5000	2.4376e12	0	4
TayassuPecari	4.0000	0.0000	0.0000	0.5000	2.4376e12	0	4
Total Weighted Probability		**0.381131349**		**0.260240873**			

Least Cost Path for adjusting camera trap locations (Stage 3)

The Least Cost Path (LCP) model shows all possible likely paths an animal can take to get from one habitat fragment to the next, no matter where the animal exits (Figure 3). The Brazil constructive corridor is smaller than the Colombia and Ecuador corridors, resulting in most of the gap between the fragments becoming covered by the LCP pixels. This means that for much of the area between the habitat fragments, placing the camera traps in any given location will give a decent chance of picking up an animal.

That being said, Cameras 3 and 7 are currently outside of the LCP model and should be adjusted to fall within the model. Camera 4 would also likely benefit from being adjusted, as it is incredibly close to falling outside of the model. In addition, placing more cameras within the LCP model area will increase the chances of recording data.

Hopefully, this model can inform Saving Nature on where to better place the camera traps in this corridor so that more data can be collected for future analysis. If more data are collected, a full analysis, such as was done for the Colombia and Ecuador corridors, can be conducted for this corridor.

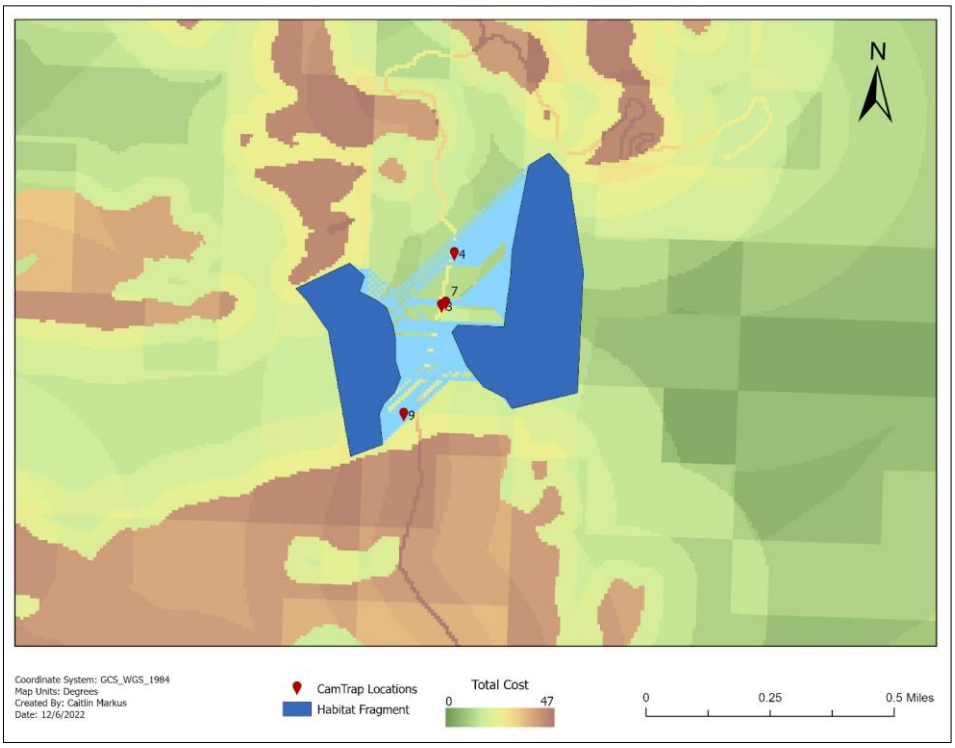

Figure 3. Least Cost Path model between the habitat fragments in the Brazil constructive corridor. Blue pixels show likely paths animals will take when traveling between the fragments

DISCUSSION

At first glance of the data after organizing them into the original Excel files, I noticed that at least half of the expected species were missing from the data in each corridor. Because of this, the occupancy models were expected to return very low probability values. However, all three corridors that were analyzed returned weighted occupancy probability values above 34% and weighted detection probability values above 18%. The Colombia corridor had the lowest of the two values, which is interesting considering that it was the first of the analyzed corridors established.

Regardless, the corridors may be simply not old enough yet to allow for the animals to return properly. Many of the species that were analyzed in this study were larger mammals with longer reproductive rates, therefore a reforestation project that is less than 10 years old may not yet be favorable to these species.

Although all three analyzed corridors – Colombia constructive, Ecuador constructive, and Brazil bridge – have adequate probability scores, there is room for improvement, as Saving Nature's goal to conserve as many species as possible has not been achieved yet.

In terms of comparing the two evaluation methods – occupancy models (Stage 1) and MaxEnt models (Stage 2) – the results are open to interpretation. The final values from each model drastically differ (e.g. 34.12% Ψ in the Colombia occupancy model vs. 2.84% percent true score in the MaxEnt model confusion matrix). However, the species distribution models (Appendix C) do show suitable habitat connections between the fragments. In addition, the jackknife graphs (Appendix C) did aid in building the equation that calculated the total cost layer that went into

the Least Cost Path models. Therefore, the MaxEnt methodology for evaluating habitat corridors has potential and should be further analyzed and developed.

In general, elevation, distance to streams, and distance to roads account for most of the gain in the MaxEnt models for Colombia and should be retained as environmental variables in future analysis. Land use land cover repeats the same information as forest habitat and can be omitted in future research. Slope consistently accounted for the lowest gain in the models and can also likely be omitted.

On the other hand, land use and land cover, forest habitat, slope, and elevation are the variables that account for the most gain in the Ecuador MaxEnt models, while distance to edge habitat, distance to roads, and distance to streams accounted for the least gain and can likely be omitted.

In conclusion, higher-ranking variables should be included in future analysis and also be considered when establishing and monitoring corridor projects. Due to the Colombia and Ecuador MaxEnt models generating differing results regarding the most important environmental variables, all variables should be included in future projects until a more definitive conclusion can be drawn.

The MaxEnt models predict that overall for any species, habitat and presence decrease with distance from streams and distance from roads, and increase with elevation, forested habitat compared to non-forest, and distance to edge habitat. This suggests that, interestingly, the presence of minor roads (like that which are present in some of the corridors) may have a positive influence on species' habitat and presence. The results were inconclusive for how slope affects suitable habitat, as increasing slope resulted in decreased suitable habitat in the Colombia corridor but increased suitable habitat in the Ecuador corridor.

It is known that the reforestation projects have been successful in reverting the land to forested habitat (Figures C1, C10, C19, Appendix C), so the corridors should potentially be operating more efficiently than they are currently. Before any drastic measures are taken to intervene and attempt to improve the corridor, a simple replacement of camera traps should first be considered.

According to the Least Cost Path models that were run for each country, the camera traps of the Colombia and Brazil corridors would benefit from a location adjustment. The Ecuador model shows that the current camera trap placement is adequate but placing even more cameras within the LCP area should improve the dataset and future analysis. Perhaps after this new camera placement, more data will be collected and it will show that the corridors act working at a higher percentage than was modeled in this analysis. This may be especially true for the Brazil constructive corridor, which lacked data and therefore could not be analyzed.

Caveats

Caveats and sources of error in this analysis, resulting from the camera trap image dataset and collection process not being my own include a lack of baseline camera trap data from before restoration began in the corridors. There are also no camera traps located outside of the corridors or fragments, making comparisons to non-reforested degraded lands impossible. Pre-reforestation and control data would make further evaluation analyses possible.

The camera trap data were sorted manually by various people and there was no hard standardization protocol for sorting. Therefore, species ID mistakes are possible. An attempt was made to rectify this issue by combining species that are hard to distinguish into guilds, but errors are still possible and are too difficult to manually correct.

In addition, the Unknown folder and grouped folders such as Avian and Mammal exist, meaning a species considered “not present” could be present but is not accounted for in the data. These additional folders and any unsorted images were not processed by me due to lack of time in the largeness of this project. There is also an issue of gaps in the dataset; perhaps cards were not recovered from the field or some files were not sorted, and these are now Absences that could have been Presences. The issue of unsorted files was rectified by entering the run times of each camera in OccupancyMatrix.exe to only include the range of dates that were sorted.

Another caveat is that these camera traps do not cover the whole corridor and were not baited, and therefore species considered “not present” could be present but were not captured by the cameras. To help with this, the first solution is to determine where traps should be placed (Stage 4 Analysis) to get the most animals on camera and acquire more data before Saving Nature invests too many resources in changing the corridor itself.

Although it was already determined the camera traps were spatially distant enough for the occupancy model to be the ideal choice in analysis for Stage 1, it's still impossible to know if an individual in one camera shows up in another just minutes later. Because of this, some individuals could be counted multiple times, resulting in skewed data.

Another potential caveat with the wildlife species is that some species may be affected by the presence of another (e.g. a puma walking through the corridor may affect the presence of prey species). There is a PRESENCE model type for two species if the presence of one influences the presence of the other, but this was not considered in the occupancy models for this analysis because there were too many species to consider all the possibilities. Saving Nature was

interested to know if a target species was present or not, and not necessarily in accurate abundance levels.

Finally, the spatial scale of the GIS layers could be a potential source of error. These areas of analysis are already fairly small, so coarser scale layers could be missing some landscape features that may influence species movement and use of the corridors. The elevation dataset, in particular, may be of concern due to its 250m spatial resolution. The land use land cover maps, although 10m in spatial resolution, may still be too coarse or simplistic for an accurate analysis. In addition, the land use land cover maps include a class for Clouds, which had some presence in both the Colombia and Ecuador MaxEnt models. These clouds could have skewed the models, as they were included in non-forested habitat.

Future Research

The occupancy probabilities and detection probabilities of the corridors, although not terribly low, could be improved. The LCP models show that camera trap locations are currently not ideal for any of the corridors, so the corridors may be operating at higher percentages than was modeled in this analysis, but the cameras are simply not collecting the proper data. Once the cameras are in the right place, the corridors can be reevaluated; analysis should be redone after the cameras are replaced and additional data is collected.

Future research should run further tests to see if MaxEnt is an appropriate evaluation model for constructive habitat corridors and if the method can be expanded to other types of corridors such as bridges. MaxEnt or Least Cost Path models were not done on the Brazil bridge corridor, but perhaps the methods can be refined even further to be used on bridges. PT scores are

traditionally used to measure how well a MaxEnt model performed, but since I am using “actual” absence instead of pseudo absence, I am tentatively proposing the score can be used in this way until future research develops a better method. Perhaps there is a better method or an ideal threshold of how many absences should be included in the calculation.

Other potential directions for future research could include the allowance for some species’ presence to affect the presence of others (e.g. a carnivore walking through the corridor will affect the presence of prey species). This may be difficult due to including so many species in the analysis. Similarly, the original database included camera trap data for domestic animals such as cows, dogs, and humans, which can affect the presence of wild species. This is a relationship that could be analyzed in future research.

Finally, it would be interesting to analyze if there is an ideal width for a habitat corridor to maximize species presence. Unfortunately, the sample size of four corridors was not enough to conclusively determine an answer to this question, but it would aid ecologists and conservation planners in establishing efficient corridors.

CONCLUSION

Overall, all corridors were determined to be working adequately, but with room for improvement. After repositioning the camera traps according to the least cost path models, more data may be automatically collected without hard improvements to the corridors. It may be so that the corridors are operating at levels higher than this analysis determined.

Finally, MaxEnt models show some potential as a method to evaluate corridor projects, but model refining and further research and development are required. The MaxEnt method needs to be improved before using it as a definitive alternative evaluation method for corridor project evaluation. This method should be explored further as Saving Nature collects more data and launches new corridor projects.

If, after further research, the MaxEnt method is determined to not be an adequate way to evaluate corridors, it should still be included in future analysis and generally when evaluating conservation projects. The MaxEnt results in this analysis provided clear visuals of habitat suitability within the corridors and helped determine rankings of environmental variable importance that directly fed into the least cost path models.

Saving Nature has several additional corridor projects in the works (Pimm, 2019). This analysis can serve as a guide for establishing and evaluating future projects.

This analysis is not only significant to Saving Nature, but to the field of wildlife ecology. These methods can assist other wildlife corridor ecologists and foresters when building future corridors and managing wildlife around the world. In addition, proposing a new way of geospatially evaluating reforestation projects has the potential to change how ecologists and forest managers use habitat corridors.

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APPENDIX

A. Data Prep Steps

Creating file directory spreadsheets

Data were already sorted into folders according to the Sanderson & Harris (2013) protocol (i.e. by camera trap -> species name -> number of individuals in the image). The names of these subfolders varied across sites and camera traps, as several people aided in this organization. Therefore, as I created Excel spreadsheets (Figure A1) of these data for each country, species names had to be normalized and were named based on *Genusspecies* or *Family* when appropriate. Text information for each image file was extracted from the OneDrive database and used to create the Excel file directory. Each image file was given its own row in the directory, with columns for metadata items such as species name, number of individuals in the image, camera trap number, location (i.e. latitude longitude), date, time, temperature, extension type (i.e. photo or video), file name, and file location in the OneDrive database. This was done for every image or video in each country's database, creating an extensive and complete directory that will make it easy for future researchers to add to and analyze the data.

Species	Number of Species	File Name	Camera Trap Station	Date	Year	Time	Format	File Size (MB)	Trap Location (Lat, Long)	Elevation	Notes
CanisLupusFam	1	DSCF0004.AVI	10	2/4/2019	2019	9:34 AM	.AVI	72.49	5.53324, -75.83974	2634	
Ghost	0	DSCF0005.AVI	10	2/4/2019	2019	2:32 AM	.AVI	45.3	5.53324, -75.83974	2634	
LeopardusParda	1	DSCF0006.AVI	10	2/7/2019	2019	8:11 AM	.AVI	73.21	5.53324, -75.83974	2634	
Ghost	0	DSCF0007.AVI	10	2/10/2019	2019	6:50 PM	.AVI	71.64	5.53324, -75.83974	2634	
Ghost	0	DSCF0008.AVI	10	2/10/2019	2019	8:31 AM	.AVI	70.85	5.53324, -75.83974	2634	
Ghost	0	DSCF0009.AVI	10	2/11/2019	2019	2:22 PM	.AVI	71.97	5.53324, -75.83974	2634	
Ghost	0	DSCF0010.AVI	10	2/11/2019	2019	2:30 PM	.AVI	71.18	5.53324, -75.83974	2634	
Mammalia	1	DSCF0011.AVI	10	2/12/2019	2019	10:28 AM	.AVI	76.62	5.53324, -75.83974	2634	
MusMusculus	1	DSCF0012.AVI	10	2/13/2019	2019	1:16 AM	.AVI	54.86	5.53324, -75.83974	2634	
CrypturellusObs	1	DSCF0013.AVI	10	2/13/2019	2019	7:15 AM	.AVI	71.97	5.53324, -75.83974	2634	
Ghost	0	DSCF0014.AVI	10	2/14/2019	2019	8:34 PM	.AVI	51.85	5.53324, -75.83974	2634	
Ghost	0	DSCF0015.AVI	10	2/14/2019	2019	3:19 PM	.AVI	76.82	5.53324, -75.83974	2634	
MazamaAmerici	1	DSCF0016.AVI	10	2/15/2019	2019	7:03 PM	.AVI	66.33	5.53324, -75.83974	2634	
MazamaAmerici	1	DSCF0017.AVI	10	2/15/2019	2019	7:27 PM	.AVI	70.07	5.53324, -75.83974	2634	
TremarctosOrna	3	DSCF0018.AVI	10	2/15/2019	2019	6:19 PM	.AVI	62.92	5.53324, -75.83974	2634	
CrypturellusObs	1	DSCF0019.AVI	10	2/15/2019	2019	4:50 PM	.AVI	76.1	5.53324, -75.83974	2634	
Ghost	0	DSCF0020.AVI	10	2/17/2019	2019	4:54 PM	.AVI	75.7	5.53324, -75.83974	2634	
Aves	1	DSCF0021.AVI	10	2/20/2019	2019	8:03 AM	.AVI	72.49	5.53324, -75.83974	2634	
Ghost	0	DSCF0022.AVI	10	2/20/2019	2019	1:49 PM	.AVI	71.9	5.53324, -75.83974	2634	
Ghost	0	DSCF0023.AVI	10	2/21/2019	2019	12:21 AM	.AVI	46.54	5.53324, -75.83974	2634	
CrypturellusObs	3	DSCF0024.AVI	10	2/27/2019	2019	4:15 PM	.AVI	75.11	5.53324, -75.83974	2634	
Ghost	0	DSCF0025.AVI	10	2/28/2019	2019	3:00 AM	.AVI	57.81	5.53324, -75.83974	2634	

Figure A1. Example entries in the comprehensive file directory for Colombia

Choosing lists of target species

The International Union for Conservation of Nature (IUCN) Red List (IUCN, 2022) was utilized to generate a list of target species for each country's site location. In the Red List, there is a tool to draw a polygon around a study area that returns every species within that range. From this list, all species of interest were entered into another Excel spreadsheet. Species that were not considered in the target list included primates, small rodents, reptiles, amphibians, small songbirds, bats, insects, plants, fungi, and marine species.

Rodents are often too small and hide under the leaf layer, making it difficult for a camera trap to pick up and identify. However, squirrels and larger rodents such as capybaras were included. In addition, there are a lot of species of rodents, and they are not only misidentified often, but they are not usually the target for conservation, as there are very few conservation threats on IUCN for rodents. Reptiles and amphibians were excluded for the same issue of species size. Small birds and bats are either too small to accurately identify from an image or are flying too fast for the camera to get a clear image of them. Flying birds and bats are also less constrained by habitat limits, as they can more easily fly between habitat fragments than, for example, a mammal can walk. Large ground birds were retained, as they are more restricted and can be more easily identified. Primates were also excluded, due to these species being arboreal and all camera traps in the sites were ground units. In addition, all of Saving Nature's corridors are relatively young, therefore there has not been ample time for the canopy habitat to grow to support primate species. Hopefully, since primates are some of the most threatened species, the corridors will help them eventually as well. This analysis could serve as a base for such future evaluations.

After this preliminary list of target species was created, species-specific parameters were drawn from each respective IUCN page, including conservation status, preferred habitat, and elevation that the species occurs. Additional sources were consulted to gather information on species-specific preferences regarding water bodies and human development to determine if any species stood out. In the end, no significant results came from this research and general parameters were used for all species, as both a way to simplify the models and analysis and to achieve Saving Nature's goal of conserving as many species as possible.

After these details were added to the spreadsheet, species were deleted if their parameters did not match the study area. Such disqualifying parameters included the wrong habitat type (i.e. not forest) or an elevation out of range from the corridor. Some of these species that remained and are similar to each other were combined into "guilds," under the assumption that it is difficult to distinguish between them, particularly from a camera trap image. These guilds were given a scientific name that all members share, such as *Genus* or *Family*, as opposed to the standard *Genusspecies* nomenclature that was adopted. For example, large ground birds were grouped (e.g. *Columbiformes*) due to their similarities and because they were often only identified at the family level in the original database.

This process left 29 species/guilds in Colombia, 32 in Ecuador, and 38 in Brazil (Tables A1-3).

Table A1. All species/guilds analyzed in Colombia with IUCN scores

Species/Guild		Common Name	IUCN Conservation Status	IUCN Score
BassaricyonNeblina		Olinguito	Near Threatened	5
CaluromysLanatus		Brown-eared Woolly Opossum	Least Concern	6
CerdocyonThous		Crab-eating Fox	Least Concern	6
Cervidae	Odocoileus virginianus leucurus	Colombian White-tailed Deer	Least Concern	6
CoendouQuichua		Andean Porcupine	Data Deficient	1
CoendouRufescens		Stump-tailed Porcupine	Least Concern	6
Columbiformes	Geotrygon frenata Leptotila rufaxilla	White-throated Quail-dove Gray-fronted Dove	Least Concern Least Concern	6 6
ConepatusSemistriatus		Striped Hog-nosed Skunk	Least Concern	6
CrypturellusObsoletus		Brown Tinamou	Least Concern	6
Cuniculus	Cuniculus paca Cuniculus taczanowski	Lowland Paca Mountain Paca	Least Concern Near Threatened	6 5
DasyproctaPunctata		Central American Agouti	Least Concern	6
DasypusNovemcinctus		Nine-banded Armadillo	Least Concern	6
Didelphis	Didelphis aurita Didelphis pernigra	Big-eared Opossum Andean White-Eared Opossum	Least Concern Least Concern	6 6
DinomysBranickii		Pacarana	Least Concern	6
EiraBarbara		Tayra	Least Concern	6
Galliformes	Ortalis columbiana Odontophorus	Chachalaca Birds Wood Quail	Least Concern Least Concern	6 6
HydrochoerusIsthmius		Lesser Capybara	Data Deficient	1
LeopardusPardalis		Ocelot	Least Concern	6
LeopardusTigrinus		Oncilla	Vulnerable	4
MustelaFelipei		Colombian Weasel	Vulnerable	4
NasuaNarica		White-nosed Coati	Least Concern	6
NasuaNasua		South American Coati	Least Concern	6
NasuellaOlivacea		Western Mountain Coati	Near Threatened	5
PantheraOnca		Jaguar	Near Threatened	5
PecariTajacu		Collared Peccary	Least Concern	6
PotosFlavus		Kinkajou	Least Concern	6
PumaConcolor		South American Cougar	Least Concern	6
Sciuridae	Sciurus granatensis Sciurus pucheranii	Red-tailed squirrel Andean Squirrel	Least Concern Data Deficient	6 1
TremarctosOrnatus		Andean Bear	Vulnerable	4

Commented [CM1]: Add column to rep how many cameras for each species

Table A2. All species/guilds analyzed in Ecuador with IUCN scores

Species/Guild		Common Name	IUCN Conservation Status	IUCN Score
BassaricyonMedius		Western Lowland Olingo	Least Concern	6
CabassousCentralis		Northern Naked-tailed Armadillo	Data Deficient	1
Caluromys	Caluromys derbianus	Central American Woolly Opossum	Least Concern	6
	Caluromys philander	Bare-tailed Woolly Opossum	Least Concern	6
CerdocyonThous		Crab-eating Fox	Least Concern	6
ChironectesMinimus		Water Opossum	Least Concern	6
CoendouQuichua		Andean Porcupine	Data Deficient	1
Columbiformes	Leptotila rufaxilla	Gray-fronted Dove	Least Concern	6
ConepatusSemistriatus		Striped Hog-nosed Skunk	Least Concern	6
CuniculusPaca		Lowland Paca	Least Concern	6
CyclopesDidactylus		Silky Anteater	Least Concern	6
Dasyprocta	Dasyprocta leporina	Red-rumped Agouti	Least Concern	6
	Dasyprocta punctata	Central American Agouti	Least Concern	6
DasypusNovemcinctus		Nine-banded Armadillo	Least Concern	6
Didelphis	Didelphis aurita	Big-eared Opossum	Least Concern	6
	Didelphis marsupialis	Common Opossum	Least Concern	6
EiraBarbara		Tayra	Least Concern	6
HerpailurusYagouaroundi		Jaguarundi	Least Concern	6
LeopardusColocolo		Pampas Cat	Near Threatened	5
LeopardusPardalis		Ocelot	Least Concern	6
LeopardusWiedii		Margay	Near Threatened	5
LycalopexCulpaeus		Culpeo	Least Concern	6
MazamaAmericana		Red Brocket Deer	Data Deficient	1
MetachirusNudicaudatus		Brown Four-eyed Opossum	Least Concern	6
NasuaNarica		White-nosed Coati	Least Concern	6
PantheraOnca		Jaguar	Near Threatened	5
PecariTajacu		Collared Peccary	Least Concern	6
PhilanderOpossum		Gray Four-eyed Opossum	Least Concern	6
PotosFlavus		Kinkajou	Least Concern	6
ProcyonCancrivorus		Crab-eating Raccoon	Least Concern	6
PumaConcolor		South American Cougar	Least Concern	6
SciurusGranatensis		Red-tailed squirrel	Least Concern	6
SpeothosVenaticus		Bush Dog	Near Threatened	5
TamanduaMexicana		Northern Tamandua	Least Concern	6
TayassuPecari		White-lipped Peccary	Vulnerable	4

Table A3. All species/guilds analyzed in Brazil with IUCN scores

Species/Guild		Common Name	IUCN Status	IUCN Score
CabassousTatouay		Greater Naked-tailed Armadillo	Least Concern	6
CaluromysPhilander		Bare-tailed Woolly Opossum	Least Concern	6
CerdocyonThous		Crab-eating Fox	Least Concern	6
ChironectesMinimus		Water Opossum	Least Concern	6
ChrysocyonBrachyurus		Maned Wolf	Near Threatened	5
Coendou	Coendou prehensilis	Brazilian Porcupine	Least Concern	6
	Coendou spinosus	Paraguaian hairy dwarf porcupine	Least Concern	6
Columbiformes	Leptotila rufaxilla	Gray-fronted Dove	Least Concern	6
CuniculusPaca		Lowland Paca	Least Concern	6
DasyproctaLeporina		Red-rumped Agouti	Least Concern	6
Dasypus	Dasypus novemcinctus	Nine-banded Armadillo	Least Concern	6
	Dasypus septemcinctus	Brazilian Lesser Long-nosed Armadillo	Least Concern	6
DidelphisAurita		Big-eared Opossum	Least Concern	6
EiraBarbara		Tayra	Least Concern	6
EuphractusSexcinctus		Yellow Armadillo	Least Concern	6
GalictisCuja		Lesser Grison	Least Concern	6
Galliformes	Penelope superciliaris	Rusty-margined guan	Near Threatened	5
HerpailurusYagouaroundi		Jaguarundi	Least Concern	6
HydrochoerusHydrochaeris		Capybara	Least Concern	6
LeopardusGuttulus		Southern Tiger Cat	Vulnerable	4
LeopardusPardalis		Ocelot	Least Concern	6
LeopardusWiedii		Margay	Near Threatened	5
LontraLongicaudis		Neotropical otter	Near Threatened	5
Marmosa	Marmosa murina	Linnaeus' Mouse Opossum	Least Concern	6
	Marmosa paraguayana	Tate's Woolly Mouse Opossum	Least Concern	6
MarmosopsIncanus		Gray Slender Mouse Opossum	Least Concern	6
Mazama	Mazama bororo	Small Red Brocket	Vulnerable	4
	Mazama gouazoubira	Gray Brocket	Least Concern	6
MetachirusNudicaudatus		Brown Four-eyed Opossum	Least Concern	6
Monodelphis	Monodelphis americana	Northern Three-striped Opossum	Least Concern	6
	Monodelphis dimidiata	Southern Short-tailed Opossum	Least Concern	6
	Monodelphis iheringi	Ihering's Short-tailed Opossum	Data Deficient	1
	Monodelphis scalops	Long-nosed Short-tailed Opossum	Least Concern	6
NasuaNasua		South American Coati	Least Concern	6
PecariTajacu		Collared Peccary	Least Concern	6
PhilanderFrenatus		Southeastern Four-eyed Opossum	Least Concern	6
PotosFlavus		Kinkajou	Least Concern	6
ProcyonCancrivorus		Crab-eating Raccoon	Least Concern	6
PumaConcolor		South American Cougar	Least Concern	6
SalvatorMerianae		Argentine black and white tegu	Least Concern	6
Sciuridae	Sciurus aestuans	Brazilian squirrel	Least Concern	6
SpeothosVenaticus		Bush Dog	Near Threatened	5
TamanduaTetradactyla		Southern Tamandua	Least Concern	6
TapirusTerrestris		Lowland Tapir	Vulnerable	4
TayassuPecari		White-lipped Peccary	Vulnerable	4

Normalizing file directories and eliminating duplicate entries

The first step for this was to copy the entire file directory for each country so that there was an archive. The Species column of this copied directory was standardized with the finalized list of the target species/guilds. For example, in one country there were multiple species of *Didelphis* opossums that were hard to differentiate between, so a *Didelphis* guild was created and any entry for *Didelphisaurita* was changed to *Didelphis* in the copied directory. Next, the CONCAT function was used to create a new column where the Species, Camera Trap Number, Date, and Time columns were combined. These entries were searched for exact matches and those rows were deleted. This was to solve problems such as when an individual resides in front of the camera and sets it off multiple times within a few minutes. This normalization procedure will have to be repeated as more data is added to the directory.

B. GIS Models

Models, Python codes, and GIS products were published on ArcOnline (link)

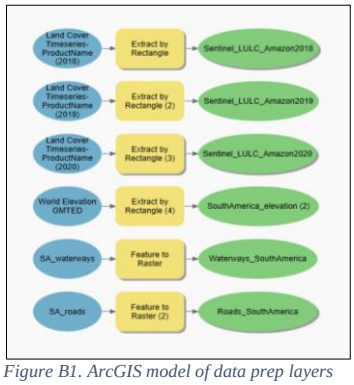


Figure B1. ArcGIS model of data prep layers

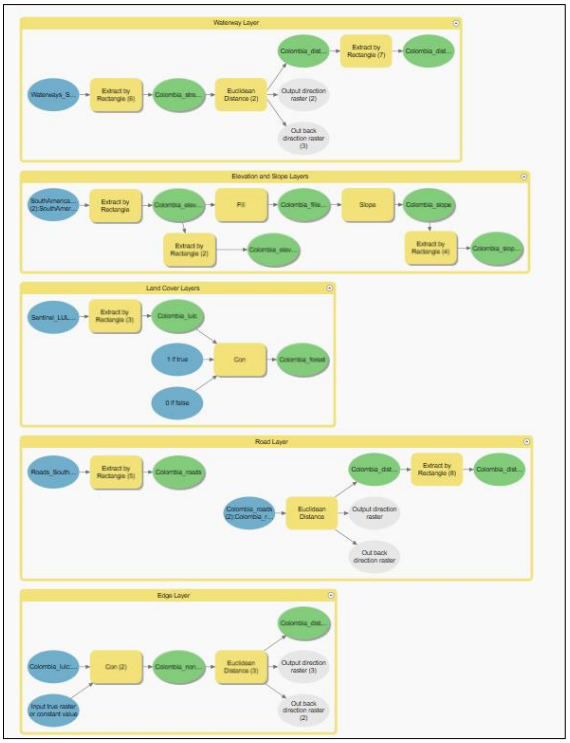


Figure B2. ArcGIS model for making the environmental variable layers for the MaxEnt program and Least Cost Path models. An identical model was used to create layers for Ecuador and Brazil.

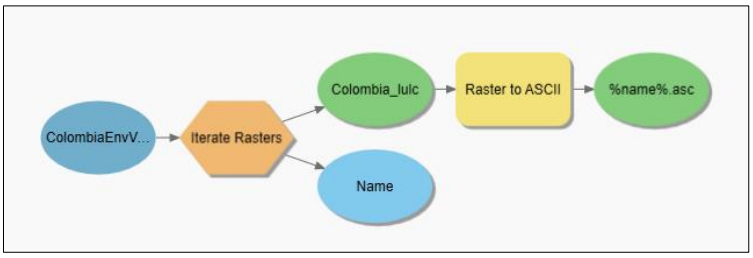


Figure B3. ArcGIS model for making the ASCII files for the MaxEnt program to read to generate the model for Colombia. An identical model was used to create ASCII files for Ecuador

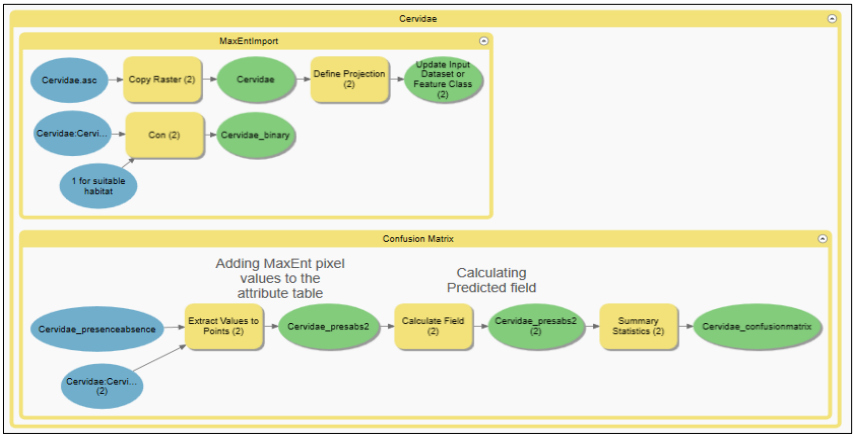


Figure B4. ArcGIS model for importing the MaxEnt program outputs into ArcGIS Pro and then computing confusion matrix statistics. An identical model was used to create confusion matrixes for every other present species in Colombia and Ecuador

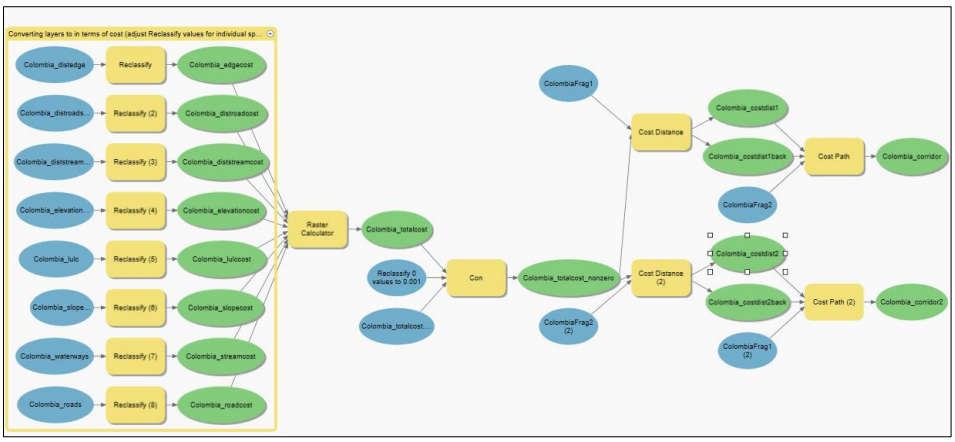


Figure B5. ArcGIS model for creating the Least Cost. An identical model was used to create models for Ecuador and Brazil.

C. GIS Layer Maps and Figures

Colombia

Figure C1. Google Earth aerial images of the Colombia corridor in 2013 (pre-reforestation) and 2014 (post-project), with camera trap locations and numbers

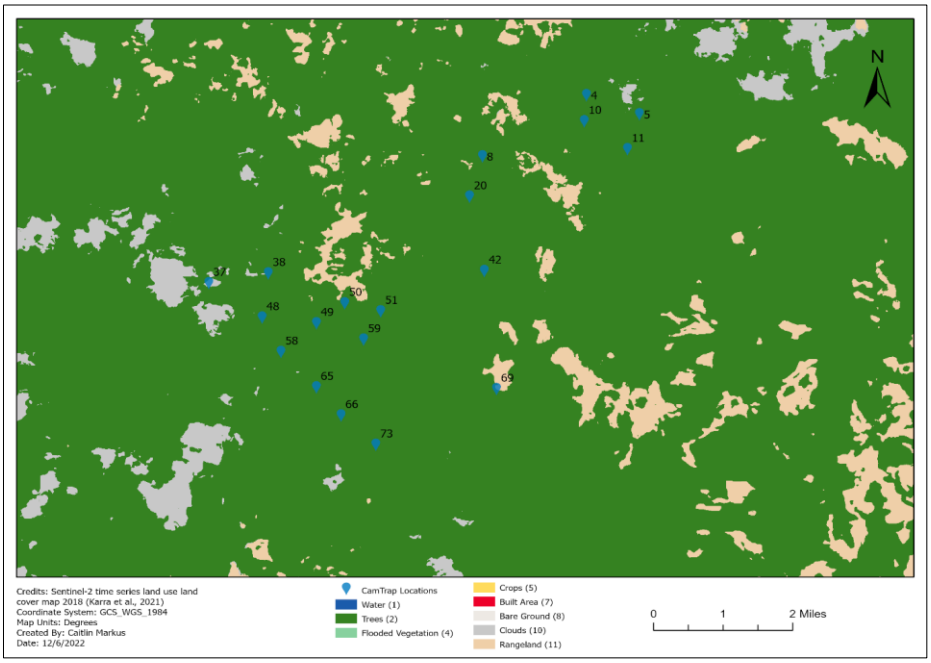


Figure C2. Land use land cover map of the Colombia corridor in 2018 with camera trap locations and numbers. Cover types include numeric code that Sentinel-2 classifications use.

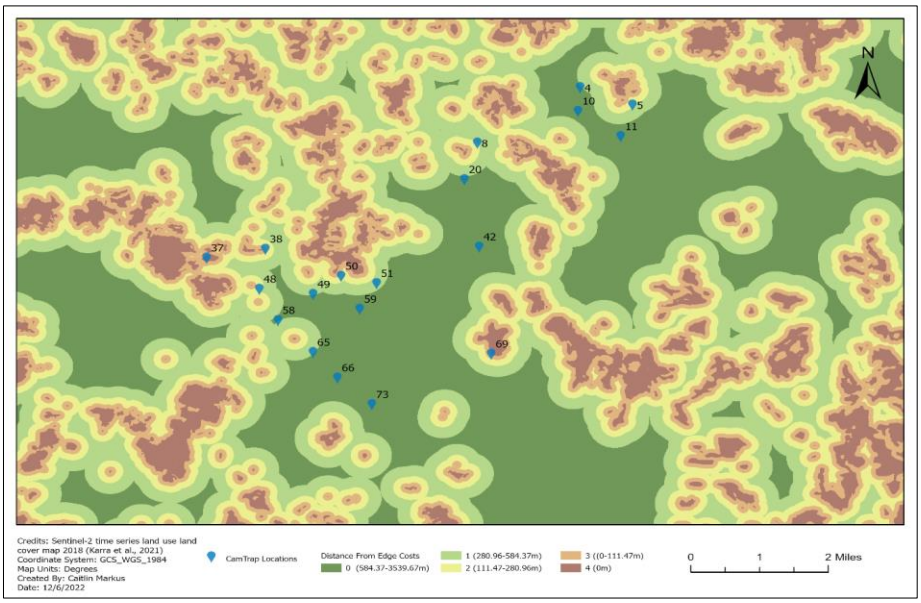


Figure C3. Distance to edge habitat, in terms of cost, in the Colombia corridor with camera trap locations and numbers. Breaks were determined by quantiles.

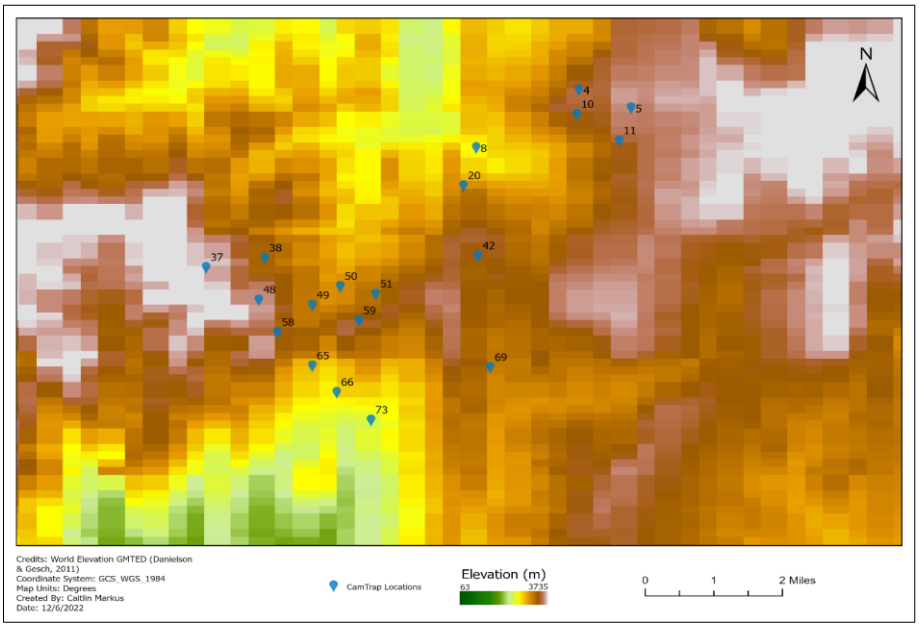


Figure C4. Elevation map of the Colombia corridor in 2011 with camera trap locations and numbers.

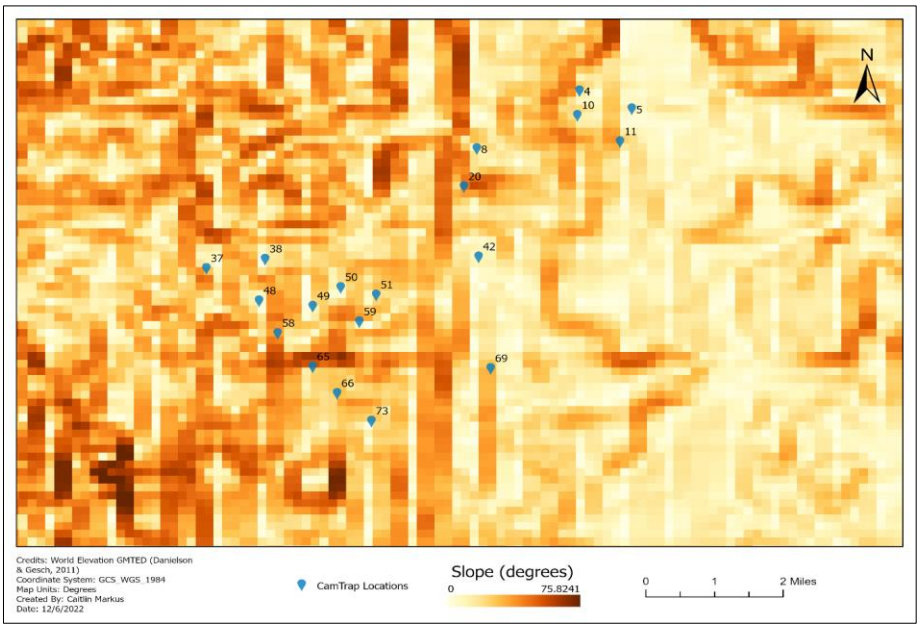


Figure C5. Slope map (derived from elevation) of the Colombia corridor in 2011 with camera trap locations and numbers.

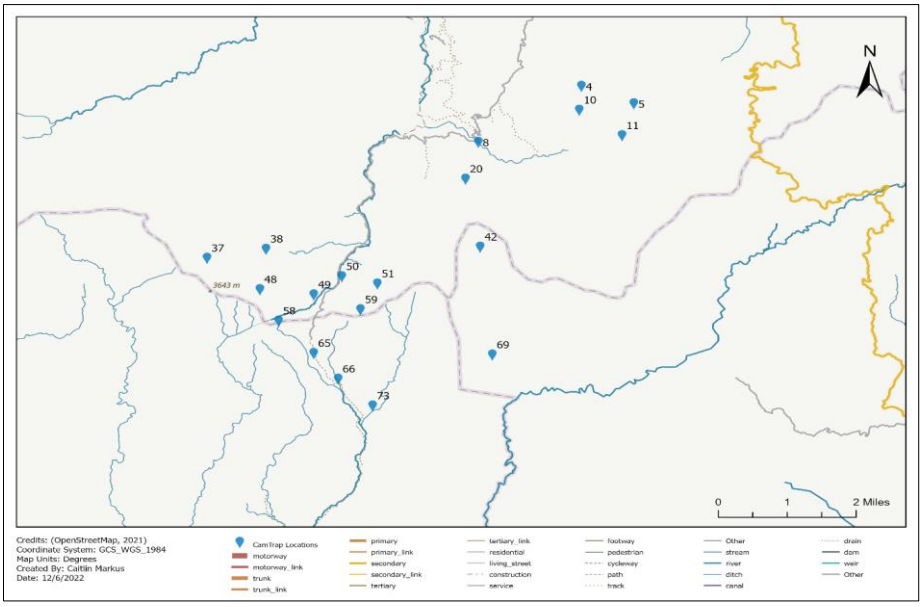


Figure C6. Road and Waterway features of the Colombia corridor as of 2022 with camera trap locations and numbers

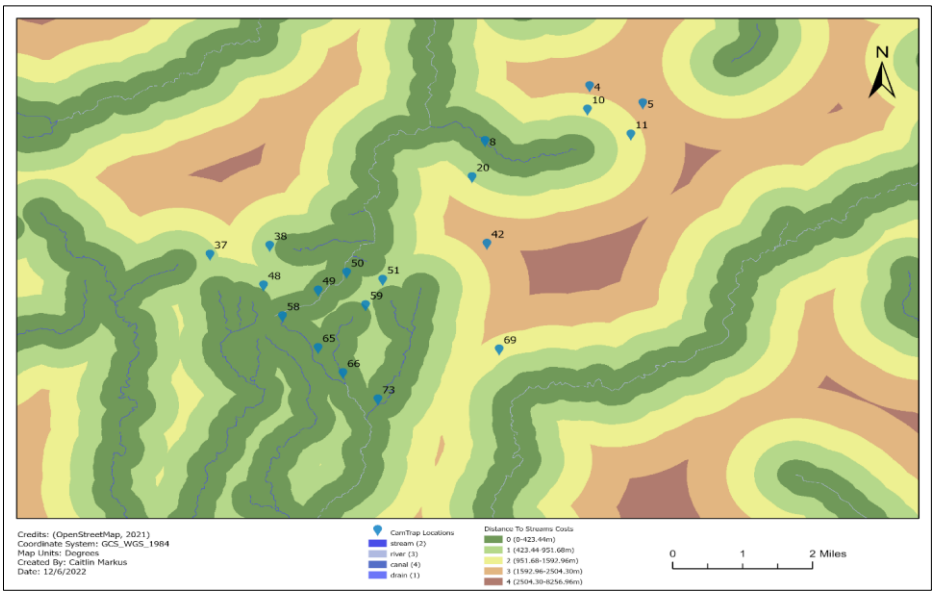


Figure C7. Waterways and distance to the nearest waterway, in terms of cost, in the Colombia corridor with camera trap locations and numbers. Breaks were determined by quantiles.

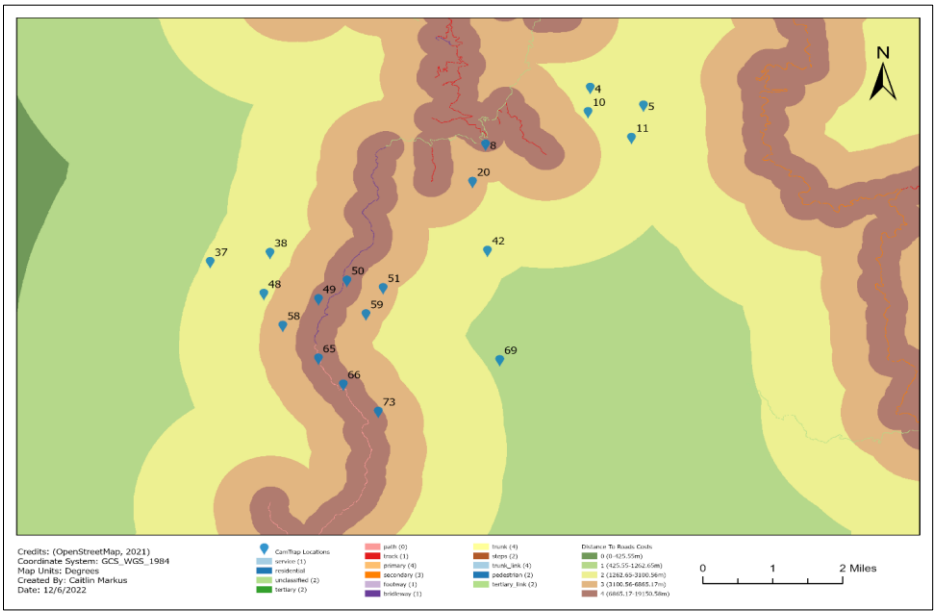


Figure C8. Roads and distance to the nearest road, in terms of cost, in the Colombia corridor with camera trap locations and numbers. Breaks were determined by quantiles.

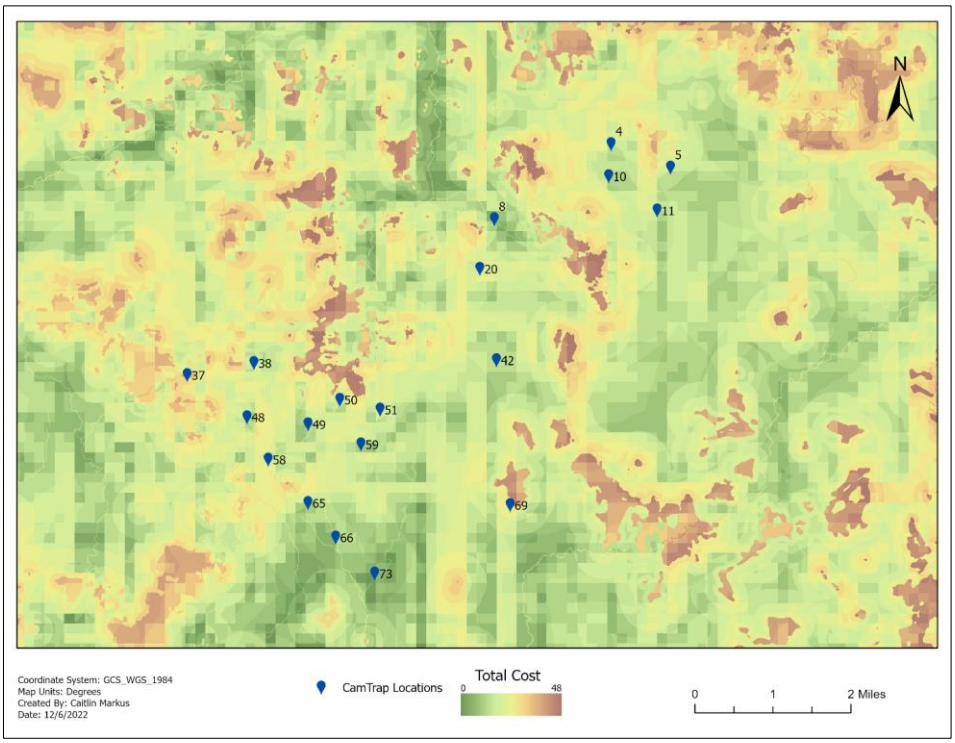


*Figure C9. Final total cost layer of the Colombia corridor, calculated with the equation: LULC*3 + E*3 + S*2 + W*2 + R*2 + DE*2 + DW + DR*

Ecuador

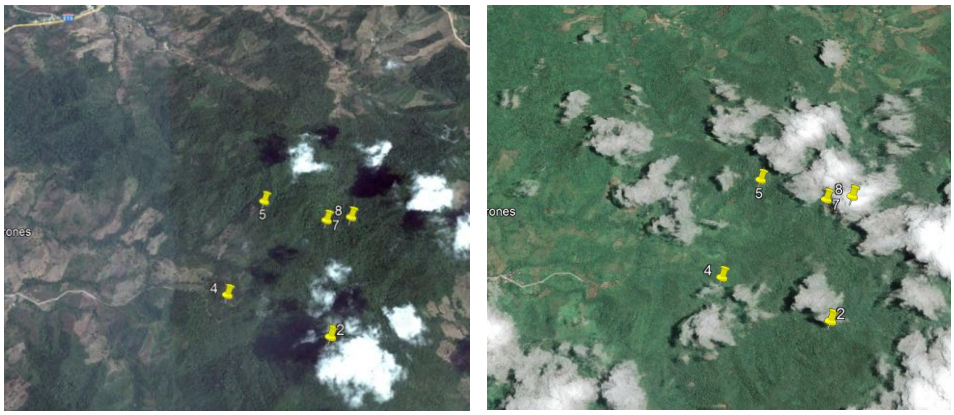


Figure C10. Google Earth aerial images of the Ecuador corridor in 2013 (pre-reforestation) and 2018 (post-project), with camera trap locations and numbers

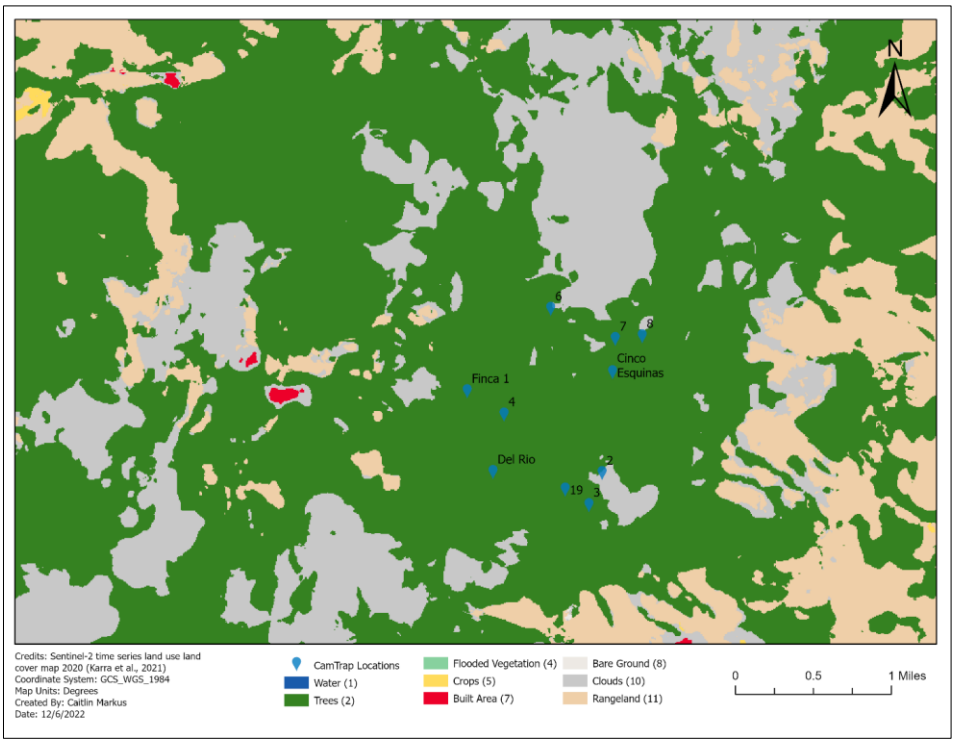


Figure C11. Land use land cover map of the Ecuador corridor in 2020 with camera trap locations and numbers. Cover types include numeric code that Sentinel-2 classifications use.

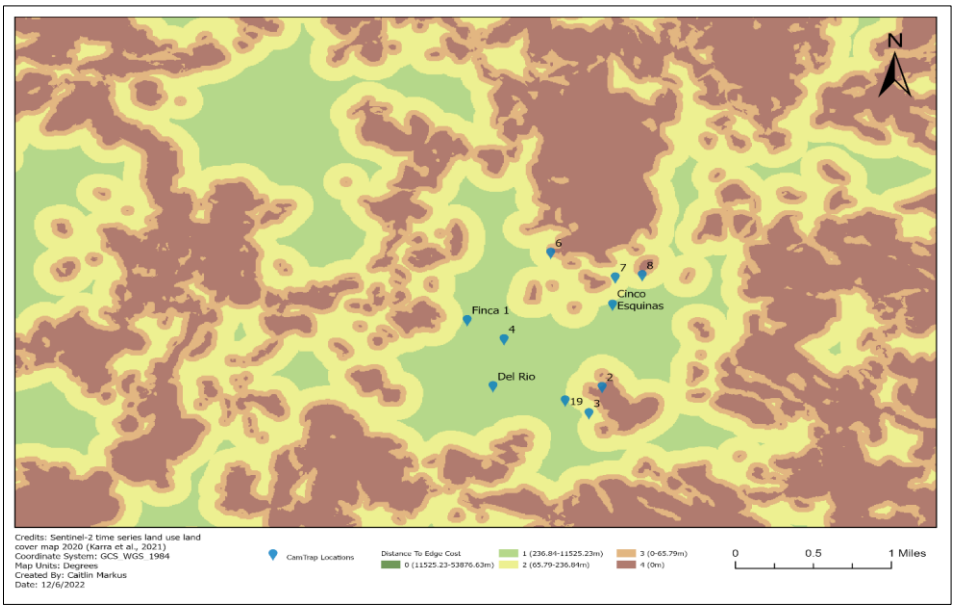


Figure C12. Distance to edge habitat, in terms of cost, in the Ecuador corridor with camera trap locations and numbers. Breaks were determined by quantiles.

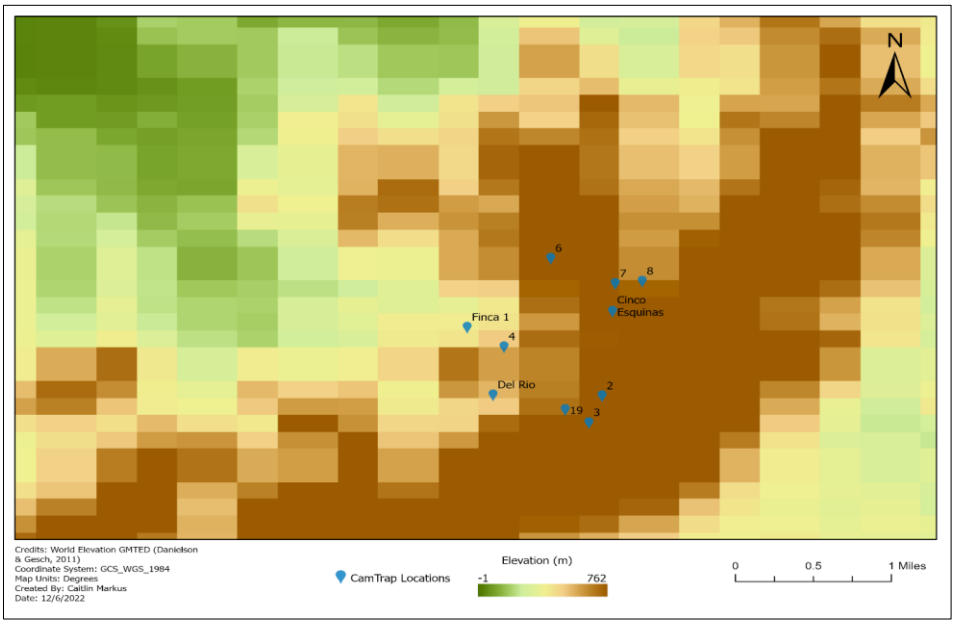


Figure C13. Elevation map of the Ecuador corridor in 2011 with camera trap locations and numbers.

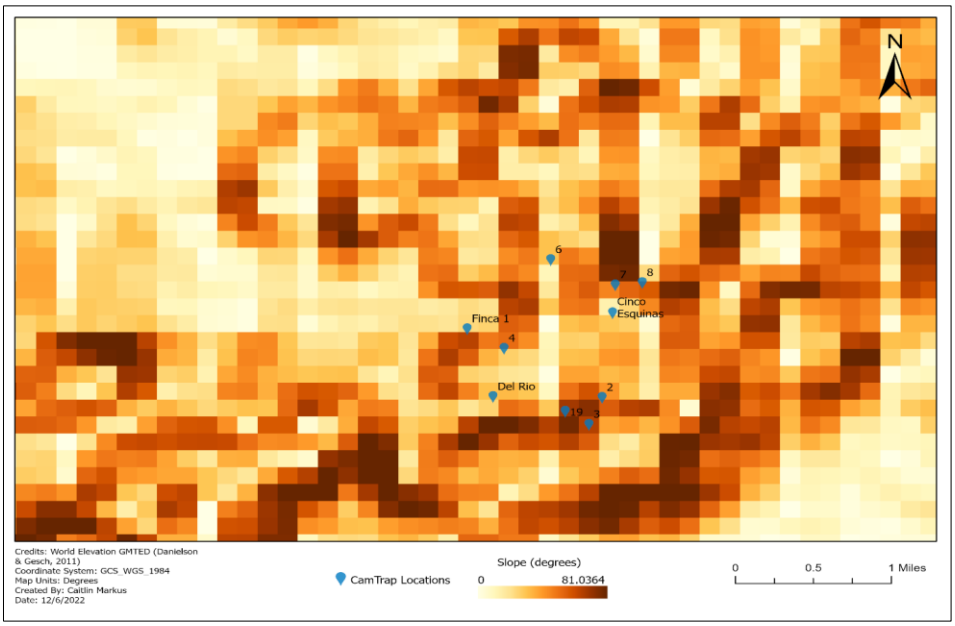


Figure C14. Slope map (derived from elevation) of the Ecuador corridor in 2011 with camera trap locations and numbers.

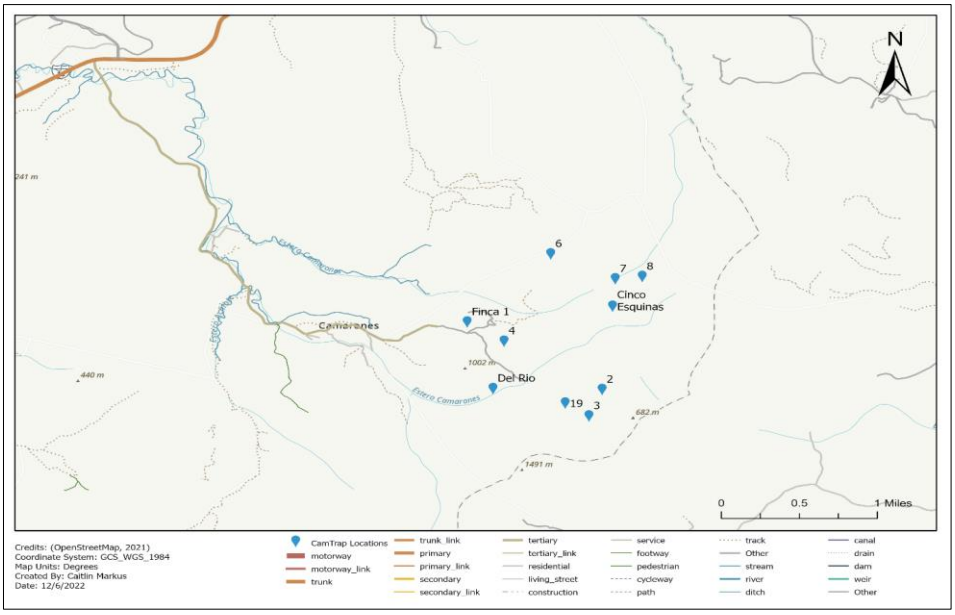


Figure C15. Road and Waterway features of the Ecuador corridor as of 2022 with camera trap locations and numbers

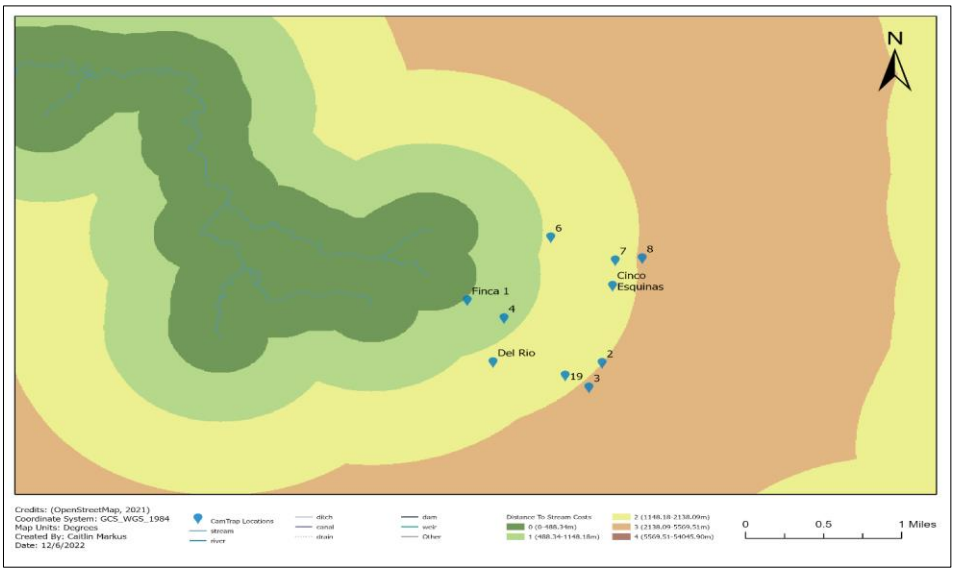


Figure C16. Waterways and distance to the nearest waterway, in terms of cost, in the Ecuador corridor with camera trap locations and numbers. Breaks were determined by quantiles.

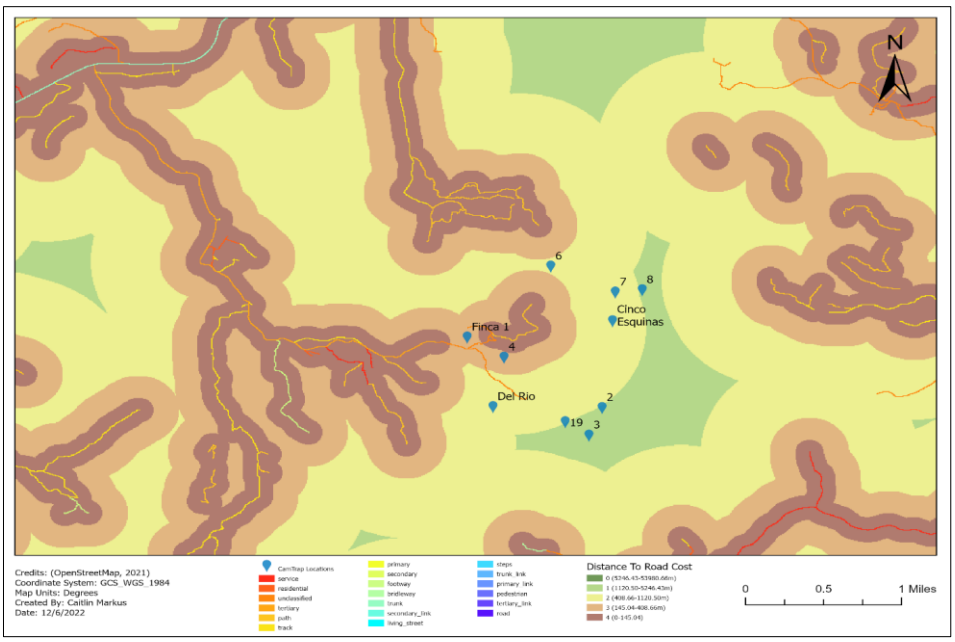


Figure C17. Roads and distance to the nearest road, in terms of cost, in the Ecuador corridor with camera trap locations and numbers. Breaks were determined by quantiles.

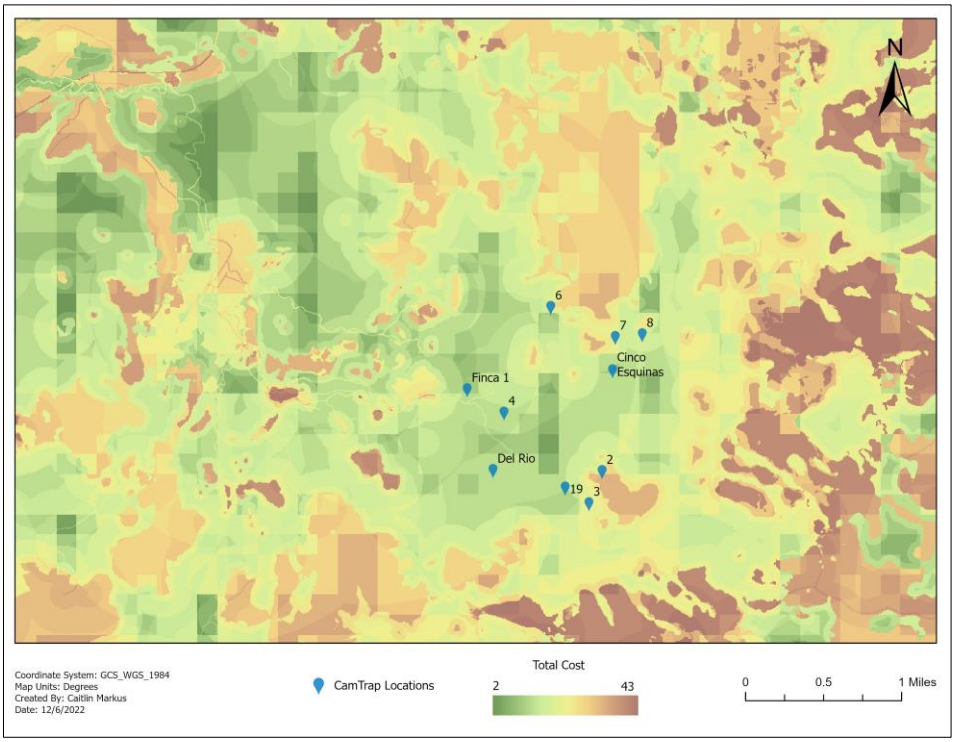


*Figure C18. Final total cost layer of the Ecuador corridor, calculated with the equation: LULC*3 + E*3 + S*2 + W*2 + R*2 + DE*2 + DW + DR*

Brazil

Figure C19. Google Earth aerial images of the Brazil constructive corridor in 2014 (pre-reforestation) and 2019 (post-project), with camera trap locations and numbers

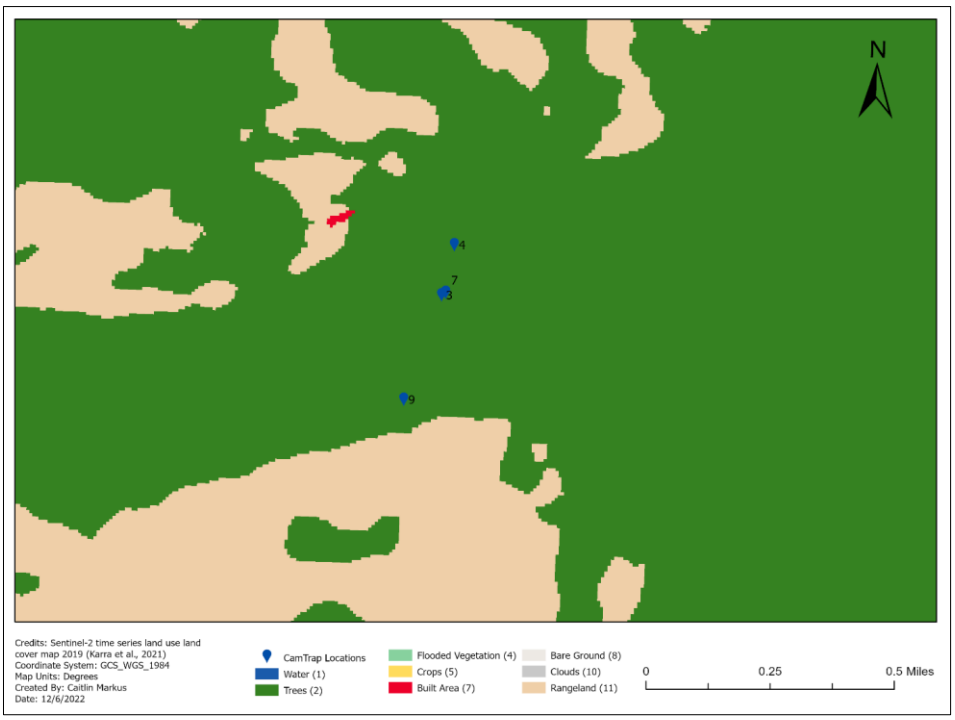


Figure C20. Land use land cover map of the Brazil constructive corridor in 2019 with camera trap locations and numbers. Cover types include numeric code that Sentinel-2 classifications use.

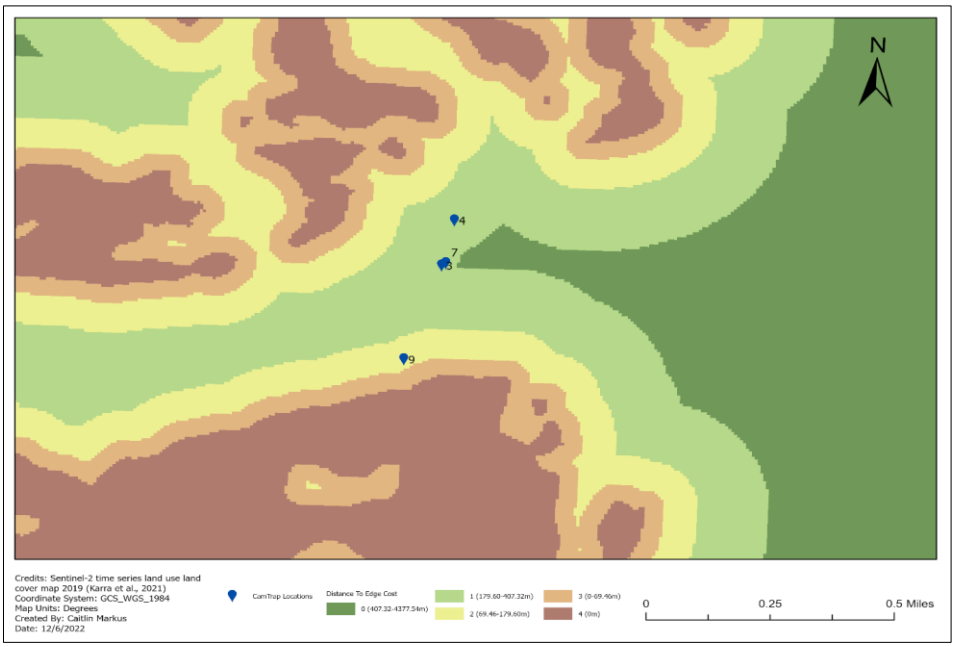


Figure C21. Distance to edge habitat, in terms of cost, in the Brazil constructive corridor with camera trap locations and numbers. Breaks were determined by quantiles.

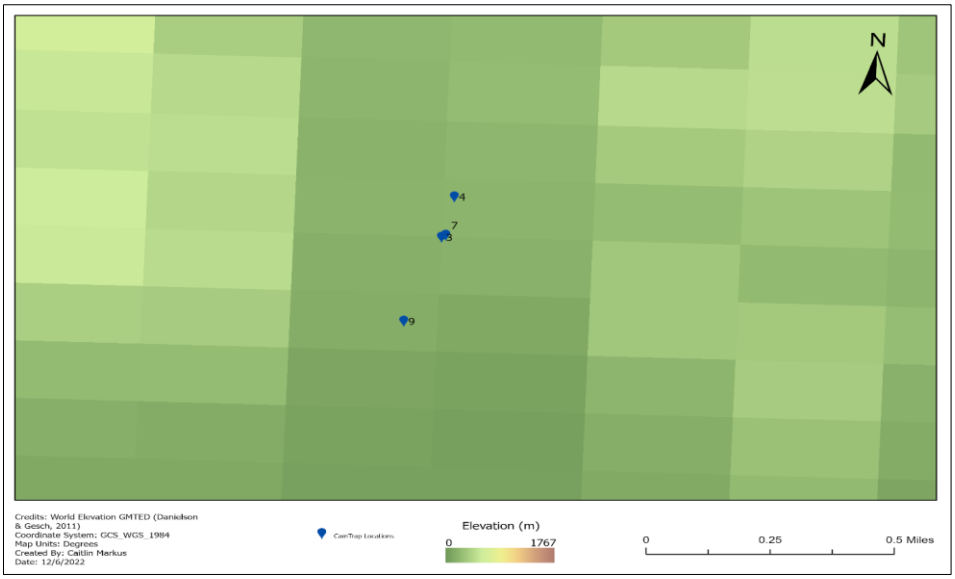


Figure C22. Elevation map of the Brazil constructive corridor in 2011 with camera trap locations and numbers.

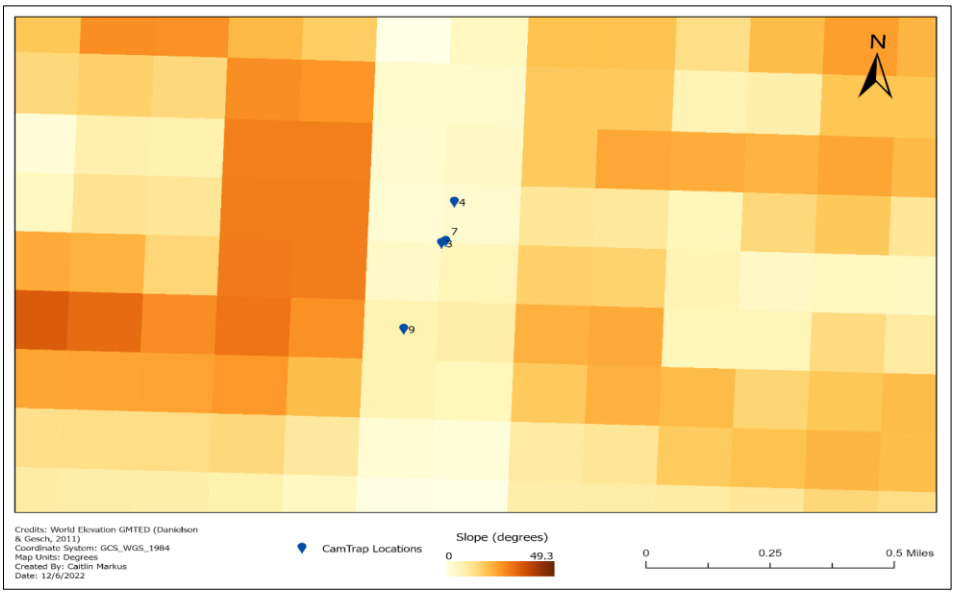


Figure C23. Slope map (derived from elevation) of the Brazil constructive corridor in 2011 with camera trap locations and numbers.

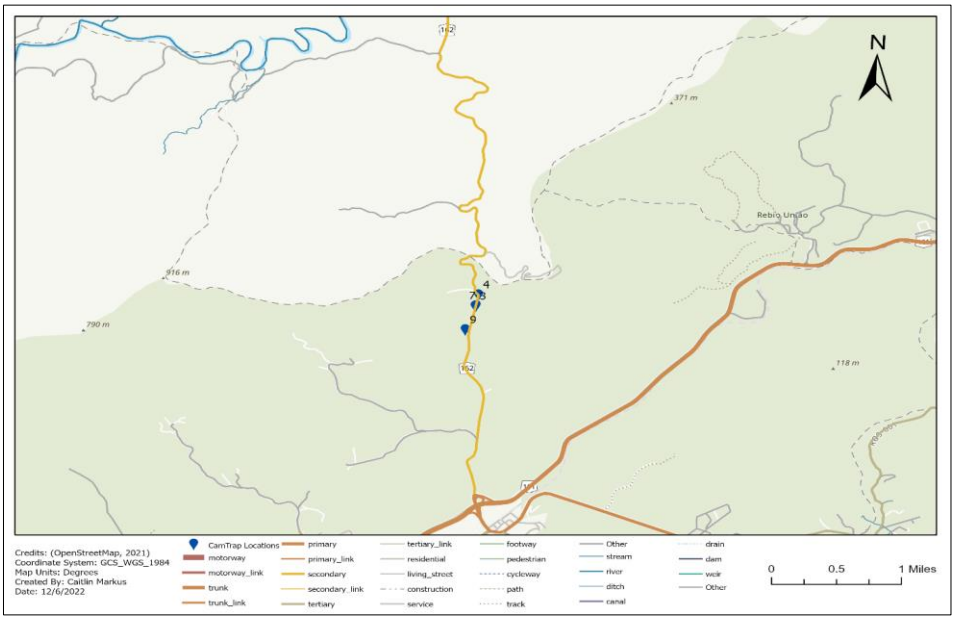


Figure C24. Road and Waterway features of the Brazil constructive corridor as of 2022 with camera trap locations and numbers

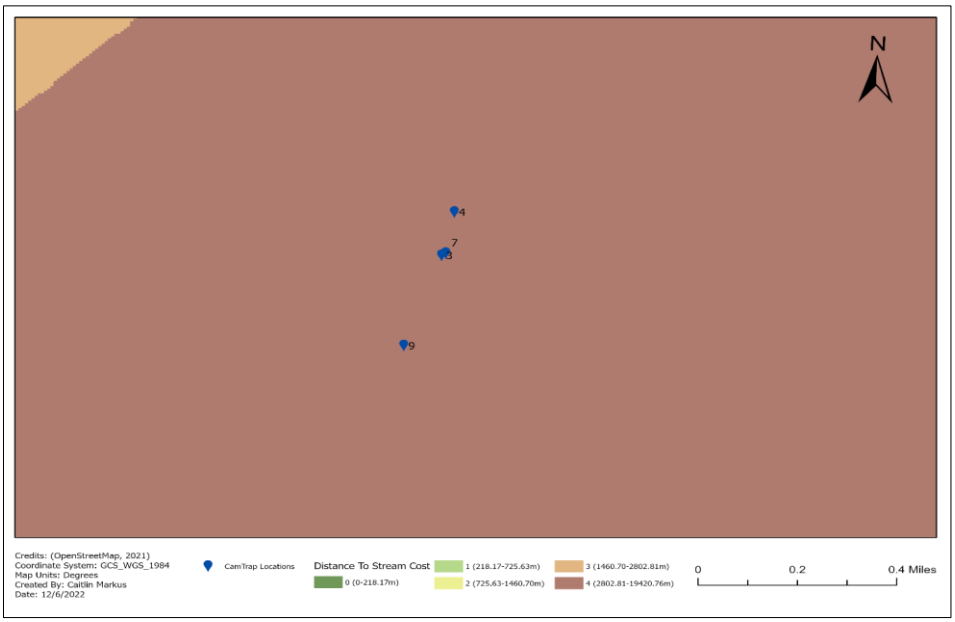


Figure C25. Waterways and distance to the nearest waterway, in terms of cost, in the Brazil constructive corridor with camera trap locations and numbers. Breaks were determined by quantiles.

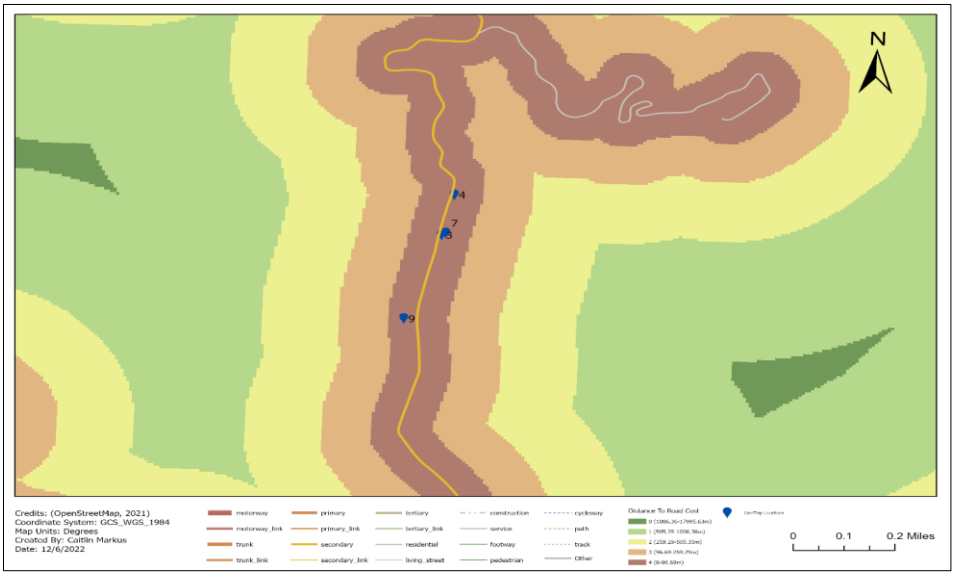


Figure C26. Roads and distance to the nearest road, in terms of cost, in the Brazil constructive corridor with camera trap locations and numbers. Breaks were determined by quantiles.

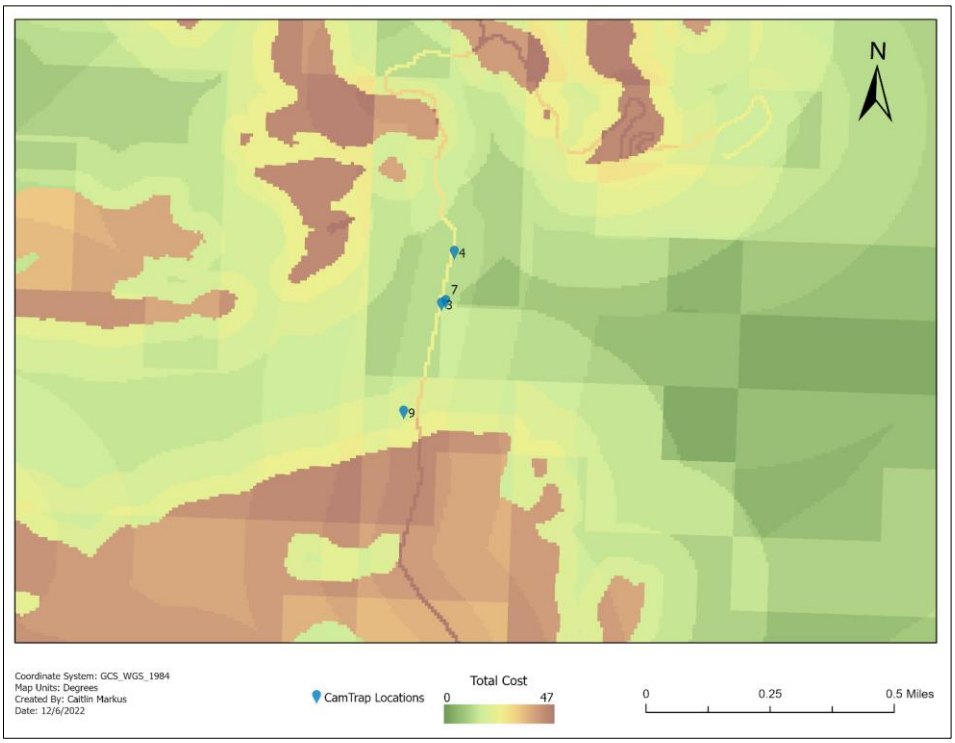


*Figure C27. Final total cost layer of the Brazil constructive corridor, calculated with the equation: LULC*3 + E*3 + S*2 + W*2 + R*2 + DE*2 + DW + DR*

D. MaxEnt Model Results

Commented [CM2]: Add in captions how many camera traps are represented with each species

Colombia

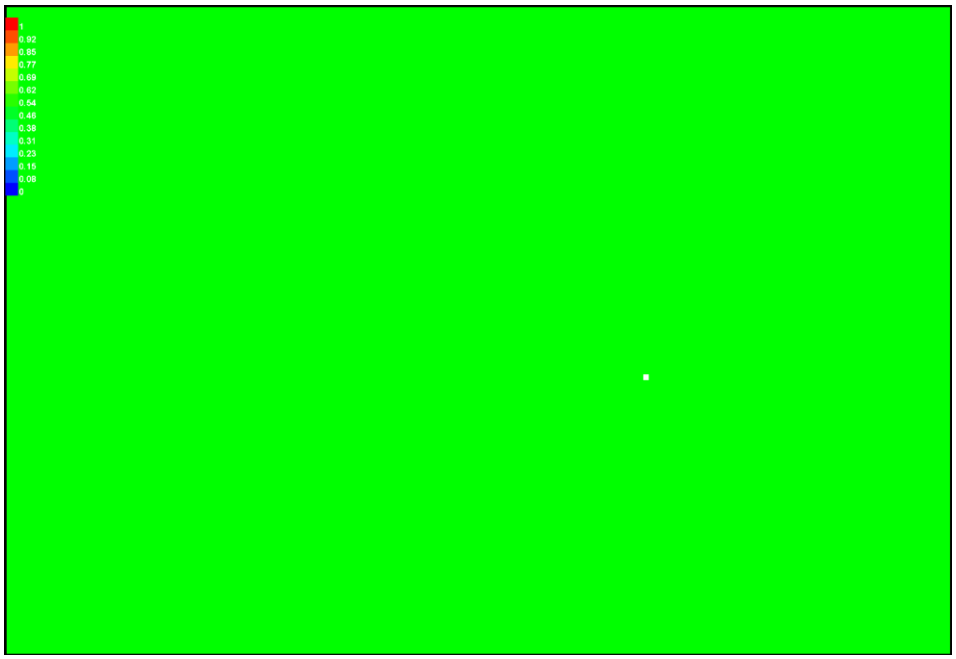


Figure D1. MaxEnt species distribution model for CerdocyonThous, Cuniculus, MustelaFelipei, NasuellaOlivaceae, and PumaConcolor in the Colombia corridor. Warmer colors show suitable habitat conditions, white dots represent presences

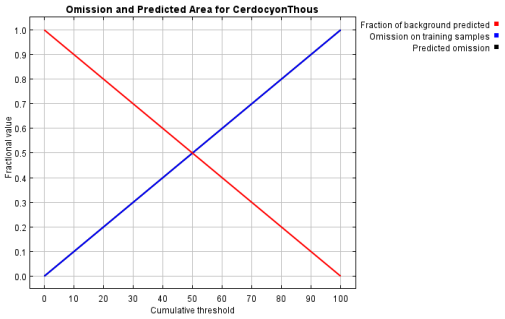


Figure D2. Omission and predicted omission rate as function of cumulative threshold of CerdocyonThous, Cuniculus, MustelaFelipei, NasuellaOlivaceae, and PumaConcolor in the Colombia corridor

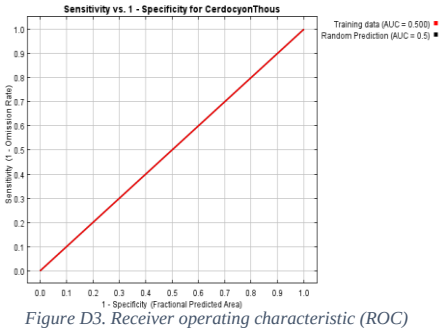


Figure D3. Receiver operating characteristic (ROC) curve of CerdocyonThous, Cuniculus, MustelaFelipei, NasuellaOlivaceae, and PumaConcolor in the Colombia corridor

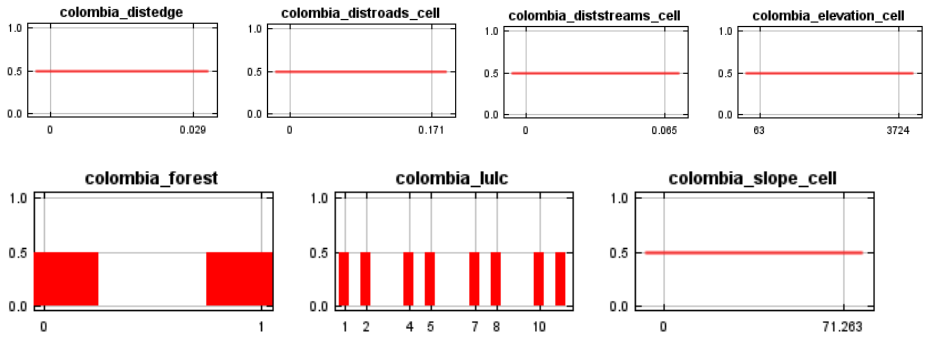


Figure D4. Dependence response curves for the CerdocyonThous, Cuniculus, MustelaFelipei, NasuellaOlivaceae, and PumaConcolor MaxEnt models in the Colombia corridor

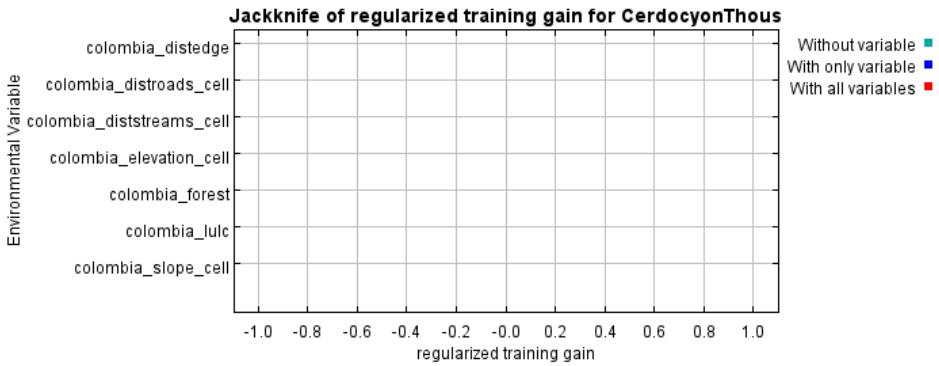


Figure D5. Results for jackknife test of variable importance for CerdocyonThous, Cuniculus, MustelaFelipei, NasuellaOlivaceae, and PumaConcolor in the Colombia corridor

Table D1. Confusion Matrix of CerdocyonThous, Cuniculus, MustelaFelipei, NasuellaOlivaceae, and PumaConcolor in the Colombia corridor, habitat/non-habitat threshold value = 0.5

		Observed Values		
		Positive (1)	Negative (0)	
Predicted Values	Positive (1)	1	1190	
	Negative (0)	0	0	
				PT = 0.00083963

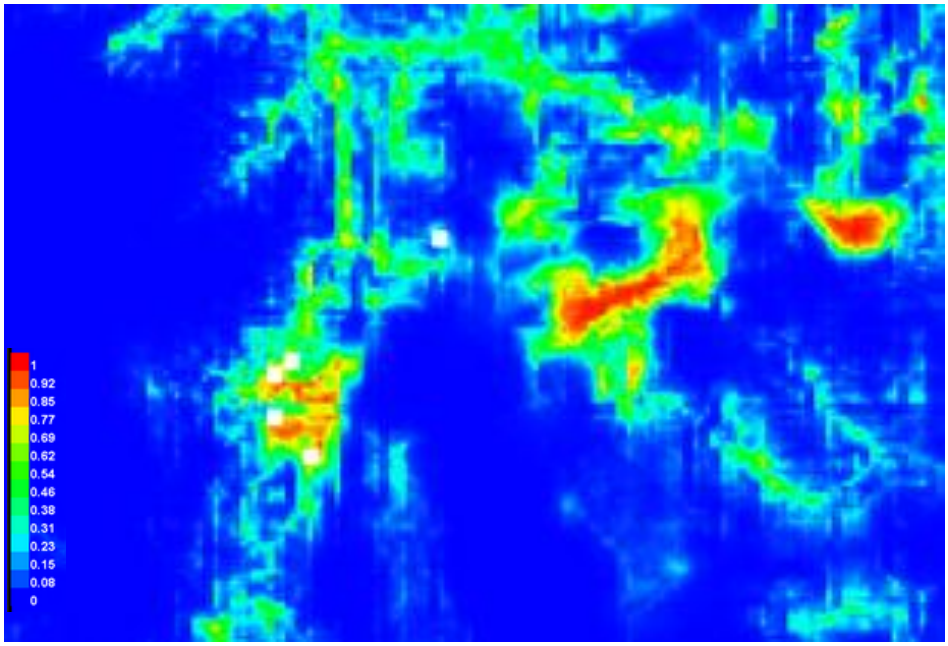


Figure D6. MaxEnt species distribution model for Cervidae in the Colombia corridor. Warmer colors show better-predicted habitat conditions, white dots represent presences

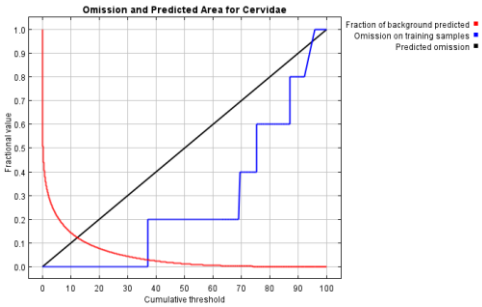


Figure D7. Omission and predicted omission rate as function of cumulative threshold of Cervidae in the Colombia corridor

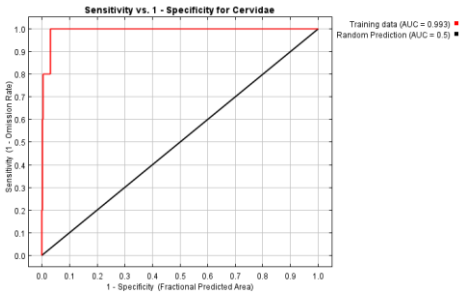


Figure D8. Receiver operating characteristic (ROC) curve of Cervidae in the Colombia corridor

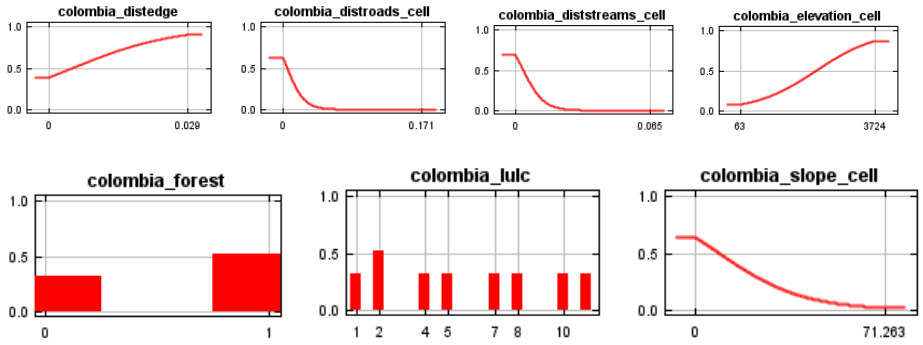


Figure D9 Dependence response curves for the Cervidae MaxEnt models in the Colombia corridor

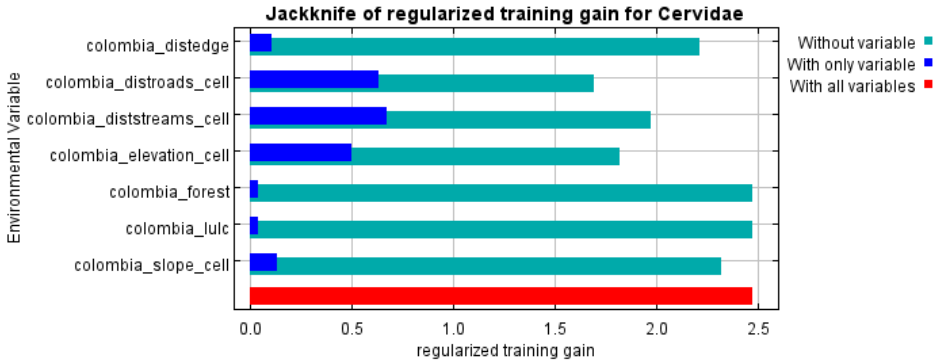


Figure D10. Results for jackknife test of variable importance for Cervidae in the Colombia corridor. Distance to streams accounted for the highest gain to the model and therefore has the most information not accounted for in other variables. Land use land cover type accounted for the lowest gain.

Table D2. Confusion Matrix of Cervidae in the Colombia corridor, habitat/non-habitat threshold value = 0.033

		Observed Values		
		Positive (1)	Negative (0)	
Predicted Values	Positive (1)	22	807	
	Negative (0)	0	362	
				PT = 0.32241814

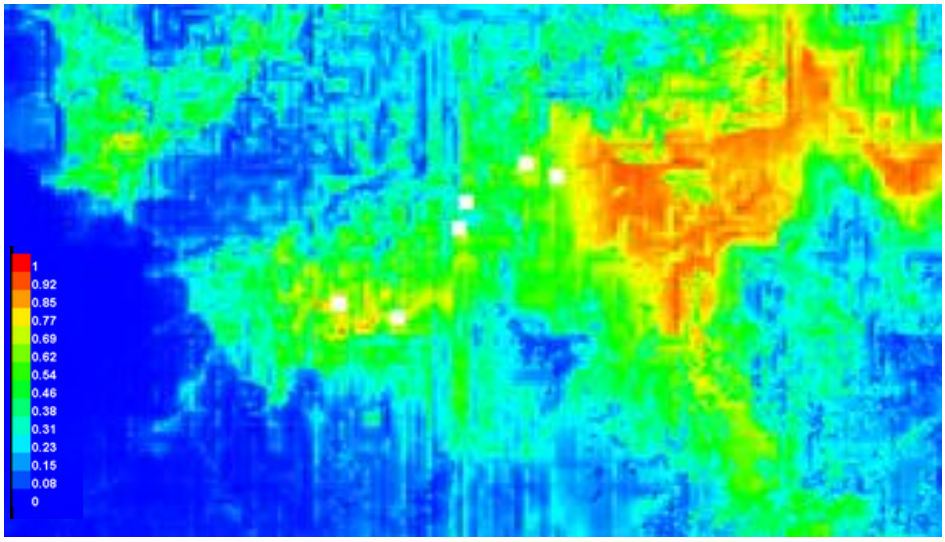


Figure D11. MaxEnt species distribution model for Columbiformes in the Colombia corridor. Warmer colors show better-predicted habitat conditions, white dots represent presences

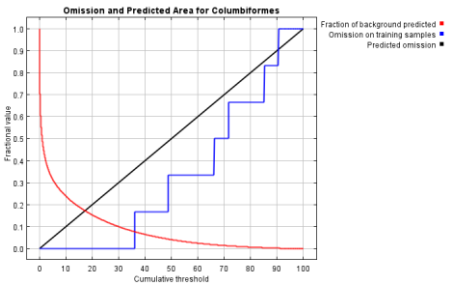


Figure D12. Omission and predicted omission rate as function of cumulative threshold of Columbiformes in the Colombia corridor

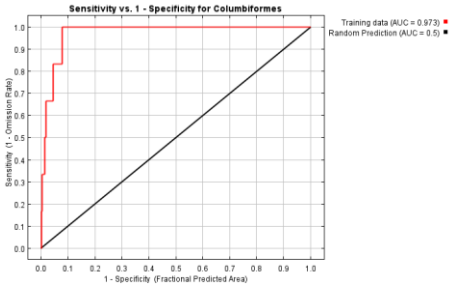


Figure D13. Receiver operating characteristic (ROC) curve of Columbiformes in the Colombia corridor

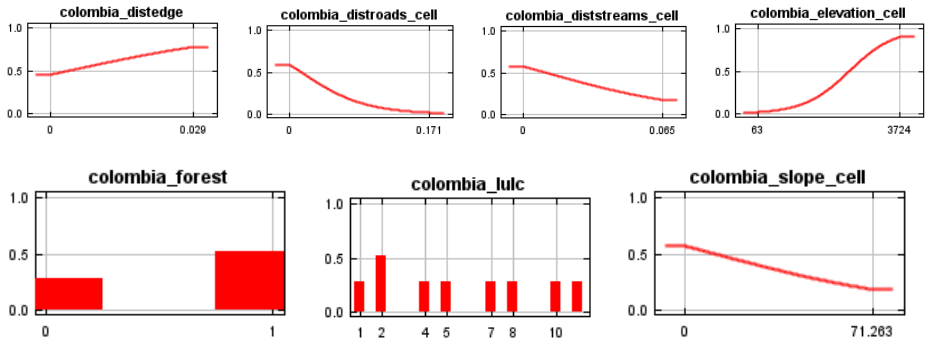


Figure D14. Dependence response curves for the Columbiformes MaxEnt models in the Colombia corridor

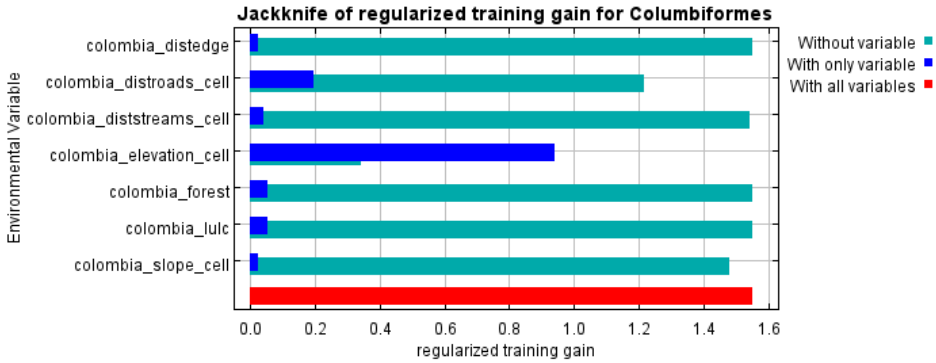


Figure D15. Results for jackknife test of variable importance for Columbiformes in the Colombia corridor. Elevation accounted for the highest gain to the model and therefore has the most information not accounted for in other variables. Slope and distance to edge accounted for the lowest gain.

Table D3. Confusion Matrix of Columbiformes in the Colombia corridor, habitat/non-habitat threshold = 0.078

		Observed Values		
		Positive (1)	Negative (0)	
Predicted Values	Positive (1)	93	1098	
	Negative (0)	0	0	
				PT = 0.07808564

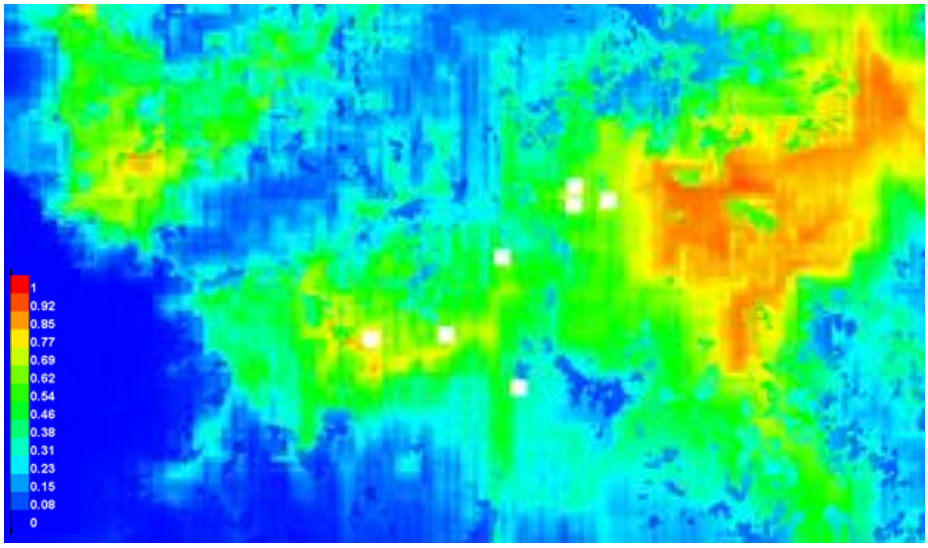


Figure D16. MaxEnt species distribution model for CrypturellusObsoletus in the Colombia corridor. Warmer colors show better-predicted habitat conditions, white dots represent presences

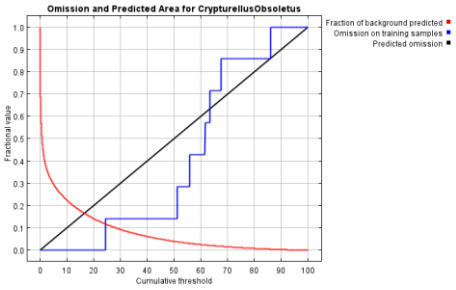


Figure D17. Omission and predicted omission rate as function of cumulative threshold of CrypturellusObsoletus in the Colombia corridor

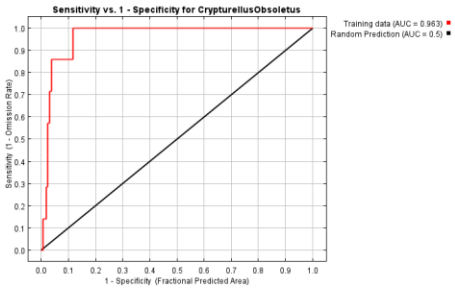


Figure D18. Receiver operating characteristic (ROC) curve of CrypturellusObsoletus in the Colombia corridor

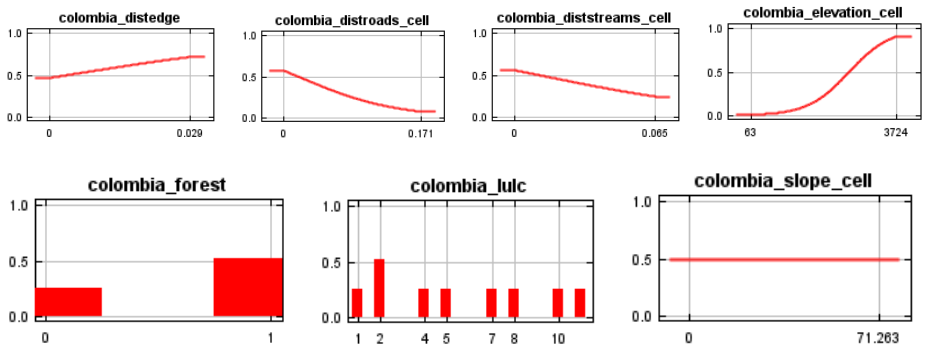


Figure D19. Dependence response curves for the CrypturellusObsoletus MaxEnt models in the Colombia corridor

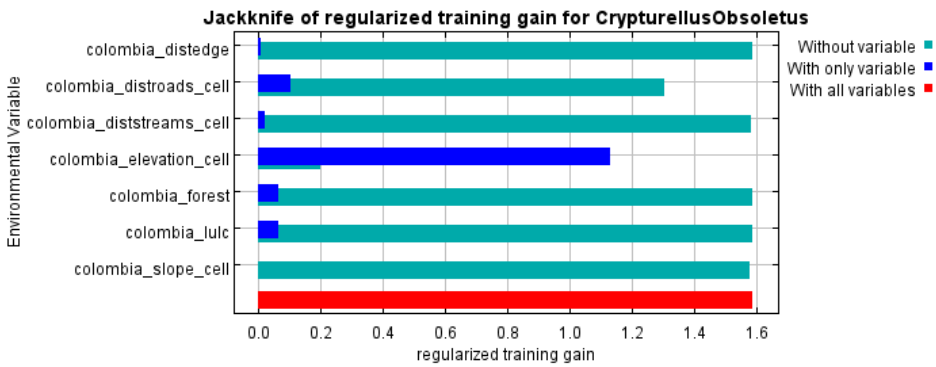


Figure D20. Results for jackknife test of variable importance for CrypturellusObsoletus in the Colombia corridor. Elevation accounted for the highest gain to the model and therefore has the most information not accounted for in other variables. Slope accounted for the lowest gain.

Table D4. Confusion Matrix of CrypturellusObsoletus in Colombia corridor, habitat/non-habitat threshold = 0.075

		Observed Values		
		Positive (1)	Negative (0)	
Predicted Values	Positive (1)	43	1148	
	Negative (0)	0	0	
				PT = 0.03610411

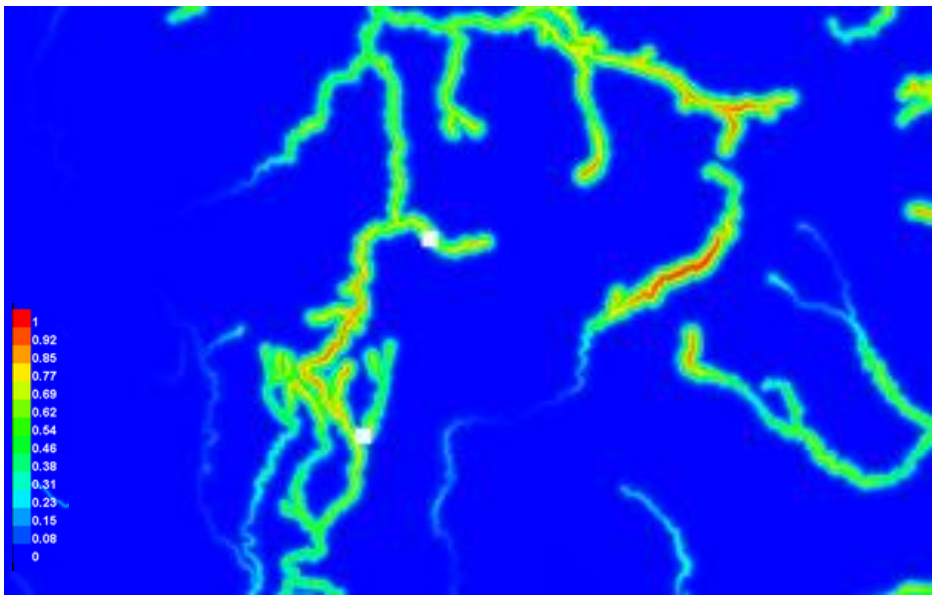


Figure D21. MaxEnt species distribution model for DasypusNovemcinctus in the Colombia corridor. Warmer colors show better-predicted habitat conditions, white dots represent presences

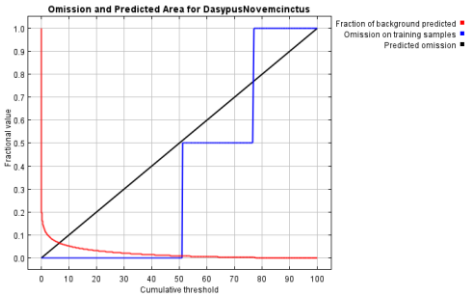


Figure D22. Omission and predicted omission rate as function of cumulative threshold of DasypusNovemcinctus in the Colombia corridor

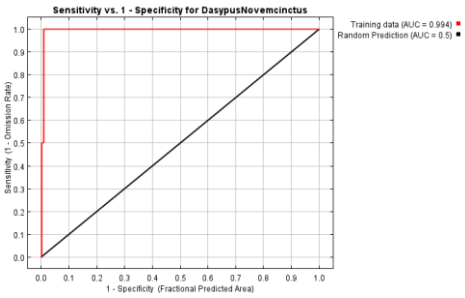


Figure D23. Receiver operating characteristic (ROC) curve of DasypusNovemcinctus in the Colombia corridor

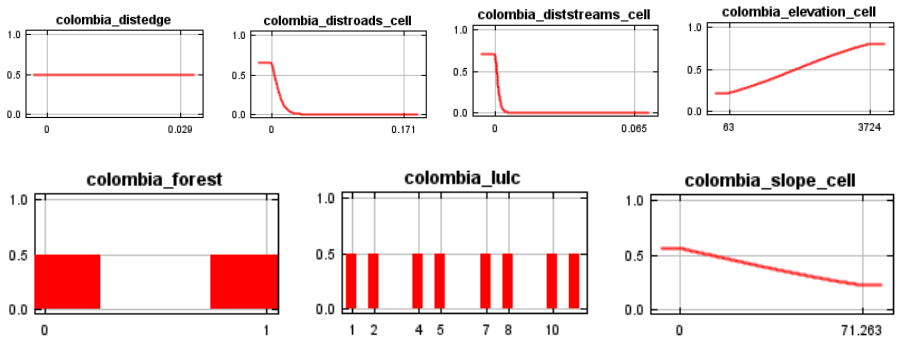


Figure D24. Dependence response curves for the DasypusNovemcinctus MaxEnt models in the Colombia corridor

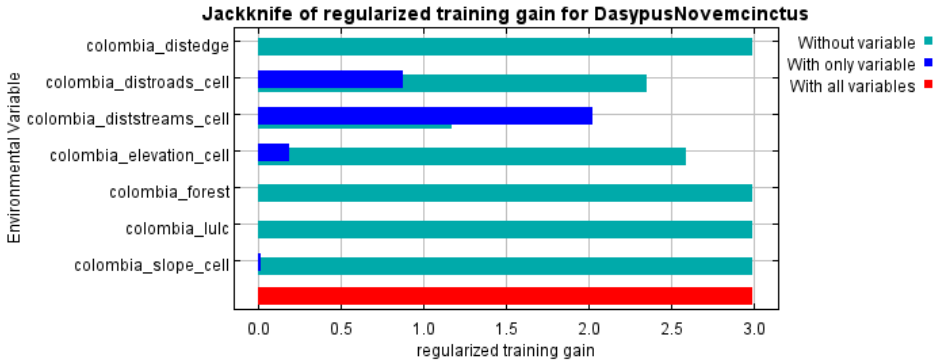


Figure D25. Results for jackknife test of variable importance for DasypusNovemcinctus in the Colombia corridor. Distance to streams accounted for the highest gain to the model and therefore has the most information not accounted for in other variables. Land use land cover, forest habitat, and distance to edge accounted for the lowest gain.

Table D5. Confusion Matrix of DasypusNovemcinctus in Colombia corridor, habitat/non-habitat threshold = 0.020

		Observed Values		
		Positive (1)	Negative (0)	
Predicted Values	Positive (1)	6	594	
	Negative (0)	0	591	
				PT = 0.50125945

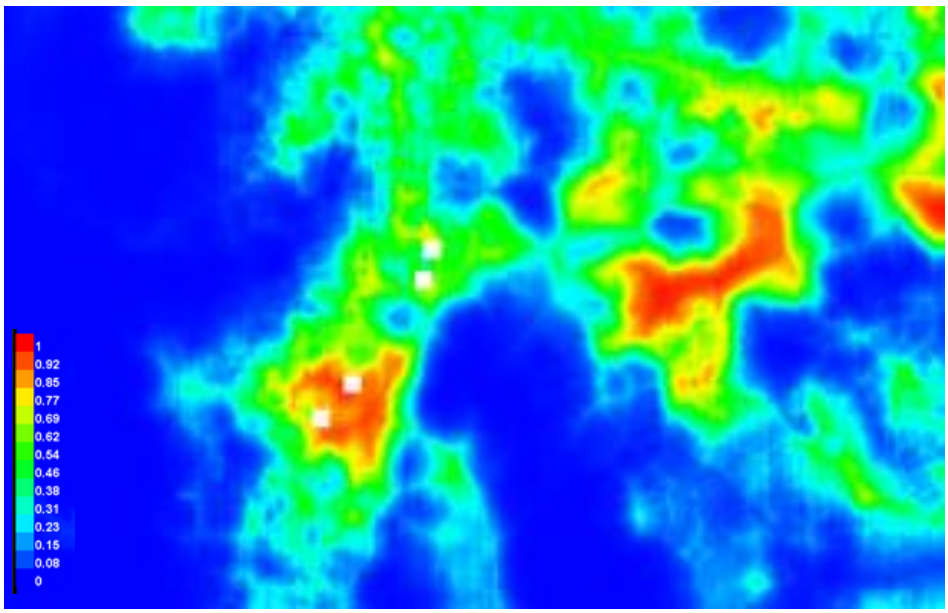


Figure D26. MaxEnt species distribution model for Didelphis in the Colombia corridor. Warmer colors show better-predicted habitat conditions, white dots represent presences

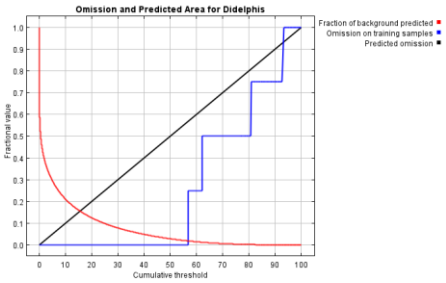


Figure D27. Omission and predicted omission rate as function of cumulative threshold of Didelphis in the Colombia corridor

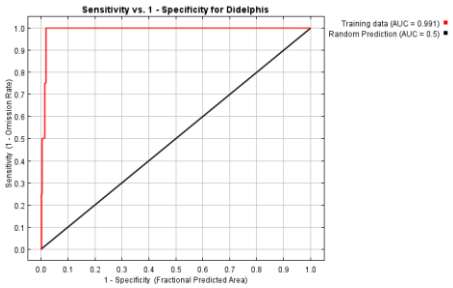


Figure D28. Receiver operating characteristic (ROC) curve of Didelphis in the Colombia corridor

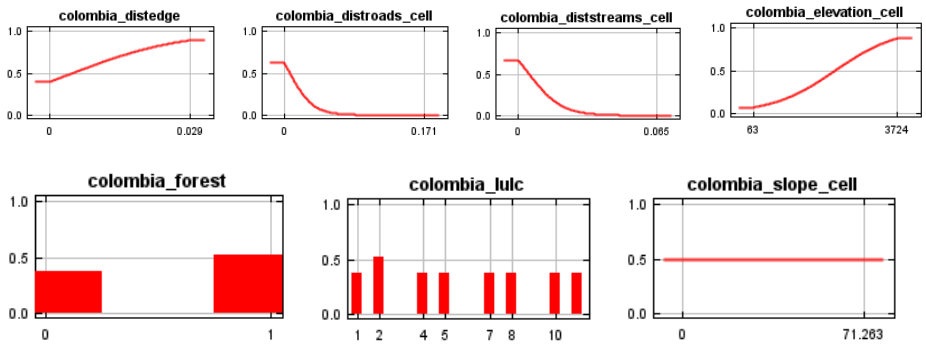


Figure D29. Dependence response curves for the Didelphis MaxEnt models in the Colombia corridor

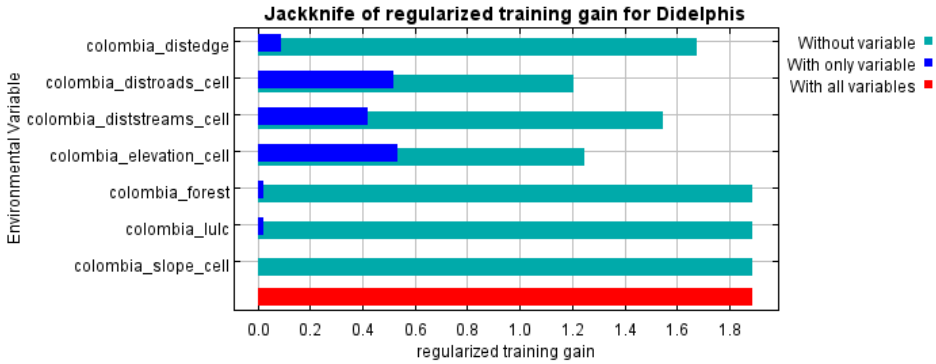


Figure D30. Results for jackknife test of variable importance for Didelphis in the Colombia corridor. Elevation accounted for the highest gain to the model and therefore has the most information not accounted for in other variables. Slope accounted for the lowest gain.

Table D6. Confusion Matrix of Didelphis in the Colombia corridor, habitat/non-habitat threshold value = 0.057

		Observed Values		
		Positive (1)	Negative (0)	
Predicted Values	Positive (1)	5	1036	
	Negative (0)	0	150	
				PT = 0.13014274

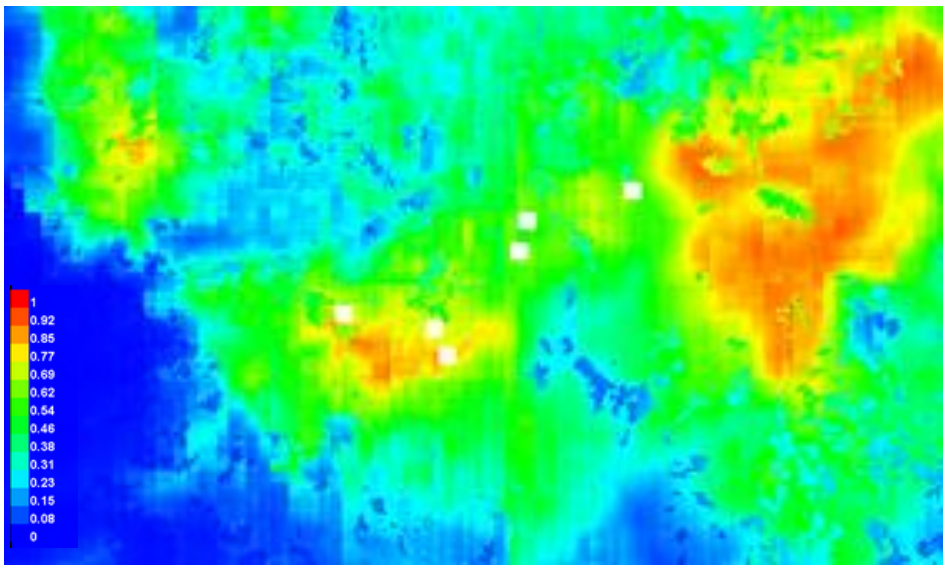


Figure D31. MaxEnt species distribution model for EiraBarbara in the Colombia corridor. Warmer colors show better-predicted habitat conditions, white dots represent presences

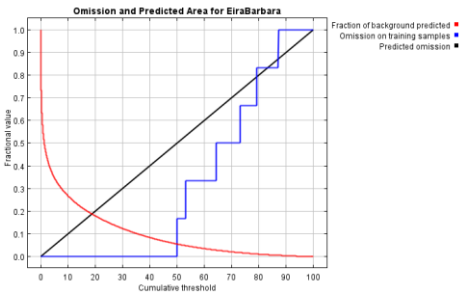


Figure D32. Omission and predicted omission rate as function of cumulative threshold of EiraBarbara in the Colombia corridor

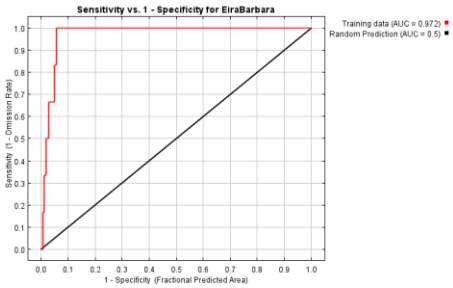


Figure D33. Receiver operating characteristic (ROC) curve of EiraBarbara in the Colombia corridor

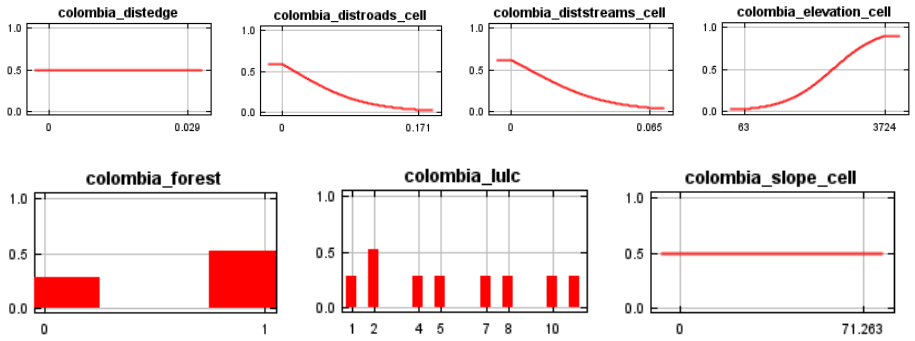


Figure D34. Dependence response curves for the EiraBarbara MaxEnt models in the Colombia corridor

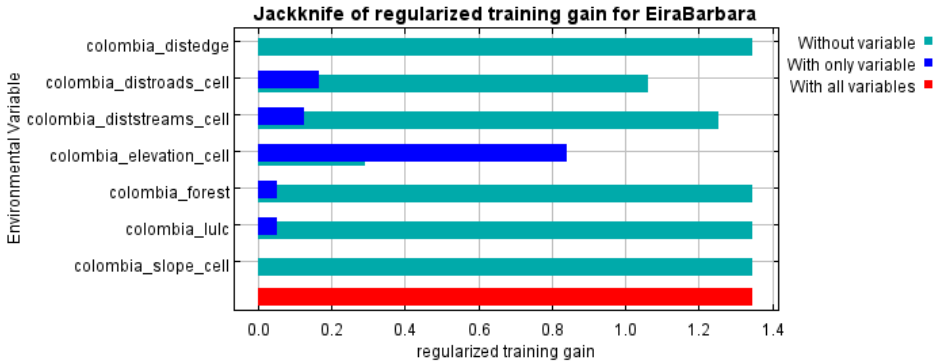


Figure D35. Results for jackknife test of variable importance for EiraBarbara in the Colombia corridor. Elevation accounted for the highest gain to the model and therefore has the most information not accounted for in other variables. Slope and distance to edge accounted for the lowest gain.

Table D7. Confusion Matrix of EiraBarbara in the Colombia corridor, habitat/non-habitat threshold value = 0.094

		Observed Values		
		Positive (1)	Negative (0)	
Predicted Values	Positive (1)	17	1174	
	Negative (0)	0	0	
				PT = 0.01427372

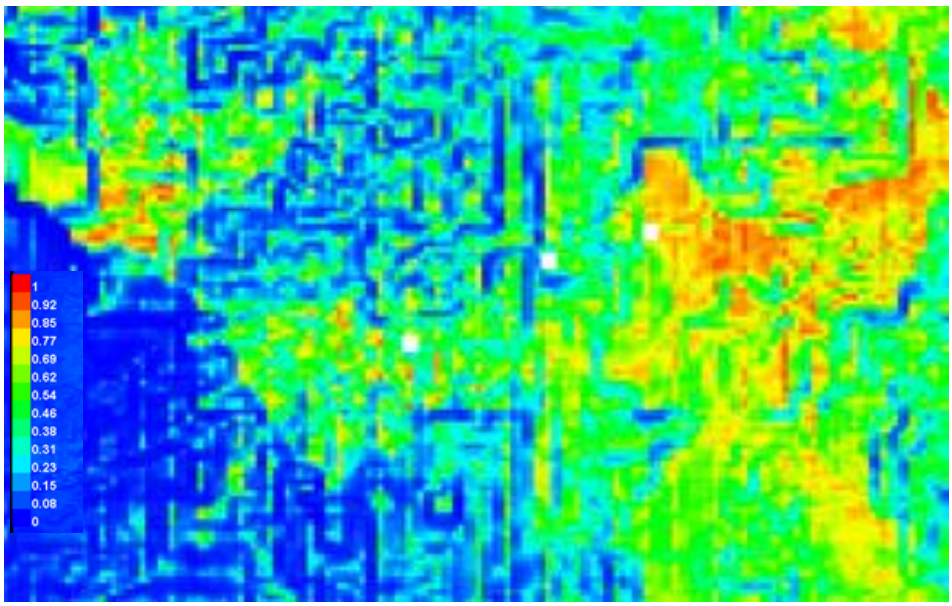


Figure D36. MaxEnt species distribution model for Galliformes in the Colombia corridor. Warmer colors show better-predicted habitat conditions, white dots represent presences

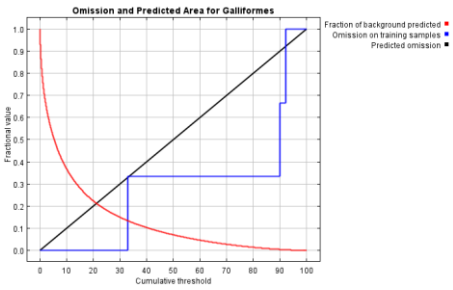


Figure D37. Omission and predicted omission rate as function of cumulative threshold of Galliformes in the Colombia corridor

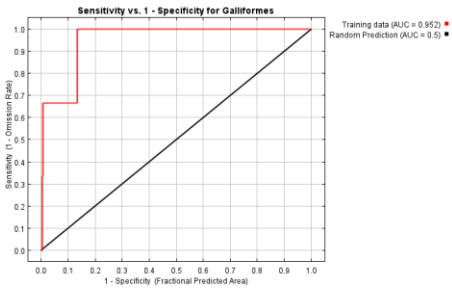


Figure D38. Receiver operating characteristic (ROC) curve of Galliformes in the Colombia corridor

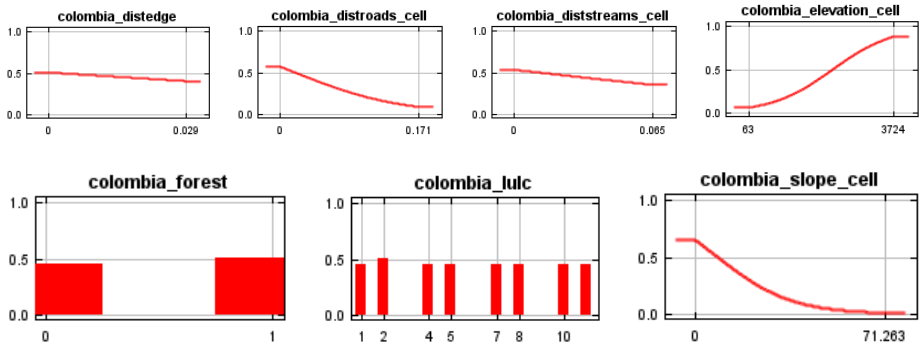


Figure D39. Dependence response curves for the Galliformes MaxEnt models in the Colombia corridor

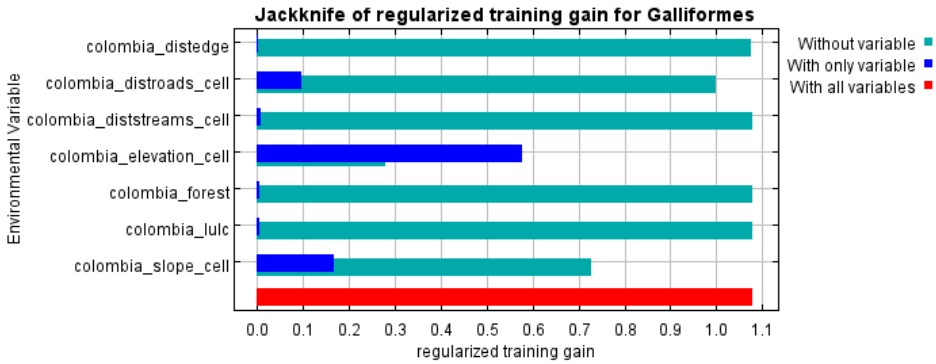


Figure D40. Results for jackknife test of variable importance for Galliformes in the Colombia corridor. Elevation accounted for the highest gain to the model and therefore has the most information not accounted for in other variables. Distance to edge accounted for the lowest gain.

Table D8. Confusion Matrix of Galliformes in the Colombia corridor, habitat/non-habitat threshold value = 0.120

		Observed Values		
		Positive (1)	Negative (0)	
Predicted Values	Positive (1)	21	1170	
	Negative (0)	0	0	
				PT = 0.01763224

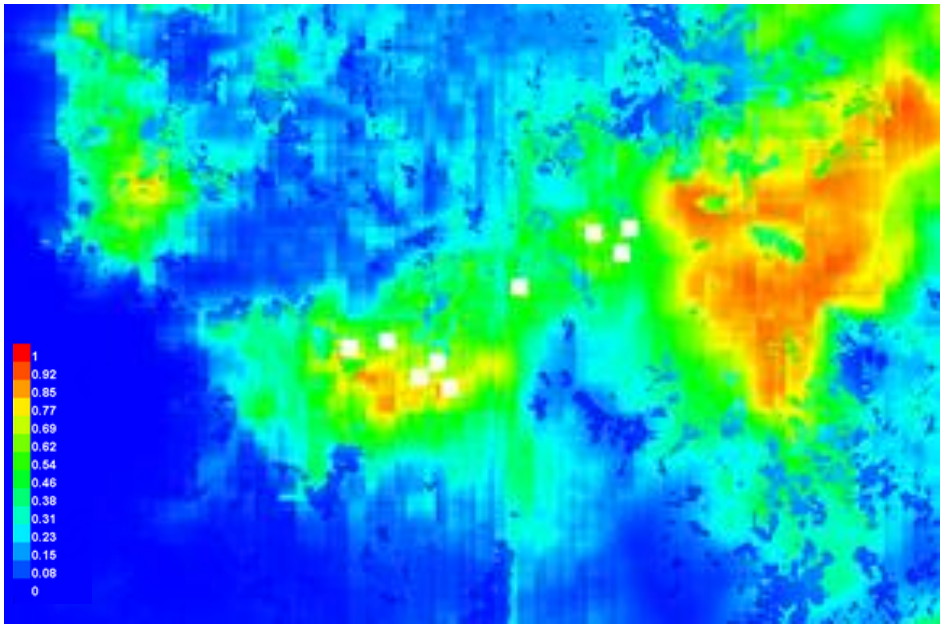


Figure D41. MaxEnt species distribution model for LeopardusPardalis in the Colombia corridor. Warmer colors show better-predicted habitat conditions, white dots represent presences

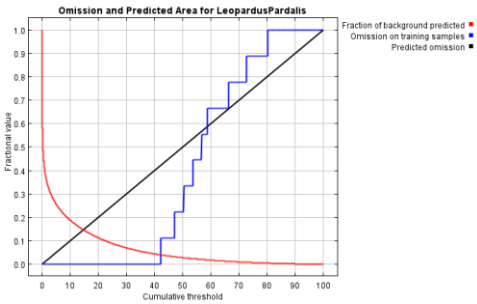


Figure D42. Omission and predicted omission rate as function of cumulative threshold of LeopardusPardalis in the Colombia corridor

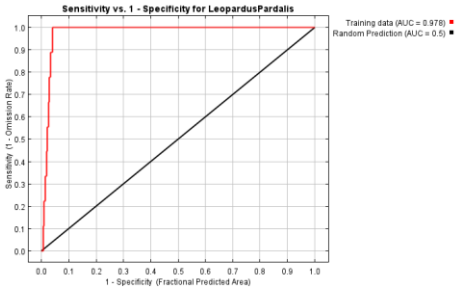


Figure D43. Receiver operating characteristic (ROC) curve of LeopardusPardalis in the Colombia corridor

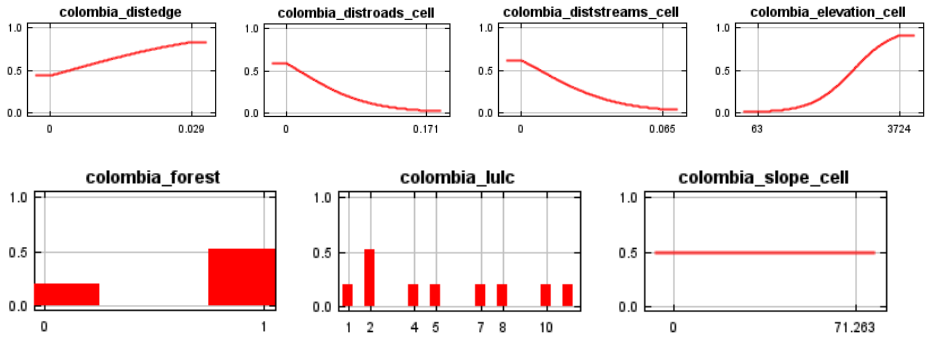


Figure D44. Dependence response curves for the LeopardusPardalis MaxEnt models in the Colombia corridor

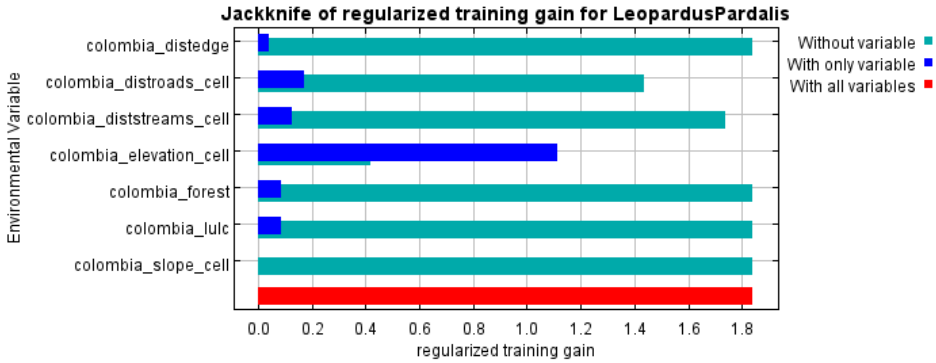


Figure D45. Results for jackknife test of variable importance for LeopardusPardalis in the Colombia corridor. Elevation accounted for the highest gain to the model and therefore has the most information not accounted for in other variables. Slope accounted for the lowest gain.

Table D9. Confusion Matrix of LeopardusPardalis in the Colombia corridor, habitat/non-habitat threshold = 0.060

		Observed Values		
		Positive (1)	Negative (0)	
Predicted Values	Positive (1)	22	1169	
	Negative (0)	0	0	
				PT = 0.01847187

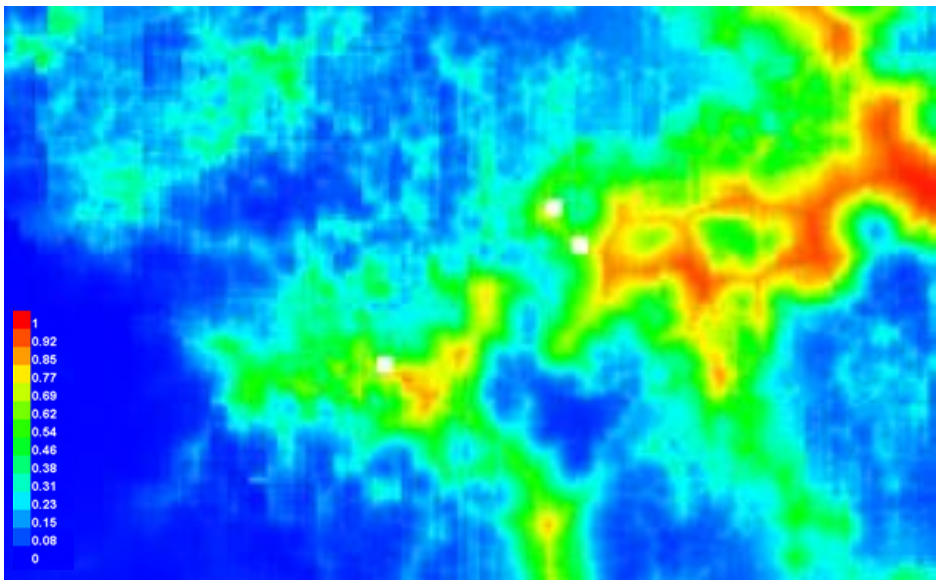


Figure D46. MaxEnt species distribution model for NasuaNasua in the Colombia corridor. Warmer colors show better-predicted habitat conditions, white dots represent presences

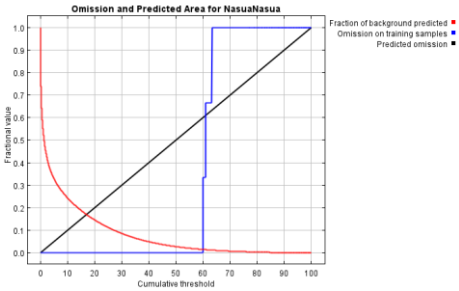


Figure D47. Omission and predicted omission rate as function of cumulative threshold of NasuaNasua in the Colombia corridor

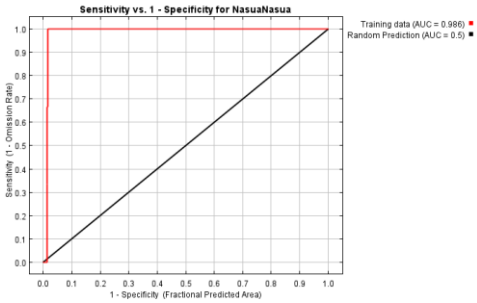


Figure D48. Receiver operating characteristic (ROC) curve of NasuaNasua in the Colombia corridor

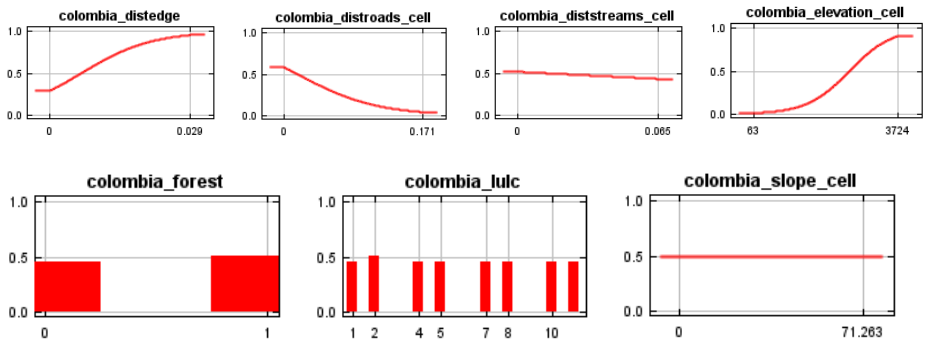


Figure D49. Dependence response curves for the NasuaNasua MaxEnt models in the Colombia corridor

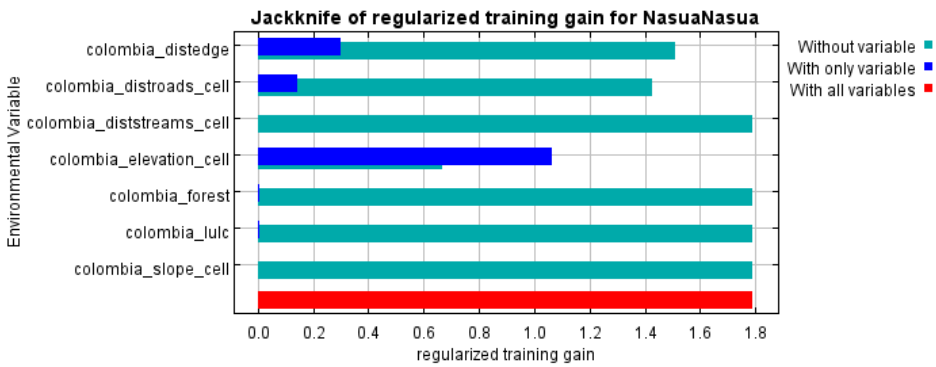


Figure D50. Results for jackknife test of variable importance for NasuaNasua in the Colombia corridor. Elevation accounted for the highest gain to the model and therefore has the most information not accounted for in other variables. Slope and distance to streams accounted for the lowest gain.

Table D10. Confusion Matrix of NasuaNasua in the Colombia corridor, habitat/non-habitat threshold value = 0.063

		Observed Values		
		Positive (1)	Negative (0)	
Predicted Values	Positive (1)	7	1185	
	Negative (0)	0	0	
				PT = 0.00587741

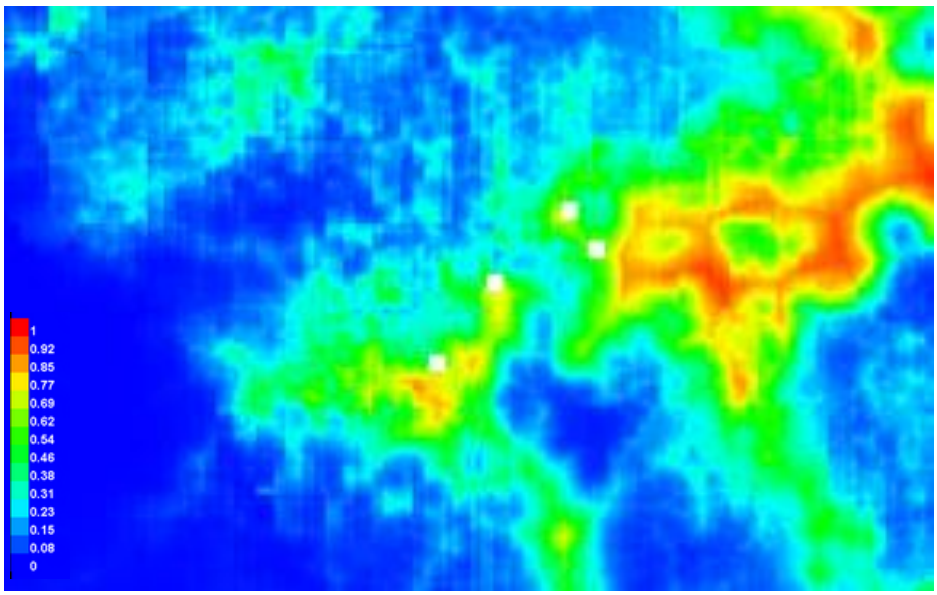


Figure D51. MaxEnt species distribution model for Sciuridae in the Colombia corridor. Warmer colors show better-predicted habitat conditions, white dots represent presences

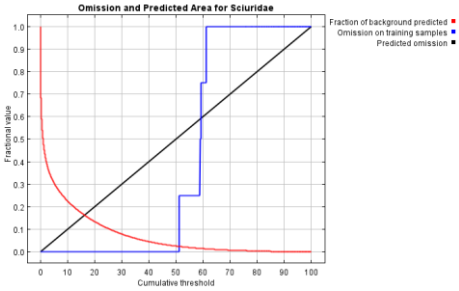


Figure D52. Omission and predicted omission rate as function of cumulative threshold of Sciuridae in the Colombia corridor

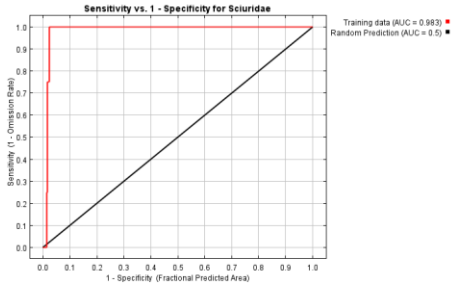


Figure D53. Receiver operating characteristic (ROC) curve of Sciuridae in the Colombia corridor

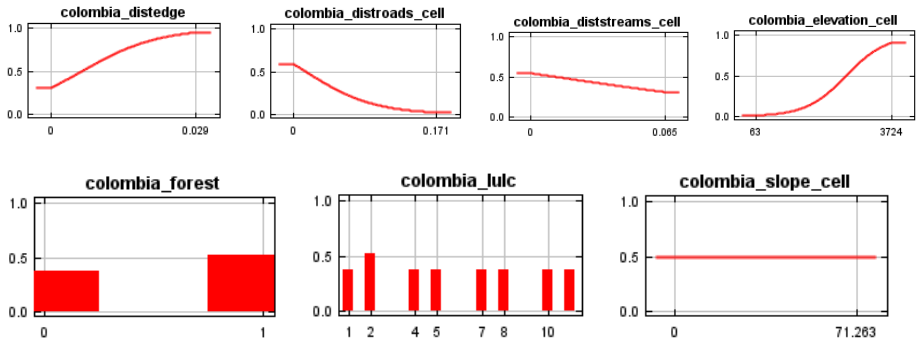


Figure D54. Dependence response curves for the Sciuridae MaxEnt models in the Colombia corridor

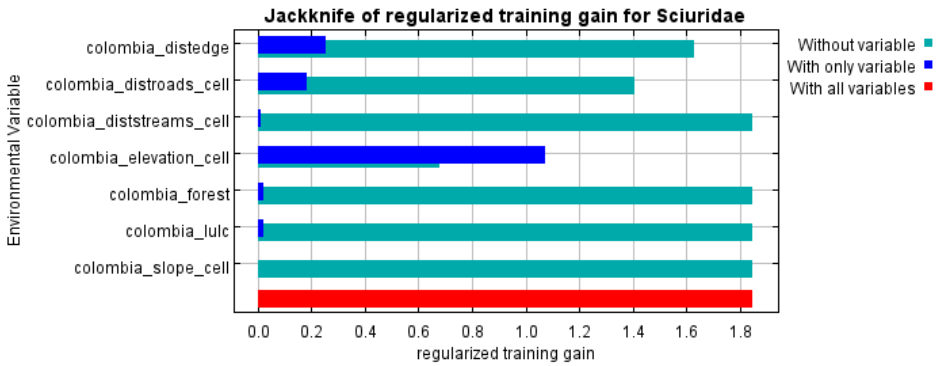


Figure D55. Results for jackknife test of variable importance for Sciuridae in the Colombia corridor. Elevation accounted for the highest gain to the model and therefore has the most information not accounted for in other variables. Slope accounted for the lowest gain.

Table D11. Confusion Matrix of Sciuridae in the Colombia corridor, habitat/non-habitat threshold value = 0.059

		Observed Values		
		Positive (1)	Negative (0)	
Predicted Values	Positive (1)	29	1162	
	Negative (0)	0	0	
				PT = 0.02434929

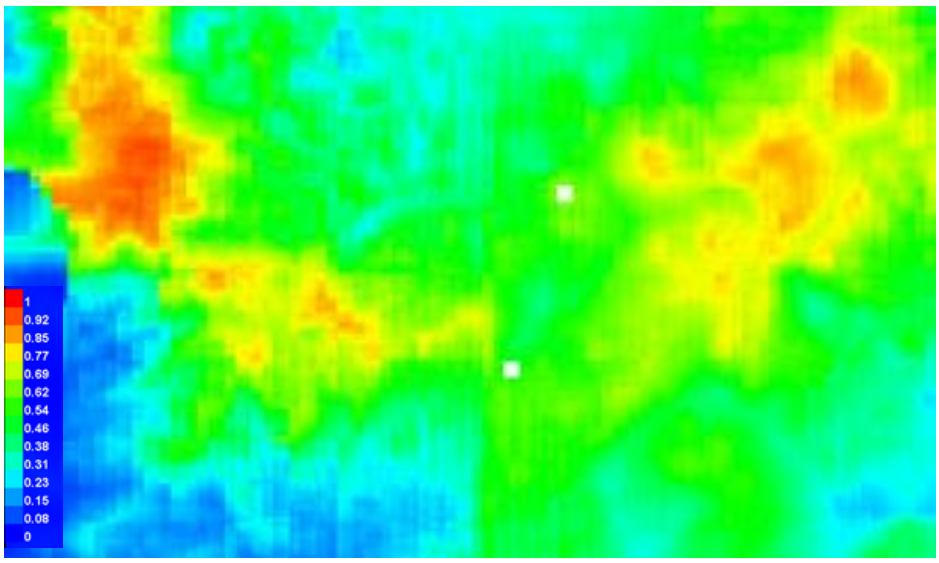


Figure D56. MaxEnt species distribution model for TremarctosOrnatus in the Colombia corridor. Warmer colors show better-predicted habitat conditions, white dots represent presences

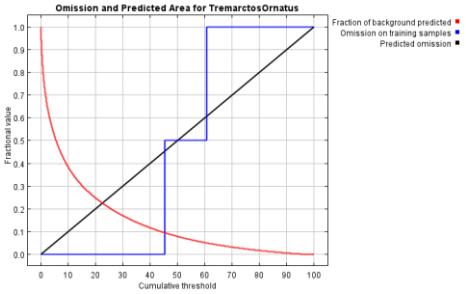


Figure D57. Omission and predicted omission rate as function of cumulative threshold of TremarctosOrnatus in the Colombia corridor

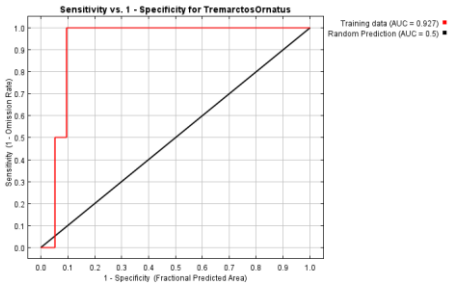


Figure D58. Receiver operating characteristic (ROC) curve of TremarctosOrnatus in the Colombia corridor

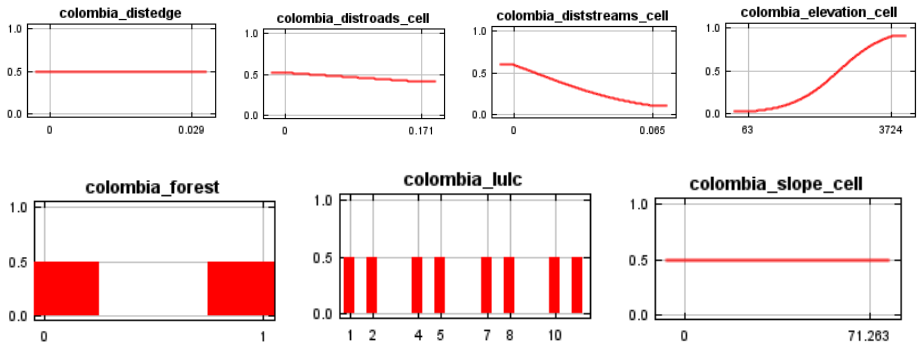


Figure D59. Dependence response curves for the TremarctosOrnatus MaxEnt models in the Colombia corridor

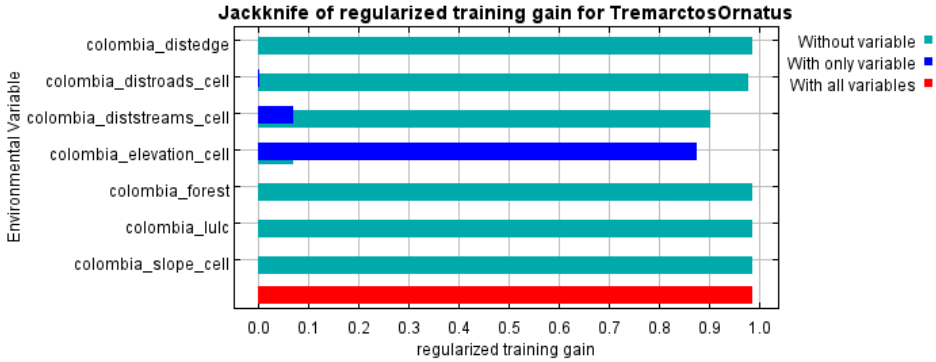


Figure D60. Results for jackknife test of variable importance for TremarctosOrnatus in the Colombia corridor. Elevation accounted for the highest gain to the model and therefore has the most information not accounted for in other variables. Slope, distance to edge, land use land cover, and forest habitat accounted for the lowest gain.

Table D12. Confusion Matrix of TremarctosOrnatus in the Colombia corridor, habitat/non-habitat threshold = 0.130

		Observed Values		
		Positive (1)	Negative (0)	
Predicted Values	Positive (1)	3	1188	
	Negative (0)	0	0	
				PT = 0.00251889

Ecuador

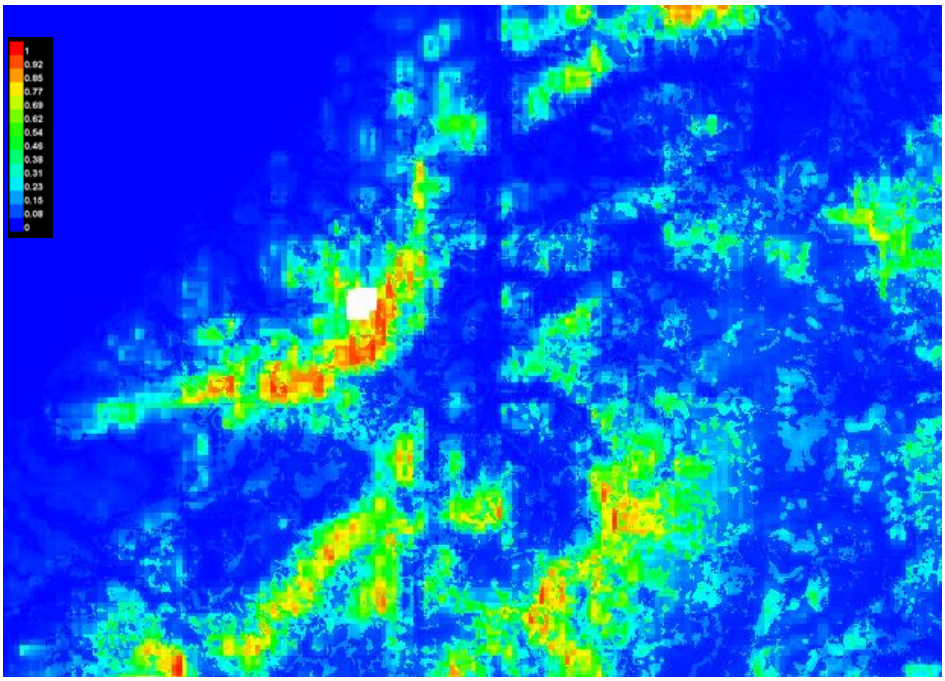


Figure D61. MaxEnt species distribution model for Caluromys in the Ecuador corridor. Warmer colors show better-predicted habitat conditions, white dots represent presences

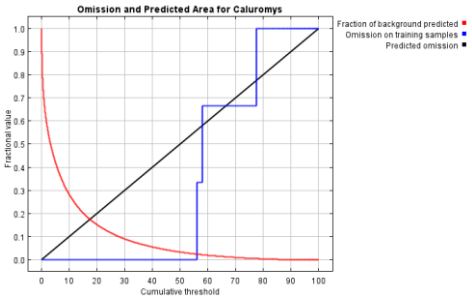


Figure D62. Omission and predicted omission rate as function of cumulative threshold of Caluromys in the Ecuador corridor

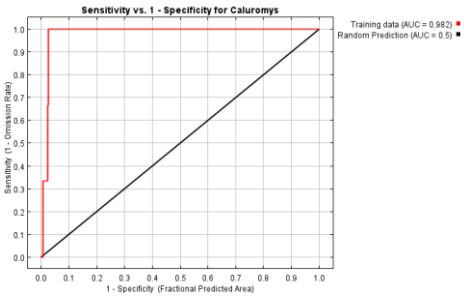


Figure D63. Receiver operating characteristic (ROC) curve of Caluromys in the Ecuador corridor

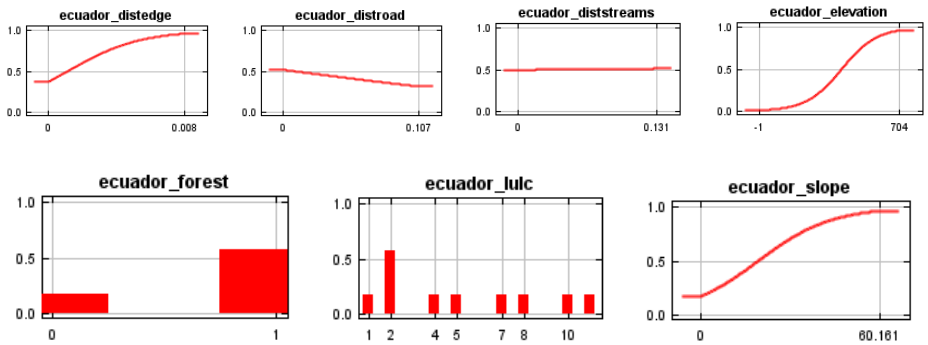


Figure D64. Dependence response curves for the Caluromys MaxEnt models in the Ecuador corridor

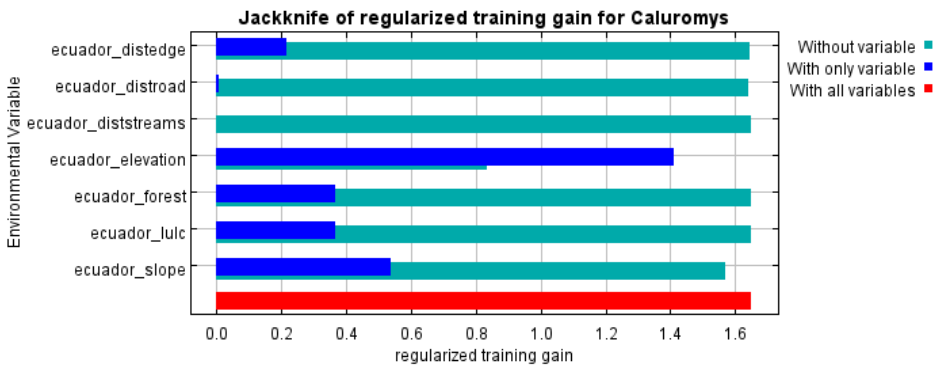


Figure D65. Results for jackknife test of variable importance for Caluromys in the Ecuador corridor. Elevation accounted for the highest gain to the model and therefore has the most information not accounted for in other variables. Distance to streams accounted for the lowest gain.

Table D13. Confusion Matrix of Caluromys in the Ecuador corridor, habitat/non-habitat threshold value = 0.071

		Observed Values		
		Positive (1)	Negative (0)	
Predicted Values	Positive (1)	35	698	
	Negative (0)	0	0	
				PT = 0.04774898

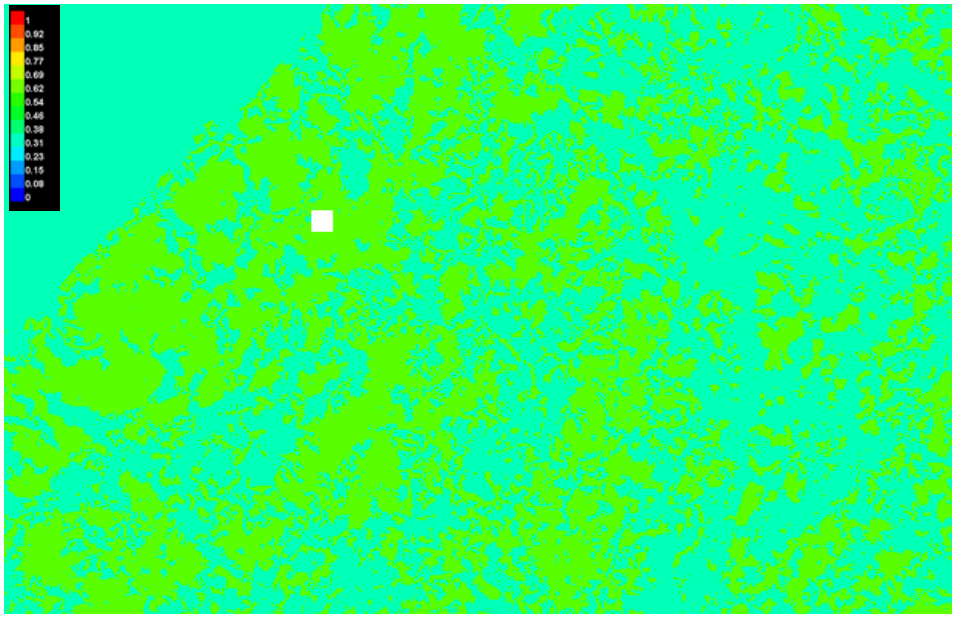


Figure D66. MaxEnt species distribution model for Columbiformes in the Ecuador corridor. Warmer colors show better-predicted habitat conditions, white dots represent presences

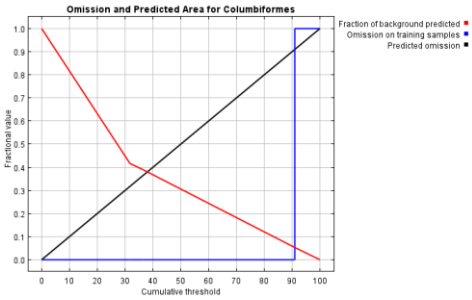


Figure D67. Omission and predicted omission rate as function of cumulative threshold of Columbiformes in the Ecuador corridor

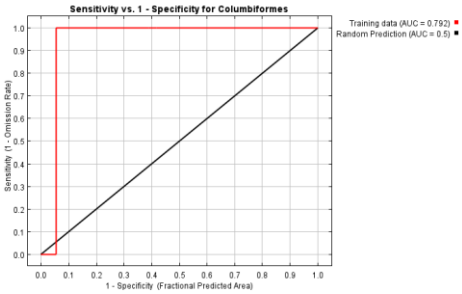


Figure D68. Receiver operating characteristic (ROC) curve of Columbiformes in the Ecuador corridor

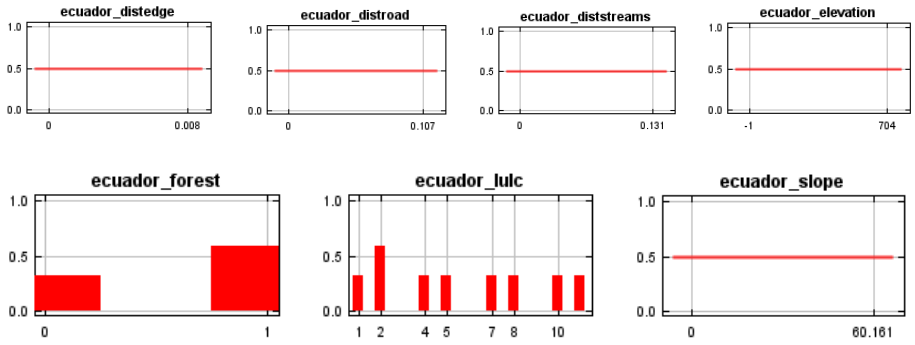


Figure D69. Dependence response curves for the Columbiformes MaxEnt models in the Ecuador corridor

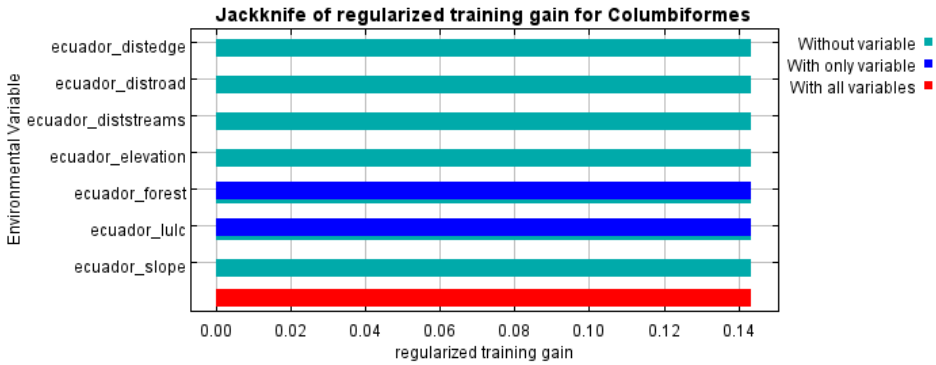


Figure D70. Results for jackknife test of variable importance for Columbiformes in the Ecuador corridor. Land use land cover and forest habitat accounted for the highest gain to the model and therefore has the most information not accounted for in other variables. Distance to edge, distance to roads, distance to streams, elevation, and slope accounted for the lowest gain.

Table D14. Confusion Matrix of Columbiformes in the Ecuador corridor, habitat/non-habitat threshold = 0.321

		Observed Values		
		Positive (1)	Negative (0)	
Predicted Values	Positive (1)	2	725	
	Negative (0)	0	6	
				PT = 0.01091405

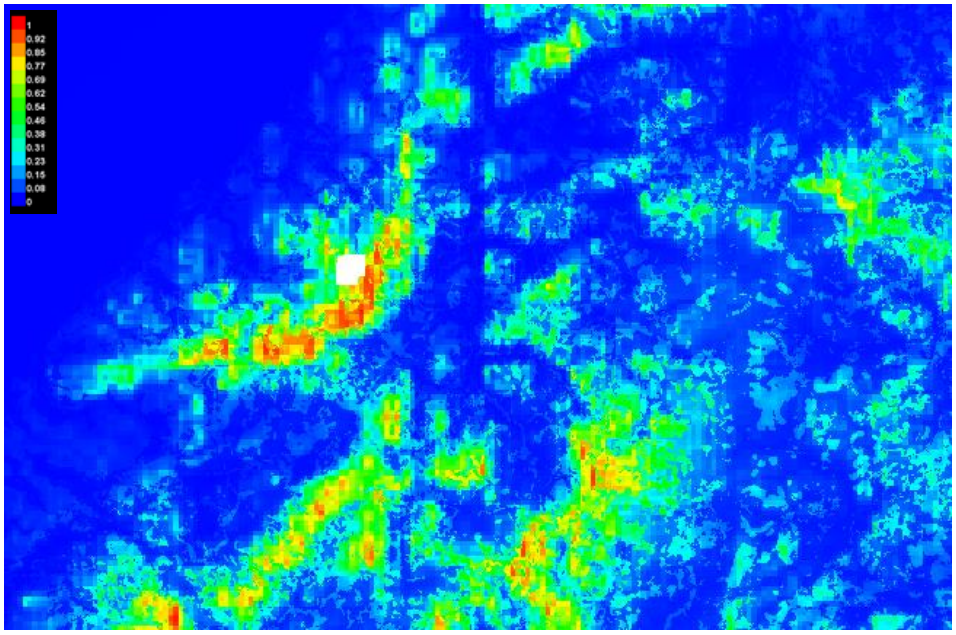


Figure D71. MaxEnt species distribution model for CuniculusPaca in the Ecuador corridor. Warmer colors show better-predicted habitat conditions, white dots represent presences

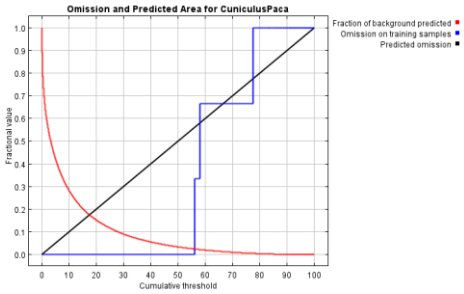


Figure D72. Omission and predicted omission rate as function of cumulative threshold of CuniculusPaca in the Ecuador corridor

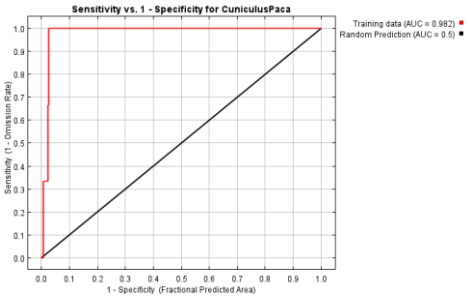


Figure D73. Receiver operating characteristic (ROC) curve of CuniculusPaca in the Ecuador corridor

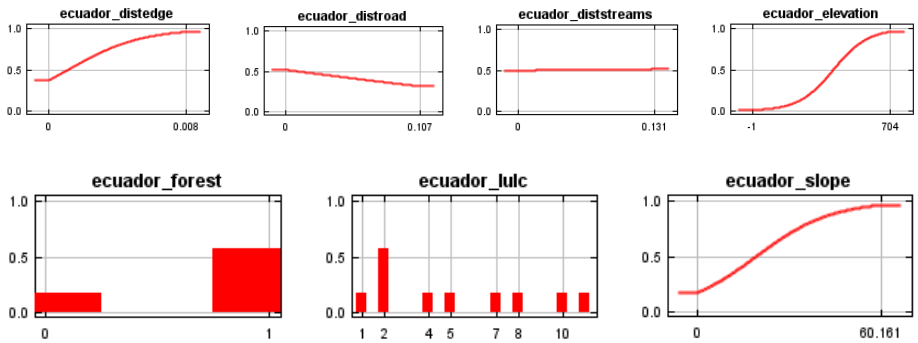


Figure D74. Dependence response curves for the CuniculusPaca MaxEnt models in the Ecuador corridor

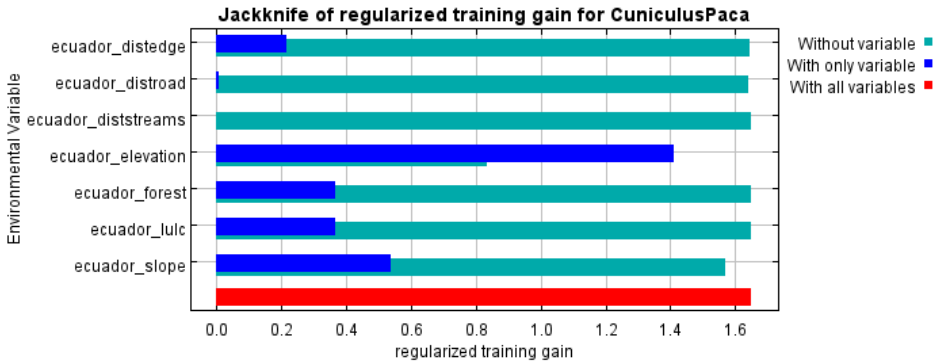


Figure D75. Results for jackknife test of variable importance for CuniculusPaca in the Ecuador corridor. Elevation accounted for the highest gain to the model and therefore has the most information not accounted for in other variables. Distance to streams accounted for the lowest gain.

Table D15. Confusion Matrix of CuniculusPaca in the Ecuador corridor, habitat/non-habitat threshold value = 0.071

		Observed Values		
		Positive (1)	Negative (0)	
Predicted Values	Positive (1)	32	701	
	Negative (0)	0	0	
				PT = 0.04365621

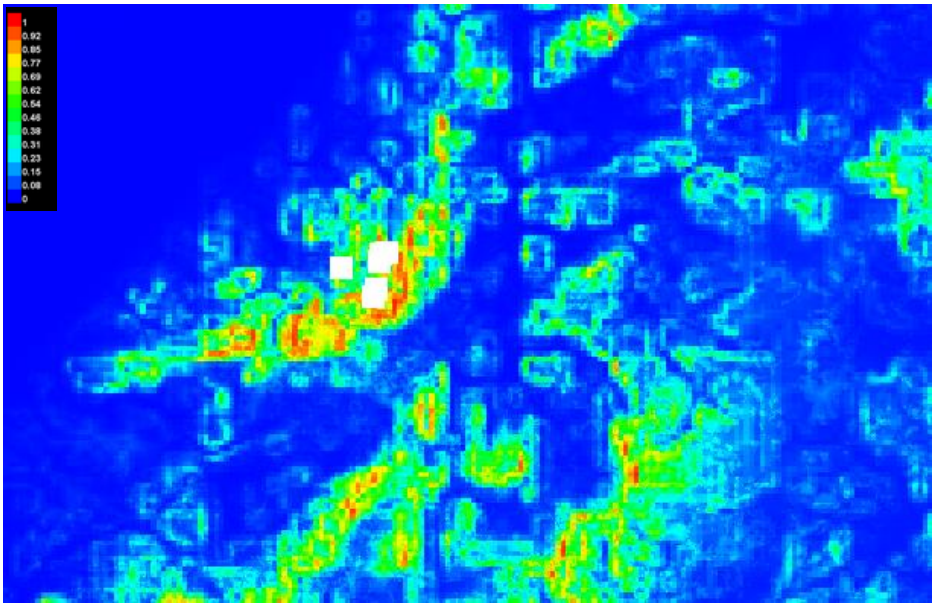


Figure D76. MaxEnt species distribution model for Dasyprocta in the Ecuador corridor. Warmer colors show better-predicted habitat conditions, white dots represent presences

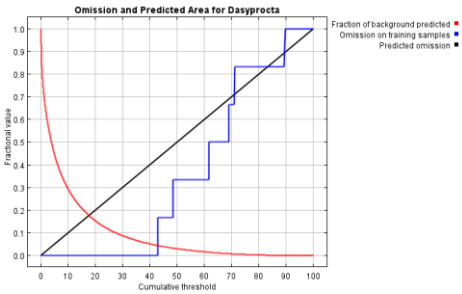


Figure D77. Omission and predicted omission rate as function of cumulative threshold of Dasyprocta in the Ecuador corridor

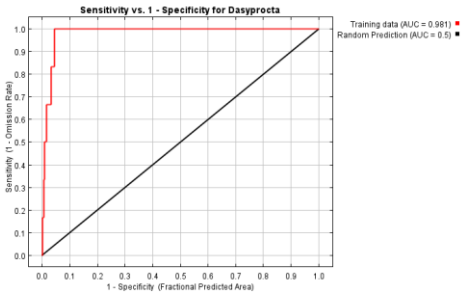


Figure D78. Receiver operating characteristic (ROC) curve of Dasyprocta in the Ecuador corridor

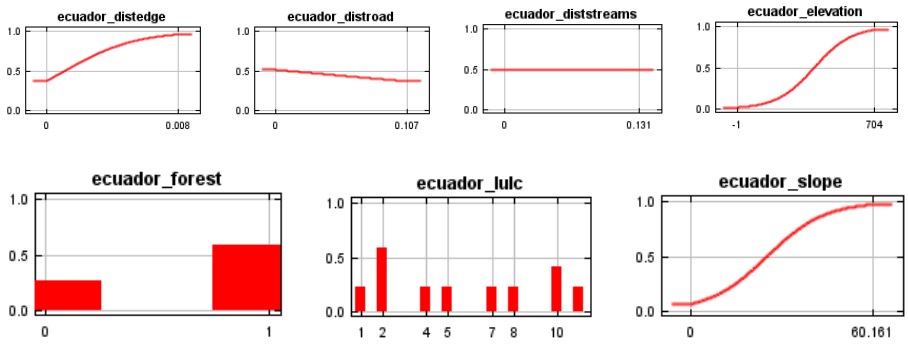


Figure D79. Dependence response curves for the Dasyprocta MaxEnt models in the Ecuador corridor

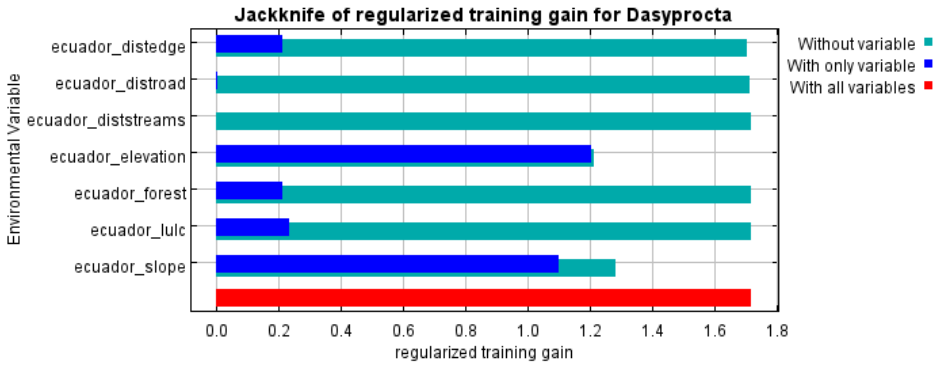


Figure D80. Results for jackknife test of variable importance for Dasyprocta in the Ecuador corridor. Elevation accounted for the highest gain to the model and therefore has the most information not accounted for in other variables. Distance to streams accounted for the lowest gain.

Table D16. Confusion Matrix of Dasyprocta in the Ecuador corridor, habitat/non-habitat threshold value = 0.067

		Observed Values		
		Positive (1)	Negative (0)	
Predicted Values	Positive (1)	240	493	
	Negative (0)	0	0	
				PT = 0.32742156

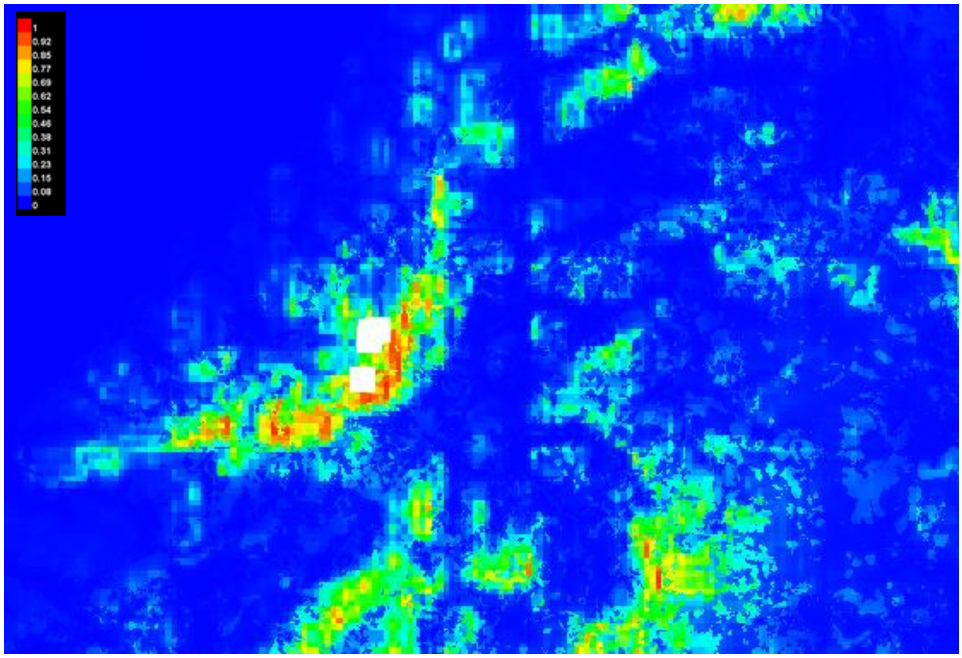


Figure D81. MaxEnt species distribution model for DasypusNovemcinctus in the Ecuador corridor. Warmer colors show better-predicted habitat conditions, white dots represent presences

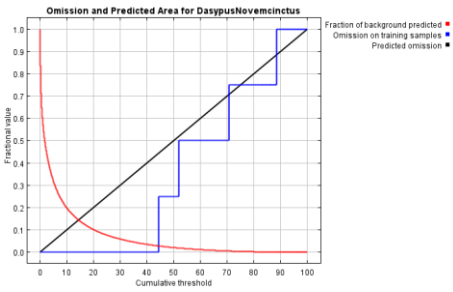


Figure D82. Omission and predicted omission rate as function of cumulative threshold of DasypusNovemcinctus in the Ecuador corridor

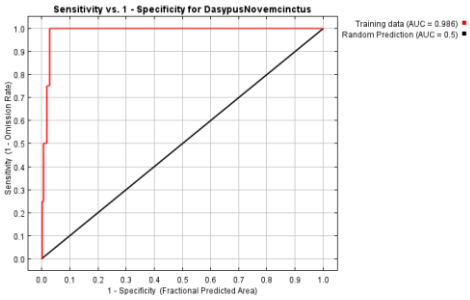


Figure D83. Receiver operating characteristic (ROC) curve of DasypusNovemcinctus in the Ecuador corridor

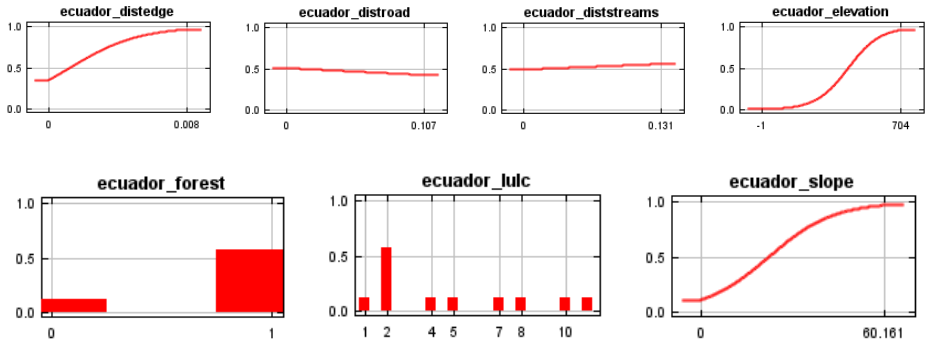


Figure D84. Dependence response curves for the DasypusNovemcinctus MaxEnt models in the Ecuador corridor

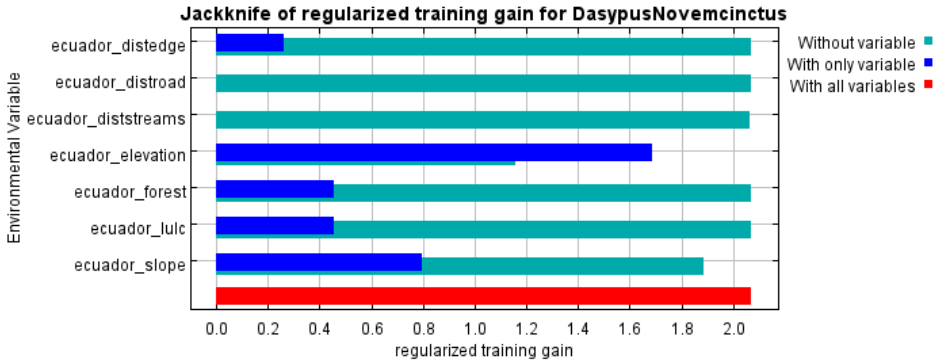


Figure D85. Results for jackknife test of variable importance for DasypusNovemcinctus in the Ecuador corridor. Elevation accounted for the highest gain to the model and therefore has the most information not accounted for in other variables. Distance to roads and distance to streams accounted for the lowest gain.

Table D17. Confusion Matrix of DasypusNovemcinctus in Ecuador corridor, habitat/non-habitat threshold = 0.048

		Observed Values		
		Positive (1)	Negative (0)	
Predicted Values	Positive (1)	20	713	
	Negative (0)	0	0	
				PT = 0.02728513

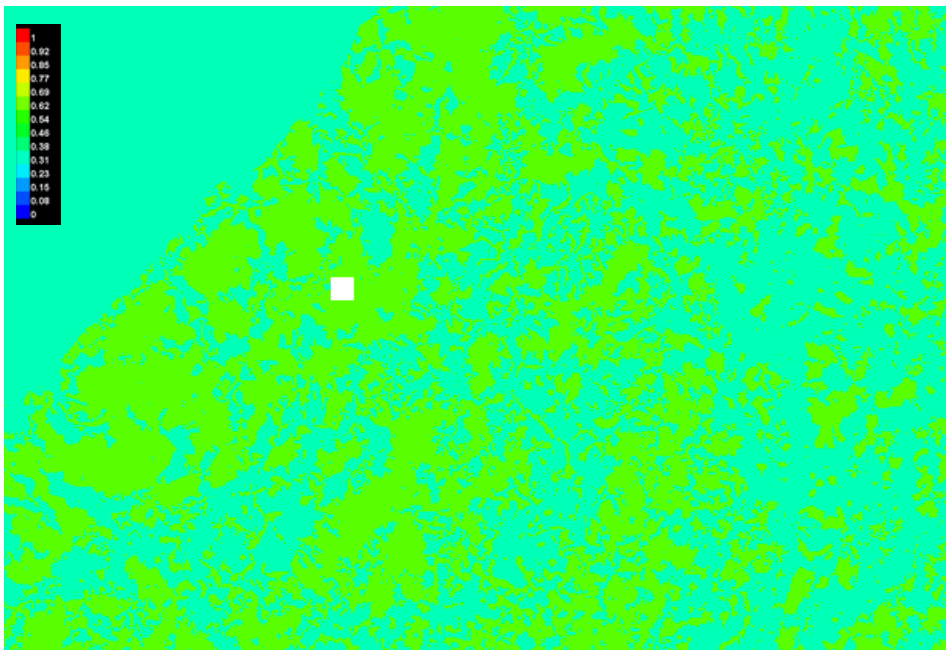


Figure D86. MaxEnt species distribution model for Didelphis in the Ecuador corridor. Warmer colors show better-predicted habitat conditions, white dots represent presences

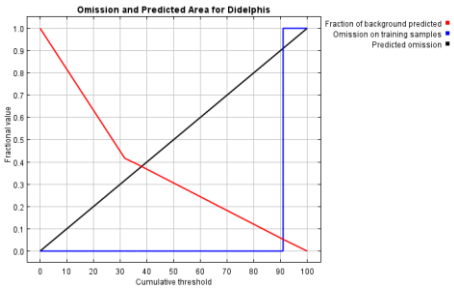


Figure D87. Omission and predicted omission rate as function of cumulative threshold of Didelphis in the Ecuador corridor

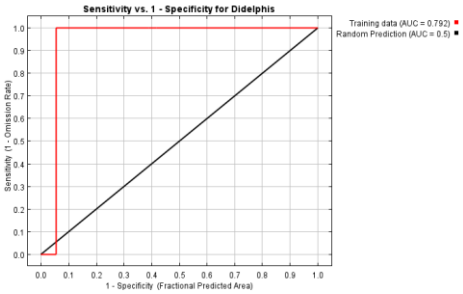


Figure D88. Receiver operating characteristic (ROC) curve of Didelphis in the Ecuador corridor

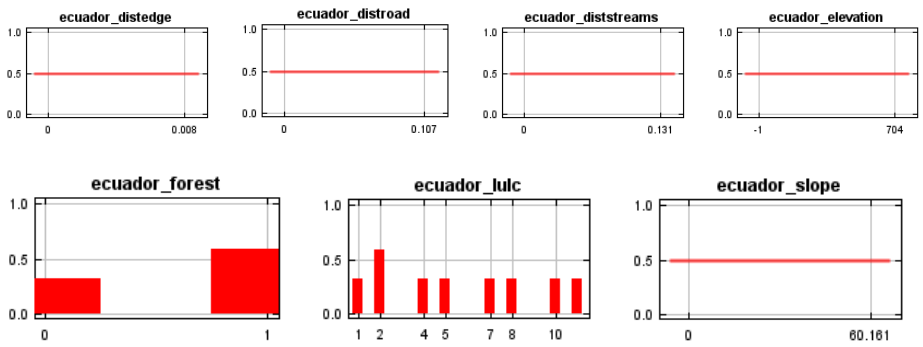


Figure D89. Dependence response curves for the Didelphis MaxEnt models in the Ecuador corridor

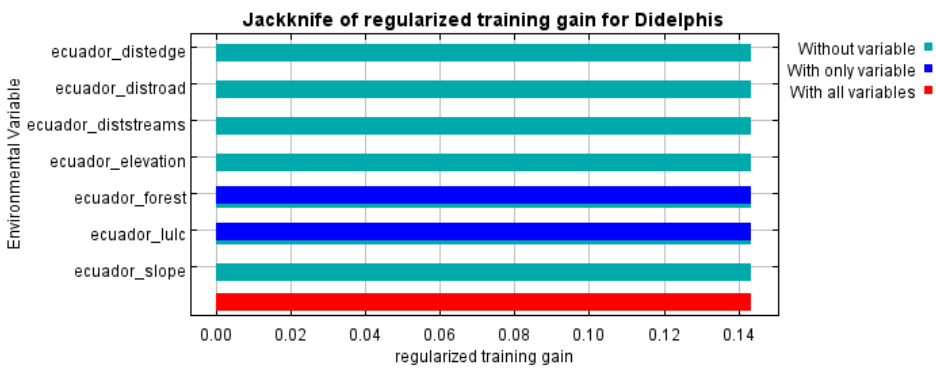


Figure D90. Results for jackknife test of variable importance for Didelphis in the Ecuador corridor. Land use land cover and forest habitat accounted for the highest gain to the model and therefore has the most information not accounted for in other variables. Distance to edge, distance to roads, distance to streams, elevation, and slope accounted for the lowest gain.

Table D18. Confusion Matrix of Didelphis in the Ecuador corridor, habitat/non-habitat threshold value = 0.321

		Observed Values		
		Positive (1)	Negative (0)	
Predicted Values	Positive (1)	1	726	
	Negative (0)	0	6	
				PT = 0.0095498

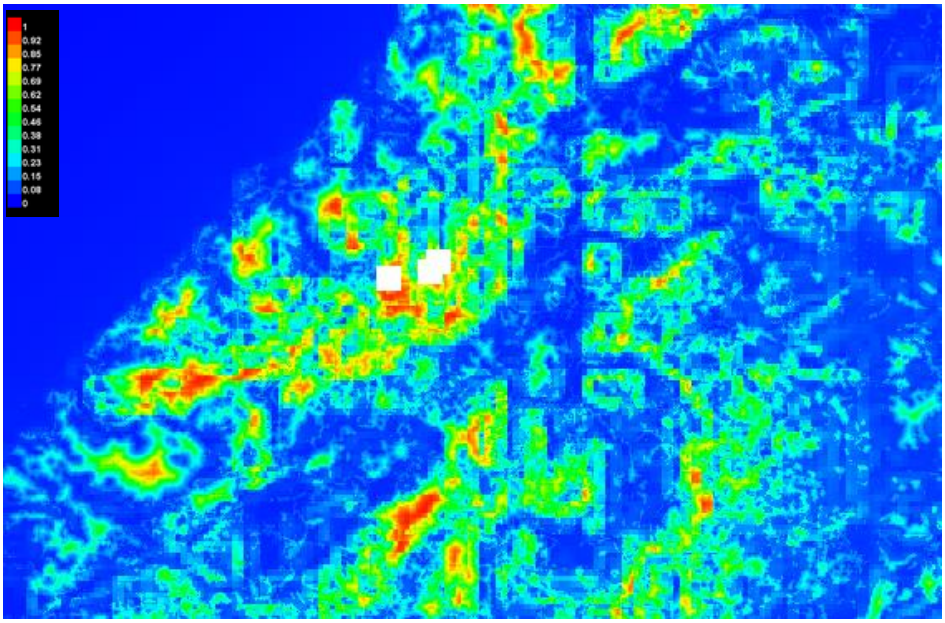


Figure D91. MaxEnt species distribution model for LeopardusPardalis in the Ecuador corridor. Warmer colors show better-predicted habitat conditions, white dots represent presences

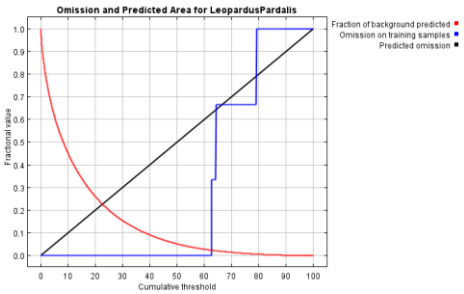


Figure D92. Omission and predicted omission rate as function of cumulative threshold of LeopardusPardalis in the Ecuador corridor

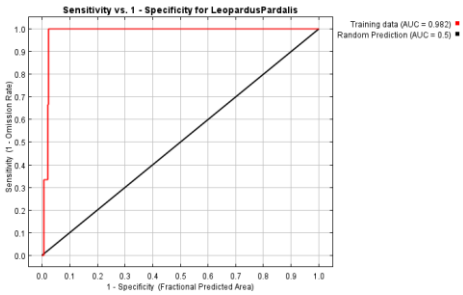


Figure D93. Receiver operating characteristic (ROC) curve of LeopardusPardalis in the Ecuador corridor

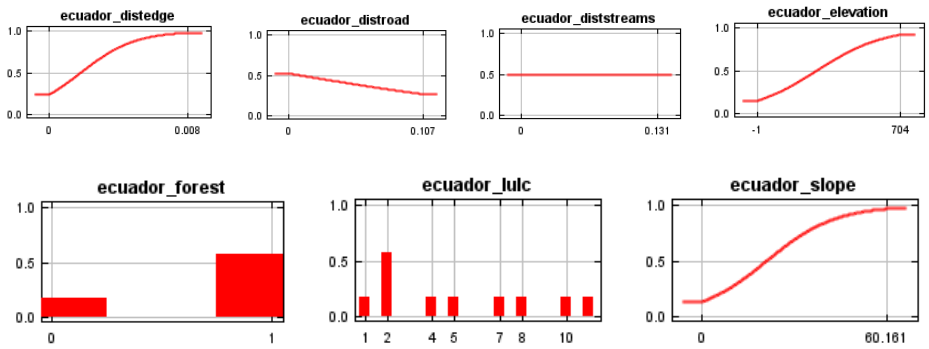


Figure D94. Dependence response curves for the LeopardusPardalis MaxEnt models in the Ecuador corridor

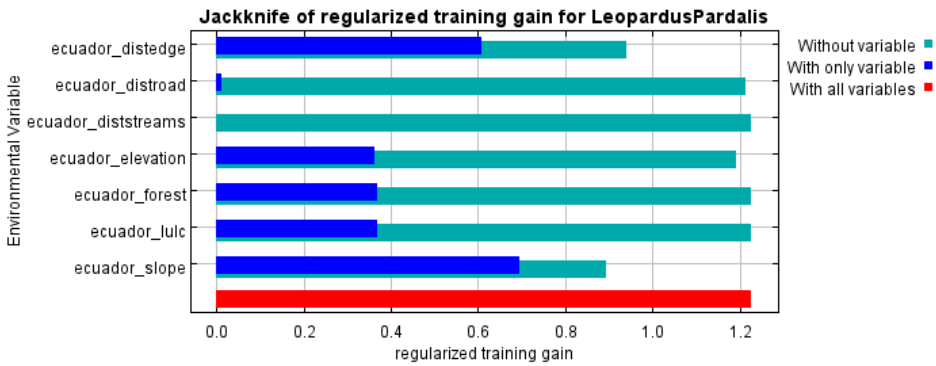


Figure D95. Results for jackknife test of variable importance for LeopardusPardalis in the Ecuador corridor. Slope accounted for the highest gain to the model and therefore has the most information not accounted for in other variables. Distance to streams accounted for the lowest gain.

Table D19. Confusion Matrix of LeopardusPardalis in the Ecuador corridor, habitat/non-habitat threshold = 0.105

		Observed Values		
		Positive (1)	Negative (0)	
Predicted Values	Positive (1)	7	726	
	Negative (0)	0	0	
				PT = 0.0095498

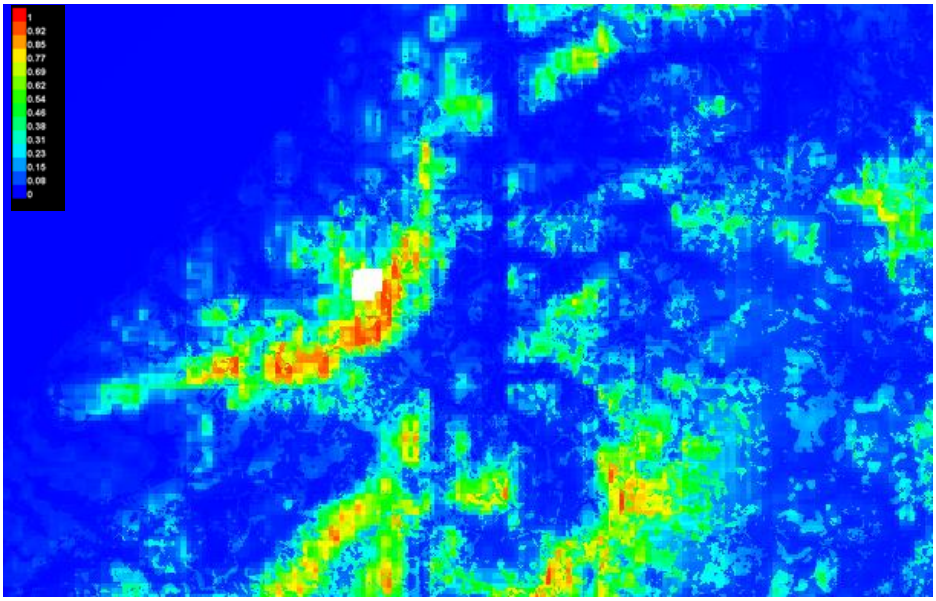


Figure D96. MaxEnt species distribution model for MazamaAmericana in the Ecuador corridor. Warmer colors show better-predicted habitat conditions, white dots represent presences

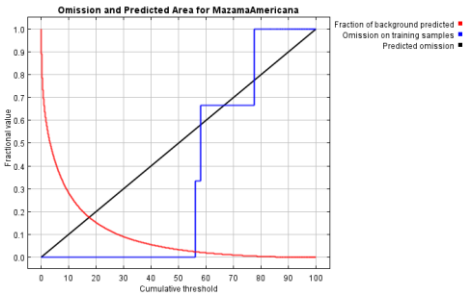


Figure D97. Omission and predicted omission rate as function of cumulative threshold of MazamaAmericana in the Ecuador corridor

Figure D98. Receiver operating characteristic (ROC) curve of MazamaAmericana in the Ecuador corridor

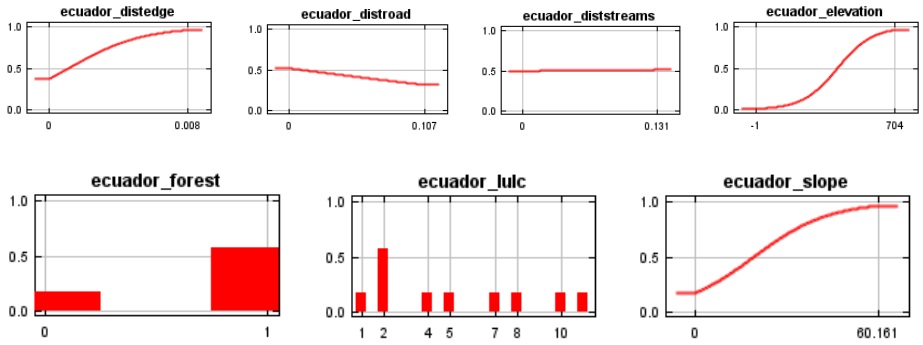


Figure D99. Dependence response curves for the MazamaAmericana MaxEnt models in the Ecuador corridor

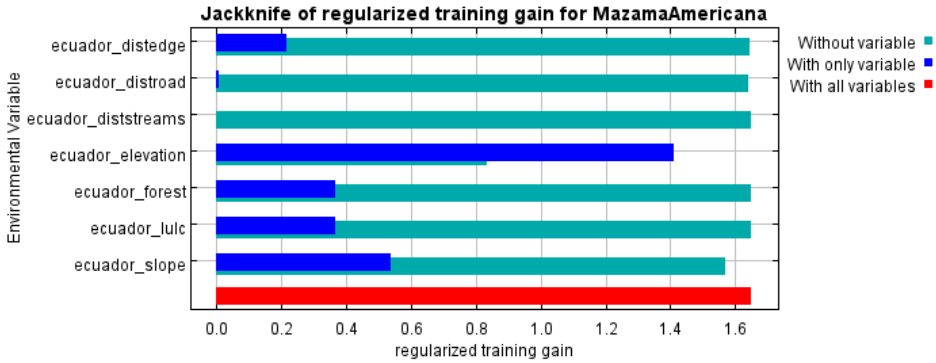


Figure D100. Results for jackknife test of variable importance for MazamaAmericana in the Ecuador corridor. Land use land cover accounted for the highest gain to the model and therefore has the most information not accounted for in other variables. Distance to streams accounted for the lowest gain.

Table D20. Confusion Matrix of MazamaAmericana in the Ecuador corridor, habitat/non-habitat threshold = 0.071

		Observed Values		
		Positive (1)	Negative (0)	
Predicted Values	Positive (1)	14	719	
	Negative (0)	0	0	
				PT = 0.01909959

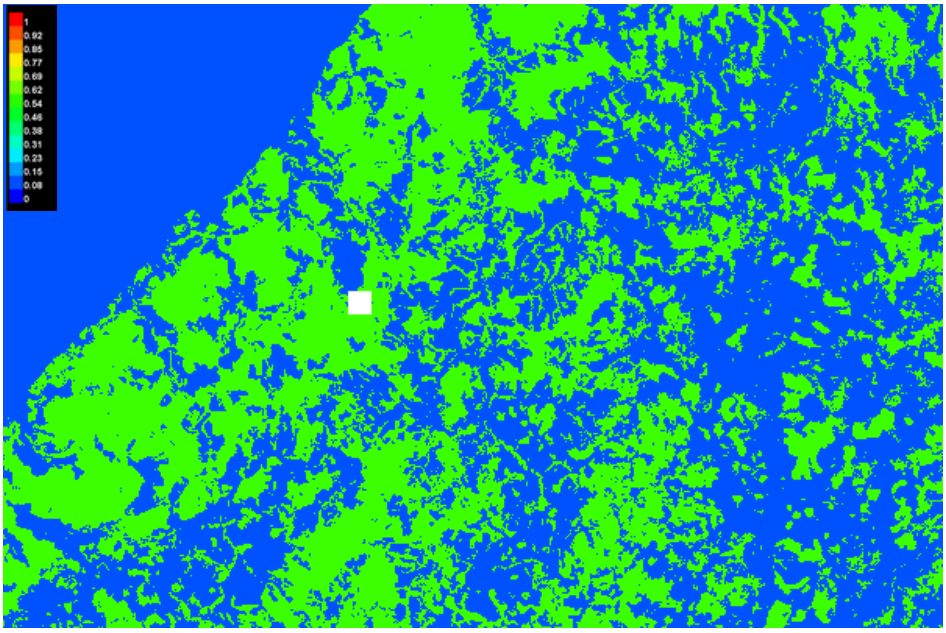


Figure D101. MaxEnt species distribution model for NasuaNarica in the Ecuador corridor. Warmer colors show better-predicted habitat conditions, white dots represent presences

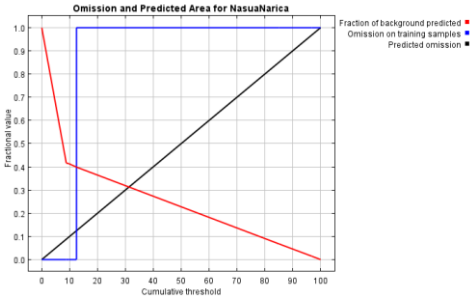


Figure D102. Omission and predicted omission rate as function of cumulative threshold of NasuaNarica in the Ecuador corridor

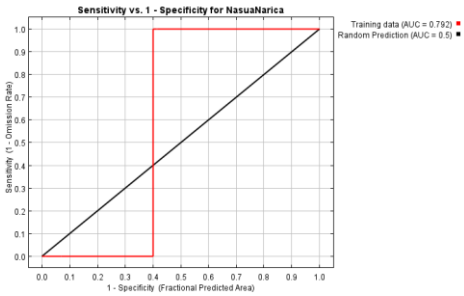


Figure D103. Receiver operating characteristic (ROC) curve of NasuaNarica in the Ecuador corridor

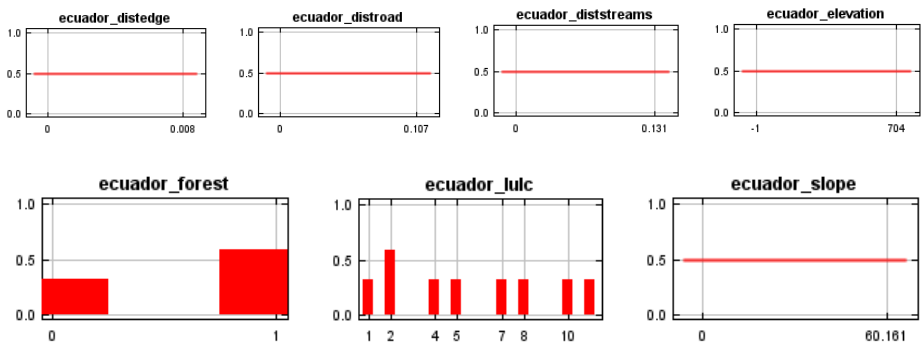


Figure D104. Dependence response curves for the NasuaNarica MaxEnt models in the Ecuador corridor

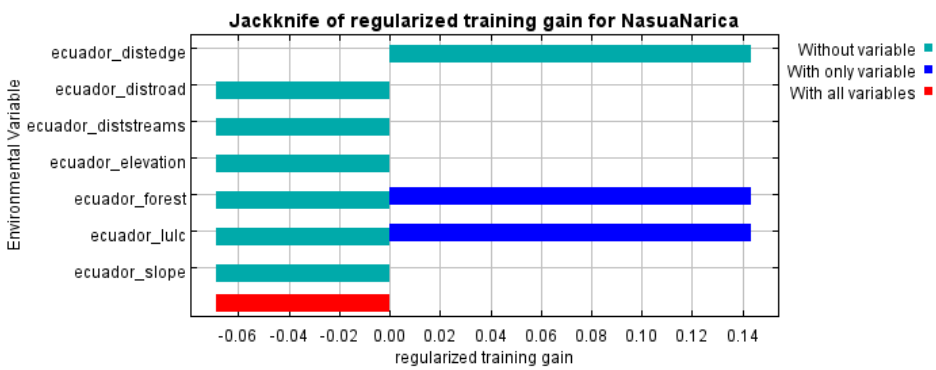


Figure D105. Results for jackknife test of variable importance for NasuaNarica in the Ecuador corridor. Land use land cover accounted for the highest gain to the model and therefore has the most information not accounted for in other variables. Distance to edge accounted for the lowest gain.

Table D21. Confusion Matrix of NasuaNarica in the Ecuador corridor, habitat/non-habitat threshold value = 0.558

		Observed Values		
		Positive (1)	Negative (0)	
Predicted Values	Positive (1)	1	726	
	Negative (0)	0	6	
				PT = 0.0095498

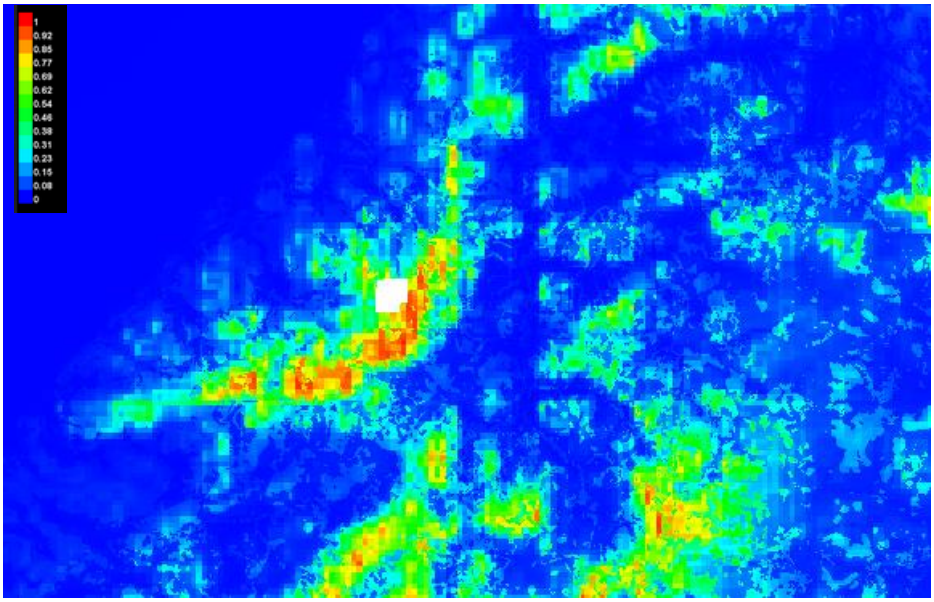


Figure D106. MaxEnt species distribution model for PecariTajacu in the Ecuador corridor. Warmer colors show better-predicted habitat conditions, white dots represent presences

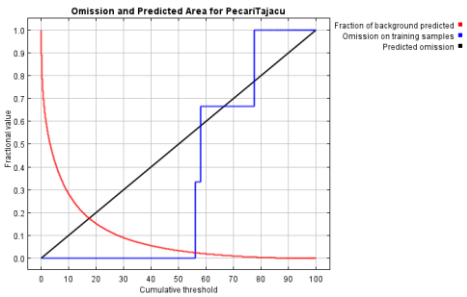


Figure D107. Omission and predicted omission rate as function of cumulative threshold of PecariTajacu in the Ecuador corridor

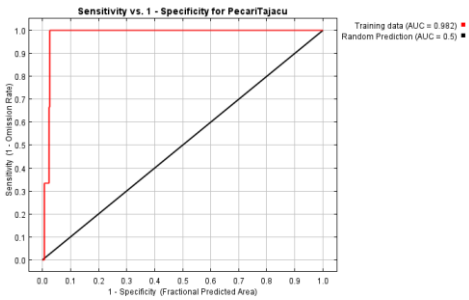


Figure D108. Receiver operating characteristic (ROC) curve of PecariTajacu in the Ecuador corridor

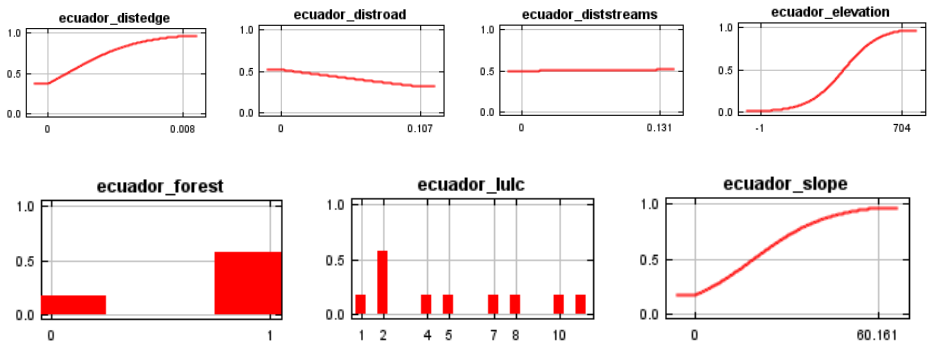


Figure D109. Dependence response curves for the PecariTajacu MaxEnt models in the Ecuador corridor

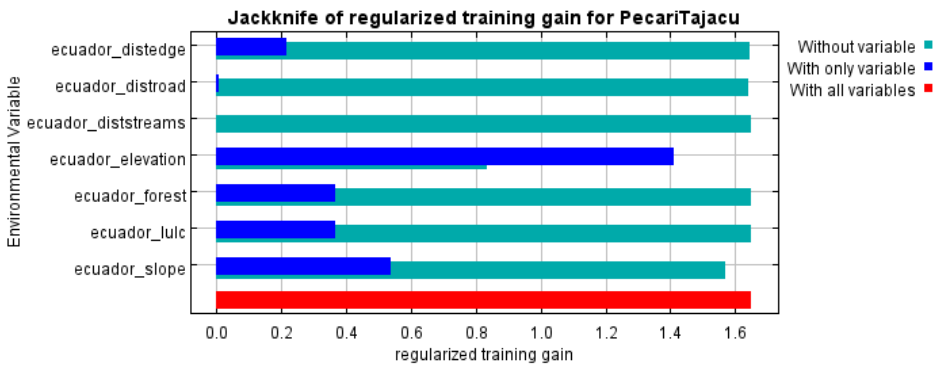


Figure D110. Results for jackknife test of variable importance for PecariTajacu in the Ecuador corridor. Elevation accounted for the highest gain to the model and therefore has the most information not accounted for in other variables. Distance to streams accounted for the lowest gain.

Table D22. Confusion Matrix of PecariTajacu in the Ecuador corridor, habitat/non-habitat threshold value = 0.071

		Observed Values		
		Positive (1)	Negative (0)	
Predicted Values	Positive (1)	36	697	
	Negative (0)	0	0	
				PT = 0.04911323

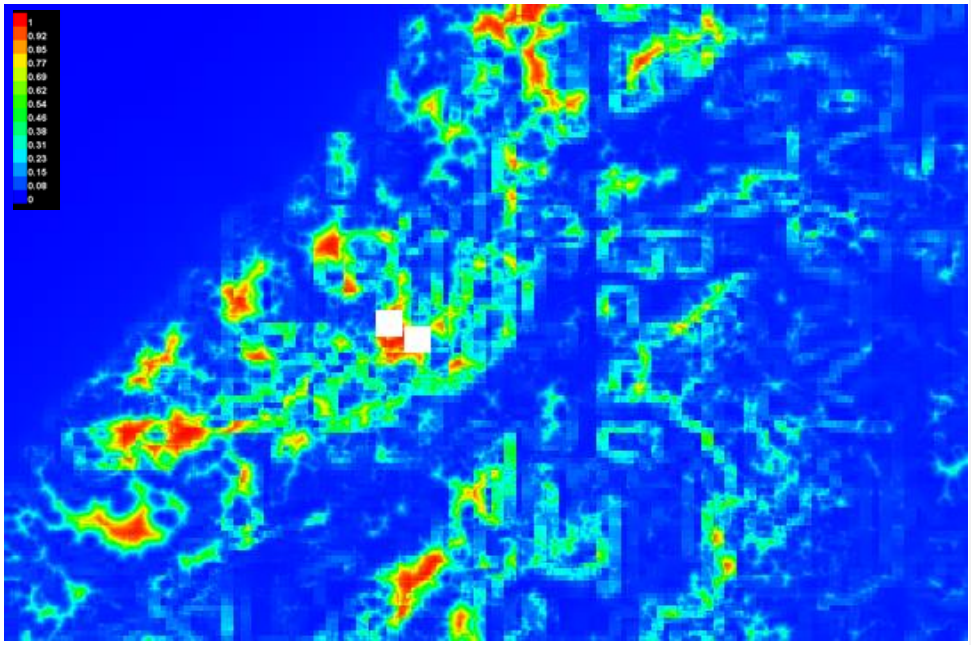


Figure D111. MaxEnt species distribution model for ProcyonCancrivorus in the Ecuador corridor. Warmer colors show better-predicted habitat conditions, white dots represent presences

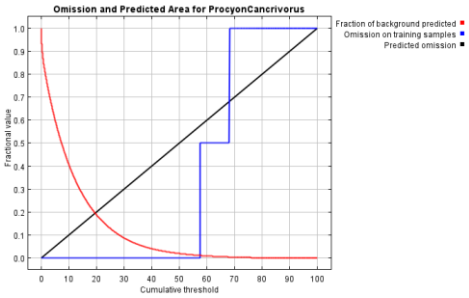


Figure D112. Omission and predicted omission rate as function of cumulative threshold of ProcyonCancrivorus in the Ecuador corridor

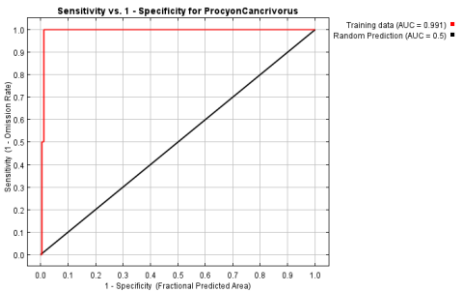
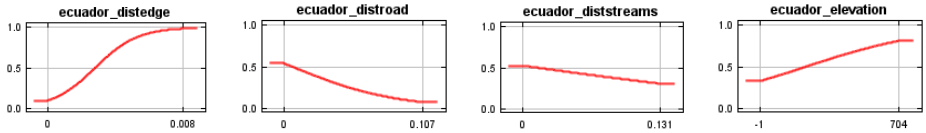


Figure D113. Receiver operating characteristic (ROC) curve of ProcyonCancrivorus in the Ecuador corridor



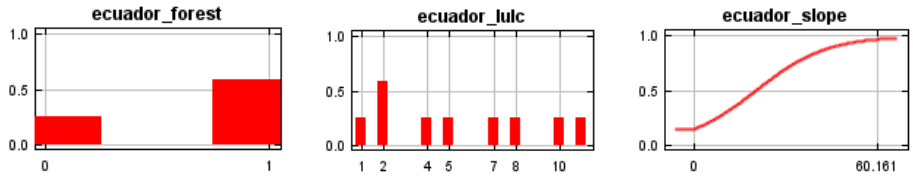


Figure D114. Dependence response curves for the ProcyonCancrivorus MaxEnt models in the Ecuador corridor

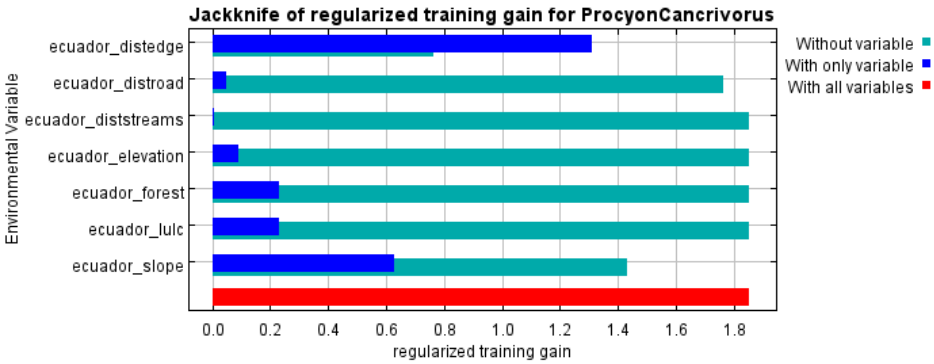


Figure D115. Results for jackknife test of variable importance for ProcyonCancrivorus in the Ecuador corridor. Distance to edge accounted for the highest gain to the model and therefore has the most information not accounted for in other variables. Distance to streams accounted for the lowest gain.

Table D23. Confusion Matrix of ProcyonCancrivorus in the Ecuador corridor, habitat/non-habitat threshold = 0.059

		Observed Values		
		Positive (1)	Negative (0)	
Predicted Values	Positive (1)	4	729	
	Negative (0)	0	0	
				PT = 0.00545703

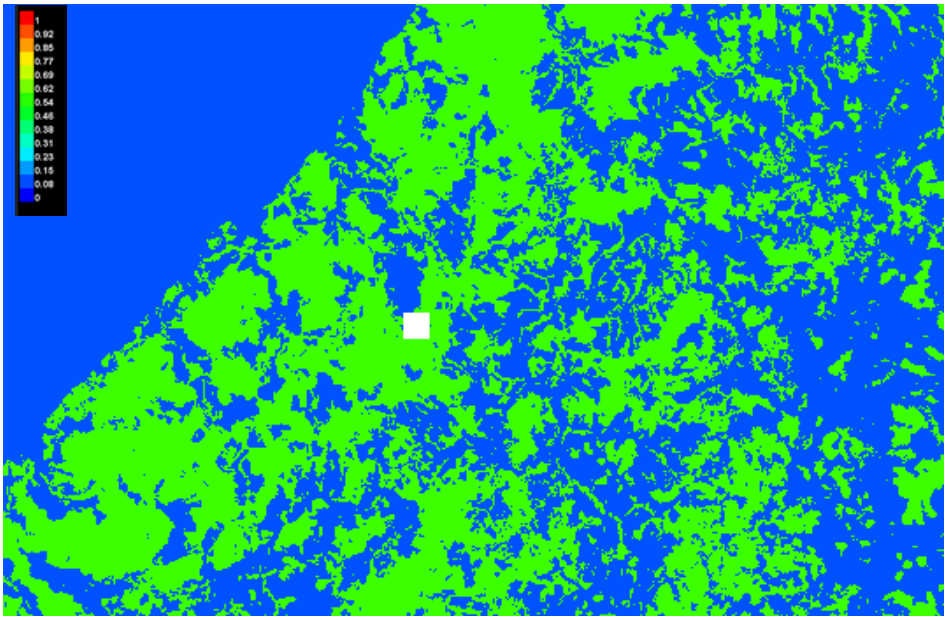


Figure D116. MaxEnt species distribution model for SciurusGranatensis in the Ecuador corridor. Warmer colors show better-predicted habitat conditions, white dots represent presences

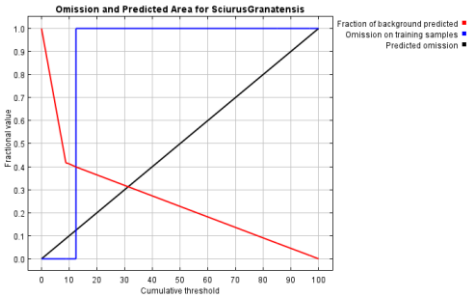


Figure D117. Omission and predicted omission rate as function of cumulative threshold of SciurusGranatensis in the Ecuador corridor

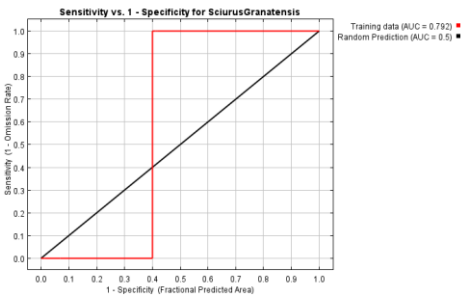


Figure D118. Receiver operating characteristic (ROC) curve of SciurusGranatensis in the Ecuador corridor

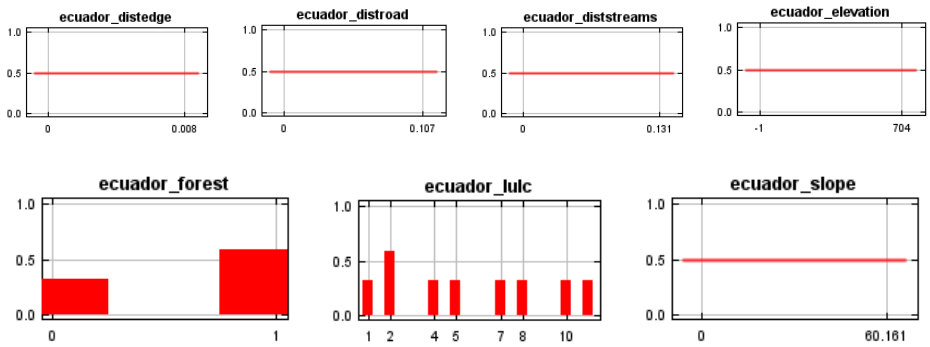


Figure D119. Dependence response curves for the SciurusGranatensis MaxEnt models in the Ecuador corridor

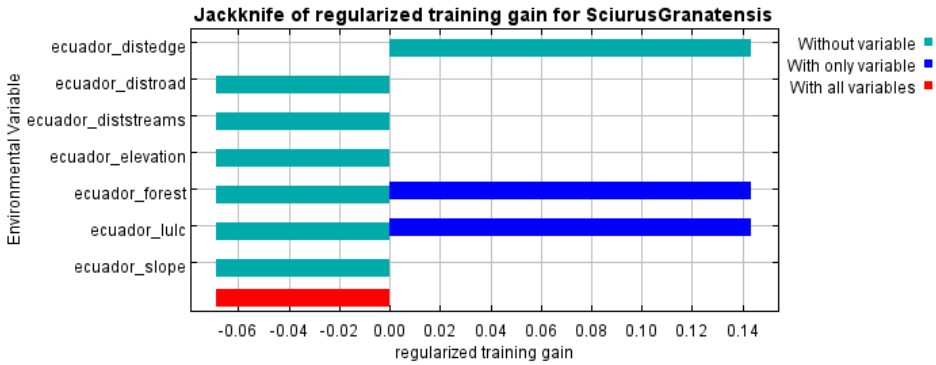


Figure D120. Results for jackknife test of variable importance for SciurusGranatensis in the Ecuador corridor. Land use land cover and forest habitat accounted for the highest gain to the model and therefore has the most information not accounted for in other variables. Distance to edge accounted for the lowest gain.

Table D24. Confusion Matrix of SciurusGranatensis in the Ecuador corridor, habitat/non-habitat threshold = 0.558

		Observed Values		
		Positive (1)	Negative (0)	
Predicted Values	Positive (1)	1	726	
	Negative (0)	0	6	
				PT = 0.0095498

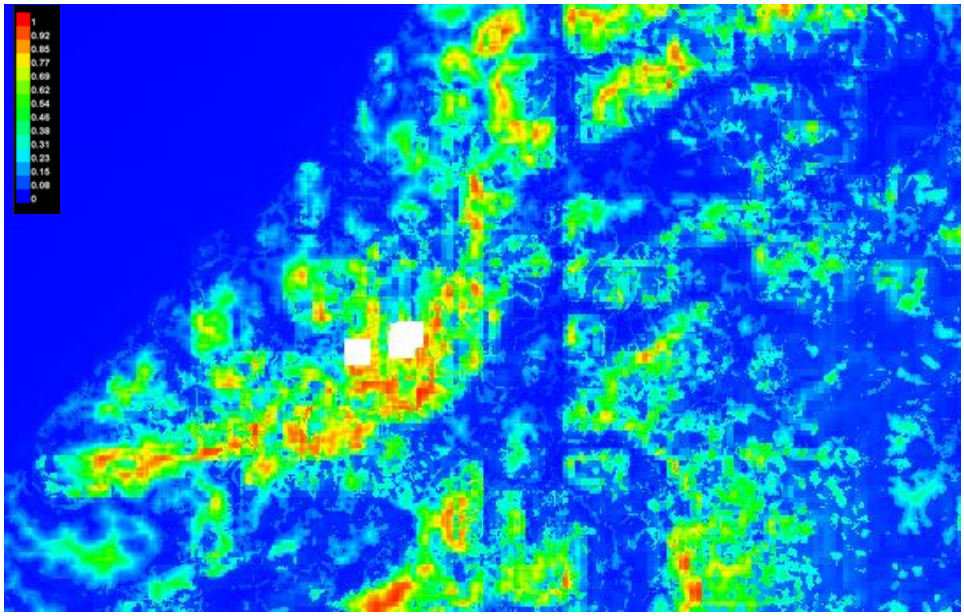


Figure D121. MaxEnt species distribution model for TamanduaMexicana in the Ecuador corridor. Warmer colors show better-predicted habitat conditions, white dots represent presences

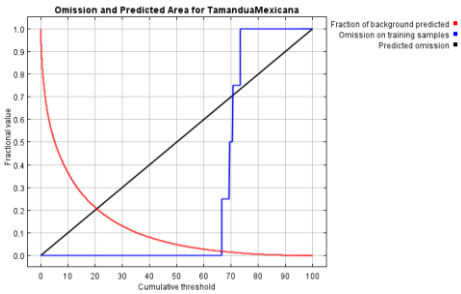


Figure D122. Omission and predicted omission rate as function of cumulative threshold of TamanduaMexicana in the Ecuador corridor

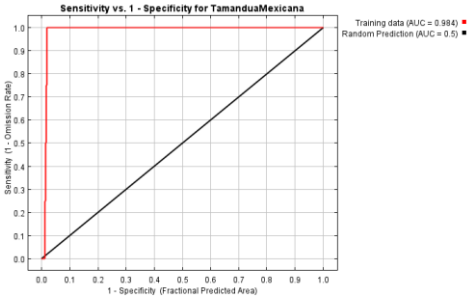


Figure D123. Receiver operating characteristic (ROC) curve of TamanduaMexicana in the Ecuador corridor

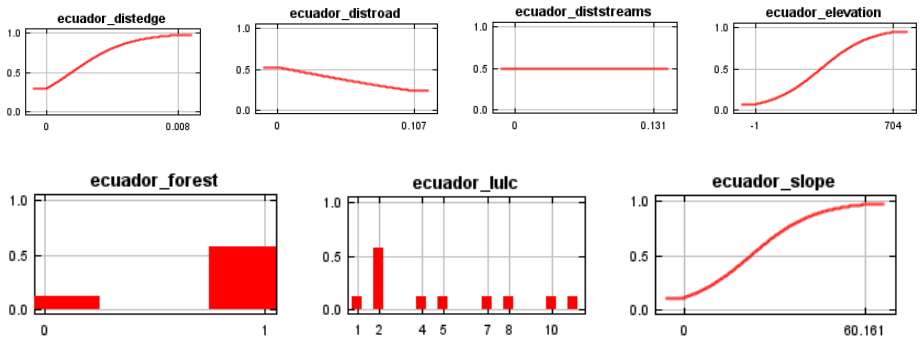


Figure D124. Dependence response curves for the TamanduaMexicana MaxEnt models in the Ecuador corridor

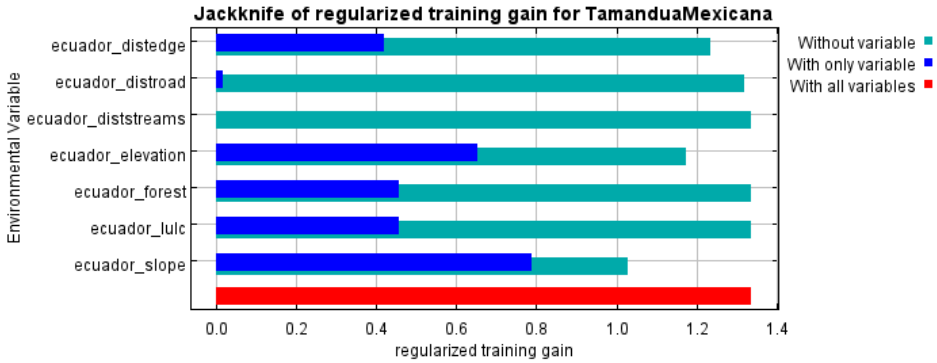


Figure D125. Results for jackknife test of variable importance for TamanduaMexicana in the Ecuador corridor. Slope accounted for the highest gain to the model and therefore has the most information not accounted for in other variables. Distance to streams accounted for the lowest gain.

Table D25. Confusion Matrix of TamanduaMexicana in the Ecuador corridor, habitat/non-habitat threshold = 0.095

		Observed Values		
		Positive (1)	Negative (0)	
Predicted Values	Positive (1)	13	720	
	Negative (0)	0	0	
				PT = 0.01773533

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