Using Geographic Information Systems to Identify Hotspots of Amphibian Biodiversity in the Andes of Southern Peru.

Usando el sistema de información geográfica para identificar zonas de biodiversidad anfibio en los Andes que están en el sur de Perú.

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Abstract
The Tropical Andes is the most amphibian diverse region of the planet. Despite this diversity the region has experienced human related disturbances for thousands of years. But now a new disturbance, the construction of the transoceanic highway, threatens to increase commercial scale resource extraction in the region. To document what might be lost, we traveled as part of a group of scientists trying to document biodiversity in the region. From information on amphibian distributions and habitat relationships, topographic maps, and satellite imagery we developed a geographic information system (GIS) model to predict areas of high amphibian diversity. This modeling process is the first step towards creating a conservation tool that will benefit conservationists and land managers in the region. We digitized a cover type map and determined the habitat suitability for each genus by cover type. Sampling the landscape then allowed us to predict areas that should show high amphibian diversity. Our models predict areas along the ecotone between cloud forest and puna grasslands to have the highest richness. The next step in the modeling process will be to improve the accuracy of cover type maps, amphibian distribution maps, and our understanding of amphibian habitat relationships.

Resumen
Los Andes tropicales es la región mas diversa de anfibios que está en el planeta. A pesar de la diversidad, la región ha tenido experiencias tumultos relacionados con los humanos por miles de años. Pero, ahora hay un nuevo tumulto, la construcción de una carretera transoceánica, amenaza con creciente la extracción de los recursos que está en la región, a un nivel comercial. Para documentar que puede perderse viajamos como parte de un grupo de científicos tratando de documentar la biodiversidad en la región. De la información que obtuvimos en los anfibios y el dato espacial, construimos un modelo de un sistema de información geográfica (SIG) para predecir las áreas con un nivel alto de la biodiversidad anfibio. Para construir el modelo, digitalizamos un mapa de uso de tierra y cubierta de la vegetación. Entonces, determinamos la idoneidad de habítate por cada especie por tipo de cubierto. Por explorar el paisaje nos permite predecir las áreas que puedan tener una diversidad alta de los anfibios. Nuestros modelos predicen que las áreas cerca de la ecotone, entre la selva de nubes y los pastos de puna tienen las riquezas genéricas mas alta. El próximo nivel en el proceso de modelismo va a ser mejorar la exactitud de los mapas de tipo cubierto y de la distribución de los anfibios, y nuestro entendimiento de las relaciones de hábitat de los anfibios. Mientras incrementamos la exactitud del modelo, llegará a ser un instrumento de conservación valioso por los Andes centrales.

Keywords: habitat modeling, conservation, frog, anuran

Introduction

In a recent study, the tropical Andes was found to be one of the most diverse regions in the world based on its high level of endemic species and the level of threat to regions biodiversity (Myers et al. 2000). Twenty-five regions were identified as global hotspots for biodiversity and of those the tropical Andes had the highest number of endemic plants and vertebrates. More specifically, 830 of the worlds ~4780 amphibian species (~17%) are found in the Tropical Andes (Glaw and Kohler 1998; Myers et al. 2000). In addition, new species of amphibians are being discovered in the Andes at an alarming rate (Duellman 1999). With one region containing such a high proportion of world's amphibians, it makes sense to put priority on preserving biodiversity in this area.

Despite high levels of diversity, the region's natural resources have been experiencing human related disturbances in the form of agriculture, mining, and deforestation for thousands of years (Stern 1987). However, these disturbances are relatively minor compared to a new threat that is making its way up and over the Andes, the construction of the transoceanic highway. Once the highway is completed it will allow resources in remote western sections of the Amazon rainforest to be removed more efficiently. In addition, it will fragment two of the most diverse protected areas in the world, Manu National Park and the Tambopata Reserve Zone, and break up Conservation International's push to create a connected corridor through the central Andes.

To address and hopefully minimize some effects of this road we traveled as part of a National Geographic research expedition to the Carabaya Mountains of southern Peru. The goal of the expedition was to document the resources that could be lost with the construction of the highway. Our specific objectives were to collect baseline data on amphibians and reptiles of the region and to use the data to begin developing a model that will eventually serve as a conservation tool in the region.

Experimental Design and Sampling Methods

Amphibian and Reptile Sampling

We sampled amphibians and reptiles in three broad ecological regions: cloud forest, puna grassland, and elfin forest (ecotone between cloud forest and puna grassland). We used a variety of techniques including time-constrained searches, drift fence/pitfall arrays, dipnetting, aquatic funnel traps, sticky traps, and arboreal tube traps (Heyer et al. 1994; Olson et al. 1997). However, due to the mobile nature of the expedition most amphibians and reptiles were found using time-constrained searches and dipnetting. We collected a subsample of each species to facilitate future identification. We deposited all specimens in the Lima Museum of Natural History and have been working with herpetologists there to identify individual species.

Model Development

The first step in developing our model was to acquire the spatial data we used to produce cover type maps. We used two forms of spatial data, topographic maps and satellite imagery, to create our cover type maps. Both data sources were coarse (~1:100,000) and prevented us from delineating fine scale vegetation types. The spatial data was then used to digitize eight cover types (agriculture; cloud forest stream; cloud forest swamp; cloud forest upland; glacier; puna grassland lake; puna grassland stream; puna grassland swamp; puna grassland upland).

Based on our survey results and literature searches we decided to focus only on amphibians in the modeling portion of this project. To build the model we needed to first understand the amphibians that could potentially occur in the Carabaya Mountains. We developed a list of all genera of amphibians know to occur in the central Andes (Duellman 1999). From this list, we created a genera/habitat matrix that included all potential genera and all cover types. A given genera would receive a value of 1 for suitable cover types and a value of 0 for unsuitable cover types. Habitat suitability was determined using our survey data combined with an extensive review of habitat relationships found in species accounts from the area.

To sample our study area for generic richness we overlaid a 1-kilometer hex grid system. We selected 1-kilometer sample areas because they represent the scale at which we would be locating future sampling areas. Once the grid was overlaid, we then quantified richness within each hex by calculating the number of genera that could potential occur within the hex (based on the genera/habitat matrix). We assigned a richness value of 1 for a genus found in one or multiple patch types within a hex. For example, if the genus *Gastrotheca* was found in both puna grassland and cloud forest uplands, *Gastrotheca* would contribute a value of 1 to the total hex's richness if only puna grassland upland, cloud forest upland, or both were present in the hex.

Results

Survey Results

We sampled a total of 3 reptile species from 2 genera and at least 13 amphibian species from 7 genera (Table 1). Most individuals were captured in the puna grassland ecological regions of the study area, although we sampled in Puna areas disproportionately more. The majority of the individuals were identified to genus but only two were identified to species (*Bufo inca*, *Bufo spinulosus*). It is possible that some of the species may be new to science, as the area has never been previously surveyed for reptiles and amphibians.

Predictive Model

We developed a cover type map for the study area (Figure 1). However, due to the coarse scale of the spatial data we used, the cover type map undoubtedly missed a great deal of fine scale habitat heterogeneity. For example, we were unable to detect many of the wetland areas in the cloud forest region due to dense canopy cover. Conversely, the model most likely is effective at predicting coarse scale patterns in diversity.

Table 1. List of the 2 reptile and 7 amphibian genera sampled in June 2000 from the Cordillera Carabaya, Peru. Some specimens have not yet been identified to the genus level; as a result some genera may have a greater number of species than displayed (genera with *). The ecological regions where species of each genus were found are reported.

Genera	Number of Species	Ecological Region
Euspondylus	1	Elfin forest
Liolaemus	2	Puna grassland
Atelopus	2	Puna grassland; Elfin forest
*Bufo**	2	Puna grassland; Cloud forest
Gastrotheca	2	Elfin forest; Cloud forest
*Leptodactylus**	1	Elfin forest
*Phrynopus**	3	Elfin forest; Cloud forest
Pleurodema	1	Puna grassland
*Telmatobius**	2	Puna grassland

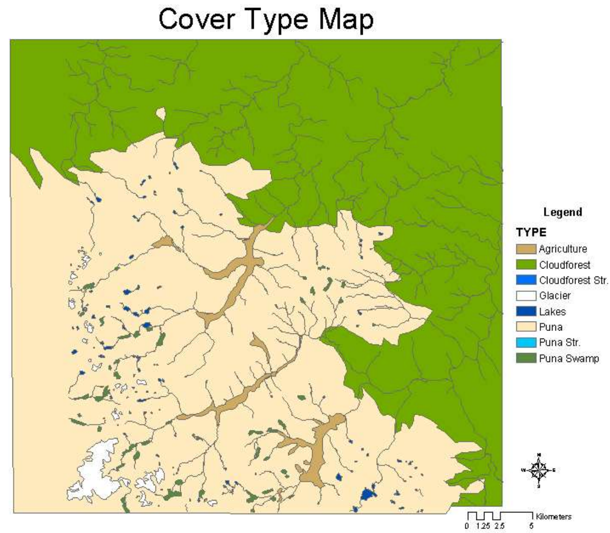

Figure 1. Cover type map for the Carabaya Mountains, Peru.

We found a total of 25 genera that could potentially occur in the Carabaya Mountains. Of the 25 genera, we were unable to find habitat relationship data on only one (*Hyalinobatrachium*). The majority of potential amphibians in the region were found in cloud forest related cover types and only 6 were associated with puna grassland related cover types (Table 2). We were unable to assess the accuracy of the matrix and variation in accuracy levels among species because the data was taken from many sources with varying sampling designs.

The areas with the highest predicted richness were on the ecotone between puna grasslands and cloud forest (Figure 2). These high richness values correspond to high richness of cover types along the ecotone. Areas in puna grassland regions have the lowest predicted richness and cloud forest areas have relatively high richness. The trend in richness corresponds to an elevational gradient where a gain in elevation results in a loss of richness.

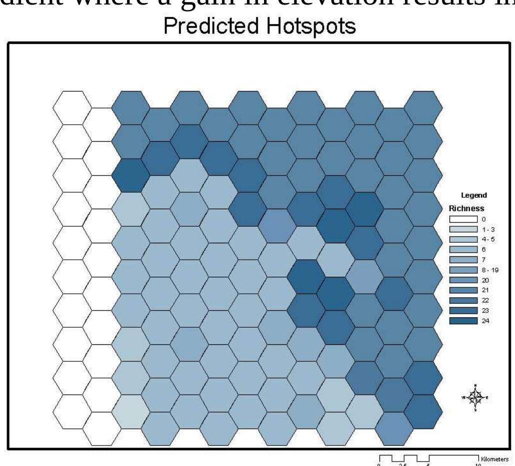

Figure 2. Predicted hotspots of generic richness´In the Carabaya Mountains, Peru. Locations on this predicted map correspond to locations on the cover type map (Figure 1).

Table 2. Genera/habitat matrix created for the Carabaya Mountains, Peru from survey data and species accounts. A value of 1 indicates that a specific cover type is suitable for specific genera, and a value of 0 indicates that the cover type is unsuitable.

	Puna Grassland				Cloud Forest				
Genus	stream	swamp	lake	upland	stream	swamp	lake	upland	agri.

Atelopus	0	0	0	0	1	0	0	0	0
Bufo	1	1	0	1	1	0	0	1	1
Centrolene	0	0	0	0	1	0	0	0	0
Cochranella	0	0	0	0	1	0	0	0	0
Colostethus	0	0	0	0	1	1	0	1	0
Dendrobates	0	0	0	0	1	0	0	1	0
Epipedobates	0	0	0	0	0	0	0	1	0
Gastrotheca	0	0	0	1	0	0	0	1	1
Hyla	0	0	0	0	1	1	0	1	1
Osteocephalus	0	0	0	0	0	0	0	1	0
Phyllomedusa	0	0	0	0	1	1	0	1	0
Scinax	0	0	0	0	0	1	0	1	0
Alsodes	0	0	0	0	0	0	0	1	0
Batrachophrynus	0	0	1	0	0	0	0	0	0
Eleutherodactylus	1	1	0	1	1	1	0	1	1
Ischnocnema	0	0	0	0	0	0	0	1	0
Leptodactylus	0	0	0	0	1	1	0	1	0
Phrynopus	0	0	0	0	1	0	0	1	0
Phyllonastes	0	0	0	0	0	0	0	1	0
Pleurodema	1	1	1	1	0	1	0	0	0
Telmatobius	1	1	1	0	0	0	0	0	0
Bolitoglossa	0	0	0	0	0	0	0	1	0
Caecilia	0	0	0	0	0	0	0	1	0
Epicrionops	0	0	0	0	1	0	0	0	0

Discussion

Improving the Model

The current model predicts areas of high generic richness based on coarse scale cover type maps. This model is the first step in developing an amphibian conservation tool for the central Andes. There are many aspects of the model that need to have improved accuracy before this tool will be useful to researchers in the region. We will continue to work on developing finer scale cover type maps, as new spatial data are available. The goal is to create a map with a resolution of approximately 30 meters for the entire Carabaya region and in the distant future to create a map with < 5-meter resolution for an intensive study area within the Carabaya. Similarly, we are working on increasing our knowledge of amphibian distributions and habitat relationships at two scales. The coarse scale will consist of observational records with explicit spatial reference throughout the Carabaya Mountains. The second scale will consist of intensive surveys and tracking of multiple species in the intensive study area mentioned above. Combining coarse scale habitat modeling with fine scale species specific studies will allow us to create a conservation tool that can be used at multiple scales.

Conservation Tools

Gap analysis is a good example of a conservation tool that predicts species distribution, richness, and diversity (Scott et al. 1993). Gap analysis can be especially useful for predicting ecosystem and species diversity because it is logistically difficult to measure biodiversity over large areas (Scott and Csuti 1997). As a result, Gap analysis has been adopted throughout the United States as one of the leading methods for modeling and predicting species diversity. As our model continues to develop, we will use the approach taken by the Gap analysis project as a template. Our plan is to use a tool developed in the United States and bring the technology to Peru to aid local conservationists in protecting biodiversity. The majority of the world's biodiversity is in tropical regions and much of the world's tropics are in third world countries (Orians 1997). However, most of the funds raised for biodiversity conservation are used to protect biodiversity in first world countries. We now have a great opportunity to utilize the resources from first world countries (development of Gap analysis) and use them to conserve areas of high biodiversity in third world countries.

As we continue to collect data on the distribution and habitat relationships of amphibians of the Carabaya Mountains, we plan to develop a field guide that will aid conservationists and researchers in the future. Before traveling to Peru on the Research expedition, we conducted extensive research trying to gain knowledge on amphibians in the area. Amphibian literature was extremely limited even for areas such as Manu National Park. This made field identification of amphibians and reptiles difficult. To help future researchers, land mangers, and conservationists, we plan to develop a field guide that outlines life history characteristics, distribution information, photographs, and conservation status of amphibians in the Carabaya.

We plan to continue raising the public's knowledge of amphibian diversity and construction of the transoceanic highway in multiple forms. First, we plan to continue presenting our work to a wide range of audiences, including the scientific community, the conservation community, and the general international public. In spring 2001 a National Geographic Explorer television program and two National Public Radio programs aired dealing with our expedition to the region. We plan to pursue similar vectors for reaching the public as our research continues. Through raising awareness we hope draw interest by the international community to a conservation issue that has been relatively underrepresented.

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