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Applications of geographic information systems and remote sensing techniques to conservation of amphibians in northwestern Ecuador

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ABSTRACT

The biodiversity of the Andean Chocó in western Ecuador and Colombia is threatened by anthropogenic changes in land cover. The main goal of this study was to contribute to conservation of 12 threatened species of amphibians at a cloud forest site in northwestern Ecuador, by identifying and proposing protection of critical areas. We used Geographic Information Systems (GIS) and remote sensing techniques to quantify land cover changes over 35 years and outline important areas for amphibian conservation. We performed a supervised classification of an IKONOS satellite image from 2011 and two aerial photographs from 1977 and 2000. The 2011 IKONOS satellite image classification was used to delineate areas important for conservation of threatened amphibians within a 200 m buffer around rivers and streams. The overall classification accuracy of the three images was $\geq$ 80%. Forest cover was reduced by 17% during the last 34 years. However, only 50% of the study area retained the initial (1977) forest cover, as land was cleared for farming and eventually reforested. Finally, using the 2011 IKONOS satellite image, we delineated areas of potential conservation interest that would benefit the long term survival of threatened amphibian species at the Ecuadorian cloud forest site studied.

1. Introduction

The cloud forest of the Chocó region in South America is considered one of the 18 sites of greatest biodiversity and high endemism of species on the planet (Dodson and Gentry, 1991; Myers et al., 2000; Olson and Dinerstein, 1998). The Andean Ecuadorian Chocó, in particular, presents environmental conditions that allow the existence of a diverse flora and fauna (Mittermeier et al., 1998), with exceptional richness and endemism, especially of amphibians (Ron et al., 2012). However, in this region, amphibian species have been reported to be declining or becoming extinct since the late 1980s (Bustamante et al., 2005; Lips et al., 2005). Likely threats to native amphibians are mostly related to drastic changes in land cover (Toral et al., 2002; Young et al., 2001), including deforestation caused by farming, fires, selective logging, urbanization, and construction of roads. A more recent threat is the introduction of exotic predatory fish in streams (Martín Torrijos, 2011). Finally, infections caused by the chytrid fungus *Batrachochytrium dendrobatidis* may have contributed to local extinctions in the region (Guayasamin et al., 2014).

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Table 1
List of endangered and vulnerable amphibian species recorded in Reserva Las Gralarias (Guayasamin et al., 2014), with threat categories according to the IUCN Red List (IUCN, 2012).

Species	Status
Centrolene ballux	Critically endangered
Centrolene heloderma	Critically endangered
Centrolene lynchi	Endangered
Pristimantis crenunguis	Endangered
Pristimantis eugeniae	Endangered
Pristimantis sobetes	Endangered
Pristimantis pteridophilus	Endangered
Centrolene peristictum	Vulnerable
Nymphargus griffithsi	Vulnerable
Pristimantis eremitus	Vulnerable
Pristimantis calcarulatus	Vulnerable
Pristimantis verecundus	Vulnerable

There are many hypotheses that aim to explain global amphibian declines, but it is evident that the most significant factors are habitat destruction, disturbance, and fragmentation (Blaustein, 1994; Brodman et al., 2006; Crump et al., 1992; Davidson et al., 2001; Dodd and Smith, 2003; Lips, 1998; Marsh and Trenham, 2001; Schiesari et al., 2007; Wake, 1991; Weyrauch and Grubb, 2004). In fact, habitat modification is the best documented cause of amphibian population declines (Alford and Richards, 1999; Gibbons et al., 2000; Smith and Green, 2005). Habitat loss influences amphibian abundance and diversity directly, by reducing populations in the areas affected (Hecnar and M'Closkey, 1996) and indirectly, by altering microclimatic regimes, compacting and desiccating soils, and reducing habitat complexity (Alford and Richards, 1999).

Amphibian conservation research focusing on drivers of population declines has generated a diverse body of information, including issues related to translocation of populations (Ficetola and De Bernardi, 2005; Miller et al., 2014), captive breeding for reintroduction (Becker et al., 2014; Kissel et al., 2014), habitat fragmentation and restoration (Bower et al., 2014; Greenwald et al., 2009), and area selection for prioritization (Pyke, 2005; Russell et al., 2002). Increasingly, in recent years, questions regarding animal habitat use and changes in vegetation cover have been addressed with satellite imagery, Geographic Information Systems (GIS), and historical aerial photography (Hooftman and Bullock, 2012; Pellikka et al., 2009; Pringle et al., 2009). Combining these powerful tools provides means of investigating the magnitude and consequences of temporal land cover change in areas of interest, and in the context of preservation of species of concern (*e.g.*, grassland birds, giant panda, resplendent quetzal; Pool et al., 2014; Solórzano et al., 2003; Zhang et al., 2013). Analyses of land cover changes can also identify areas that may be included in conservation planning (Fuller et al., 1998), but to our knowledge, this research avenue has received less attention in the amphibian conservation field. This observation is based on our review of ISI indexed journals, via Web of Science database searches with combinations of keywords ("amphibian", "conservation", "land cover", "land use", and "prioritization"), restricted to 1995–2015. Our study illustrates the use of remote sensing techniques to study long-term, landscape scale changes of land cover associated with endangered and vulnerable amphibians in a cloud forest of western Ecuador and to delineate areas of conservation priority for protecting amphibians. Thus, we investigated land cover conversion as a strategic step to conserving critical habitat for amphibians in northwestern Ecuador.

2. Methods

2.1. Study area

The study area was comprised of Reserva Las Gralarias, a privately-owned reserve, and adjacent multi-use private lands, encompassing a region of approximately 5000 ha where the presence of 12 species of amphibians listed as endangered or vulnerable by the International Union for Conservation of Nature (IUCN) has been documented (Table 1; Guayasamin et al., 2014; IUCN, 2012). Reserva Las Gralarias protects 425 ha out of the total study area of 5000 ha in the parish of Mindo, Pichincha province, on the western slopes of the Andes in the Chocó region (Fig. 1; Josse et al., 2003). From a hydrological standpoint, the area lies within the Esmeraldas river basin and the sub-basins of the Guayllabamba and Blanco rivers. The physiography and vegetation of the area correspond to the Western Montane Forest region of Ecuador (Sierra et al., 1999), covering an elevation range of 1300–3400 m (Sierra et al., 1999). In this evergreen montane forest, the canopy is generally less than 25 m tall, with a high abundance of epiphytes, especially mosses, ferns, orchids, and bromeliads. At intermediate elevations, particularly during the evenings, the forest is covered in fog and precipitation is horizontal, from low clouds. These conditions are favorable to direct-development amphibians, such as *Pristimantis spp.* (Craugastoridae; Ron et al., 2012). Glassfrog species (Centrolenidae), adapted to developing from larvae in permanent streams (Haddad and Prado, 2005), are also present in high numbers in this region (Guayasamin et al., 2014), probably because of the intermediate elevations, climatic conditions (Hutter et al., 2013), and abundance of fast-flowing streams. The area contains primary and secondary forests, with both high biodiversity and anthropogenic pressures.