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.

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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).

<table>
<thead>
<tr>
<th>Species</th>
<th>Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>Centrolene ballux</td>
<td>Critically endangered</td>
</tr>
<tr>
<td>Centrolene heloderma</td>
<td>Critically endangered</td>
</tr>
<tr>
<td>Centrolene lynchi</td>
<td>Endangered</td>
</tr>
<tr>
<td>Pristimantis crenunguis</td>
<td>Endangered</td>
</tr>
<tr>
<td>Pristimantis eugeniae</td>
<td>Endangered</td>
</tr>
<tr>
<td>Pristimantis sobetes</td>
<td>Endangered</td>
</tr>
<tr>
<td>Pristimantis pteridophilus</td>
<td>Endangered</td>
</tr>
<tr>
<td>Centrolene peristictum</td>
<td>Vulnerable</td>
</tr>
<tr>
<td>Nymphargus griffithi</td>
<td>Vulnerable</td>
</tr>
<tr>
<td>Pristimantis eremitus</td>
<td>Vulnerable</td>
</tr>
<tr>
<td>Pristimantis calcarulatus</td>
<td>Vulnerable</td>
</tr>
<tr>
<td>Pristimantis verecundus</td>
<td>Vulnerable</td>
</tr>
</tbody>
</table>

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; Kisselel 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 (Hoofman 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 preserving species of concern (e.g., grassland birds, giant panda, resplendent quetzal; Pool et al., 2014; Solórzano et al., 2003 and 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 and 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.
Fig. 1. Location of the study area (white star) in northwestern Ecuador, on an elevation map with province boundaries outlined, and zoomed in over the 2011 IKONOS satellite image. The two polygons represent Reserva Las Gralarias and the black squares with white dots the known locations of 12 threatened amphibian species.

2.2. Satellite image and aerial photo acquisition and processing

Frequent cloudy conditions in the moist tropical regions complicate capturing of satellite or aerial optical sensor data (Lu and Weng, 2007). Thus, a combination of multisensor data with various image characteristics is usually beneficial for investigations in such environments (Lefsky and Cohen, 2003). Typical applications of remote sensing involve the use of images from passive optical systems, either satellite or aerial imagery (Goward and Williams, 1997). The present study was conducted using historical aerial photographs and a recent IKONOS satellite image, with the aim of quantifying the changes in land cover that could have affected the amphibian presence in the region in the last three decades.

Two black-and-white aerial photos (scale 1:60,000), taken on 9 November 1977 (flight line No. 5701 R-28 9-11-77) and 9 November 2000 (flight line No. 15279 R64RC30 9-11-2000), respectively, were acquired from Instituto Geográfico Militar (IGM), Quito, Ecuador. The aerial photos were georeferenced and rectified for inherent geometric errors using four digital topographic maps (scale 1:50,000; UTM coordinate system) acquired from IGM, corresponding to the quadrants of San Miguel de los Bancos, Calacali, Mindo, and Nono. Registration to the digital topographic maps was carried out using road intersections that are usually very distinctive and clearly visible on images (Gautam et al., 2003). Finally, we applied first-degree rotation scaling and translation transformation, with the nearest neighbor resampling method (Gautam et al., 2003; Richards, 2013). This procedure allowed for direct comparison of features between aerial photographs and IKONOS, during the selection of sample plots to use in image classification and accuracy assessment of classified images (Gautam et al., 2003).
The IKONOS satellite image was acquired on 26 June 2011, 1553 h GMT. The IKONOS sensor has advanced spectral, spatial, and radiometric characteristics (Diak et al., 2003; Lu and Weng, 2007; Thienkabail et al., 2004), and collects 1-m panchromatic and 4-m multispectral images in four bands with 11-bit resolution (Diak et al., 2003). We created a multiband raster composite of the four IKONOS multispectral bands in ESRI ArcMap and, although the IKONOS image was geometrically corrected and projected to UTM zone 17S and datum WGS84, we performed a second orthorectification. This process removes distortions in the imagery caused by topography (Jensen, 1996), resulting in a more accurate product (Jensen, 1996; Vassilopoulou et al., 2002). We used the orthorectification function in ENVI 5.0 (Exelis Visual Information Solutions, Boulder, CO, USA) which required a Digital Elevation Model (DEM) and Rational Polynomial Coefficients (RPC). We used the NASA SRTM 90-m resolution DEM (Jarvis et al., 2008), masked to the study area, and the RPC captured by the satellite at the time of image acquisition to improve the relative accuracy of the initial IKONOS image registration (Cheng et al., 2008; Grodecki and Dial, 2003; Vassilopoulou et al., 2002).

2.3. Field data collection

Field reference data (ground-truthing) for IKONOS image classification were collected in Reserva Las Gralarias between 3 and 10 July 2012 (Table 2). Inventory field plots were 30 × 30 m and each plot encompassed approximately 52 IKONOS pixels (Thienkabail et al., 2004). Plots were established within homogeneous areas for the class under consideration, thus avoiding mixed or small patches of other vegetation classes (Thienkabail et al., 2004). The specific location of each plot was recorded as a point in the center of the plot, using a Global Positioning System (GPS) Garmin e-Trex® unit. In addition, qualitative observations of land cover were noted at these and other locations in the region to identify vegetation classes to consider (Ramirez, unpub. data). Vegetation classes included in this study were as follows: (1) forest with no (or minimal) evidence of anthropogenic disturbance, (2) riverine forest, (3) pasture (grazed by cattle), and (4) pasture in regeneration since 2000, when grazing was eliminated as land was acquired for establishing Reserva Las Gralarias (Table 2). In the latter plots, reforestation has been occurring by natural or assisted means (i.e., planting native species of trees and shrubs), and vegetation is dominated by the introduced African grass (Setaria glauca) of > 1 m height, surrounded by medium or high canopy trees (Fig. 2). The field plots were supplemented with on-screen selection of additional reference sites for pasture (Table 2), as well as 50 references for a non-vegetation class, roads.

2.4. Supervised classification

Image classification consists of automatically categorizing all pixels in an image into different classes of land cover (Lillesand et al., 2004). Since the spectral signature of some objects often varies (Tiwari, 2008), a supervised approach involves the selection of training areas (pixels) on the image which statistically characterize the target land cover classes (Richards, 2013). This information allows estimating the extent occupied by objects with different spectral signatures and assigning them to land cover classes. Herein, we applied a supervised classification using ENVI 5.0 (Exelis Visual Information Solutions, Boulder, CO, USA).

To classify the aerial photos, we selected the training samples for each class by means of on-screen drawing of polygons. We used three classes: (1) forest with no (or minimal) evidence of anthropogenic disturbance, (2) pasture, and (3) road. Training sites were chosen for each aerial photo separately to ensure that all classes were adequately represented. In contrast with the classification of IKONOS satellite image (see below), we did not include pasture in regeneration as a separate class because it represents a relatively new vegetation cover that could not be identified in the aerial photographs.

We used a minimum distance algorithm that calculates the mean vectors of each spectral end member (corresponding to the class selected) and the Euclidean distance from each unknown pixel to the mean vector for each class, a method recommended when limited training samples are available (Richards, 2013). All pixels were classified to the nearest spectral end member (class) and the results were refined with the aggregate minimum size approach. For the IKONOS satellite image we used a maximum likelihood algorithm with training samples collected in the field and additional pasture sites and roads digitized on-screen (described above). The maximum likelihood classifier assigns a pixel to a particular class based on both the variance and the covariance of the spectral information (Shalaby and Tateishi, 2007). This classifier is one of the frequently used supervised classification techniques (Richards, 2013). We used the maximum likelihood classifier because the

<table>
<thead>
<tr>
<th>Class</th>
<th>Number of plots</th>
<th>Dominant taxa</th>
</tr>
</thead>
<tbody>
<tr>
<td>Riverine forest</td>
<td>6</td>
<td>Cyathea sp., Melastomataceae, Clusiaceae, bryophytes, Araceae, bromeliads, Merania maxima</td>
</tr>
<tr>
<td>Montane forest</td>
<td>77</td>
<td>Croton floccosus, C. magdalensis, Solanum lepidopterus, Cecropia aff. montana, M. maxima, Cyathea sp., Prestoea cf acuminata, Weinmannia balbisiana</td>
</tr>
<tr>
<td>Pasture</td>
<td>14 (+201)</td>
<td>Setaria glauca</td>
</tr>
<tr>
<td>Pasture in regeneration</td>
<td>42</td>
<td>C. floccosus, P. cf acuminata, C. magdalensis, S. glauca</td>
</tr>
</tbody>
</table>

Table 2

Land cover classes, number of field reference plots used for the IKONOS satellite image classification, and dominant taxa in each class. The number of plots for pasture was increased by on-screen selection of additional sites, indicated by the number in parentheses.
number of field reference plots was higher than ten times the number of spectral bands (four IKONOS bands), a sample size considered adequate for this classifier (Richards, 2013). However, we only located six field plots for the riverine forest class, thus we combined these with the montane forest plots into a single training dataset for a forest class, given the similarities in the spectral signature between the two types of forest cover. Finally, we also digitized on-screen areas with clouds to train the classifier and mask out cloud pixels from subsequent land use change analyses.

2.5. Classification accuracy assessment

Image classification accuracy is assessed by comparing obtained classes to reference data that are assumed to be true (Foody, 2002; Lillesand et al., 2004). We generated a typical error matrix for the aerial photos and the IKONOS satellite image classification results, showing pixels correctly identified for a class either as a fraction of the “true” (known) number of pixels in that class (producer’s accuracy), or as a fraction of the number classified in that class (user’s accuracy; Jones and Vaughan, 2010). Misclassification with producer’s accuracy is termed omission error and indicates the number of known pixels for that class that were not correctly identified (Jones and Vaughan, 2010). We also calculated the kappa statistic, a measurement of agreement between the producer’s accuracy and user’s accuracy (Jones and Vaughan, 2010). The kappa statistic takes values from 0 to 1, with suggested strengths of agreement proposed by Landis and Koch (1977) as follows: moderate below 0.6, substantial 0.61–0.80, and almost perfect 0.81–1.

2.6. Detecting changes in the land cover

We first quantified the percent forest, pasture, and roads of the study area to compare the overall changes in land cover between consecutive time frames (1977–2000 and 2000–2011). Our justification of the selection of these classes was tri-fold: (1) achieving the objective of this study (quantification of changes in forest cover); (2) relying on a reasonable degree of classification accuracy, and (3) avoiding identification errors associated with the aerial photographs (Gautam et al., 2003). In addition to calculating overall percent land cover change between two consecutive time frames, we also quantified the change in forest and pasture cover types from one time frame to another. Of all possible transitions, we tracked the ones that cumulatively represented 95% of the entire study area. Specifically, for initial (1977) forest cover areas, we calculated the following transitional patterns, by the three time frames: forest–pasture–forest, forest–forest–pasture, forest–pasture–pasture, and no change (forest in all three time frames). For initial (1977) pasture cover areas, we calculated transitions of pasture–forest–pasture, pasture–pasture–pasture, pasture–forest–pasture, and no change (pasture in all three time frames).
Table 3
Error matrix of the classification accuracy of the aerial photograph from 1977. Shaded cells along the diagonal represent the number of correctly classified reference training pixels.

<table>
<thead>
<tr>
<th>Classification</th>
<th>Forest</th>
<th>Pasture</th>
<th>Road</th>
<th>Total</th>
<th>User accuracy</th>
<th>Commission error</th>
</tr>
</thead>
<tbody>
<tr>
<td>Forest</td>
<td>4866</td>
<td>39</td>
<td>1</td>
<td>4906</td>
<td>4866/4906 = 0.99</td>
<td>40/4906 = 0.008</td>
</tr>
<tr>
<td>Pasture</td>
<td>81</td>
<td>1407</td>
<td>28</td>
<td>1516</td>
<td>1407/1516 = 0.93</td>
<td>109/1516 = 0.07</td>
</tr>
<tr>
<td>Road</td>
<td>0</td>
<td>50</td>
<td>212</td>
<td>262</td>
<td>212/262 = 0.80</td>
<td>50/262 = 0.19</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>4947</td>
<td>1496</td>
<td>241</td>
<td>6684</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Proper's accuracy: 4866/4947 = 0.98, 1407/1496 = 0.94, 212/241 = 0.87
Omission error: 81/4947 = 0.0163, 89/1496 = 0.059, 29/241 = 0.12
Kappa: 0.93

analyzing these transitional patterns, we were able to more specifically quantify the land cover dynamics in the study area and to make inferences about the effect of recent conservation initiatives led by the Ecuadorian government (see below) on land cover changes in the region studied. We excluded the regions with cloud cover from all our land use change calculations.

2.7. Identifying critical areas for conservation of endangered and vulnerable amphibians

Semiaquatic species require combinations of terrestrial and aquatic habitats to survive (Roe and Georges, 2007), which has fueled a growing interest in delineation of riparian terrestrial buffers surrounding aquatic habitats. Buffer zones surrounding rivers and wetlands are frequently limited to a few tens of meters (Correll, 2005). This width delimits the amount of terrestrial habitat considered important for the conservation of water resources (Correll, 2005). Nevertheless, recent analyses suggest that much larger areas may be needed for the conservation of semiaquatic species. Semlitsch and Bodie (2003) showed that at least 200–300 m of terrestrial habitat surrounding wetlands and rivers should be preserved to allow survival of terrestrial life stages of amphibians. We applied this concept for prioritization analysis of riverine regions in our study area.

We digitized 33 rivers and streams as polylines from the classified IKONOS satellite image and topographic maps, and defined as aquatic amphibian habitat a 200 m buffer surrounding these features (Semlitsch and Bodie, 2003). We then intersected the buffers with the land cover map derived from the IKONOS image classification. Within the study region, we identified areas belonging to the Socio Bosque program, a conservation initiative led by the Ministry of Environment of Ecuador since 2008, which protects 338 ha in the study region. This information was provided by the Socio Bosque Program (Ministerio del Ambiente, Ecuador). We also mapped presence records for the 12 threatened species of amphibians, available from a previous study conducted at Reserva Las Galerías (Guayasamin et al., 2014). All spatial analyses were performed in ArcMap 9.3 (ESRI, Redlands, CA, USA).

Finally, we defined various areas for conservation and restoration based on their current land cover, as identified through the classification of IKONOS 2011 satellite imagery (i.e., forest, pasture, pasture in regeneration, and road), and their importance for the protection of endangered and vulnerable amphibians. Firstly, “areas for conservation” require minimal habitat restoration, that does not change the fundamental characteristics of the area, and human use is limited to ecological services such as water supply and climate regulation (Van Der Hammen and Andrade, 2003). Secondly, “areas for restoration” are those modified by degradation and environmental conflict, requiring intervention to restore their ability to serve as conservation areas (Van Der Hammen and Andrade, 2003).

3. Results

3.1. Classification accuracy

Overall, the classification accuracy was 97% for 1977, 80% for 2000, and 94% for 2011 and kappa statistic indicated substantial (0.63 for 2000) to excellent classification performance (0.93 for 1977 and 0.88 for 2011). Details of accuracy assessment of classification results obtained for 1977, 2000, and 2011 are shown in Tables 3-5, respectively. We obtained the lowest classification accuracy for pasture in regeneration (user’s accuracy of 0.5; Table 5), a class that we attempted to identify only in the IKONOS satellite image. Cloud cover represented 8% of the study area in the IKONOS satellite image; no clouds were identified in the aerial photographs. The regions affected by cloud cover in the IKONOS satellite image were discarded from subsequent analyses, including from those of aerial photographs, to control for extent of area when comparing land cover changes between time frames. This is a limitation when performing passive monitoring by remote sensing sensors, especially in areas where cloud cover is persistent throughout the year.

3.2. Detecting landscape land use changes over time

The supervised classification of land cover for three time frames, from aerial photos (1977 and 2000), and from IKONOS satellite image (2011), illustrated an increase of pasture cover in 2000, followed by a decrease in 2011 (Fig. 3). Based on
Table 4
Error matrix of the classification accuracy of the aerial photograph from 2000. Shaded cells along the diagonal represent the number of correctly classified reference training pixels.

<table>
<thead>
<tr>
<th>Classification</th>
<th>Forest</th>
<th>Pasture</th>
<th>Road</th>
<th>Total</th>
<th>User accuracy</th>
<th>Commission error</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>4646</td>
<td>325</td>
<td>10</td>
<td>4981</td>
<td>4646/4981 = 0.93</td>
<td>353/4981 = 0.067</td>
</tr>
<tr>
<td></td>
<td>1436</td>
<td>2749</td>
<td>72</td>
<td>4257</td>
<td>2749/4257 = 0.64</td>
<td>1508/4257 = 0.35</td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>193</td>
<td>538</td>
<td>732</td>
<td>538/732 = 0.73</td>
<td>194/732 = 0.265</td>
</tr>
<tr>
<td>Total</td>
<td>6083</td>
<td>3267</td>
<td>620</td>
<td>9970</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Producer's accuracy</th>
<th>Forest/Pasture = 0.76</th>
<th>Pasture/Road = 0.84</th>
<th>Road/Tota = 0.86</th>
<th>Overall accuracy: 7933/9970 = 0.80</th>
</tr>
</thead>
<tbody>
<tr>
<td>Omission error</td>
<td>1437/6083 = 0.23</td>
<td>518/3267 = 0.158</td>
<td>82/620 = 0.132</td>
<td>Kappa: 0.63</td>
</tr>
</tbody>
</table>

Table 5
Error matrix of the classification accuracy of the IKONOS image from 2011. Shaded cells along the diagonal represent the number of correctly classified reference training pixels.

<table>
<thead>
<tr>
<th>Classification</th>
<th>Pasture</th>
<th>Forest</th>
<th>Pasture in regeneration</th>
<th>Clouds</th>
<th>Road</th>
<th>Total</th>
<th>User accuracy</th>
<th>Commission error</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pasture</td>
<td>188</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>14</td>
<td>203</td>
<td>188/203 = 0.92</td>
<td>15/203 = 0.07</td>
</tr>
<tr>
<td>Forest</td>
<td>6</td>
<td>70</td>
<td>7</td>
<td>0</td>
<td>3</td>
<td>86</td>
<td>70/86 = 0.81</td>
<td>16/86 = 0.18</td>
</tr>
<tr>
<td>Pasture in regeneration</td>
<td>20</td>
<td>12</td>
<td>34</td>
<td>0</td>
<td>1</td>
<td>67</td>
<td>34/67 = 0.5</td>
<td>33/67 = 0.49</td>
</tr>
<tr>
<td>Clouds</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>958</td>
<td>0</td>
<td>959</td>
<td>958/959 = 0.99</td>
<td>1/959 = 0.001</td>
</tr>
<tr>
<td>Road</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>7</td>
<td>32</td>
<td>40</td>
<td>32/40 = 0.8</td>
<td>8/40 = 0.2</td>
</tr>
<tr>
<td>Total</td>
<td>215</td>
<td>83</td>
<td>42</td>
<td>965</td>
<td>50</td>
<td>1355</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Producer's accuracy</th>
<th>Pasture/Forest = 0.87</th>
<th>Clouds/Road = 0.81</th>
<th>Road/Total = 0.99</th>
<th>Overall accuracy: 1282/1355 = 0.94</th>
</tr>
</thead>
<tbody>
<tr>
<td>Omission error</td>
<td>27/215 = 0.13/83</td>
<td>8/42 = 0.19</td>
<td>7/965 = 0.073</td>
<td>Kappa: 0.88</td>
</tr>
</tbody>
</table>

Table 6
Comparison of area (ha) and percentage of study area in each land cover class, analyzed by year. Changes in each class were calculated for two time periods, 1977–2000 and 2000–2011.

<table>
<thead>
<tr>
<th>Land cover type</th>
<th>Extent of land cover by time frame</th>
<th>Change between time frames</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>ha</td>
<td>%</td>
</tr>
<tr>
<td>Forest</td>
<td>4152</td>
<td>87.4</td>
</tr>
<tr>
<td>Pasture</td>
<td>5812</td>
<td>12.2</td>
</tr>
<tr>
<td>Road</td>
<td>16.7</td>
<td>0.4</td>
</tr>
<tr>
<td>Pasture in regeneration</td>
<td>n/a</td>
<td>n/a</td>
</tr>
<tr>
<td>Total</td>
<td>4750</td>
<td>100</td>
</tr>
</tbody>
</table>

the classification results, we calculated that in any of the three time frames the forest cover represented >70% of the study area, specifically 87.4% (4152 ha), 70.2% (3335 ha), and 71.5% (3397 ha) of the total area for years 1977, 2000, and 2011, respectively (Table 6). Pasture cover increased during 1977–2000 from 12.2 to 28.1% and decreased during 2000–2011 from 28.1 to 14.4%. The total area covered by roads increased slightly from 1977 to 2000, by 1.2%, and from 2000 to 2011, by 0.2% (Table 6). Since pasture in regeneration class was only produced with IKONOS satellite image classification, we could not include it in the temporal analysis. For 2011, this land cover class represented 12.3% of the study area, but this area estimation may be confounded by the low user’s accuracy for this class (0.5; Table 5), as derived from the IKONOS satellite image.

While the forest cover was >70% in all three time frames, the analysis of transitional patterns in land cover change by time frame showed that in 2011 only 50% of the study area was represented by forest cover unchanged since 1977. Ten percent of the forest cover was converted to pasture, while a similar extent of the forest cover transitioned to pasture in regeneration stage by 2011 (Fig. 4). The calculation of change from forest to pasture in regeneration may be confounded by the low user’s accuracy for the pasture in generation class (0.5; Table 5). We consider this class important from a conservation standpoint (transition to forest is ongoing) thus we retained it in this analysis, but we present it in the context of changes to pasture, a class that had higher classification accuracy (0.85 ± 0.11). Other regions experienced reversed changes from pasture in 2000 to forest in 2011, thus by comparing only initial (1977) and final (2011) land cover types, the extent of forests unaffected by
Fig. 3. Classifications of aerial photographs (1977 and 2000) and IKONOS satellite image (2011). Due to lack of detail of aerial photographs, the class pasture in regeneration was used only for IKONOS satellite image classification.

Table 7
Type and size of priority areas selected within river buffers, summarized by land cover class (based on IKONOS 2011 satellite image classification). The percentages are calculated relative to the total surface of the study area (4750 ha).

<table>
<thead>
<tr>
<th>Land cover class</th>
<th>Management proposal</th>
<th>Area within river buffers (ha)</th>
<th>Percent of total study area</th>
</tr>
</thead>
<tbody>
<tr>
<td>Montane forest</td>
<td>Conservation</td>
<td>2184.6</td>
<td>46</td>
</tr>
<tr>
<td>Pasture</td>
<td>Restoration</td>
<td>260.7</td>
<td>5.5</td>
</tr>
<tr>
<td>Pasture in regeneration</td>
<td>Restoration</td>
<td>348.9</td>
<td>7.3</td>
</tr>
<tr>
<td>Road</td>
<td>Restoration</td>
<td>36.1</td>
<td>0.7</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>2830.3</td>
<td>59.5</td>
</tr>
</tbody>
</table>

Farming would have been overestimated. Reforestation of pasture cover in 1977 occurred on about 6% of the study area by 2011 (Fig. 4).

3.3. Identifying critical areas for conservation of endangered and vulnerable amphibians

We outlined areas of conservation and restoration priority by overlapping the 2011 IKONOS derived land cover map with the limits of Reserva Las Gralarias and Socio Bosque program, the riverine habitat (200 m buffers around 33 digitized rivers and streams), and the presence records of endangered and vulnerable amphibians (Fig. 5). We identified a limited number of regions that qualified as areas for conservation, especially in the core region of Reserva Las Gralarias and in the southern part of the study area. Most of the regions outlined in this study qualified as areas for restoration, whereby conversion of patches of pasture or pasture in regeneration to forest would be required (Fig. 5).

Overall, we identified 2830.3 ha of conservation and restoration priority, representing 59.5% of the entire study area (Table 7). Most of the patches outlined fall in the area for conservation category (2184.6 ha; 46%; Table 7).

4. Discussion

Multiple factors are involved in amphibian population declines (Kiesecker et al., 2001; Lips et al., 2005). We focused on the major effect of land cover change, with the main goal of illustrating the role of GIS and remote sensing techniques as tools for analyzing such changes that could affect amphibians. We analyzed land cover changes at three points in time, over a 34-year period (1977–2011), in the area of Reserva Las Gralarias and adjacent private, multi-use lands. This area encompasses a region that contains 12 species of amphibians listed as threatened by IUCN (Guayasamin et al., 2014). Our aim was to inform conservation efforts by providing an understanding of historical land cover changes, as well as incorporating current herpetological and geographical information available for this area.

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The supervised classification of IKONOS satellite imagery and aerial photographs had high accuracy for forest and pasture classes (> 80%, except for forest class in 2000, at 74%). Overall, classification using the minimum distance for aerial photos and maximum likelihood for the IKONOS satellite image generated thematic maps with relatively good reliability (overall classification accuracy ≥ 80%; kappa statistic ≥ 0.63). We were able to discriminate well up to three land cover classes in both the aerial photos and in the IKONOS satellite image. A fourth class derived from IKONOS image only, pasture in generation, had the lowest user's accuracy (0.5; Table 5).

The analysis of land cover changes among three time frames, over 34 years (1977–2011), represented the basis for assessing the potential deterioration of amphibian habitat at a landscape scale. Our study showed that, over three decades, the montane forest cover was preserved in about 50% of the region of Reserva Las Gralarias and adjacent lands, although forest represented over 70% of the study area in each time frame analyzed. A visible decrease in montane forest cover took place during 1977–2000, but this trend slowly reversed during 2000–2011. It is important to note that the first period coincides with the implementation of the agrarian reform and colonization program that occurred during 1960–1990 (Gondard and Mazurek, 2001). This program, promoted by the Ecuadorian government, consisted of turning forests into “productive land” and stimulating agricultural expansion (Gondard and Mazurek, 2001), and it is likely partially responsible for the forest loss in the region. However, it is difficult to assess how these changes in forest cover contributed to amphibian declines in the study area because no amphibian demographic studies were conducted during 1977–2000. On the other hand, the increase in mountain forest cover observed over 2000–2011 could be related to the implementation of private conservation initiatives that have been thriving in the study area in the last decade (Toral et al., 2002). In particular, the transition from pasture to forest or to pasture in generation, totaling 24% of the study area in 2011, represents a change in the land management that could positively affect persistence of amphibians. In addition, forest regeneration may have been promoted by the opening of alternate and faster roads (e.g., Calacalí-La Independencia road), which have re-directed human land use patterns out of the study area.

The recovery rate of montane forest cover may be enhanced in the near future by the great potential for assisted and natural forest regeneration derived from both public and private initiatives. In 2008, the Ministry of Environment of Ecuador
MAE established the Socio Bosque program. This initiative consists of providing direct monetary incentives to landowners to conserve forests and other natural ecosystems and seeks to maintain biodiversity, reduce carbon emissions from deforestation, and reduce poverty in rural areas (MAE, 2012). In addition, in recent years a growing number of private protected areas have been established in the high Chocó region (independently or associated to Socio Bosque program), that have been dedicated to habitat conservation and restoration, tourism, or ecological research (MAE, 2012).

The ongoing process of forest conservation and regeneration in the region, combined with other specific actions for the conservation of amphibians, may lower the probability of amphibian extinctions in the future. For example, it is well known that semi-aquatic organisms such as amphibians depend on both aquatic and terrestrial habitats to complete their life cycle and maintain viable populations (Burke and Gibbons, 1995; Semlitsch and Bodie, 2003). However, environmental policies and regulations in Ecuador tend to focus only on the protection of rivers or arbitrarily defined portions of the adjacent terrestrial habitat (Echeverría, 2008). Terrestrial habitats adjacent to rivers are usually not protected, in part because of lack of a clear understanding of distances from river banks that are biologically relevant to maintaining wetland and river fauna (Semlitsch, 1998), as well as ecosystem functions and services. Such information is critical for delineation of terrestrial “buffer zones” for rivers, and thus for conservation of semi-aquatic organisms (Semlitsch, 1998).

To assist the habitat preservation for 12 endangered and vulnerable amphibian species, we generated a priority map based on the overlap of the 2011 IKONOS derived land cover classes with river buffers that delineated 200 m of habitat around streams and rivers, following recent recommendations (Burke and Gibbons, 1995; Ficetola et al., 2009; Roe and Georges, 2007; Semlitsch and Bodie, 2003). The map outlines specific areas for conservation and restoration that would benefit amphibian communities (Fig. 5), which may promote conservation initiatives that are centered on protecting am-

Fig. 5. Map showing priority areas within the 200 m buffers around digitized rivers and streams. These areas are proposed in the present study to either conserve (A; dark gray) or restore (B; light gray and white) habitat for endangered and vulnerable amphibians in the greater region of Reserva Las Gralarias.
Fig. 6. Location of patches of forest that have not been converted to pasture 1977–2011, within the 200 m buffers around digitized rivers and streams. In this study, these patches are identified as of priority conservation for amphibians in the greater region of Reserva Las Gralarias.

In the region studied, if the land cover transitions that have occurred within the river buffers are considered, within areas for conservation, priority could be given to patches of forest that have not been converted to pasture throughout the three decades analyzed here (Fig. 6), since they would not require restoration investments. These patches amount to approximately 1550 ha, representing 55% of the total area of river buffers outlined for conservation and restoration. The near contiguous forest areas in the southern and northeastern part of the region studied could be of particular interest for future conservation initiatives.

More broadly, the recognition that terrestrial habitat is vital for semiaquatic species (Gibbons, 2003) implies that conservation focusing only on aquatic habitats is not sufficient. It has been shown that large terrestrial buffers are needed for terrestrial life stages of semiaquatic species (Burke and Gibbons, 1995; Crawford and Semlitsch, 2007; Denoël and Ficetola, 2008; Semlitsch, 1998). Furthermore, different life stages require different landscape components, and permeable corridors are needed for maintenance of population processes (Ficetola et al., 2009). Therefore, a landscape-based approach should expand on the habitat approach (Joyal et al., 2001; Roe and Georges, 2007). The former may be complex because different landscape elements require different spatial extents. Nevertheless, a shift of attention toward the management of different elements is necessary for the long-term persistence of semiaquatic populations (Semlitsch and Bodie, 2003).

5. Conclusions

The integration of GIS and remote sensing techniques facilitated both quantifying land cover changes that threaten amphibian habitats and prioritizing areas for conservation and restoration. Such an assessment provides conservation planners and natural resource managers with specific information on the location and size of the candidate areas for restoration and protection. This strategy could improve the allocation of financial resources at both broad and local scales. However, to further refine conservation prioritization initiatives, additional information is needed, for example to correlate the change of landscape and the loss of species with water quality and environmental parameters, and possibly carry out comprehensive studies on the presence of invasive species, amphibian diseases (e.g., infection by the fungus Batrachochytrium dendrobatidis), and effects of global warming (Lips et al., 2005; Young et al., 2001). Finally, frequent amphibian monitoring is necessary to ultimately create an adaptive management framework to understand how these variables, as well as land management and restoration initiatives, influence amphibian population survival.
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References


Martín Torrijos, L., 2011. Rainbow trout (Oncorhynchus mykiss) as a threat to amphibian populations. Universidad Internacional Menéndez Pelayo, Madrid, Spain.


Sierra, R., Cerón, C., Palacios, W., Valencia, R., 1999. Mapa de vegetación del Ecuador Continental 1:1’000.000. GEF, Quito, Programa INEFAN/GEF-BIRF, Nicaragua.

Wildlife Conservation Society and Escoczia.


