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New Mining Concessions Could Severely Decrease Biodiversity and Ecosystem Services in Ecuador

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Abstract

Ecuador has among the world's highest biodiversity, despite being a tiny fraction of the world's land area. The threat of extinction for some of this biodiversity has dramatically increased since April 2016, during which time the Ecuadorian government has opened around 13% of the country to mining exploration, with many of the concessions in previously *protected forests*. Herein, we describe the system of protected lands in Ecuador, their mining laws, and outline the scale of threat by comparing the mammals, amphibians, reptiles, birds, and orchids from several now threatened protected areas, classed as "Bosques Protectores," in the northwestern montane cloud forests. Together, these reserves form a buffer and a southern corridor for the still-protected Cotacachi-Cayapas Ecological Reserve, which is otherwise now surrounded by mining concessions. We gathered published literature, "gray literature," information from reserve records and websites, and our previously unpublished observations to make comparative species tables for each reserve. Our results reveal the potential losses that mining could cause: eight critically endangered species, including two primates (brown-headed spider monkey and white-fronted capuchin), 37 endangered species, 153 vulnerable, 89 near threatened, and a large number of less threatened species. Our data show that each reserve protects a unique subset of taxa in this region of highly localized endemics and the reserves also generate sustainable income for local people. The short-term national profits from mining will not compensate for the permanent biodiversity losses, and the long-term ecosystem service and economic losses at the local and regional level.

Keywords

birds, bosque protector, cloud forest, copper mining, endangered, orchids, Reserva Los Cedros, Sistema Nacional de Áreas Protegidas

Introduction

New Mining Concessions in Ecuador

During the years of 2016 and 2017, the Ecuadorian Ministry of Mining increased exploratory mining concessions across the country from roughly 3% to around 13% of the country's continental land area (Vandegrift et al., 2017). If exploration or exploitation occurs, these new concessions will significantly decrease forest protected areas, given that more than 30% of the total land area protected by Bosques Protectores (BPs) is included in new exploratory mining concessions (Vandegrift et al., 2017). The majority of the concessions are located in the hyperdiverse Andean Forest Zone, composed of montane and

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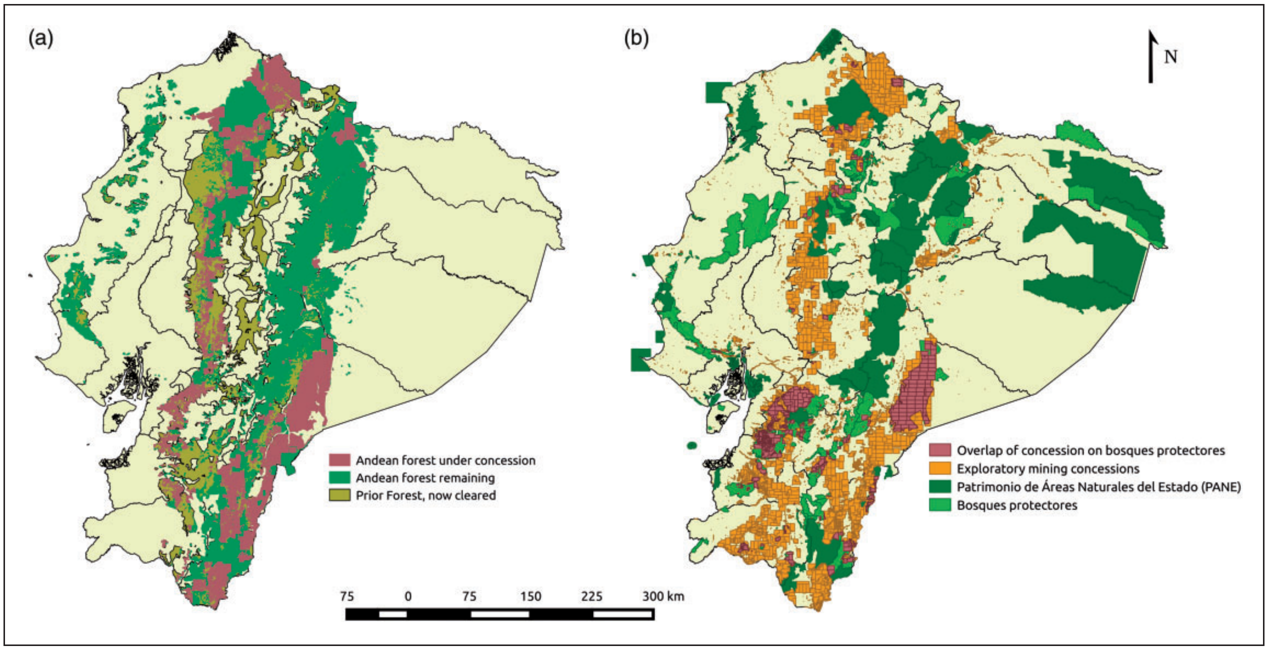

Figure 1. Maps showing the overlap between mining concessions and extant Andean forests and protected areas. In (a), the Andean forest zone is shown, with deforested areas (yellow green), existing forest (dark green), and existing forest under mining concession (plum red). In (b), mining concession are shown in yellow; national protected areas (Patrimonio de Áreas Naturales del Estado, PANE) are shown in dark green, Bosques Protectores (BPs) are in light green, and the overlap of mining concessions with BPs is shown in purple. Since January 2018, the government has annulled some concessions (often ones that had no mining interest), and additional concessions have also been granted, but they have not made the changes public, nor updated their website, so these maps are approximately but not perfectly correct. Figure 1(a) used with permission from (Vandegrift, Thomas, Roy, & Levy, 2017). Data are from Ecuadorian Ministry of Mines (2017) and Ecuadorian Ministry of the Environment (MAE, 2017).

cloud forests (Figure 1(a)), the eco-region with the highest biodiversity in the region (Gentry, 1992; Leon-Yanez et al., 2012), and one of the most threatened eco-regions on the planet (Myers, Mittermeier, Mittermeier, da Fonseca, & Kent, 2000). These new mining concessions also overlap strongly with International Bird and Biodiversity Areas, another strong indicator of biodiversity (Vandegrift et al., 2017).

The exploration and exploitation phases of metal-mining decrease biodiversity primarily through deforestation (Figure 2(a)), disturbance from road construction, and associated river sedimentation (Asner et al., 2010; Bolton, 2009; Gross, 2017; Sonter et al., 2017). Forest cover is of key importance for both water quantity and quality. Forests capture water, filter it, slow its movement through the landscape, and are themselves important for generating the clouds that produce the rain (Brauman, Daily, Duarte, & Mooney, 2007; Bruijnzeel, 2004; Foley et al., 2005). Water quality is best measured by aquatic macroinvertebrates because they live in the water and integrate both its physical and chemical environments (Rios-Touma, Acosta, & Prat, 2014). A recent study of macroinvertebrates showed that water quality was excellent in Andean streams only when the headwater catchments were unlogged with undisturbed native vegetation cover of $>70\%$ (Iniguez-Armijos, Leiva, Frede, Hampel, & Breuer, 2014).

Deforestation reduces inputs of leaf litter into streams, changing energy inputs to the streams and shifting trophic structure toward algal-based autotroph systems in Montane Choco-Andean Streams (Encalada, Calles, Ferreira, Canhoto, & Graca, 2010), leading to diminished aquatic macroinvertebrate and fish assemblages (Allard, Popee, Vigouroux, & Brosse, 2016; Teresa & Casatti, 2012). Moreover, after deforestation, mercury mobilization from soil is the main source of methylated mercury in aquatic systems in the northern Amazon basin (Roulet et al., 2000), with enormous negative effects on aquatic life and human health (Webb, 2005). Landslides, soil loss, increased stream sediments, and changes in stream flows are additional problems that result from deforestation, see Figure 2 (Molina, Vanacker, Balthazar, Mora, & Govers, 2012; Restrepo & Vargas, 1999; Roering, Schmidt, Stock, Dietrich, & Montgomery, 2003).

For Some Organisms, Ecuador is the Hottest Hotspot of Biodiversity in the World

The tropical Andes of Ecuador are at the top of the world list of biodiversity hotspots in terms of vertebrate species,

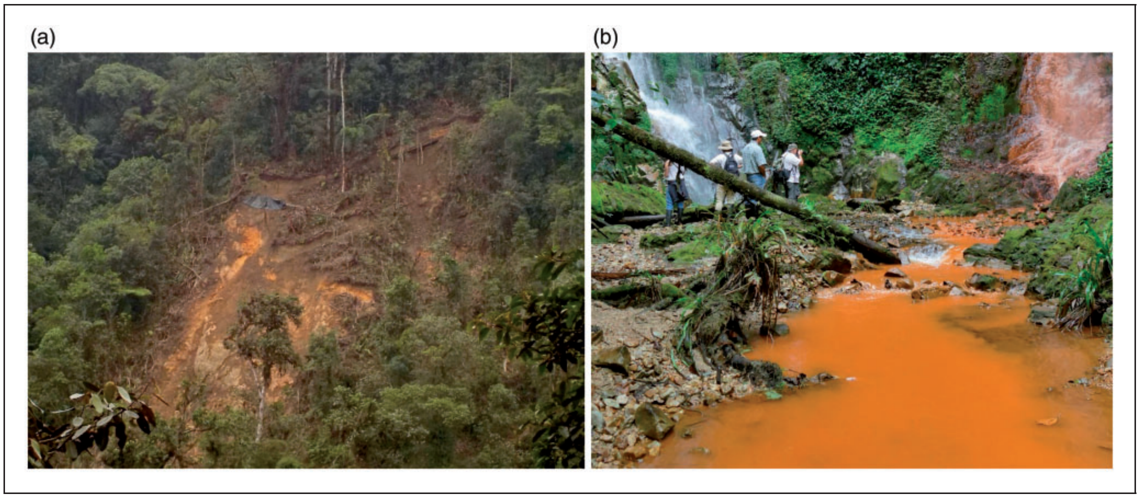

Figure 2. Consequences of mining exploration. (a) Image of deforestation and landslide associated with mineral exploration in the Intag Valley, Ecuador, taken in September 2017. Photographer: P. Gualotuña. (b) Water quality degradation (waterfall to right compared to left) caused by the exploration activities of Corporación Nacional del Cobre de Chile (CODELCO) in the Junín Community Cloud Forest Reserve in late 2017. Photographer: C. Zorrilla.

endemic vertebrates, and endemic plants (Myers et al., 2000). Biodiversity increases toward the equator and decreases toward the poles (Brown, 2014). Roughly half of all plant species occur in tropical forests that represent only 7% of the world's total land surface area (Eiserhardt, Couvreur, & Baker, 2017). Tree diversity is highest in the tropical lowlands of the Amazon basin, including Ecuador's Amazonia, whereas nontree vascular plant diversity is concentrated in the highly dissected mountainous terrain and cloud forests of Northwestern South America, largely due to the high levels of endemism in such terrain (Gentry, 1992; Jørgensen & Léon-Yánez, 1999; Leon-Yanez et al., 2012; Ulloa et al., 2017). The persistently foggy and rainy forests of the NW are speciose with epiphytes, such as orchids and bromeliads (Gentry & Dodson, 1987; Kuper, Kreft, Nieder, Koster, & Barthlott, 2004). Several other taxa have higher diversity in the cloud forest zone relative to either higher or lower elevations as well, including moths (Brehm et al., 2016), frogs (Willig & Presley, 2016), caddisflies (Ríos-Touma, Holzenthal, Huisman, Thomson, & Rázuri-Gonzales, 2017), and tree ferns (Ramirez-Barahona, Luna-Vega, & Tejero-Diez, 2011). Ecuador is divided by two main Andean ranges, the Cordillera Occidental and the Cordillera Real (Oriental), each with cloud forest zones that differ in floristic composition and that harbor specialized microhabitats with narrow endemic species (Jørgensen & Léon-Yánez, 1999).

Equatorial regions are diverse, to a large degree, because there is a constant supply of energy from the direct angle of the sun and high rainfall as a result of heating (Kreft & Jetz, 2007). Water supply and energy drive about 70% of the variation in species diversity (Kreft & Jetz, 2007). However, some diversity can also be ascribed to habitat stability. Both fossil and phylogenetic methods suggest that some lineages have been present for 67 to 115 million years, indicating climatic stability and low extinction rates (Eiserhardt et al., 2017). Juxtaposed with the stability of climate at the low elevations, the Andes' recent uplift, steep elevation and climatic gradients, and spatial complexity, have led to dramatic shifts in species composition on short spatial scales (Kreft & Jetz, 2007). The rapidity of the uplift of the Andes has also increased speciation by opening up new niches, and by forming physical and climatic barriers to gene flow (Bell, 2004; Eiserhardt et al., 2017; Hughes & Eastwood, 2006; Kreft & Jetz, 2007; Scherson, Vidal, & Sanderson, 2008). Thus, the Neotropics are acting both as a *museum of biodiversity* accumulated over a long time in the lowlands, and as a *cradle of new adaptations* and speciation spurred by the uplift of the Andes (Kreft & Jetz, 2007).

The spatial complexity that is partially responsible for Ecuador's hyperdiversity also represents a particular vulnerability to land-use changes such as those proposed by the mining concessions. Many Andean species have very limited ranges due to a combination of microclimatic and topographical barriers reducing dispersal (Eiserhardt et al., 2017; Hughes & Eastwood, 2006). For example, 27% of the known plants in Ecuador are endemic, and many of the endemics are known from only one or a few localities in a single province, and are thus not found anywhere else in the world (Jørgensen & Léon-Yánez, 1999; Leon-Yanez et al., 2012; Valencia, Pitman, León-Yánez, & Jorgensen, 2000). The rates of endemism are greater in the mountains than in the lowlands that they straddle (Borchsenius, 1997; Pitman & Jorgensen, 2002). With such spatially limited endemism, even a single mining project threatens the survival of species, such as the critically endangered longnose harlequin frog (*Atelopus longirostris*), which is in danger of extinction by the Llurimagua mining project (Tapia, Coloma, Pazmiño-Otamendi, & Peñafiel, 2017).

Protected Lands in Ecuador

There are several major types of protected areas in Ecuador (Horstman, 2017; López-Rodríguez & Rosado, 2017; Ministerio del Ambiente [MAE], 2014). The Ecuadorian constitution (Art. 405) mandates the creation of "subsystems" within a National System of Protected Areas Sistema Nacional de Áreas Protegidas = (SNAP; MAE, 2014). The following categories, including PANE, (Patrimonio de Áreas Naturales del Estado) are technically all considered subsystems of SNAP. However, comprehensive management has not yet expanded beyond those included in PANE.

1. Heritage Natural Areas (PANE, including National Parks, are set aside and funded by the Ecuadorian national government and run as public institutions).
2. Areas of Forest and Protected Vegetation (Áreas de Bosque y Vegetación Protectora = BP) are recognized by the national government but not funded by it. Recognition by the government of BPs enables legal support when conflicts in land use occur, including help with illegal logging and squatters (Horstman, 2017).
3. Private reserves are not regulated by the national government, nor funded by it. However, some national programs exist to promote the conservation of forests by private landowners, such as the successful Socio Bosque program (Krause & Loft, 2013).
4. Community reserves are private reserves that are owned and managed by the community, a legal entity that is particularly common in indigenous areas.
5. Local government reserves are owned and managed by provincial, municipal, or parish governments. In NW Ecuador, forested watershed reserves owned by parishes have become increasingly common, but management practices vary due to the lack of oversight from the national government (Knee & Encalada, 2014).

There are numerous habitats and associated biodiversity that are underrepresented in the PANE system, but three stand out in particular as needing more protection: coastal dry forests, which are located near population centers (Horstman, 2017), and the forests of southern and western Ecuador (Borchsenius, 1997; Sierra, Campos, & Chamberlin, 2002). The forests of the west, including cloud forests, have been largely deforested, with some sources estimating a loss of 75% or more (Gonzalez-Jaramillo et al., 2016; Myers et al., 2000; MAE, 2015). A large portion of the remaining west-side forest is in BPs (Figure 1), and now >30% of these are under threat due to new mining concessions. Figure 1(a) shows how the concessions disproportionately affect the southern and northwestern regions of the Andes, the areas with the highest biodiversity.

BPs arose in the late 1980s, with the enactment of the National Forestry Law (Horstman, 2017). While typically smaller than the nationally protected PANE areas, BPs are still often relatively large (averaging 13,155 ha), and in total they currently make up about one third of protected lands in Ecuador (Vandegrift et al., 2017). Because they cover a wide diversity of habitats, even small BPs are of great importance for protecting a diversity of endemic species, which are typically found at only a few localities (Borchsenius, 1997). In addition to BPs, the Ministry of the Environment manages the Socio Bosque program, where landowners are paid up to $30/ha to conserve native forests on their land. Private reserves and community reserves often fail to qualify for formal status as protected areas but represent a significant portion of conserved land in Ecuador. In the Intag Valley, the local organization DECOIN (Organización de Defensa y Conservación Ecológica de Intag) has helped 38 communities purchase and manage community reserves, leading to the protection of some 12,000 ha (28,650 acres) of land (Veintimilla, 2017), including the Junín Community Cloud Forest Reserve (discussed later).

Mining and Environmental Legislation

Metal mining in Ecuador has historically been small-scale and artisanal, the majority of it concentrated in the south of the country. Ecuador's mining legislation was correspondingly rudimentary and was not well defined until 1937, when subsoil metals were named property of the state. Environmental legislation specific to mining was absent from Ecuador until new laws came into effect in 1991. This legislation limited the granting of concessions in protected lands and mandated environmental impact assessments for all mining activities. In 1994, the World Bank funded the Project for Mining Development and Environmental Control (Spanish acronym: PRODEMINCA) with the aim of developing the Ecuadorian mining sector (Davidov, 2013). The project collected mineralogical information from 3.6 million ha of mostly western Ecuador, including seven protected regions. The regulatory recommendations made by PRODEMINCA were codified into law in 2000, identifying mining as a national priority and significantly deregulated the sector (Congreso Nacional, 2000). However, under the revamped regulations, mining development remained prohibited in government protected areas

(Tarras-Wahlberg et al., 2000), which have thus far been interpreted to be only the PANE protected areas described earlier, leaving the BPs vulnerable.

The next major changes occurred with the adoption of Ecuador's new constitution in 2008, which included the Mining Mandate that reverted the majority of mining concessions to state ownership (Wacaster, 2010). The new constitution also included the historic decision to give nature inherent rights (Articles 71–74, Asamblea Nacional, 2008). However, the new laws also allowed mining in protected areas by special request of the president and approval by the National Assembly. In 2009, the government of Rafael Correa authored a new Mining Law, which increased regulation on mining companies. While the law did augment some environmental standards, it was met by widespread protests by indigenous and social movements that had hoped for stronger environmental and social guarantees. In 2015 and 2016, the Correa government made deregulatory modifications to the mining law to incentivize foreign investment. These changes included decreasing the corporate tax rate and windfall tax on mining companies (Unda, 2017). This made the acquisition of mining concessions much easier, leading to the bidding and auctioning of mineral concessions in State possession throughout that year (Ministry of Mines, 2016), and resulting in the recent increase in granted concessions (Figure 1).

A More Sustainable Way Forward

Responsible development of the region's infrastructure with an eye for long-term sustainability, education, ecotourism, and research represents a much more sustainable way forward for Ecuador's last uncut forests, and the people who call them home (Asquith, Vargas, & Wunder, 2008; Kocian, Batker, & Harrison-Cox, 2011; Pozo, Aguirre, & López, 2016; Welford & Barilla, 2013). In fact, stable local businesses already exist adjacent to many BPs, and these are increasingly productive due to the regional expansion of agriculture, including shade-grown coffee, and ecotourism has also experienced steady growth (Kocian et al., 2011). This economic activity typically involves community members of all ages and genders. This is in sharp contrast to the effects of mining, which typically creates a short-term economy that ends when the mines close, and with 95% of the jobs being held by men (Walter, Tomás, Munda, & Larrea, 2016).

In the rest of this review, we illustrate the major role that BPs are playing in preservation of biodiversity and related ecosystem services, while also serving as a sustainable engine for local economies. To illustrate the biodiversity, we have built comparative species lists from several reserves in the exceptionally biodiverse Chocó and Tropical Andes regions of NW Ecuador. We also briefly indicate how each reserve is benefiting the local economy.

Methods

The BPs

The medium and large BPs discussed herein are shown in Figure 3(a). They lie just to the South of the Cotacachi-Cayapas Ecological Reserve, and include: Los Cedros, 68% in concession, El Chontal, 95% in concession, Mashpi, 96% in concession, and Maquipucuna, 36% in concession. Two of the reserves, Los Cedros and El Chontal, share a border with the nationally protected Cotacachi-Cayapas Ecological Reserve. Since BP El Chontal is so poorly explored and has virtually no published data, we used several other small reserves (<500 ha) in the Intag Valley from which we could find data to gain an idea of the biodiversity in that region (BP La Florida Cloud Forest Reserve (La Florida), El Refugio de Intag Lodge (El Refugio), and the Junín Community Cloud Forest Reserve (Junín), see Figure 3(b). Hereafter, we will refer to this set of reserves as the Intag.

Data collection

Species lists were assembled for all the reserves for mammals, birds, amphibians, and reptiles (Online Appendices 1–4). The orchids were assembled for the two reserves with specimen vouchered data (Maquipucuna and Los Cedros, Online Appendix 5), and a partial list of plants was assembled for Los Cedros, primarily from published papers, but also including some previously unpublished data (Online Appendix 6). Plant nomenclature follows that of the Tropicos (2017) plant database.

To assemble the bird table, we used records from eBird for each of the localities for which these lists existed (Los Cedros (eBird, 2017a), La Florida (eBird, 2017b), Maquipucuna (eBird, 2017c), Mashpi (eBird, 2017d), and El Refugio (eBird, 2017e)). eBird is an open access dataset vetted by local experts who verify the occurrences, it uses a standardized format, and the data are now being used to designate Important Bird Areas (IBAs; Sullivan et al., 2017). All taxonomy follows the Clements system used by eBird. When a locality has more than 300 bird species, then eBird colors the locality red, indicating the hottest kind of hotspot (eBird 2017f); hereafter, we refer to these as "red bird hotspots". In Online Appendix 2, we added in any published bird data found, if it was not yet in eBird, and additional data from the reserve managers at La Florida and El Refugio. For common bird names in English, we used eBird, for common names in Spanish we used the *Lista de las Aves del Ecuador* (Freile et al., 2015–2017).

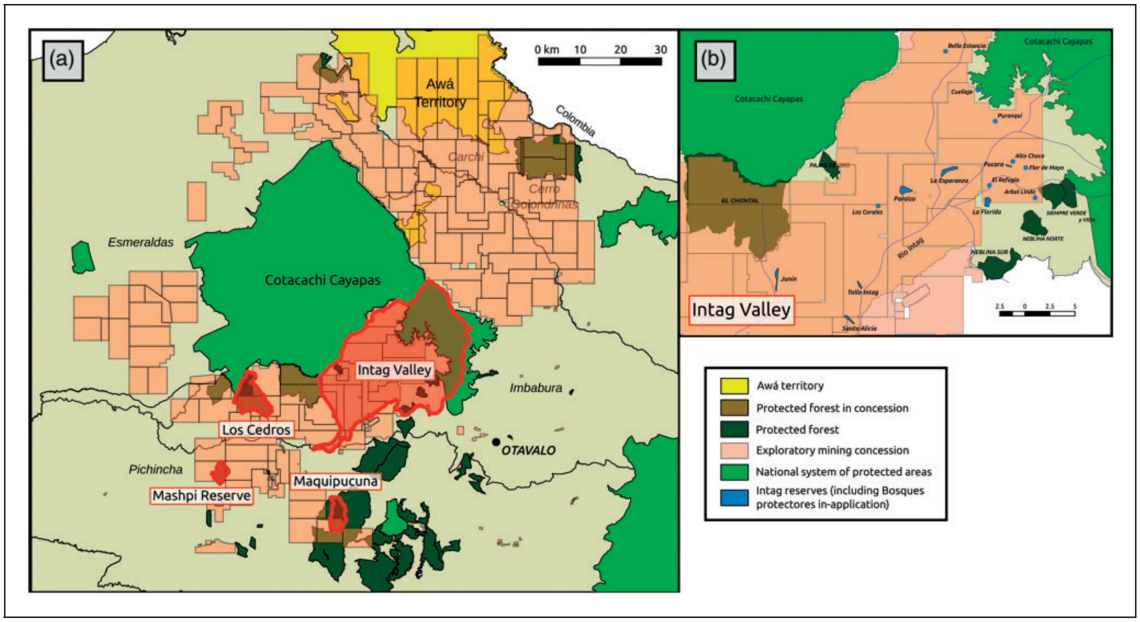

Figure 3. Maps showing the extent of the mining concessions and overlap with Bosques Protectores and Indigenous lands in the region around the Cotacachi-Cayapas Ecological Reserve. (a). The Indigenous Awá lands (yellow) are to the north and are covered by almost 70% concessions, indicated in darker yellow; indigenous lands are discussed in a different publication (Vandegrift et al., 2017). All the Bosques Protectores under discussion herein are to the South of Cotacachi; they are dark green, unless covered by a concession, then they are brown. (b) An expanded panel of the Intag Valley showing the smaller reserves in blue.

To assemble the nonbird species lists, we used reserve records when backed up by photos, videos, or experts, and we used the reserve names as keywords in Google Scholar, Web of Science, and the Google search engines to search for publications. We also searched for protected area place names in the excellent online databases for amphibians (Ron, Yanez-Muñoz, Merino-Viteri, & Ortiz, 2017), reptiles (Torres-Carvajal, Pazmiño-Otamendi, & Salazar-Valenzuela, 2017), and mammals (Brito, Camacho, Romero, & Vallejo, 2017) produced by the Museo de Zoología, Pontificia Universidad Católica del Ecuador (PUCE). We used the taxonomy and Spanish common names for all animals from these databases, and the English common names from either the Museo de Zoología websites or International Union for Conservation (IUCN; 2017).

To report endangered status, we present both national (Ecuadorian) and international IUCN (2017) data, when available, in our Online Appendices. If these databases differed, we focused the text on the Ecuadorean data because the international databases are not updated as regularly as the Ecuadorian Red lists, and because most of the endangered species in Ecuador are endemics that do not occur anywhere else, the Ecuador Red list is usually the most accurate assessment. For birds, we used the *Lista de las Aves del Ecuador* Freile et al. (2015–2017) because it is the most up to date; it does not separately list Ecuador status (because most birds are not endemic to Ecuador, the IUCN threat assessment is reasonable). For the plants, which are not well represented in the IUCN Red list, we used the Tropicos (2017) database, which incorporates information from Ecuador. For the mammals, amphibians, and reptiles, we used the Museo de Zoología databases (Brito et al., 2017; Ron et al., 2017; Torres-Carvajal et al., 2017), which list both the Ecuadorean and IUCN threat status. All the databases use the IUCN graduated system of endangered status (IUCN, 2017), ranging from threatened to extinct: NT = near threatened, VU = vulnerable to extinction, EN = endangered, CR = critically endangered, EW = extinct in the wild, EX = extinct. There are three other categories not included as endangered in our lists: LC = least concern, DD = data deficient, and NE = never evaluated. We note, however, that quite often organisms that are in the DD or NE categories are also endangered, they simply have not been assessed yet (NE) or there is insufficient data to assess them (DD), which is often an indication of at-risk status.

Finally, for each reserve, we summarize its economic influence on the communities around it.

Results

Los Cedros (0° 18′35.62″N, 78° 46′47.01″W)

The elevation of Los Cedros ranges from 980 to 2,200 m, which places it fully in the lower montane rainforest zone, also known as cloud forest (Jørgensen & Léon-Yánez, 1999). It receives 2903 ± 186 mm of rain per year at the 1,300 m elevation of the fieldstation, based on 15 years of reserve records (J. DeCoux, personal communication), but at higher elevations, there is considerably more rain. Los Cedros is the most remote of the reserves detailed here; it takes 6–7 hr to get there from Quito, including a 2-hr mule ride. Sixty-eight percent of its 5,256 ha of protected cloud forest have recently been put into mining concessions. Candidate areas for copper-containing porphyries in the reserve were identified by aeromagnetic surveys, conducted without permission of the landowners. Prospectors are currently attempting land-based incursions into the reserve, again without permission. Los Cedros is not accessible by road, and for this reason has been, until now, both better protected, and less scientifically explored than some other BPs.

Species. Los Cedros is known to protect at least 178 species with high extinction risks (CR = 2, endangered, EN = 24, vulnerable, VU = 99, and near threatened, NT = 53) see Table 1 and Online Appendices 1–6). Its remoteness is why it still has three species of monkey: the CR brown-headed spider monkey, *Ateles fusciceps fusciceps,* the VU white-headed capuchin, *Cebus capucinus*, and the EN-mantled howler monkey, *Alouatta palliata*, as well as the VU Andean Spectacled Bear, *Tremarctos ornatus* (Online Appendix 1). Remoteness and high-quality habitat also explain why there are six species of cats, including the CR Jaguar, *Panthera onca*, the VU Oncilla, *Leopardus tigrinus*, and the NT Margay, *Leopardus wiedii*. Jaguars are now extremely endangered in western Ecuador due to habitat loss and need for large territories (de la Torre, González-Maya, Zarza, Ceballos, & Medellín, 2017; Mendoza, Cun, Horstman, Carabajo, & Alava, 2017; Zapata-Ríos & Araguillin, 2013). Jaguar has been reported from Los Cedros (BirdLife International, 2017), and a Jaguar was recently photographed in nearby (<5 km) Manduriacu Reserve (Jost, 2016) on the Manduriacu river, which originates in Los Cedros. Jaguars are also known from the adjacent Cotacachi-Cayapas Ecological Reserve (Zapata-Ríos & Araguillin, 2013). Prey include the VU Little Red Brocket Deer, which—along with other prey such as the agouti, peccary, and monkeys—are rapidly hunted out of reserves by people when there are nearby roads.

Los Cedros is a red bird hotspot (eBird, 2017a), and by itself forms an IBA (EC039, BirdLife International, 2017). Of the 309 bird species seen at Los Cedros (Online Appendix 2), at least 26 are endangered, vulnerable, or near threatened due to habitat loss, even before the latest mining concessions. Many of the birds at Los Cedros are found only in the cloud forests of the Chocó region (BirdLife International, 2017; Cooper, Gelis, Ridgely, Freile, & Jahn, 2006) and include very recently described species such as the cloud-forest pygmy owl, *Glaucidium nubicola* (Freile & Castro, 2013). In addition, these forests harbor a number of vulnerable and near threatened Neotropical migrants that summer in Canada and the United States, such as cerulean warblers, *Setophaga cerulean,* and olive-sided flycatchers, *Contopus cooperi*, whose populations depend on having suitable winter habitat. Comparing the reserves being highlighted here, 23 species of birds are only found at Los Cedros and not at the other reserves, including 5 of the 26 at-risk birds (Online Appendix 2). Based on the number of reported species in nearby reserves, and habitats present, it is expected that the final list for Los Cedros will have around 400 bird species; it is less frequently "birded" than more accessible reserves.

The frogs are remarkable, almost all endangered, and found only in the local cloud forests (Online Appendix 3). For example, the recently described rainfrog, *Pristimantis mutabilis*, is only known from two streams, one of which

Table 1. The 178 species With High Extinction Risk Known to Occur at Bosque Protector Reserva Los Cedros as of March 2018.

Group	(CR)	(EN)	(VU)	(NT)	(LC)	(DD)	(NE)	Total	Unique
Orchids[a]	0	2	57	12	16	2	97	186	106
Birds	0	4	9	13	283	0	1	309	33
Mammals[b]	2	2	9	4	14	2	0	33	7
Reptiles	0	1	3	8	3	1	1	17	7
Amphibians	0	6	4	5	2	2	1	20	4
Other plants[c]	0	9	17	11	11	0	157	205	—
Total	2	24	99	53	328	8	257	770	

Note. Orange color indicates the endangered classes, in order of most endangered, as defined by the International Union for Conservation of Nature (IUCN). Unique species are those not found at any of the other areas we studied.
CR = critically endangered; EN = endangered; VU = vulnerable to extinction; NT = near threatened; LC = least concern, DD = data deficient.
[a]Understudied: About 200 more are likely (Bird Life International, 2016).[b]Bats have not yet been studied at Los Cedros. [c]Understudied; expected number of plants is over 2,000. The reserve has never been cataloged.

is at Los Cedros (Guayasamin, Krynak, Krynak, Culebras, & Hutter, 2015). This unusual frog is able to change its skin texture, a feature never before seen in frogs. Another of the rainfrogs was described from and named for Los Cedros: *Pristimantis cedros*. This species is locally common at Los Cedros but has not been collected elsewhere (Hutter & Guayasamin, 2015).

Reptiles (Online Appendix 4) and bats (Online Appendix 1) are yet to be systematically studied at Los Cedros, but incidental records indicate that they are likely to be interesting. For example, there are coral snakes (*Micrurus ancoralis*, NT) and their mimics (*Oxyrhopus petiolaris*, LC). The most endangered is the EN Ecuadorian toad-headed pitviper, *Bothrocophias campbelli*. This snake is restricted to mature or primary forests between 800 and 2,000 m and is not commonly seen in Imbabura province (Cisneros-Heredia, Borja, Proaño, & Touzet, 2006). Bats tend to be widespread without local endemics, as can be seen in Table 2, but it would still be useful to determine which bats are at Los Cedros.

The Los Cedros forest is extraordinarily rich in plant species, with at least 299 tree species/ha (Peck et al., 2010; Thomas, Vandegrift, Ludden, Carroll, & Roy, 2016). Associated with this forest are many fungi (Dentinger & Roy, 2010; Policha et al., 2016; Thomas et al., 2016), which are essential for forest growth (Vandenkoornhuyse, Quaiser, Duhamel, Le Van, & Dufresne, 2015) and decomposition (Yang et al., 2016). Two species of fungi proposed to the relatively new IUCN Global Fungal Red List Initiative, *Lamelloporus americanus* and *Hygrocybe aphylla*, are known from Los Cedros (Newman, Vandegrift, Roy and Dentinger, unpublished data), and many additional endangered taxa are anticipated. Collections made there since 2008 have resulted in several hundred morphospecies, whose precise identifications are the subject of ongoing research.

Many plants in the Los Cedros forest are local endemics with small ranges (Online Appendix 6), including several orchids only known from Los Cedros (Online Appendix 5). Los Cedros currently has 186 orchid species on its list (Online Appendix 5). Of these, 71 (38.0 %) are known to be some category of endangered (CR, EN, VU, and NT) and most are localized endemics. Seventeen of these at-risk orchids were originally described from Los Cedros, and at least seven of these have never been found elsewhere. Ninety-seven (52%) of the orchid species from Los Cedros have never been evaluated (NE) for endangerment status because they are not endemics and it is difficult to assess extinction risk across country borders (Endara & Jost, 2011). However, we note that at least a dozen of the NE species barely range into Colombia and are thus also likely threatened.

The numbers of orchid species found to date at Los Cedros (Online Appendix 5) are underestimates because of its inaccessibility; the final list is likely to be near 400 species (C. Dodson, personal communication). The absolute size of the orchid floras cannot be compared with our data, since the orchids have not been completely cataloged at Los Cedros, but we could examine the overlap of what was known at Los Cedros with the only other reserve for which orchid data were available, the better studied Maquipucuna. Los Cedros shares only 43% of its known orchid diversity with Maquipucuna. For a specific example, there are 14 species in the orchid genus *Dracula* at Los Cedros (Online Appendix 5), all of but three of which are endangered or vulnerable. Only four of the 14 *Dracula* species at Los Cedros also occur at Maquipucuna, at which only five species of *Dracula* have been recorded (Online Appendix 5; Webster & Rhode, 2001).

Note that each orchid species is associated with pollinators, which themselves are speciose and understudied. For example, studies of the mushroom-mimicking orchid

Table 2. The 70 Species With High Extinction Risk Known to Occur at Bosque Protector Mashpi as of March 2018.

Group	(CR)	(EN)	(VU)	(NT)	(LC)	(DD)	(NE)	Totals	Unique
Orchids[a]	—	—	—	—	—	—	—	—	—
Birds[b]	0	4	5	13	279	0	0	301	33
Mammals	1	2	6	5	30	4	3	51	15
Reptiles	0	2	7	9	10	1	0	29	20
Amphibians	0	2	8	6	7	8	0	31	18
Other plants[a]	—	—	—	—	—	—	—	—	—
Total	1	10	26	33	327	13	4	414	

Note. Orange color indicates the endangered classes, in order of most endangered, as defined by the International Union for Conservation of Nature (IUCN). Unique species are those not found at any of the other areas we studied.
CR = critically endangered; EN = endangered; VU = vulnerable to extinction; NT = near threatened; LC = least concern, DD = data deficient.
[a]Not yet systematically studied at the reserve. [b]There are several eBird localities near Mashpi; we used the records from the lodge and the reserve trails (i.e., not including the road in), as this is most similar to Los Cedros and Maquipucuna.

Dracula lafleurii uncovered at least 60 new species of fruit flies that pollinate it (Endara, Grimaldi, & Roy, 2010; Policha, 2014; Policha et al., 2016). These unnamed flies are related to a model organism, the common fruit fly (*Drosophila melanogaster*), which is widely used in genetics and neurobiology studies that benefit humans (Roberts, 2006).

Los Cedros protects the origins of three rivers: the Río Manduriacu, the Río Verde, and the Río Los Cedros, plus it encompasses the south bank of the upper Río Magdalena Chico. These rivers supply freshwater to people and are the habitat for an amazing diversity of life themselves. In an exploratory three-night survey, almost 40 species of caddisflies (Trichoptera) were collected, of which more than a third are probably new to science (Ríos-Touma, Morabowen, Tobes, & Morochz, 2017). Considering that this is only 1 of the 11 orders of aquatic macroinvertebrates in the area (Knee & Encalada, 2014), the potential number of novel species is enormous.

Social and economic. The field station at Los Cedros can lodge up to 40 people at a time and is visited by local and university classes, ecotourists, and scientists. It benefits the nearby communities of Magdalena Alta and Chontal with employment (guides, cooks, etc.) and by buying supplies and services there. Ecuadorian visitors and scientists are charged lower rates than tourists and foreign scientists. For the last 7 years, Los Cedros has been working on a comanagement plan with local communities and the Ministry of the Environment, but aggressive mining interests have delayed implementation. Four of eight elected members of the comanagement organization were recently employed by the concession holding company, Cornerstone. This is an extreme conflict of interest, and they have been asked to resign (reserve manager, J. DeCoux, personal communication).

Mashpi (0°9′57.17″N, 78°52′39.38″W)

The elevation of Mashpi ranges from 550 to 1,400 m and thus it encompasses both lowland tropical forest and lower montane cloud forest (Jørgensen & Léon-Yánez, 1999). The reserve website states Mashpi receives up to 6 m of rain, but to our knowledge, there is not a weather station at the lodge. Mashpi is less remote than Los Cedros—about a 3-hr drive from Quito. Ninety-six percent of its 1,178 ha are currently in mining concessions.

Species. Mashpi is known to protect at least 70 species with high extinction risk (CR = 1, EN = 10, VU = 26, and NT = 33, see Table 2 and Online Appendices 1–5). The forest at Mashpi is still in excellent condition, as indicated by the presence of two primate species, the CR white-fronted capuchin, *Cebus aequatorialis,* and the EN howler monkey, *Alouatta palliata*, as well as several cats (Table 2). Historically, Mashpi was part of the range for the critically endangered brown-headed spider monkeys (Peck et al., 2010), though they no longer occur there. The lower elevation of Mashpi compared with all the others we discuss in this region enables the presence of species that occur in warmer, lower elevation forests, such as anteaters, *Tamandua mexicana*.

Mashpi is also a red bird hotspot (eBird, 2017d), with 301 species recorded from the lodge and trail system of the reserve (Online Appendix 2). It protects a different set of birds than Los Cedros, with 33 unique species (Online Appendix 2), in part, reflecting lower elevation than the other reserves, and its combination of montane tropical and lower cloud forests. We note that if the larger conservation area (17,200 ha vs 1,178 ha) of the Area of Conservation and Sustainable Use Mashpi-Guaycuyacu-Sahuangal is considered, the number of bird species increases to 450 (EC108; BirdLife International, 2018c). To be consistent among BPs, we only present lists from the reserves themselves. Of the 22 endangered bird species at Mashpi (Online Appendix 2), seven are not found at any of the other reserves examined. Perhaps the most interesting of these is the endangered Chocó vireo (*Vireo masteri*), which is only known from a few localities in Ecuador (BirdLife International, 2018d).

About half of Mashpi's observed amphibians, 15/31, are endangered, vulnerable, or near threatened, and about a third are endemic to Ecuador (Table 2, Online Appendix 3). The amphibians very clearly indicate the lower elevation of Mashpi. Eighteen of its 31 amphibians have thus far only been found there (Online Appendix 3) and not at the other reserves we are profiling, and all 18 of these have range limits mostly under 900 m (Online Appendix 3), the lower elevation limit for the other reserves included herein. Most of the lower elevation amphibians are widespread lowland forest "chocoan" species, whereas endemism and endangerment are concentrated in the higher elevation cloud forest taxa (Online Appendix 3). Mashpi is the primary home for the Mashpi stream tree frog (*Hyloscirtus mashpi*), which was described from its watershed. This frog is only known from a total of three localities and is most common at Mashpi (Guayasamin, Rivera-Correa, et al., 2015).

Of the reserves reported on here, Mashpi is the only one that has had dedicated attention paid to the reptiles and thus its list is more complete—29 species to date. Similar to the amphibians, many of the reptiles at Mashpi are reported from there and not the other reserves (18/29 or 62%, Table 2, Online Appendix 4). Warmer, lower elevations likely led to a higher number of species present, including the South American snapping turtle, *Chelydra acutirostris,* and the Northern eyelash boa, *Trachyboa boulengeri*. More than half the reptiles are endangered, including two vipers, which are usually killed when encountered by humans.

Mashpi has also paid attention to its aquatic biodiversity. Preliminary results indicate there are at least 21 fish species and up to 96 genera of aquatic macroinvertebrates, including around 60 species of caddisflies (Ríos-Touma, B., Holzenthal, R. W., Huisman, J., Thomson, R., & Rázuri-Gonzales, E. (2017)).

Social and economic. The ecolodge at Mashpi is a five-star hotel that has garnered international praise for its innovation and sustainability (Mashpi, 2018). As part of their commitment to sustainability, they use some of their profits to maintain a scientist on staff. Support of the local communities includes education opportunities, the hiring of guides and staff for the lodge and buying of supplies from local producers. Also, at San José de Mashpi, reserves like Mashpishungo and Pambiliño work in conservation, grow sustainable produce, and attain community empowerment through ecotourism.

Maquipucuna (0° 7′0.12″N, 78°37′45.23″W)

The elevation of Maquipucuna is similar to Los Cedros, ranging from 900 to 2,700 m, which places it in the lower montane/cloudforest zone (Jørgensen & Léon-Yánez, 1999). Rainfall has never been systematically measured at Maquipucuna but is likely to be at or above that of nearby Nanegalito (3,230 mm) according to Webster and Rhode (2001). Thirty-six percent of its 2,474 ha of protected land are currently in mining concessions. Of the reserves detailed here, Maquipucuna is the least remote; taking only 2 hr on developed roads from Quito. For this reason, it has more visitors and is better understood scientifically, but its wildlife and birds are adversely affected by the proximity to roads. For example, there are no longer monkeys at Maquipucuna (Online Appendix 1).

Species. Maquipucuna is known to protect at least 119 species with high extinction risk (CR = 1, EN = 15, VU = 63, and NT = 40, see Tables 3 and Online Appendices 1–5). The most interesting mammal (Online Appendix 1) is the endangered Spectacled Bear, *Tremarctos ornatus*, the only South American bear, which also occurs at two of our other highlighted reserves, Los Cedros and in the Intag Valley. When the wild avocados, *Ocotea* and *Persea*, are fruiting, the bears migrate to a few places where they are easily seen in Maquipucuna, creating a tourist attraction (Maquipucuna, 2018). About a third (9/30) of the nonbat mammals at Maquipucuna do not appear on the lists of any of our other studied reserves (Online Appendix 1). Of these, six are common LC species but two are interesting near threatened small mammals, the water opossum *Chironectes minimus* and the mountain paca, *Cuniculus taczanowskii,* and one, the beady-eyed mouse, *Thomasomys baeops*, is data deficient.

Maquipucuna is part of a larger IBA, EC042, that includes a lot of countryside surrounding it (BirdLife International, 2018b). Maquipucuna reserve is also a red bird hotspot (eBird, 2017c), with 308 species recorded from the lodge and trail system (Online Appendix 2). It protects a different set of birds than the other reserves, with 18 unique species. However, of the 11 at-risk bird species at Maquipucuna (Online Appendix 2), none are unique to Maquipucuna. Some of the endangered birds missing from Maquipucuna, but present at the other reserves, are the ground dwellers such as the banded ground cuckoo, *Neomorphus radiolosus*, and edible ones, such as the Baudo guan, *Penelope ortini,* which suffer when nearby roads facilitate illegal hunting.

Thirteen of the 20 amphibians reported from Maquipucuna are at some risk of extinction, including 10 species of frog, one toad, and one salamander (Table 3, Online Appendix 3). Similar to Los Cedros and Mashpi, Maquipucuna has a frog species,

Table 3. The 119 Species With High Extinction Risk Known to Occur at Bosque Protector Maquipucuna as of March 2018.

Group	(CR)	(EN)	(VU)	(NT)	(LC)	(DD)	(NE)	Totals	Unique
Orchids	0	1	46	15	16	2	204	284	207
Birds	0	1	4	6	297	0	0	308	18
Mammals	0	2	4	5	26	4	0	41	12
Reptiles	1	0	2	4	6	2	2	17	6
Amphibians	0	7	3	3	4	1	2	20	5
Other plants[a]	0	4	4	7	8	0	90	113	—
Total	1	15	63	40	357	9	298	783	

Note. Orange color indicates the endangered classes, in order of most endangered, as defined by the International Union for Conservation of Nature (IUCN). Unique species are those not found at any of the other areas we studied.
CR = critically endangered; EN = endangered; VU = vulnerable to extinction; NT = near threatened; LC = least concern, DD = data deficient.
[a]A flora has been completed (Webster & Rhode, 2001, 2005) but with the exception of the 284 orchids and 113 other plants shared with Los Cedros, we did not individually query each of the 1,996 species in Tropicos for endangered status; quite a few will be endangered.

Hyloxalus maquipucuna, that was discovered there and is known only from this locality (Coloma, 1995), but in this case, it is member of the poison dart frog family (Dendrobatidae) instead of being a rainfrog (Strabomantidae). Four other frog species from Maquipucuna are also not found at our other reserves (Online Appendix 3), following the pattern of localized cloud forest endemics.

Seventeen species of reptiles have been reported from Maquipucuna (Online Appendix 4). The most endangered species is an endemic snake, *Tantilla insulamontana,* which is critically endangered. Very little is known about this snake, which has been rarely seen; the main threats are habitat destruction, fragmentation, and contamination (Torres-Carvajal et al., 2017).

Orchids (Online Appendix 5) were largely discussed under Los Cedros, the only other BP under discussion here for which we have detailed and vouchered data for orchids. Maquipucuna has one endangered orchid species, *Masdevallia ventricularia*, which is also at Los Cedros, and it has 45 vulnerable and 14 near threatened orchids (Table 3 and Online Appendix 5). Maquipucuna only shared 75 (26%) of its 284 orchid species with Los Cedros. While Los Cedros is particularly rich in *Dracula* and other pleurothallids such as *Acronia*, Maquipucuna is richer in *Cyrtochilum*, *Elleanthus,* and *Epidendrum* species. These differences may be real due to topographic or climatic differences (e.g., the Río Guayllabamba runs between the reserves and could be a barrier), or they may be due to collection bias at Los Cedros. We hope that our lists spur future work.

Social and economic. Maquipucuna has an ecolodge frequented by birders and other ecotourists, and its website (Maquipucuna, 2018) states that ‘‘over 120 families benefit from ecotourism projects initiated and supported by Maquipucuna.’’ For example, they helped the nearby village of Yunguilla to switch from charcoal production to reforestation and ecotourism (Gosdenovich, 2015; Houns, 2013) and are working to find ways to grow coffee and cacao more sustainably (Gosdenovich, 2015; Justicia, 2007).

Intag Valley

The Intag Valley is a region in the Cotacachi canton of the Imbabura province, partially defined by its location as the watershed of the Intag river, but also defined culturally by the network of communities in eastern Cotacachi canton that cooperate on conservation and economic development projects. We aggregated all data from the Intag area into a single column (‘‘Intag’’) in the Online Appendices but kept the sources of the data separate; most of what we found was from reserves 2 to 4, below, for location in the Intag Valley see Figure 3:

1. Bosque Protector El Chontal (0°21′45″N, 78°42′4″W). The elevation ranges between 1,000 and 4,200 m and thus this BP includes lower and upper montane cloud forests as well as páramos grasslands above 3,000 m (Jørgensen & Léon-Yánez, 1999) Ninety five percent of its 6,989 ha are now in mining concessions (Ministry of Mines, 2017; Vandegrift et al., 2017).
2. Bosque Protector La Florida Cloud Forest Reserve (0°22′0.01″N, 78°28′54.17″W) The elevation ranges between 1,800 and 2,800 m., encompassing both lower and upper montane cloud forest.
3. El Refugio de Intag Lodge (0°22′25.32″N, 78° 28′ 33.6″W). This privately owned lodge is at 1,923 m in lower montane cloud forest.
4. Junín Community Cloud Forest Reserve (0°17′18.11″N, 78°40′0.47″W). This community owned reserve has an elevation range of 1,800 m to 2,800 m and includes lower and upper montane cloud forests.

Due to earlier mining concessions and rich copper deposits, exploration has progressed the furthest in the Intag Valley as compared to elsewhere in NW Ecuador, with significant environmental consequences already apparent, just from exploration (Figure 2). Advanced exploration by the Chilean state company CODELCO in the Junín Community Reserve has contaminated water sources and disrupted the local community's tourism program (LGP, 2016).

Species. The Intag Valley is known to protect at least 58 species at high extinction risk (CR = 3 + 2?, EN = 10 + 1?, VU = 28, and NT = 17, see Table 4 and Online Appendices 1–5). The Intag Valley is home to three critically endangered species (Table 1): two frogs, *Ectopoglossus confusus* and *Hyloxalus jacobuspetersi*, and a toad, confusingly called the harlequin frog, *Atelopus longirostris*. A fourth CR species, the black-breasted puffleg, *Eriocnemis nigrivestis*, occurs in the surrounding mountains; it is thus not in the Intag as we defined it, though it is in the same watershed. A fifth critically endangered species, the brown-headed spider monkey, is likely to be in the underexplored Bosque Protector El Chontal (Peck et al., 2010).

The only nonbat mammals that have been reported from Intag are all large, and all but one is endangered (Table 4, Online Appendix 1), including the EN Spectacled Bear, *Tremarctos ornatus*. Another endangered mammal that may be in El Chontal/Intag Valley is the mountain tapir, *Tapirus pinchaque*. According to the El Chontal website (Fundación Zoobreviven, 2018), mountain tapirs are present and being hunted, but there are no photos and we could find no other modern records

Table 4. The 58 Species With High Extinction Risk Known to Occur in the Intag Valley as of March 2018.

Group	(CR)	(EN)	(VU)	(NT)	(LC)	(DD)	(NE)	Totals	Unique
Orchids[a]	0	0	11	2	0	0	0	13	—
Birds	1?[b]	1	3	4	275	0	1	285	50
Mammals	1?[c]	1 + 1?[c]	3	0	13	0	0	16	8+
Reptiles	0	1	3	1	3	1	1	10	4
Amphibians	3	7	8	7	7	4	0	36	19
Other plants[a]	—	—	—	—	—	—	—	—	—
Total	3 + 2?	10 + 1?	28	17	298	5	3	364	

Note. Orange color indicates the endangered classes, in order of most endangered, as defined by the International Union for Conservation of Nature (IUCN). Unique species are those not found at any of the other areas we studied.
[a]Not yet studied in the Valley; any records are from isolated studies. [b]The CR black-breasted puffleg was recently rediscovered in the Toisán range, which borders the Intag Valley (Jahn, 2008). [c]The CR brown-headed spider monkey is not known from the Valley but is thought likely in Bosque Protector El Chontal, and we found little evidence of the EN mountain tapir; both these are indicated by question marks.

of this species being present in the Intag, so we represent the potential presence of this species with a question mark in Online Appendix 1. There are good data on the bat fauna of the Intag Valley, because they were mist netted in the Junín Cloud Forest Reserve (Cueva-A, Pozo, & Peck, 2013). The only other reserve that has comparable bat data is Maquipucuna (Online Appendix 1). None of the bats in Maquipucuna are endangered but three are NT in the Intag.

The Intag Valley forms an IBA (EC038, BirdLife International, 2018a). Intag's combined list of birds is 276, just a few short of the 300 eBird uses to define the red bird hotspot. This list (Online Appendix 2) is likely incomplete since neither the extensive El Chontal Reserve nor nearby Junín have been surveyed. The Intag Valley provides homes for a different subset of birds than Los Cedros, Mashpi, or Maquipucuna, with the most unique species (50, Online Appendix 2). Some of the difference in species from the other reserves may be due to the region's proximity to drier, inter-Andean valleys, and others, such as the critically endangered hummingbird (*Eriocnemis nigrivestis*) reflect the high elevations (>1,500 m and up to 4,200 m) in this valley.

The amphibian fauna from the Intag is breathtaking, with an astonishing 36 species, mostly frogs, in some form of endangerment (Online Appendix 3), including three that are critically endangered. The majority of the endangered amphibians in Ecuador are in the montane cloud forests, such as in the Intag Valley, where the localized responses to small climate differences led to numerous speciation events and the formation of localized endemics (Arteaga et al., 2016). In 2016, researchers rediscovered the longnose harlequin frog (*Atelopus longirostris*) within the Junín Cloud Forest Reserve (the same reserve shown in Figure 2(b) damaged by mineral exploration in 2017). This is an endemic species last seen in 1989 and previously listed as Extinct by the IUCN (Tapia et al., 2017). The rediscovery of the harlequin frog highlights the need for further research on amphibian diversity in the Intag.

Reptiles (Online Appendix 4) and orchids (Table 4) have not been well-studied in the Intag region; the steep altitudinal gradients suggest the community of orchid species in Intag's upper montane cloud forests are likely to differ significantly from those found in Los Cedros and other lower elevation forests (Gentry, 1992).

Social and economic. El Chontal is run by the community Chalguayacu Alto, the Association Ganaderos y Agricultores, and Fundación Zoobreviven. The Junín Cloud Forest Reserve is owned and managed by a community organization that also manages a tourism business, the Ecocabañas Junín. Founded in 2000 with the help of DECOIN, the Ecocabañas provide an additional source of income for 40 local community members (Murillo & Sacher, 2017). The La Florida Cloud Forest Reserve is privately managed and also supports the livelihoods of surrounding families via a tourism and education center. In addition to guiding and homestays, the center provides environmental education to local and visiting students. Similarly, the El Refugío Lodge is a social enterprise that employs only local community members and supports cultural events in the town of Santa Rosa. The reserve managers and associated tourism operators regularly coordinate with local schools to host field trips, encouraging students to learn about their local watersheds as well as the wildlife that can be found within them.

Discussion

The reserves highlighted in this article collectively protect a remarkable 286 species at risk of extinction, including seven CR species—of which two are primates, the brown-headed spider monkey and white-fronted capuchin—37 EN, 153 VU, and 89 NT species, as well as a very large number of less threatened species. Importantly, each reserve protects a unique subset of species that are not found at the other reserves. The reserves also serve their surrounding communities by providing sustainable jobs, which have gradually been increasing over time (Walter et al., 2016) and through ecosystem services such as clean and abundant water.

The still federally protected PANE areas in Ecuador are not able to adequately protect localized endemics, particularly in montane forest ecosystems (Endara, Williams, & León-Yánez, 2009). Moreover, the national government's failure to fully implement SNAP as a comprehensive management system has meant that potential impacts on SNAP areas, such as Bosque Protectores, are not considered when mining concessions are granted. We show here that a large number of endemics are currently being protected in BPs, but that these are now endangered by mining.

The BPs highlighted are near or adjacent to the Cotacachi-Cayapas Ecological Reserve and are acting both as buffers and corridors for it (Figure 3). Cotacachi is in danger of becoming an island surrounded by mines. Islands loose biodiversity and ecosystem services because of increased isolation and from edge effects such as forest drying and increased predation (Haddad et al., 2015). There is another reason to maintain corridors: rapid and ongoing climate change. As the climate warms and dries, connections between the lower elevations and higher elevations become necessary for migration of organisms responding to it, as is already occurring in Ecuador (Báez, Jaramillo, Cuesta, & Donoso, 2016).

In fact, permanent protection for Los Cedros and its linkage to the Cotacachi-Cayapas is essential for the functioning of western Andean corridors (the Chocó Andean and Andean Bear Corridors and the recently proposed Biosphere Reserve) because of steep elevation differences. The southern border of Cotacachi-Cayapas runs along a ridgetop with elevations around 3,000 m. The only place where the elevations drop below 2,000 m is where it borders the western edge of Bosque Protector Reserva Los Cedros. Thus, the elevation gradient of Los Cedros, which ranges from 900 m to 2,710 m, links the lower elevation fauna and flora with the higher elevation of the southern edge of the Cotacachi-Cayapas. In addition, its large size, species composition, and proximity to the proposed protected areas surrounding Mashpi, make Reserva Los Cedros ideally located to form the connecting point of a southern corridor to Cotacachi. This corridor includes habitats preferred by the most endangered species in our study, including the primates (Jack & Campos, 2012; Peck et al., 2010) cats (de la Torre et al., 2017; Mendoza et al., 2017; Zapata-Ríos & Araguillin, 2013), and bears (Castellanos, 2011), as well as the frogs (Arteaga et al., 2016; Tapia et al., 2017), birds (Jahn, 2008; Willig & Presley, 2016), and orchids (Endara et al., 2009).

We have collected and collated biodiversity data for Los Cedros and the Intag, much of it previously unpublished, and collated the data for the other two BP reserves. Los Cedros stands out for its exceptional diversity, and the Intag has the highest concentration of critically endangered species. These two areas are in Imbabura province and are less well known than the two reserves S. of the Río Guayllabamba, in Pichincha province. Mashpi and Maquipucuna are better known and better protected from mining, in part, because they are closer to the large ($\gg$1 million) city of Quito, and even fall within the metropolitan district of Quito (the DMQ). There is considerable interest in conservation in Quito, primarily around watershed conservation and biodiversity (MECN-SADMQ, 2010). Recently, both Mashpi and Maquipucuna became protected Municipal Protection – Conservation and Sustainable Use as Areas of Municipal Protection – Conservation and Sustainable Use Conservation and Sustainable Use (APM-ACUS), which the Metropolitan district of Quito declared to be Natural Heritage Reserves of the State (International Model Forest Network, 2017). This added layer of protection, even if not yet formally accepted into the PANE system, means that it is much less likely that the mining concessions on these two reserves will be developed.

On the other hand, Los Cedros and the Intag, which are essential for corridors to Cotacachi, and are exceptional in terms of biodiversity, are already dealing with damaging exploration (Figure 2), and exploitation in the Intag is imminent. On March 8, 2018, Cornerstone, the company that holds the concessions at Bosque Protector Los Cedros, attempted to obtain a lodging agreement for prospectors at the fieldstation (permission for exploration was never granted and they were told that they need to have permits to work in a BP). On March 10, 2018, the Moreno government signed an agreement with the Chilean company CODELCO to exploit the Junín mine in the Intag (Cambero, 2018).

The concessions that we show in Figure 1(b) cover about a third of the Bosques protectors in Ecuador. A central question is whether or not the presence of mining concessions, *per se*, are damaging to ecosystems and the biodiversity that they harbor, or if it is only mining *exploitation* which is damaging. There is little debate over the harm that mining exploitation causes to the biodiversity and water resources adjacent to and downstream from such extractive activities (Asner & Tupayachi, 2017; Bianchini et al., 2015; Sonter et al., 2017). The probability that a concession will yield an active mine is generally agreed to be low, though exact figures are lacking for modern prospecting methodologies and will depend on the mineral in question. Exploratory programs, however, often have their own damaging effects on the biodiversity and ecosystems of an area (e.g., Figure 2). We argue that mineral exploration is particularly damaging in the tropical montane forests of Ecuador given the high rainfall and dispersed biodiversity.

Exploration of a mineral concession to determine if it will be profitable to open a mine involves several steps. In this case, initial survey via fly-over magnetic sensing was accomplished (without permission of landowners) before concessions were granted as part of the Ecuador Mining Development and Environmental Control Technical Assistance Project (PRODEMICA), at the request of the Ecuadorian government in the early 1990s (Davidov, 2013). This information was used to attract investment in concessions. Next, on-the-ground surveys are conducted, typically involving clearing patches of land, often extensively (Figure 2(a)), to allow the entry of heavy equipment, and to expose the subsoils for survey, drilling test-sites to extract subsurface minerals for analysis, and surveying sites for infrastructure development, such as tailings reservoirs (Moon, Whateley, & Evans, 2005; Environmental Law Alliance Worldwide, 2010). If analysis of subsoil chemistry and subsurface minerals indicates deposits of minerals that will significantly offset costs of development, the project may move forward.

At a minimum, thorough mineral exploration involves clearing land for roads to access the site, clearing land for subsoil access, and drilling to access subsurface minerals (Environmental Law Alliance Worldwide, 2010). Of these, the activity with the greatest impact on biodiversity and ecosystem services by far is the combination of *deforestation* and *road building*: The impact of roads on protected lands is well known (Chapman & Onderdonk, 1998; Laurance, Goosem, & Laurance, 2009; Sonter et al., 2017), but it is particularly impactful in areas that are protected largely by their isolation and areas where colonization and illegal logging are primary environmental impacts, as with many of the BPs in Ecuador. Impacts of proximity to roads are highlighted throughout our Results section, and the correlation between road access and biodiversity is seen in our species lists (Online Appendices 1–5). Maquipucuna, for example, is adjacent to roads and as a result is lacking primates, ground dwelling birds and species that are hunted. Illegal logging, even in the absence of ready access via roads, is one of the major pressures on Reserva Los Cedros (J. DeCoux, personal communication) and plays a major role in forest degradation throughout the region (Ebeling & Yasue, 2009; Southgate, Salazar-Canelos, Camacho-Saa, & Stewart, 2000). Mineral exploration in these reserves will necessitate road building and deforestation, which will in turn have devastating and irreversible consequences on the conservation status of the areas affected.

Given the potential for grave, irreversible ecological harm, it is particularly troubling that the Ecuadorian government and the transnational mining companies are not abiding by the legal principle of informed consent (Title II: Chapter 4, Article 57.7 of the Constitution; Asamblea Nacional, 2008), which is intended to allow communities to decide for themselves if the risks of metal mining are worth the potential benefits. There has been conflict between the Government-sponsored projects to expand international investment in the mining sector in Ecuador and the communities located around mining, particularly in NW Ecuador, for decades (Walter et al., 2016), but the recent rapid expansion of mineral concession has come largely without prior consultation of local communities, and in some cases in direct opposition to the desires of local communities (Boletín de Prensa, 2017; Mecham, Zorrilla, Thomas, & Downes, 2018; Warnaars, CEDHU, & FIDH, 2010).

We recommend that the entire Bosque Protector system be extended the same protections as the PANE system, particularly with regard to prohibition of metal mining.

As water resources throughout the world increasingly come under pressure, unlogged watersheds in BPs and other reserves are accordingly precious. The tropical montane cloud forests of Ecuador are particularly important for water cycling across a much larger area than they cover due to water capture by their biodiverse epiphytes (plants such as orchids that live on top of other plants). The epiphytes comb water out of the fog, helping these forests to capture up to 75% additional water through fog drip (Bruijnzeel, Mulligan, & Scatena, 2011; Cavelier, Solis, & Jaramillo, 1996), enabling cloud forests to maintain dependable flow downstream during dry periods (Bruijnzeel et al., 2011). Our results underscore that these montane forested ecosystems are valuable for not only for water, they also contain a very large number of at-risk species. Mining, particularly of copper and gold, will not only destroy the biodiversity and its water generating and holding capacity but also strongly decrease the quality of water downstream—where people, invertebrates, and fish depend on it—for generations, by changing acidity and releasing toxic compounds such as mercury and arsenic (Bundschuh et al., 2012; Leblanc, Morales, Borrego, & Elbaz-Poulichet, 2000; Oyarzun et al., 2006).

Preservation of the primary forests in BPs would allow the current economic benefits of these reserves to grow. It would also enable future economies through ethical and ecologically minded bioprospecting by Ecuadorian researchers, leading to long-term economic returns for the people of Ecuador and scientific and medical rewards for all of humanity (Bundschuh et al., 2012; Cragg & Newman, 2013; Rafiq et al., 2017; Strobel & Daisy, 2003). For example, a recently described species found at Los Cedros, *Cuatresia physalana* (Rafiq et al., 2017), is related to tomatoes and potatoes and thus may contain genetic materials valuable for agriculture. Furthermore, *Cuatresia* are known to contain antimalarial compounds (Deharo et al., 1992; Krugliak, Deharo, & Shalmiev, 1995). It is not only plants that are a source of antimicrobials and other bioactive compounds, so are plant- and soil-associated microbes (Cragg & Newman, 2013; Strobel & Daisy, 2003); microbes too are lost with deforestation and land conversion (Rodrigues et al., 2013).

In 2008, Ecuador set a new moral standard for the world when the National Assembly included the rights of Nature in the Constitution of Ecuador (Articles 71–74; Asamblea Nacional, 2008). It is time to follow through on this commitment.

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