

The extent of recent mining concessions in Ecuador

A report detailing the overlap of exploratory mining concessions with protected forests and other regions of conservation and human rights interest in Ecuador.

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Abstract

In 2017, the Ecuadorian government announced concessions to over 2.4 million hectares (6.15 million acres) of land for mining exploration. Many of these exploratory concessions are in previously protected forests and indigenous territories, as well in headwater ecosystems and biodiversity hotspots of global importance. Additionally, many of these concessions appear to be in violation of Ecuadorian law and international treaties. Here, we analyze the extent of exploratory mining concessions in Ecuador, examining the way that such concessions overlap with protected areas, indigenous territories, and forest types of conservation interest.

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Introduction

Recent history in Ecuador has been heavily influenced by the use of extractive industry as a means of economic development for the country. Since the 1990s, the government has sought to further open the country to mining through the liberal granting of mineral concessions. In many cases, such concessions have overlapped with protected areas, the headwaters of rivers, and indigenous territories; in 2008 a ‘mining mandate’ was issued to revoke these concessions because they violated the country’s current environmental laws, although this mandate was eventually abandoned and left unfulfilled (Wacaster 2010).

Under President Rafael Correa’s government, which

began in 2007, extraction of oil and mineral resources was used to drive spending for social and economic programs, reducing unemployment and poverty (Latorre, Farrell, and Martínez-Alier 2015). This economic model is often called “extractivism”. This was made possible, in part, but the promulgation of new mining laws in 2009, which eased restrictions on mineral exploration and extraction (Wacaster 2012). Yet, alongside the development of extractive industries, Ecuador under Correa became the first nation on Earth to enshrine the rights of nature into its constitution, under the guiding principle of *sumak kawsay* (kichwa for “good life”, which defines the relationship between people, the state, and nature) (Revkin 2008). While extractivism and a recognition of the rights of nature may seem contradictory, the Ecuadorian constitution — as a reflection of the political philosophy of Correa and his ruling PAIS coalition — applies the concept of *sumak kawsay* in such a way as to link it to state sovereignty and the management of natural resources (Bernal and Panel 2013).

The interplay between extractivism and development in Ecuador has been further complicated by rampant government corruption, culminating in the arrest of Vice President Jorge Glas on 3 Oct 2017 (Associate Press 2017). Mr. Glas is under investigation for corruption related to the dispensation of oil extraction concession in the Amazon basin while he was Coordinating Director for the office of Strategic Sectors. His office was also responsible for promoting and negotiating new mining concessions.



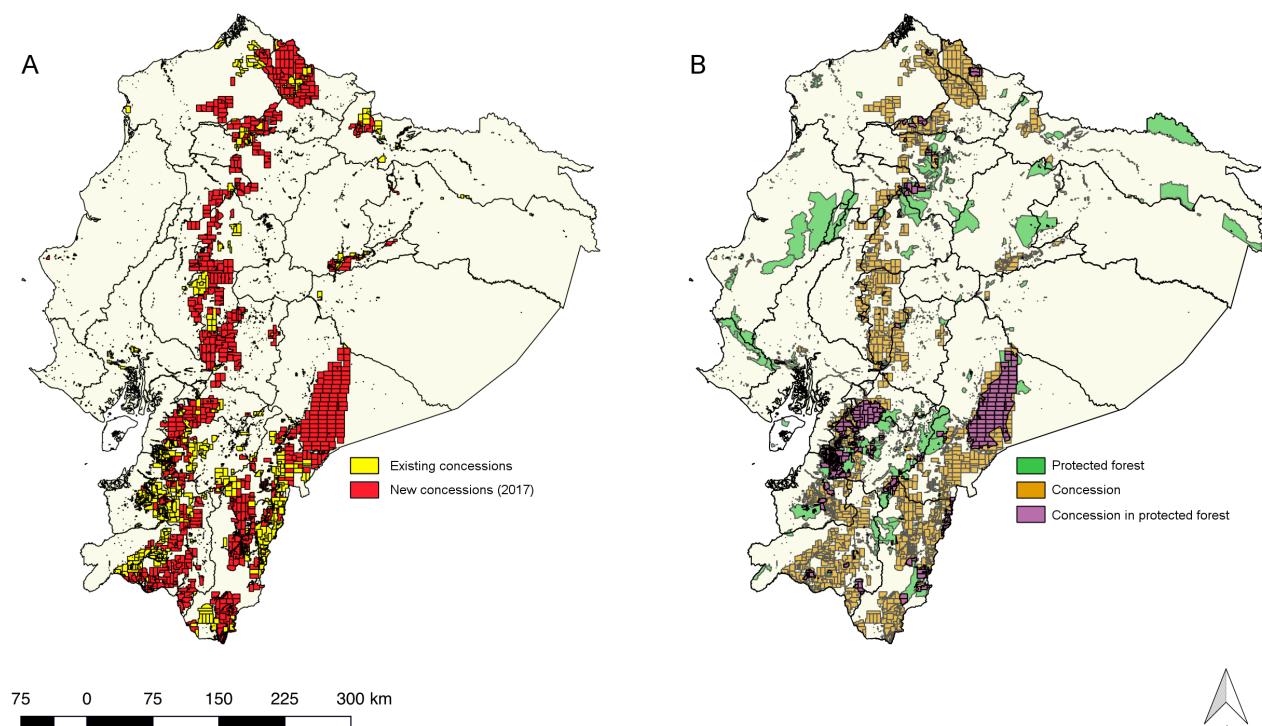


Figure 1. Maps showing mining concessions and the overlap between mining concessions and protected forests in Ecuador. In **A**, new mining concessions (both registered and in-process) are shown in red, while mining concession granted prior to 2017 are shown in yellow. For a larger version of this map, click [here](#). In **B**, these concessions are shown in orange; Ecuador's system of protected forests is shown in green, and the overlap of these concessions with that system is shown in purple. For a larger version of this map, click [here](#).

New Mining Concessions

The Ministry of Mines issued new rules governing the acquisition of mining concessions in the spring of 2016, leading to the bidding and auctioning of mineral concessions in State possession throughout that year (Ministry of Mines 2016). In August of this year, the Ecuadorian Ministry of Mining made public a massive increase in exploratory mining concessions across the country (Fig. 1A) through the Ministry's website, largely resulting from the auctions that followed the announcement of these new rules (Minka Urbana 2017; "Agencia de Regulación Y Control Minero" 2017). Though Ecuador elected a new president, Lenín Moreno (also representing the left-leaning PAIS coalition), these concessions are the product of regulatory changes under Correa's administration. The newly elected president, likely responding to allegations of corruption, has announced a plebiscite, which will include a referendum question on mining in protected areas: "Do you agree to amend the Constitution of the Republic of Ecuador to prohibit, without exception, metal mining at all stages in protected areas, intangible zones, and urban centers?" (Staff 2017). Here, we hope to add to the interest in this referendum by providing concrete visualization of how these new mining concessions interact with the national system of protected lands,

ecosystems of particular conservation interest, and the territories of Indigenous peoples in Ecuador.

These mining concessions dramatically increase the land area available for mineral exploration in Ecuador (Fig. 1A). Prior to the announcement of this large batch of concessions, we estimate that 1,204,250 hectares of land in Ecuador was available to mineral exploration and exploitation, roughly 4% of the country. After these newly announced concession, 3,693,000 hectares is available to mineral exploration or exploitation, more than 13% of Ecuador's approximately 28 million hectares of continental land area ("Agencia de Regulación Y Control Minero" 2017; Hanratty 1989).

Protected lands and conservation impacts

These concessions disproportionately impact protected forests in Ecuador (Fig. 1B). Ecuador's system of protected lands is heterogeneous, including both the National System of Protected Areas (Sistema Nacional de Áreas Protegidas, SNAP), as well as a mosaic of *bosques protectores* (Áreas de Bosque y Vegetación Protectora, ABVP), public or privately managed protected forest reserves, generally of smaller extent, but making up a large portion of protected land in Ecuador. SNAP protects roughly 4,588,812 ha of land within continental Ecuador; *bosques*

Table 1. Bosques protectores above 1000 ha with greater than 10% of their total protected area included in mining concessions. These 37 bosques protectores account for more than 98% of mineral concession within protected forests in Ecuador.

BP Code	Name	Protected Area (ha)	Area (ha) in concession	Percent in concession
BP011	Asociacion Agricola Carchi – Imbabura	2364	2364	100%
BP091	La Chorrera	2045	2045	100%
	Microcuenca quebrada Jorupe y Cerros Jatopamba,			
BP104	Shulo Chuqui y Murinuma	8027	7984	99%
BP116	Cuenca del Río Moro – Moro	3139	3042	97%
BP201	Cebú	2216	2145	97%
BP259	Mashpi	1178	1132	96%
BP073	Intag (El Chontal)	6989	6656	95%
BP180	Cordillera Chongón Colonche	17599	16290	93%
BP023	Cerro Golondrinas	13550	12350	91%
BP202	Cordillera Kutuku y Shaimi	342025	310440	91%
BP108	Molleturo y Mollepungo	140593	126329	90%
BP075	El Ingenio y Santa Rosa	12417	10563	85%
BP016	Casacay	12577	9083	72%
BP225	Uzchurrumi, La Cadena, Peña Dorada, Brasil	109282	76466	70%
BP240	Los Cedros	5256	3568	68%
BP136	Santa Rita	2141	1413	66%
BP022	Gineales Samana y Mumbes	3425	2029	59%
BP036	Río Lelia	3234	1685	52%
BP190	Cuenca alta del Río Nangaritza	77330	35881	46%
BP017	Cashca Totoras	6472	2983	46%
BP103	Mazán	2396	1041	43%
BP041	Cuenca Río Guayllabamba (Área 2)	1174	504	43%
BP067	Chillanes Bucay	1918	776	40%
BP074	El Guabo	2305	922	40%
	Subcuenca alta del Río León y microcuenca de los Ríos			
BNP14	San Felipe de Oña y Shincata	51970	19386	37%
BNP16	Morocumba	9903	3692	37%
BP101	Maquipucuna	2474	889	36%
BNP17	Chorro	4807	1700	35%
BP039	Cuenca Río Guayllabamba (Área 1)	14452	3742	26%
BNP8	Micha Nunke	1613	372	23%
BP207	Cooperativa Jima Ltda.	5290	1179	22%
BP156	Toachi Pilatón	96622	21261	22%
BP151	Sun Sun Yanasacha	4851	909	19%
BP054	Río Arenillas presa Tahuin	47211	7422	16%
BP145	Subcuenca del Río Chongón	17037	2658	16%
BP042	15 Áreas del interior de la Cuenca del Río Paute Flanco Oriental de Pichincha y Cinturón Verde de	152336	19574	13%
BP262	Quito	25299	2613	10%

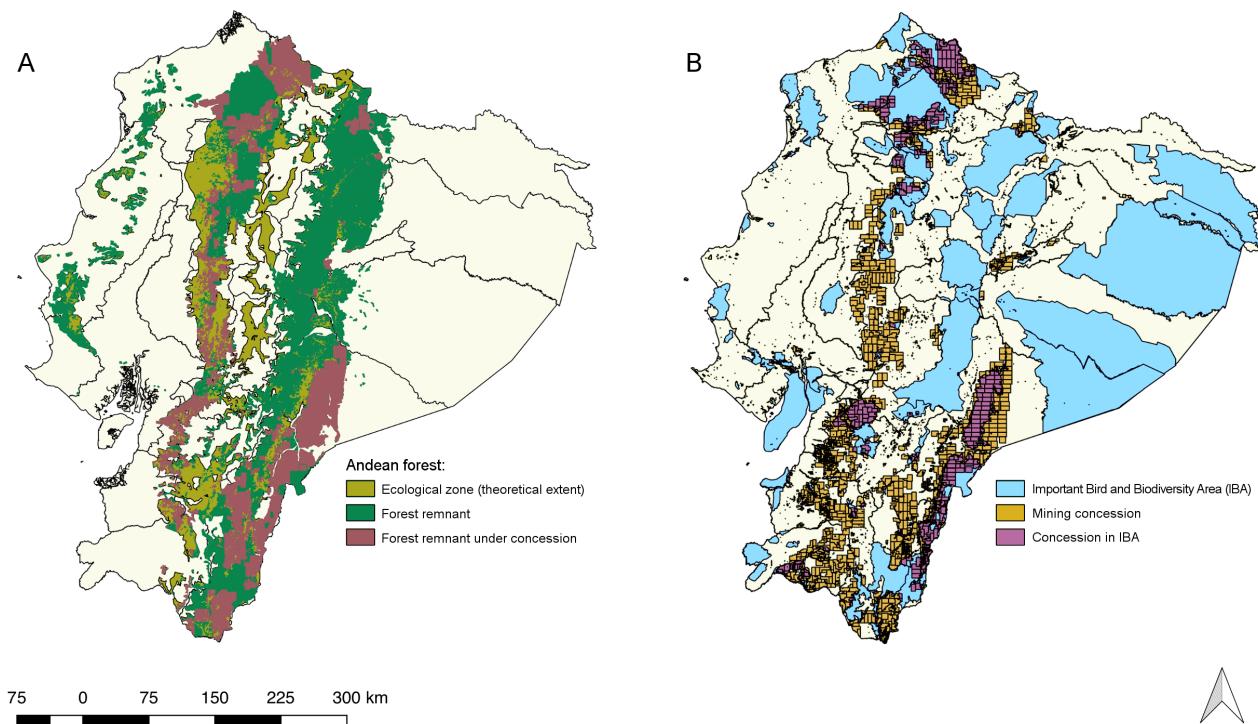


Figure 2. Maps showing the overlap between mining concessions and extant Andean forests and the overlap between mining concessions and important bird and biodiversity areas (IBAs). In A, the Andean forest zone is shown, with deforested areas (yellow green), existing forest (dark green), and existing forest under mining concession (plum red). For a larger version of this map, click [here](#). In B, mining concession are shown in yellow; Important Bird and Biodiversity Areas (IBAs) are shown in blue, and the overlap of these concessions with IBAs is shown in purple. For a larger version of this map, click [here](#).

protectores protect some 2,422,879 ha, more than a third of the combined area of the two classes of protected lands. *Bosques protectores* originated with the National Forestry Law in 1980, and are legally recognized by the government as protected (Horstman 2017). The area of *bosques protectores* currently under some kind of exploratory concession is roughly 735,597 ha, or more than 30% of the total land area protected by *bosques protectores*. Of protected forests affected, 27 reserves have more than 50% of their total area included in mining concessions; 15 have more than 90% of their total area included in mining concessions.

Ecuador's system of protected forests is of particular importance, because it protects Andean mountain forest habitat, much of which is cloud forest (Fig. 2A). Cloud forests play important roles in the hydrological cycle of tropical mountain systems (Postel and Thompson 2005) and harbor great biological diversity, including extremely high rates of endemism (Gentry 1992). Because of these factors, the tropical Andes are often considered one of the most critical conservation priorities worldwide (Myers et al. 2000). In Ecuador, much of this montane forest zone is particularly degraded through land-use change, including logging, clearing for agriculture, and urbanization (Mosandl et al. 2008). The vast majority of mining

concessions in Ecuador are in the Andean forest (Fig. 2A). In total, 78% of all existing concessions are in this incredibly important zone, and roughly 35% of Ecuador's Andean forest zone is currently under concession, somewhere around 2,890,000 ha.

BirdLife International's Important Bird and Biodiversity Areas (IBAs) are defined by key indicator taxa (Boyla and Estrada 2005), and seem to work well for delimiting conservation priorities (Mugica et al. 2009). These areas of conservation priority are also heavily impacted by new mining concessions in Ecuador (Fig. 2B), with around 1 mil ha of land designated IBAs under mining concession. For example, the *bosque protector* Molleturo y Mulopungo is almost entirely included in new mining concessions. This reserve is home to two endangered Ecuadorian endemics, the El Oro Parakeet (*Pyrrhura orcesi*) and the Ecuadorian Tapaculo (*Scytalopus robbinsi*); sixteen other IBA trigger species are also found in this reserve (BirdLife International 2017).

Indigenous lands

The country of Ecuador contains traditional lands of several extant Indigenous peoples. There have been conflicts between extractivist policies of the Ecuadorian government and the Indigenous people that live on land

conceded for extraction in the past (Sawyer 2016), so it is no surprise that the current increase in mineral concessions impacts Indigenous lands (Fig. 3).

We would like to caution here that the extent of Indigenous lands is approximate for all group discussed, save for the Awá. Data for Indigenous territories were gathered from various sources in Ecuador, including Indigenous rights and anti-mining activists, who prefer not to be named in this publication. Data for the extent of the Awá lands was directly from the Federación de Centros Awá del Ecuador. While these are merely our best estimates at the extent of infringement on Indigenous lands, it should be noted that the unofficial nature of these boundaries does not diminish the impacts these mining concessions will have on Indigenous peoples. The post-colonial governments of the world have a vested interest in downplaying the holdings of their indigenous people (Frankema 2005).

Among the territories of largest landholding Indigenous groups, approximately 995,426 ha are within mining concession, or nearly 14% of estimated Indigenous lands in Ecuador (Fig. 3). Some groups are more highly affected than others. For example, Awá lands cover roughly 116,544 ha of land in the northwest of Ecuador, along the Colombian border; 81,179 ha of their land is included in recent mining concessions, nearly 70% of Awá territory. The territory of the Shuar people spans an estimated 1.6 million hectares of land in the Amazonian rainforests in the southeast of Ecuador. Of this, more than 860,000 ha are included in mining concession, more than half of their territory.

Mineral concessions were granted without free and informed consultation of the affected Indigenous groups, as is required by the Ecuadorian constitution (Title II: Chapter 4, Article 57.7; (República del Ecuador 2008). This is of particular concern, given the history of violence that has accompanied both the exploration and installation of mineral extractive projects in Indigenous communities (van Hulst Miranda 2016).

Discussion

The contradiction between Ecuadorian extractive and conservationist policies expands to all conservation categories, not just those mentioned herein. Of particular note, mining concessions in Ecuador also overlap with Intangible (or “no-go”) Zones, the System of National Parks (SNAP), and the lands governed under the Socio Bosque program (Ministerio del Ambiente 2017), which allows for designation of individually or communally owned land as protected. Of note, mineral concessions do not generally overlap with the boundaries of the 11 large National Parks in the SNAP system, though some concessions exist in other classes of SNAP land; however, roughly 11% of land managed under the Socio Bosque program is included in new mining concessions.

While not all categories of protected land in Ecuador

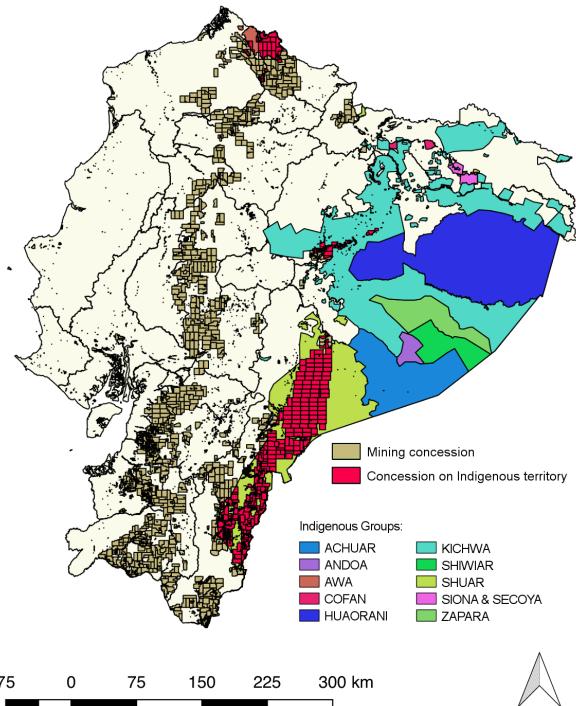


Figure 3. Maps showing the overlap between mining concessions and Indigenous territories. Mining concession are shown in gold; traditional territories for major Indigenous groups in Ecuador are shown in various colors (legend below), and the overlap of concessions with Indigenous lands is shown in red. For a larger version of this map, click [here](#).

have the same conservation objectives nor the same rules governing them (some may even allow certain exploitation activities), this does not negate the contradiction apparent within the Ecuadorian state: the fact remains that policy governing conservation and policy governing non-renewable resource extraction are in direct contravention to each other. It should also be noted that these categories of protected areas—*bosques protectores*, the IBAs, and ancestral Indigenous territories—are intrinsically linked and mutually produced: *bosques protectores* may cover Important Bird and Biodiversity Areas on Indigenous lands. It is important to not forget that these areas are interconnected, and often refer to the same space, which is impacted by mining activities leading to the process of deterritorialization (Haesbaert and Mondardo 2011).

While exploratory mining concessions may only cover a small portion of a protected area, the process of exploration often leads to the permanent degradation of protected lands; the building of roads increases accessibility to remote forests, leading to erosion, logging, and clearing of forests for farmland by landless people, regardless of the legality of such actions. The imposition of mining concessions on protected land does not necessarily scale with the size of the area impacted: even unsuccessful

exploration may lead to the permanent degradation or degazettement of a protected area (Mascia and Pailler 2011). Additionally, seemingly small-area disturbances relative to the total area of a reserve can have far-reaching environmental consequences, particularly with regards to watershed health (Tarras-Wahlberg et al. 2001). It is important to consider that mining may have impacts far downstream of active projects, impacting conservation and social outcomes (Velásquez 2012).

While we hope that the information provided herein will help lead to beneficial conservation outcomes in the upcoming referendum vote, it is important to acknowledge the fundamental conflict between Ecuador's existing mining and conservation policy frameworks. Such a 'correctional' vote on mining policy is only a stopgap; eventually, the Ecuadorian people will have to address this fundamental conflict.

Methods

Maps were created using publicly available data from the Ecuadorian Ministry of Mines ("Agencia de Regulación Y Control Minero" 2017), the Ecuadorian Ministry of the Environment ("National System of Protected Forests and Vegetation" 2017), and the Ecuadorian Ministry of Agriculture ("Mapa de Cobertura Y Uso de La Tierra En El Ecuador Continental 2013–2014 1:100000" 2017). Additional data came from AmphiWeb Ecuador ("Regiones Naturales" 2017; Sierra et al. 1999), Aves y Conservación and BirdLife International (Aves y Conservación and BirdLife International 2017), and the Federación de Centros Awá del Ecuador (Federación de Centros Awá del Ecuador 2017).

Mapping was done using QGIS (Quantum GIS Development Team 2017), a free and open source graphical information system, supported by Python tools, including Pandas (McKinney 2010) and NumPy (Walt, Colbert, and Varoquaux 2011).

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Works cited

- "Agencia de Regulación Y Control Minero." 2017. *Ecuadorian Ministry of Mines*. Accessed August.
Associate Press. 2017. "Ecuador's Vice President Jorge Glas Imprisoned as Corruption Investigation Gets Underway." *Independent*, October 3. <http://www.independent.co.uk/news/world/americas/ecuador-vice-president-jorge-glas-arrested-jailed-corruption-bribery-investigation-odebrecht-supreme-a7980691.html>.
Aves y Conservación, and BirdLife International. 2017. "Aves Y Conservación." *Aves Y Conservación: BirdLife En Ecuador*. Accessed September. avesconservacion.org.

Bernal, Angélica Maria, and Afr Panel. 2013. "The Law and Politics of the 'Good Life' in Ecuador: Sumak Kawsay, Extrativism, and the Naturalization of Sovereignty." In *Unpublished Conference Paper Presented at Latin American Studies Association Meeting May*, 30:2013.

BirdLife International. 2017. "Important Bird Areas Factsheet: Bosque Protector Molleturo Mulopungo." <http://www.birdlife.org>.

Boyla, Kerem, and Angélica Estrada. 2005. *Áreas Importantes Para La Conservación de Las Aves En Los Andes Tropicales: Sitos Prioritarios Para La Conservación de La Biodiversidad*. Vol. 14. BirdLife International.

Federación de Centros Awá del Ecuador. 2017. "Map of Awá Territory in Ecuador."

Frankema, Ewout Hielke Pieter. 2005. "The Colonial Origins of Inequality: Exploring the Causes and Consequences of Land Distribution." Discussion papers//Ibero America Institute for Economic Research. <https://www.econstor.eu/handle/10419/27410>.

Gentry, Alwyn H. 1992. "Tropical Forest Biodiversity: Distributional Patterns and Their Conservational Significance." *Oikos*, 19–28.

Haesbaert, R., and M. Mondardo. 2011. "Tranterritorialidade E Antropofagia: Territorialidades de Trânsito Numa Perspectiva Brasileiro-Latino-Americana." *GEOgraphia* 12 (24): 19–50.

Hanratty, Dennis M. 1989. "Area Handbook Series: Ecuador: A Country Study." In . LIBRARY OF CONGRESS WASHINGTON DC FEDERAL RESEARCH DIV. <http://www.dtic.mil/docs/citations/ADA247998>.

Horstman, Eric. 2017. "Establishing a Private Protected Area in Ecuador: Lessons Learned in the Management of Cerro Blanco Protected Forest in the City of Guayaquil." *Case Studies in the Environment*. University of California Press Journals. <http://cse.ucpress.edu/content/early/2017/06/24/cse.2017.sc.452964.abstract>.

Hulst Miranda, Bryan van. 2016. "Shuar Tribe Face Government in Amazon Mining Protests." *Aljazeera*, December 29, Web edition.

Latorre, Sara, Katharine N. Farrell, and Joan Martínez-Alier. 2015. "The Commodification of Nature and Socio-Environmental Resistance in Ecuador: An Inventory of Accumulation by Dispossession Cases, 1980–2013." *Ecological Economics: The Journal of the International Society for Ecological Economics* 116 (Supplement C): 58–69.

"Mapa de Cobertura Y Uso de La Tierra En El Ecuador Continental 2013–2014 1:100000." 2017. *Ecuadorian Ministry of Agriculture*. Accessed August.

Mascia, Michael B., and Sharon Pailler. 2011. "Protected Area Downgrading, Downsizing, and Degazettement (PADDD) and Its Conservation Implications." *Conservation Letters* 4 (1). Blackwell Publishing Inc: 9–20.

McKinney, Wes. 2010. "Data Structures for Statistical Computing in Python." In *Proceedings of the 9th Python in Science Conference*, 445:51–56. SciPy Austin, TX.

Ministerio del Ambiente. 2017. "Programa Socio Bosque." *Ministerio Del Ambiente*. <http://sociobosque.ambiente.gob.ec/>.

Ministry of Mines. 2016. "Ministerial Decree No. 2016-002." *Official Gazette*, March 30.

Minka Urbana. 2017. "Festín Minero – Un Regalo a Los Capitales Megaminerios: Estado de Situación de La Megaminería En El Ecuador. [Trans: 'Festín Minero – A Gift of Capital for Megaminers: Status of Megamining in Ecuador']. http://www.entrepueblos.org/files/analisis_megamineria_mink_a.pdf.

Mosandl, R., S. Günter, B. Stimm, and M. Weber. 2008. "Ecuador Suffers the Highest Deforestation Rate in South America."

- In *Gradients in a Tropical Mountain Ecosystem of Ecuador*, 37–40. Ecological Studies. Springer, Berlin, Heidelberg.
- Mugica, Susana Aguilar, David C. Wege, Verónica Anadón-Irizarry, and Mark Balman. 2009. *Important Bird Areas Americas: Priority Sites for Biodiversity Conservation*. BirdLife International.
- Myers, Norman, Russell A. Mittermeier, Cristina G. Mittermeier, Gustavo A. B. Da Fonseca, and Jennifer Kent. 2000. "Biodiversity Hotspots for Conservation Priorities." *Nature* 403 (6772): 853–58.
- "National System of Protected Forests and Vegetation." 2017. *Ecuadorian Ministry of the Environment*. Accessed August.
- Postel, Sandra L., and Barton H. Thompson. 2005. "Watershed Protection: Capturing the Benefits of Nature's Water Supply Services." *Natural Resources Forum* 29 (2). Blackwell Publishing, Ltd.: 98–108.
- Quantum GIS Development Team. 2017. *Quantum GIS Geographic Information System* (version 2.18). Open Source Geospatial Foundation Project. <http://qgis.osgeo.org>.
- "Regiones Naturales." 2017. *AmphibiaWeb Ecuador*. Accessed October. zoolo-gia.puce.edu.ec/Vertebrados/Anfibios/AnfibiosEcuador/regionesNaturales.aspx.
- República del Ecuador. 2008. "Constitution of the Republic of Ecuador." <http://pdःba.georgetown.edu/Constitutions/Ecuador/english08.html>.
- Revkin, Andrew. 2008. "Ecuador Constitution Grants Rights to Nature." *The New York Times*, *Http://dotearth.Blogs.Nytimes.com/2008/09/29/ecuadorconstitution-Grants-Nature-Rights*.
- Sawyer, Suzana. 2016. "Indigenous Initiatives and Petroleum Politics in the Ecuadorian Amazon." *The Environment in Anthropology: A Reader in Ecology, Culture, and Sustainable Living*. NYU Press, 222.
- Sierra, Rodrigo, Carlos Cerón, Walter Palacios, and Rodrigo Valencia. 1999. "Mapa de Vegetación Del Ecuador Continental. 1: 1'000.000. Proyecto INEFAN-GEFBIRF." *Wildlife Conservation Society/Ecocencia*. Quito.
- Staff. 2017. "Estas Son Las Preguntas Oficiales Para Referéndum Y Consulta Popular." *El Telégrafo*, October 2, Web edition. <http://www.eltelegrafo.com.ec/noticias/politica/2/estas-son-las-preguntas-oficiales-para-el-referendum-y-consulta-popular-en-ecuador>.
- Tarras-Wahlberg, N. H., A. Flachier, S. N. Lane, and O. Sangfors. 2001. "Environmental Impacts and Metal Exposure of Aquatic Ecosystems in Rivers Contaminated by Small Scale Gold Mining: The Puyango River Basin, Southern Ecuador." *The Science of the Total Environment* 278 (1-3): 239–61.
- Velásquez, Teresa A. 2012. "The Science of Corporate Social Responsibility (CSR): Contamination and Conflict in a Mining Project in the Southern Ecuadorian Andes." *Resources Policy* 37 (2): 233–40.
- Wacaster, Susan. 2010. "The Mineral Industry of Ecuador 2008." In *USGS Minerals Yearbook 2008, Volume III, Area Reports—International*. United States Geological Survey.
- . 2012. "The Mineral Industry of Ecuador 2010." In *USGS Minerals Yearbook 2010, Volume III, Area Reports—International*. United States Geological Survey.
- Walt, Stéfan van der, S. Chris Colbert, and Gaël Varoquaux. 2011. "The NumPy Array: A Structure for Efficient Numerical Computation." *Computing in Science & Engineering* 13 (2). IEEE Computer Society: 22–30.