

An update on Ecuador's national carbon assessment, and its relationship with protected areas and indigenous peoples

Actualización de la evaluación nacional de carbono en el Ecuador, y su relación con áreas protegidas y poblaciones indígenas

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Citar como: Rodríguez-González M. and Torres-Garrido K. (2023). An update on Ecuador's national carbon assessment, and its relationship with protected areas and indigenous peoples. *South Sustainability* 4(1) e67. DOI: 10.21142/SS-0401-2023-e067

Artículo recibido: 21/10/2022
Arbitrado por pares
Artículo aceptado: 22/12/2022



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ABSTRACT

Land-cover change is one of the major drivers of land degradation and associated greenhouse gas emissions. Tracking existing carbon stocks and related fluctuations is crucial to the development and employing of climate mitigation strategies. However, this cannot be properly achieved without updated datasets. In the case of the Republic of Ecuador, the most recent carbon map does not account for multiple types of carbon pools, and the most recent socio-ecological assessment of national carbon stocks is at least a decade old. Continuing to employ national policies based on such data can be limiting. In this research work, we quantified the country's carbon stocks and examined the relationship between carbon and the distribution of protected areas and indigenous peoples. The resulting carbon map was developed using the Integrated Valuation of Ecosystem Services and Tradeoffs (InVEST) tool, employing the WorldCover 10-meter spatial resolution European Space Agency (ESA) product, as well as national and regional carbon values. The resulting carbon map constitutes a contribution to current efforts to update national geospatial products, in order to help inform future climate mitigation policies.

Keywords: carbon, climate change, land cover, protected areas, indigenous peoples, Global South

RESUMEN

El cambio en la cobertura de suelos es uno de los principales causantes de degradación ecológica y emisión de gases de efecto invernadero. Cuantificar las reservas de carbono existentes es crucial para desarrollar estrategias de mitigación climática. Sin embargo, esto no se puede llevar a cabo sin datos actuales. Para la República del Ecuador, el mapa de carbono más reciente no toma en cuenta múltiples tipos de depósitos de carbono. Además, el último informe nacional que evaluó la relación entre carbono y diversas variables socioecológicas tuvo lugar hace más de una década. Basar políticas nacionales en estos productos puede resultar limitante. En este trabajo investigativo, cuantificamos las reservas de carbono del Ecuador y examinamos la relación entre carbono y la distribución de áreas protegidas y poblaciones indígenas. El producto de carbono desarrollado se simuló con la herramienta de Valoración Integrada de Servicios Ecosistémicos y Compensaciones (InVEST), a partir del producto ESA WorldCover de 10 metros de resolución espacial y valores de carbono nacionales y regionales. Este mapa de carbono contribuye a la actualización de productos geoespaciales nacionales con el fin de ayudar a informar futuras políticas de mitigación climática.

Palabras clave: carbono, cambio climático, cobertura de suelos, áreas protegidas, población indígena, sur global



Introduction

Climate change is both an ecological and a humanitarian crisis (de Sherbinin, 2014; O'Neill *et al.*, 2018). Vulnerable populations, often «those with the fewest resources and who've contributed the least to the crisis» (Nakate, 2021), are the most impacted by climate change —often to the point of displacement (Jayawardhan, 2017). The planet is at risk of continued sea level rises, pervasive weather events (including droughts, hurricanes and floods) and detrimental effects on local biodiversity (Catullo *et al.*, 2019; Cook *et al.*, 2018; Hoegh-Guldberg *et al.*, 2018; Nazarnia *et al.*, 2020). The only plausible solution to the planet surpassing pre-industrial temperature thresholds is to drastically cut back on greenhouse gas emissions (IPCC, 2022; Steffen *et al.*, 2015). However, the development of policies that address the climate crisis requires data that quickly and effectively expresses social and ecological dimensions (O'Neill *et al.*, 2018; Soto-Navarro *et al.*, 2020; Stallworthy, 2009).

In the Global South, limited access to «big data» (which includes remote sensing and spatial data) damages the policy and decision-making process (Arora, 2016; Mahrenbach *et al.*, 2018). These types of data must be open source and easy to access in order to effectively support climate mitigation as a global commitment (Mahrenbach *et al.*, 2018). Making basic carbon maps widely available can serve as a first step towards enabling managers, decision makers and other stakeholders to conduct the analysis required to inform local policies (Soto-Navarro *et al.*, 2020). For example, socio-ecological analyses based on basic carbon quantifications may include: analysis of the relationship between carbon and protected areas; identifying tradeoffs between carbon and the provisioning of other ecological goods; and the identifying of correlations between the distribution of carbon pools and vulnerable populations (e.g., Bertzky *et al.*, 2010; Soto-Navarro *et al.*, 2020).

Carbon itself is a key component of the dynamics behind the mitigation of anthropogenic fossil fuel emissions, with carbon dioxide (CO₂) making up the majority of greenhouse gas emissions (Doğan *et al.*, 2021; IPCC, 2022; United States EPA, 2022). Climatic fluctuations can be offset by the sequestration and storage of carbon, through which carbon dioxide is captured from the atmosphere and stored in slow-turnover pools with global-scale impact (Hardiman *et al.*, 2017). Although it may have a global-scale impact in terms of its role in climate change mitigation, quantifying stored carbon locally also facilitates the assessing of access to other key nature-derived benefits, or ecosystem services, important for human wellbeing (Chisholm, 2010; Daba and Dejene, 2018; Girardello *et al.*, 2019; Lin *et al.*, 2018). For example, ecological functions such as those associated with primary productivity and the regulation of local microclimates are directly related to biomass (Chisholm, 2010; Hardiman *et al.*, 2017).

In order to contribute to the discussion around the national-level socio-ecological implications of today's climate crisis, we conducted a national carbon assessment for the Republic of Ecuador and evaluated the relationship between carbon stocks, protected areas and indigenous peoples. We chose Ecuador for this assessment because, in common with other Global South countries, it has limited «big data» availability. Specifically, its most recent carbon map does not account for multiple types of carbon pools (only soil organic carbon) (Loayza *et al.*, 2020), and the country's most recent socio-ecological assessment of national carbon stocks is at least a decade old (Bertzky *et al.*, 2010).

Materials and methods

Study site: Ecuador has a land area of 283,560 square kilometers, divided into four regions (the insular region, comprising the Galapagos Islands; «costa», or the coastal region; «sierra», or the highland region; and the «oriente», or eastern region). The country is divided into twenty-four provinces (Figure 1). The dominant land-cover classification is vegetative, with sixty-nine percent of the country covered by trees (Zanaga *et al.*, 2021). Only twenty-three percent of Ecuador is composed of protected areas, mostly located in the «oriente» (United Nations' Environment Programme and the International Union for Conservation of Nature, 2020). For the year 2010, national carbon storage was estimated at 1,630 megatons, primarily through aboveground pools (Bertzky *et al.*, 2010). There are 1.1 million members of indigenous peoples in Ecuador (out of a total population of 17.88 million people, as of 2021) (INEC, 2010; The World Bank Group, 2022).

Modeling: The Integrated Valuation of Ecosystem Services and Tradeoffs (InVEST) tool is a Natural Capital open-source software that allows users to map nature's benefits, including carbon (Sharp *et al.*, 2020). The InVEST Carbon Storage and Sequestration model uses land-cover data along with estimates of various carbon pools (i.e., soil organic carbon and carbon from above and belowground biomass) to estimate regional carbon amounts for different land-cover classes. For our assessment, we used the open-source European Space Agency (ESA) WorldCover product (10-meter spatial resolution) (Zanaga *et al.*, 2021). We chose this dataset due to its land cover categories (a total of up to eleven classes), which are comparable to those of historical land cover products for the country (e.g., Climate Justice Jean Monnet Centre of Excellence, 2021), and because it is one of the most recent global land-cover products including the entire country (i.e., it does not exclude the insular region). To parametrize the InVEST model, we used carbon estimates of vegetated land-cover classifications from recent national carbon reports (Table 1). When a pool was unavailable, relationships of proportionality were used as estimates (as suggested by InVEST's user guide —see Sharp *et al.*, 2020). If multiple

Table 1. Input carbon values (t/ha) for the Integrated Valuation of Ecosystem Services and Tradeoffs' (InVEST) Carbon Storage and Sequestration model. Unless otherwise specified, values were obtained from national reports. Non-vegetated land cover classifications were assumed to have a value of zero.

Vegetative land cover	Aboveground carbon (t/ha)		Belowground carbon (t/ha)		Soil organic carbon (t/ha)	
	Value	Source	Value	Source	Value	Source
Tree cover	410.12	Ministry of Environment of the Republic of Ecuador (2014)	98.43	Ministry of Environment of the Republic of Ecuador (2014)	71.65	Bertzky <i>et al.</i> (2010)
Shrubland	100.56	Bertzky <i>et al.</i> (2010)	2.41	Rhoades, Eckert, and Coleman (2000)	201.11	Bertzky <i>et al.</i> (2010)
Grassland	71.10	proportional relationship used (half of cropland value, because some land is used for animal husbandry)	2.19	proportional relationship used (half of cropland value, because some land is used for animal husbandry)	108.76	proportional relationship used (half of cropland value, because some land is used for animal husbandry)
Cropland	142.20	Bertzky <i>et al.</i> (2010)	4.38	Rhoades, Eckert, and Coleman (2000)	217.52	Rhoades, Eckert, and Coleman (2000)
Herbaceous wetland	127.05	proportional relationship used (half of forested wetlands, i.e., mangrove)	30.50	proportional relationship used (half of forested wetlands, i.e., mangrove)	179.00	proportional relationship used (half of forested wetlands, i.e., mangrove)
Mangroves	254.10	Ministry of Environment of the Republic of Ecuador (2014)	60.99	Ministry of Environment of the Republic of Ecuador (2014)	358.00	proportional relationship used (up to 5 times what is stored in the tree cover classification (Chatting <i>et al.</i> , 2022, and Donato <i>et al.</i> , 2011))
Moss and lichen	0.00	negligible at 10-meter spatial resolution (Bertzky <i>et al.</i> , 2010)	0.00	negligible at 10-meter resolution (Bertzky <i>et al.</i> , 2010)	0.00	negligible at 10-meter spatial resolution (Bertzky <i>et al.</i> , 2010)

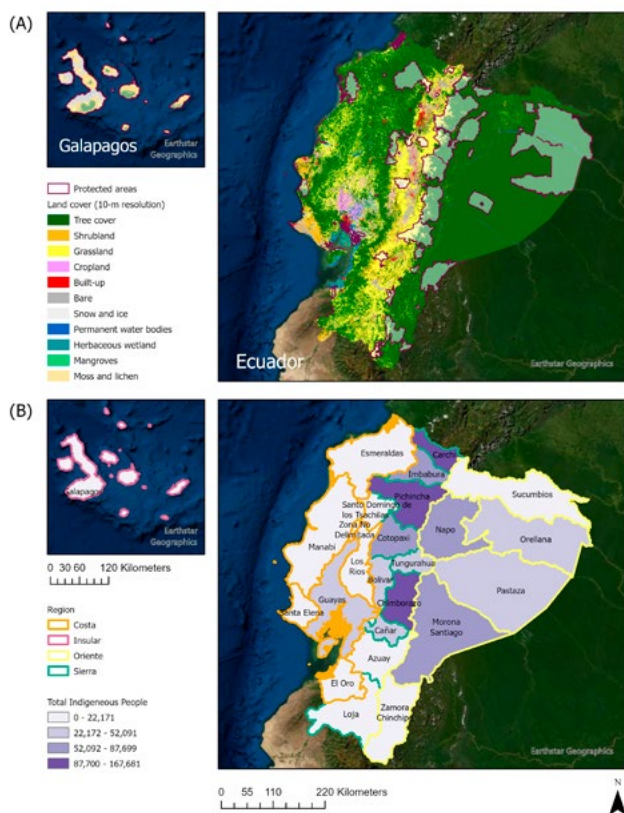


Figure 1. Ecuador's land cover map (a) and the distribution of indigenous populations (b), with delimitations for regions, provinces and protected areas. Data for the Galapagos Islands, or the «insular» region, is shown in the small maps on the left.

values were found for a given land-cover classification, these were averaged (e.g., for cropland-specific studies such as Rhoades *et al.*, 2000, all crop types were averaged). If total carbon was reported rather than tons of carbon per hectare, the value was divided by the total land area of the land-cover classification.

Summarized statistics We summarized output values for each of the regions of Ecuador using Esri's ArcGIS Pro 3.0.0 (2022), contextualizing them within Ecuador's historical land-cover and carbon trends (Bertzky *et al.*, 2010; Ministry of Environment of the Republic of Ecuador, 2014). We further summarized our findings in relation to the distribution of protected areas and indigenous populations. Delimitations of protected areas were obtained from the United Nations' Environment Programme and International Union for Conservation of Nature World Database on Protected Areas (2020). We used this data source rather than a local source because the data was easier to access and process, and it was consistent with the national delimitations of protected areas. Indigenous population data was extracted at the province level from Ecuador's 2010 national census, publicly available through the country's National Institute of Statistics and Censuses (INEC). All administrative boundaries, including regions and provinces, were downloaded from the Humanitarian Data Exchange (v1.60.3) (<https://data.humdata.org/>) (OCHA Latin America and the Caribbean, 2020).

Results and discussion



The easternmost region of Ecuador, or «*oriente*», stores the largest amount of carbon, due to its extensive forestland (Figure 1a, Figure 2). There is also high carbon storage between the «*sierra*» and the «*costa*» regions (Figure 1a, Figure 2). As per model assumptions, carbon storage is lower where vegetation types other than forest or wetland dominate (Figure 1a, Figure 2). When quantified, these patterns translate into a total of 2,766.56, 180.95, 6,497.69 and 2,250.85 megatons of carbon stored in the «*costa*», «*insular*», «*oriente*» and «*sierra*» regions, respectively (Table 2). High and low distribution of carbon follows similar patterns as those from the past decade (see supplementary Figure A1 for a comparison with historical aboveground carbon patterns), but the actual amounts may have been influenced by the presence of intensive land use (e.g., urban development or extractive industries such as oil exploration and logging, which are associated with national shifts in economic and ecological policies –see Curatola Fernández *et al.*, 2015; Llerena-Montoya *et al.*, 2021; Mosandl *et al.*, 2008). High-resolution mapping (i.e., greater than 10 meters) going back a couple of decades and evaluating changes at a subregional or more local scale may be necessary in order to fully assess land-cover change impacts.

Protected areas are valuable sources of carbon storage (Table 2). In total, protected areas store 286.27 megatons of carbon. The type of protected area which sequesters the highest amount of carbon per hectare is wetland (Figure 2, inset map). This is consistent with our understanding of the role of wetlands as global carbon pools («mangrove forests hold some of the highest densities of carbon recorded in any ecosystem» –see Richards, Thompson and Wijedasa, 2020).

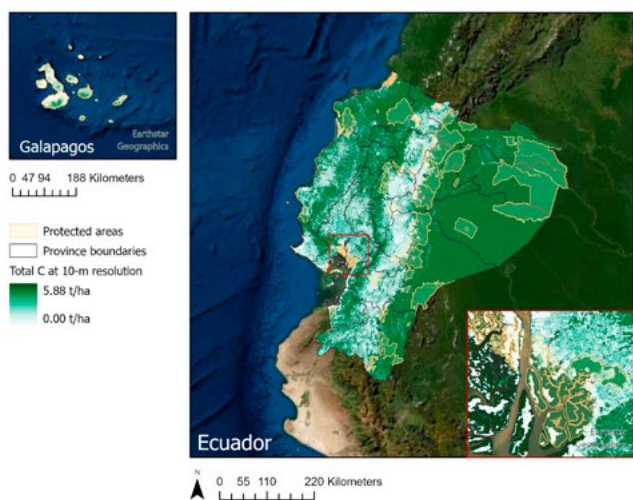


Figure 2. Carbon storage (tons/ha) in Ecuador, with the boundaries of provinces and protected areas marked. The Galapagos Islands, also known as the «insular» region, are shown in the small map on the left.

Table 2. Total carbon storage (megatons) per region and province in Ecuador, with totals and percentages of indigenous populations.

Region / Province	Megatons of carbon		Indigenous population	
	Total	In protected areas	Total	Percentage (%)
COSTA	2,766.56	291.24	72,005	0.01
El Oro	226.56	7.07	4,054	0.01
Esmeraldas	851.14	202.13	13,875	0.03
Guayas	533.24	37.35	44,490	0.01
Los Rios	259.33	1.24	4,419	0.01
Manabi	773.40	43.34	3,009	0.00
Santa Elena	122.89	0.11	2,158	0.02
INSULAR	180.95	180.95	1,681	0.07
Galapagos	180.95	180.95	1,681	0.07
ORIENTE	6,497.69	2,176.84	224,903	0.32
Morona Santiago	1342.31	353.08	63,599	0.47
Napo	643.47	344.63	58,783	0.57
Orellana	1229.91	604.19	40,849	0.32
Pastaza	1706.32	298.67	26,771	0.37
Sucumbios	1014.64	461.72	22,171	0.13
Zamora Chinchipe	561.03	114.56	12,730	0.14
SIERRA	2,250.85	213.62	809,327	0.13
Azuay	259.16	11.01	17,605	0.02
Bolivar	155.94	1.80	46,266	0.26
Cañar	95.42	9.87	34,184	0.15
Carchi	158.20	12.54	164,524	1.00
Chimborazo	157.48	25.39	167,681	0.37
Cotopaxi	207.60	55.77	81,832	0.22
Imbabura	180.77	13.99	87,699	0.25
Loja	382.25	9.24	16,104	0.04
Pichincha	366.23	29.13	135,023	0.05
Santo Domingo de los Tsachilas	170.53	0.01	6,318	0.02
Tungurahua	117.27	44.89	52,091	0.12
NON-DELIMITED	35.56	0.00	0	0.00
Zona No Delimitada	35.56	0.00	0	0.00

It is true that previous studies have observed strong positive relationships between designated indigenous territories (generally located in the «*oriente*» –see supplemental Figure A2) and protected land (including the protected area delimitations used in this study) (Bertzky *et al.*, 2010); however, in this study, we looked specifically at the numbers of indigenous peoples identified in census data and observed that there are large indigenous populations in those provinces with lower

carbon storage capacity (e.g., the «sierra» region, which is not dominated by tree cover —see Figure 1b and Figure 2). In addition to geographic and biophysical conditions characteristic of the ecosystems of the «sierra» region, certain socioeconomic sectors (for example, in Ecuador, some areas classified as grassland are used for animal husbandry —see Rhoades, Eckert, and Coleman, 2000) may be driving the patterns of carbon storage observed in these areas. Policy analysis will be required in order to determine how best to support indigenous peoples outside designated indigenous territories and protected areas. If the aim is to address issues related to greater benefits of ecological production for indigenous populations outside designated indigenous territories and protected areas, the expansion of existing programs could prove helpful, through initiatives such as payments for land conservation, which would provide both ecological and financial support for indigenous populations (De Koning *et al.*, 2011). This would also facilitate a pathway towards enhancement of the provision of other nature-derived benefits or ecosystem services (Daba and Dejene, 2018; Girardello *et al.*, 2019; Lin *et al.*, 2018).

Concluding remarks

In this study, we conducted nationwide carbon mapping for the country of Ecuador. The 10-meter spatial resolution product used in this study could be used to update other socio-ecological assessments that have been conducted in Ecuador, in order to inform climate mitigation and nature conservation policies, beyond the summarized statistics contained in this study. Despite some resolution limitations, the product developed for this study could allow for sub-regional assessments that inherently account for land-cover variability and different carbon

pools (both of which form part of the modeling approach employed). Our basic assessment emphasizes the need to strategize on how to best support indigenous populations residing in areas outside designated indigenous territories and designated protected areas, because large indigenous populations reside in areas not classified as indigenous, in provinces with lower carbon storage.

Data availability

The carbon product in this study can be requested through direct correspondence with the authors.

Acknowledgements

We would like to thank our reviewers for their comments and insights.

Authorship contribution

The corresponding author conducted the geospatial modeling and produced the maps. The co-author obtained and prepared the data and produced the tables. Both authors contributed equally to the text.

Conflicts of interest

The authors have no conflicts of interest to declare.

Sources of financing

This study used only spatial data that was readily available online, together with open-source modeling software. Access to ArcGIS Pro and academic journals (for carbon values) was provided through institutional affiliation. No additional costs were associated with the conducting this study.

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