Priorities of action and research for the protection of biodiversity and ecosystem services in continental Ecuador

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Janina Kleemann
Martin Luther University Halle-Wittenberg

Hongmi Koo
Martin Luther University Halle-Wittenberg

Glenda Mendieta-Leiva
Philipps University of Marburg

Belinda Kahnt
Martin Luther University Halle-Wittenberg

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Review

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J. Kleemann[a,*], H. Koo[a], I. Hensen[b,c], G. Mendieta-Leiva[d,h], B. Kahnt[e], C. Kurze[f], D.J. Inclan[g], P. Cuenca[h], J.K. Noh[h], M.H. Hoffmann[b], A. Factos[i], M. Lehnert[b], P. Lozano[j], C. Fürst[a,c]

[a] Martin Luther University Halle-Wittenberg, Institute for Geosciences and Geography, Dept. Sustainable Landscape Development, Von-Seckendorff-Platz 4, 06120 Halle (Saale), Germany
[b] Martin Luther University Halle-Wittenberg, Institute of Geobotany and Botanical Garden, Am Kirchtor 1, 06108 Halle (Saale), Germany
[c] German Centre for Integrative Biodiversity Research (iDiv) Halle-Jena-Leipzig, Puschstr. 4, 04103 Leipzig, Germany
[d] University of Marburg, Institute of Geography, Deutschhausstraße 10, 35032 Marburg, Germany
[e] Martin Luther University Halle-Wittenberg, Institute of General Zoology, Hoher Weg 8, 06120 Halle (Saale), Germany
[f] University of Regensburg, Institute of Zoology, Universitätsstraße 31, 93053 Regensburg, Germany
[g] Instituto Nacional de Biodiversidad (INABIO), Pje. Rumipamba N. 341 y Av. de los Shyris (Parque La Carolina), Quito, Ecuador
[h] Tropical Ecosystems and Global Change Research Group, Universidad Regional Amazónica Ikiam, Vía Muyuna, Km. 7, Tena, Ecuador
[i] Ministerio de Ambiente, Agua y Transición Ecológica (MAATE), 170525 Quito, Ecuador
[j] Universidad Estatal Amazónica, Puyo, Ecuador
[h] Centro de Ornitología y Biodiversidad (CORBIDI), Plant Ecology Division, Lima, Peru

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ABSTRACT

Ecuador belongs to the megadiverse countries of the world. However, the high diversity in species, ecosystems and their services are under threat by land use changes, invasive species, overexploitation, pollution and climate change. There is a need to monitor, manage, protect and improve biodiversity and ecosystem services (BES) in Ecuador; however, Ecuador is marginally represented in the international policy-science interface for the protection of BES. We analyzed 266 international peer-reviewed papers that were published between 2000 and 2020 to assess the current impact of human disturbance and climate change on BES in continental Ecuador. We found that there were more studies available on the impact of human disturbance on BES than on climate change effects. Birds represented the most studied taxon in Ecuador (70 studies), whereas the total amount of available international scientific publications for other Ecuadorian plant and animal taxa were rather low (< 34 studies) and spatially and thematically scattered. Among ecosystem services, water provision was analyzed relatively often. Our literature review revealed that there is a need to conduct more studies on impacts of human disturbance and climate change on BES. Further research is needed; particularly in the coastal hinterland, in the central Andes and in the Amazon. We suggest that the investment of time, resources and effort into the documentation, standardization, sharing, and publishing of data are key towards supporting the monitoring and maintenance of BES.

Abbreviations: BES, Biodiversity and ecosystem services; CBD, Convention on Biological Diversity; CICES, Common International Classification of Ecosystem Services; CITES, Convention on International Trade in Endangered Species of Wild Fauna and Flora; ES, Ecosystem services; INABIO, National Institute of Biodiversity of Ecuador (Instituto Nacional de Biodiversidad); IPBES, Intergovernmental Platform on Biodiversity and Ecosystem Services; IUCN, International Union for Conservation of Nature; MAATE, Ministry of Environment, Water and Ecological Transition of Ecuador (renamed in 2021); MAE, Ministry of Environment of Water of Ecuador; PA, Protected Area; SNAP, National System of Protected Areas (Sistema Nacional de Areas Protegidas); SBP, Socio Bosque Program.

* Corresponding author.
E-mail addresses: janina.kleemann@geo.uni-halle.de (J. Kleemann), hongmi.koo@geo.uni-halle.de (H. Koo), isabell.hensen@botanik.uni-halle.de (I. Hensen), glenda.mendieta@geo.uni-marburg.de (G. Mendieta-Leiva), belinda.kahnt@zoologie.uni-halle.de (B. Kahnt), Christoph.Kurze@biologie.uni-regensburg.de (C. Kurze), diego.inclan@biodiversidad.gob.ec (D.J. Inclan), pablo.cuenca@ikiam.edu.ec (P. Cuenca), jin.noh@ikiam.edu.ec (J.K. Noh), matthias.hoffmann@botanik.uni-halle.de (M.H. Hoffmann), andres.factos@ambiente.gob.ec (A. Factos), marcus.lehnert@botanik.uni-halle.de (M. Lehnert), christine.fuerst@geo.uni-halle.de (C. Fürst).

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1. Introduction

Ecuador belongs to the most biodiverse countries on earth (Mittermeier et al., 2011; Yang et al., 2020). The country covers two of the five biodiversity hotspots in South America – the Tropical Andes, and the Tumbes-Chocó-Magdalena Corridor (Mittermeier et al., 2011). Ecuador is a biodiversity hotspot for endemic vertebrates (Roy et al., 2018 citing Myers et al., 2000), particularly for amphibians (approx. 45% of the local species; Ortega-Andrade et al., 2021) and reptiles (Reyes-Puig et al., 2017); and also, for endemic vascular plant species (approx. 26%; Cuesta et al., 2017 citing Jørgensen et al., 2011). Furthermore, continental Ecuador contains a high variety of different ecosystems such as Páramo (alpine tundra), mangroves, cloud forest and rainforest; this includes three biomes: the Coast, the Andes and the Amazon (see Annex Fig. A.1 for the spatial delineation). The Yasuni National Park in Ecuador appears to be home for at least 100,000 terrestrial arthropod species in a single hectare of Amazon rainforest with high species richness in ants and beetles (Bass et al., 2010). In order to protect this unique biodiversity, Ecuador has a national system of protected areas (*Sistema Nacional de Areas Protegidas,* SNAP) that covers about 20% of Ecuador's surface (MAE, 2015; see the glossary for further explanation). In addition, Ecuador has a national program of payments for biodiversity conservation, the Socio Bosque Program that supports the conservation and management of protected areas and its buffer zones (de Koning et al., 2011; Cuenca et al., 2018). Many species in Ecuador are also protected by the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) and the Nagoya Protocol and the Convention on Biological Diversity (CBD) in order to prevent illegal trade.

Despite these conservation efforts, Ecuador has the second highest number of threatened species in the world with a total of 2,501 species, including 47 mammals, 86 reptiles, 169 amphibians,[1] 102 birds, 70 invertebrates, 66 fish, and 1,954 plant species being endangered (IUCN Red List, 2020). Causes of biodiversity loss are land use changes due to agriculture and urbanization, invasive species, overexploitation, and pollution (e.g., see Buytaert et al., 2006; Fremout et al., 2020; Killeen and Solorzano, 2008; Menéndez-Guerrero and Graham, 2013; Roy et al., 2018; Tapia-Armijos et al., 2015). Ecuador belongs to the countries in South America with the highest infrastructural development within and around their protected areas (Andrade-Núñez and Aide, 2020), potentially leading to a high pressure on protected areas and their fragmentation into isolated habitats. Even worse, 72% of the 4,437 endemic vascular plants and about 10% of the threatened amphibian species in Ecuador are not protected because they occur outside the protected areas (Cuesta et al., 2017; Ortega-Andrade et al., 2021). Furthermore, climate change is increasing the pressure on biodiversity and ecosystem services in Ecuador (Cheng et al., 2013; Esquivel-Muelbert et al., 2018; Fadrique et al., 2018; Lippi et al., 2019).

Considering the threats and their international relevance to conservation, coordinated national and international efforts are needed to monitor, manage, protect and improve biodiversity and ecosystem services (BES) in Ecuador. In order to support BES conservation and management based on the interface between policy and science, the Intergovernmental Platform on Biodiversity and Ecosystem Services (IPBES) has carried out regional and global assessments of BES. The most recent global assessment showed that intact ecosystems and biodiversity are constantly decreasing and there is a worsening trend in future scenarios for BES (IPBES, 2019). The IPBES regional report for the "Americas" (covering North and South America) stated that 65% of ecosystem services are diminishing and 21% of them are in steep decline (IPBES, 2018). Ecuador currently holds minor relevance in the international policy-science interface on biodiversity conservation as can be seen in the IPBES Regional Report in contrast to Brazil and Mexico. Balvanera et al. (2012) assumed that Ecuador did not join the IPBES because the economic valuation of BES was strongly emphasized in the IPBES process; which is also against the concept of *Buen Vivir ("Sumak Kawsay"; good living;* MAE, 2016b). With the incorporation of the rights of nature and the indigenous concept of *Buen Vivir* in its constitution, the Ecuadorian government has shown promising approaches to sustainable development (Asamblea Constituyente de Ecuador, 2008). However, the Ecuadorian government faces many social and economic challenges which cannot comply with nature conservation (Lalander, 2016). Bioeconomy was considered to be a compromise between economy and nature. For example, the economic benefits from the use and management of natural resources was pointed out by the National Plan of *Buen Vivir* 2017–2021 and the National Biodiversity Strategy 2015–2030 (guideline 3.6 in Senplades, 2017 and MAE, 2016a). The government is often confronted with the tempting prospects of the extractive industry and the innovative constitution aiming for a respectful and responsible relationship with nature (Vogt, 2018). The government opened in 2016 approx. 13% of the Ecuadorian mainland to mining exploration (Vandegrift et al., 2017) causing deforestation, fragmentation and sedimentation (Roy et al., 2018). A prominent example is the oil extraction in the Yasuni National Park (for further reading, e.g., Sovacool and Scarpaci, 2016; Bass et al., 2010). Ecuador's gross domestic product is highly dependent on oil and gas resources, which accounts for about a third of their export earnings in 2017 (CIA World Fact Book, 2020). This indicates that the economic argument provided by Balvanera et al. (2012) cannot be the reason for the low representation of Ecuador in IPBES. In addition, the Socio Bosque Program was launched in 2008 as part of *Buen Vivir,* which is also an economic valuation of BES.

Knowledge gaps are other challenges for BES management in Ecuador. Data and information on BES in Ecuador have not yet been sufficiently synthesized. Ecuador's performance in research regarding the amount of publications, funding and research fields ranks in the mid-range among the South American countries (Titley et al., 2017; Tydecks et al., 2018). The northern part of South America is understudied considering the number of threatened animal species occurring in this region and the number of biodiversity studies that have been conducted there (Titley et al., 2017). However, according to Freile et al. (2014) and Soh et al. (2019), research for bird species and tropical montane biodiversity seems to be well developed for Ecuador among South American countries. In addition, condensed information about biodiversity in Ecuador can be found in Báez et al. (2016) who analyzed the impact of climate change on Andean biodiversity. Campos (2014, in MAE, 2016a) conducted a review of biodiversity in Ecuador looking at taxonomy, evolution, reproduction, behavior, anatomy, and physiology of species, but he did not specifically look at the impact of human disturbance and climatic change on BES. None of the reviews on Ecuador have analyzed both the effects of human disturbance *and* climate change on BES in one review. Furthermore, we investigated the impact of human and climate pressures on different spatial and ecological scales.

We analyzed the research status of the impact of human disturbance and climate change on BES through a literature review of peer-reviewed publications of the last 20 years in Ecuador to identify BES-related knowledge and research gaps. We hypothesized that the majority of studies report a negative effect of human disturbance and climate change on BES. In order to support our research objectives, we analyzed the papers according to different criteria (see Section 2 for methods, results in Section 3, and Annex Table A.1) in general (Section 3.1) and per taxa (Section 3.2). We also analyzed priority areas for biodiversity conservation in Ecuador on the national level (Section 3.3). In addition, based on our findings and an author's workshop conducted at Martin-Luther University Halle-Wittenberg, Germany, July 3–5, 2020 in combination with online meetings with the Ecuadorian partners, we provided recommendations for policy, science and conservation (Section

[1] Ortega-Andrade et al. (2021) reports that even 363 amphibian species are threatened in Ecuador. This difference assumes data deficiencies (also for reptiles; Reyes-Puig et al., 2017).

4.1) in order to go beyond a mere review of papers. Finally, we discussed the review critically (Section 4.2) and concluded based on our findings (Section 5).

2. Methods

2.1. Literature review

The focus of our review was on international peer-reviewed scientific papers published in English from 2000 to 2020, and an analysis of the impact of human disturbance and climate change on BES in Ecuador. In our review, we concentrated on the biodiversity of birds, mammals, reptiles, amphibians, arthropods, epiphytes, terrestrial ferns, grasses and herbaceous vegetation, trees, palms and other woody vegetation. In addition to biodiversity assessed at the taxon level, we included ecosystems and their services, e.g., food, water, pollination, water and air filtration, recreation, among others (MEA, 2005) (tables are provided in the Annex Tables B.1–B.10). Epiphytes and terrestrial ferns were considered as relevant flora because of their high representation, especially in tropical forests. Epiphytes contribute up to 27% to the total plant species in Ecuador (Jørgensen and Léon-Yánez, 1999). Regarding other relevant ecological systems, we excluded marine ecosystems and inhabiting species because the focus was on the terrestrial biodiversity of Ecuador. However, water provision was included as an important ecosystem service (ES). Galapagos Islands were excluded because of their status of being a very specific biome with unique biodiversity and conservation concerns that are very different from continental Ecuador; hereafter referred to as Ecuador.

The core literature search was conducted between July 1, 2020 and September 30, 2020. Summaries per taxa, updates for the year 2020, and refinements were carried out between October 1, 2020 and January 31, 2021. The search terms in Google Scholar were 'climate change' / 'human disturbance' OR 'fragmentation[2]' AND '[taxa]' / 'ecosystem' / 'ecosystem service*' AND 'Ecuador' AND 'biodiversity'. The exact search terms for the taxa were: 'gras*' / 'poaceae' / 'herb*', 'epiphyte*', 'tree*' / 'wood'* / 'palm'*, 'fern*', 'bird*' / *ave.*', 'amphibia*', 'repti*', 'arthropod[3]*' and 'mammal*'. We selected the studies according to several criteria (Annex Table A.1). Only studies that directly analyzed the impact of human disturbance and/or climate change were included, and thus, reviews or studies merely citing other sources were excluded (Annex Table A.1). Thematically fitting studies that were included in addition to the studies found with the search terms listed above were marked with an asterisk in the summary tables (see Annex Tables B.1–B.10).

Ecosystem Services (ES) were classified according to the Common International Classification of Ecosystem Services (CICES; Haines-Young and Potschin, 2018): provisioning ES (e.g., food and water provision), regulating ES (e.g., water purification) and cultural ES (e.g., landscape aesthetics). Biodiversity was separately analyzed from ES because biodiversity is considered to be underlying structures that support ecosystem processes and functions to provide ES but not ES per se (Naeem et al., 1995; Cardinale et al., 2012).

The main measures for analysis of the status of biodiversity were abundance, occurrence, richness, composition, and turnover. Genetic diversity was only marginally addressed. We further classified the studies according to different geographical scales (micro, meso and macro), and ecological scale (coastal, Andes and Amazon; only for studies on micro and meso levels). We categorized the effect of human disturbance and climate change into: positive, negative, or no effects. Studies showing positive as well as negative effects on different species within one taxon were considered "trade-offs". Studies showing different / opposite effects on the same taxon at different geographic scales (micro, meso and macro; see text below Table A.1 for explanation of the different scales) or on different biodiversity metrics were also mentioned as trade-offs. Studies including different taxa (e.g. birds and mammals) were included separately for each taxon. We further analyzed the spatial scale of analysis and author affiliation (see Annex Table A.1).

2.2. Mapping hotspots of biodiversity and ecosystem services

2.2.1. Map of reviewed studies per province

The number of studies per province in Ecuador was analyzed to identify the spatial distribution. The geographical location of each study was obtained from its methodological description in the respective papers. In cases in which geographic coordinates were not provided, its location was estimated considering the information given in the study. Only province level could be used as the lowest geographical scale due to a lack of precise information in some studies. All geographical coordinates were in decimal degrees (WGS84) and reprojection was done when needed in QGIS Version 3.6. Each geographical location was then spatially related to the province level.

2.2.2. Map of studies of BES hotspots on the national level and in protected areas

In the analysis to identify overlaps between protected areas and biodiversity hotspots, only studies providing information about biodiversity hotspots on the national level were included. In this case, studies including national IUCN Red Lists were also considered, which were excluded from our literature review because of the different focus (priority areas of conservation versus the impact of human disturbance and climate change on BES in the literature review). Cuesta et al. (2017), Lessmann et al. (2014), Noh et al. (2020), and Sierra et al. (2002) provided spatially explicit maps of very low, medium and very high priority areas for biodiversity conservation based on biodiversity hotspots. We delineated the very high to medium priority areas in QGIS and overlapped them with existing public and private areas of nature protection in Ecuador (data were taken from MAATE, 2021[4]). Protection areas smaller than 1,000 ha were excluded from the map, since these areas were too small for spatial representation on the national level. The protection aims in the above-mentioned papers varied due to the focus on either species, ecosystems or both, different biodiversity target groups and approaches (Table A.2).

3. Results

3.1. General research trends regarding the impact of human disturbance and climate change on BES in Ecuador

In total, we found 266 international peer-reviewed publications concerning the impact of human disturbance and climate change on BES in Ecuador. In general, there were more publications on human disturbance than on climate change effects (Fig. 1a and b). The majority of studies reported a negative effect of human disturbance and climate change for most taxa, although signals were not as strong as expected.

[2] By fragmentation and human disturbance, we refer to: disturbed habitats, degraded habitats, habitat loss, habitat alteration, habitat fragmentation, habitat modification, human-modified habitats, fragmentation, human land use, land use change, human activity, anthropogenic pressures, (oil) exploration, exploitation, habitat quality reduction, reduction in connectivity, gradient of land use, land use intensity, forest alteration, deterioration, degradation, and deforestation.

[3] Besides "Arthropods", we also searched specifically for the main groups "insects" or "Insecta", "Myriapoda" or "myriapods", and "spiders" or "Chelicerata".

[4] The Ministry of Environment of Water (MAE) has been renamed in 2020 to the "Ministry of Environment and Water of Ecuador" (MAAE). In 2021, it was renamed to the "Ministry of Environment, Water and Ecological Transition" (El Ministerio de Ambiente, Agua y Transición Ecológica - MAATE).

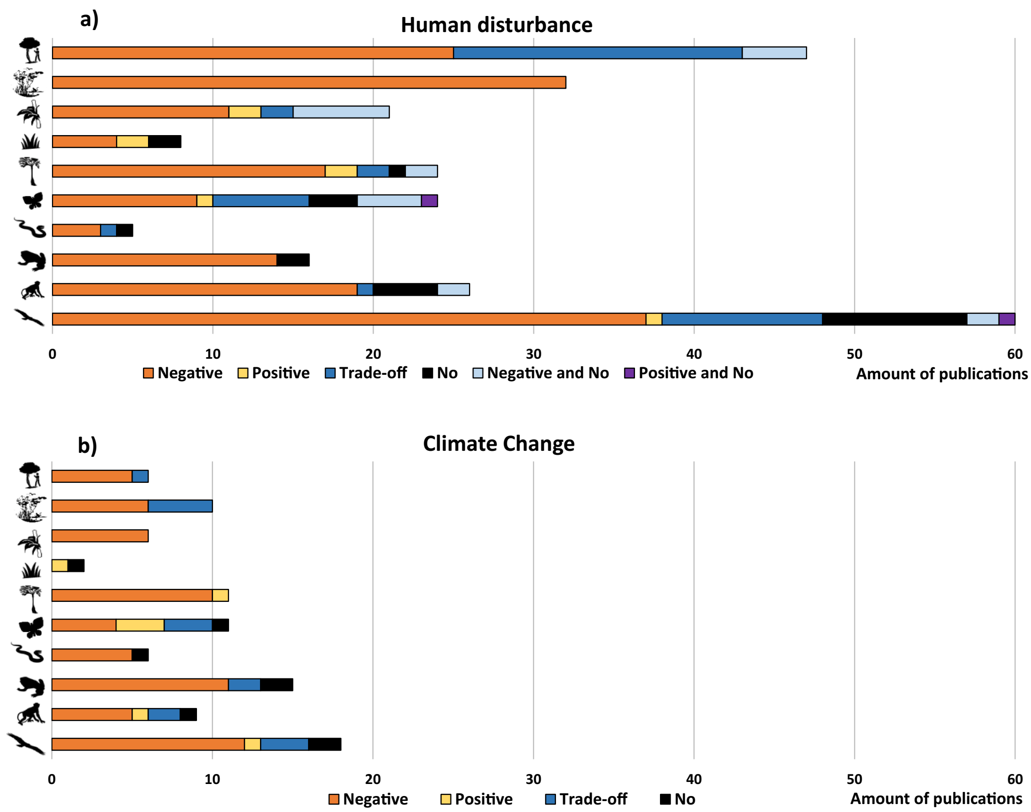

Fig. 1. a, b: Amount of international, peer-reviewed publications per taxon in 2000–2020 investigating the impact of a) human disturbance and b) climate change. Studies that considered human disturbance and climate change were included in both graphs. Trade-off effects: positive and negative impact on BES; negative and no: negative and no impact on BES, e.g., effects are negative for a certain species but these have no effect on other species within the same taxon or they have a different impact on biodiversity metrics, e.g., a negative effect on species richness but no effect on species abundance. Considering the impact of climate change, we found no studies that recorded "negative and no" effect or "positive and no" effect.

Studies with "negative and no" as well as "positive and no" effects on BES were found for human disturbance, but not for climate change. Trade-off effects of human disturbance were particularly found for birds, arthropods, and ES.

The majority of studies concentrated on bird species (70 papers); followed by ES (48) and ecosystems (42). Fewer publications addressed grasses and herbaceous vegetation (10). For spiders, myriapods and terrestrial ferns, specifically, we could not find any relevant publication for Ecuador according to our criteria. Although lycophytes and ferns (aka. pteridophytes) have long been studied in Ecuador in the last 20 years (e.g., Kessler et al., 2009; Lehnert, 2017; Oldekop et al., 2011; Sirén et al., 2013), none of the studies have specifically analyzed the impact of human disturbance or climate change on terrestrial ferns. Regarding spiders, only reports, experimental studies and analyses on social behavior of spiders were available for Ecuador. Publications simultaneously assessing the effect of human disturbance and climate change were mainly available for birds (7), epiphytes (5), mammals (5), trees and ES (5; Annex Fig. A.2). Concerning biodiversity metrics, mainly abundance, species richness and species distribution were analyzed in the papers (Annex Fig. A.3).

Comparing the effects of human disturbance on the different taxa, we noted that deforestation, for example, had positive effects on herbaceous vegetation (as vegetation favoring open canopy) but negative effects on forest ecosystems (e.g., Bonilla-Bedoya et al., 2014). Similarly, ES such as food provision might increase due to agricultural expansion even though biodiversity decreases (e.g., Kleemann et al., 2020; Quintana et al., 2019). For example, hunting in the Amazon forest has negative effects on mammal and bird species but can be regarded as positive for food provision and income generation (Franzen, 2006; Zapata-Ríos et al., 2009). Regarding the total amount of publications, we found more publications that studied the effects of human disturbance on the fauna (173) than on the flora (62) of Ecuador. Studies on climate change effects (including those studies which also analyzed human disturbance) were also more obtainable for animals (59) than for plants (29). Even when including studies on ecosystems as a part of the flora, there were fewer papers available on the effects of climate change on plants (104) than on animal species.

Most of the studies were conducted at the micro and meso level (242 studies including double counting if the study analyzed different taxa). However, the amount of analyses on the micro, meso, macro and mega level was balanced for reptiles, for example (Annex Fig. A.4). Globally conducted analyses were not available for epiphytes. Considering biomes, the majority of the studies was conducted in the Andes (Fig. 2). The Amazon biome was less researched for effects of human disturbances and climate change on epiphytes and ecosystems even though studies on the macro and mega level existed for ecosystems in the Amazon, e.g., Esquivel-Muelbert et al. (2018), and Killeen and Solorzano (2008). In contrast to ecosystems, tree species were at least represented in 6 (from a total of 21) studies in the Amazon. The coastal biome was especially underrepresented in studies on reptiles, trees and other woody vegetation (Fig. 2).

Authorship of our analyzed papers was mainly from abroad. However, 69 of the collected papers (26%) were led by an author affiliated to an Ecuadorian institution. For 49 papers (18%), the last author was affiliated to an Ecuadorian institution in the publication year of the respective paper. 29 papers (11%) had the first, last and at least one of the intermediate authors from Ecuador. However, the amount of papers on human disturbance and climate change effects on BES in Ecuador has steadily increased per year. Similarly, the number of papers with a higher proportion of Ecuadorian authors has increased since 2013 (Annex Fig. A.5).

Considering the spatial location of the studies analyzed, it was striking that the Andes were not as well represented on the province level as on the biome level (Fig. 3). This could be due to the fact that the spatial location per province was only counted once while the location per biome was counted per taxa. Most of the studies were conducted around Quito in Pichincha, Napo, and Zamora Chinchipe Province. Fewer studies were available for the southern coastal (hinter-) land, the

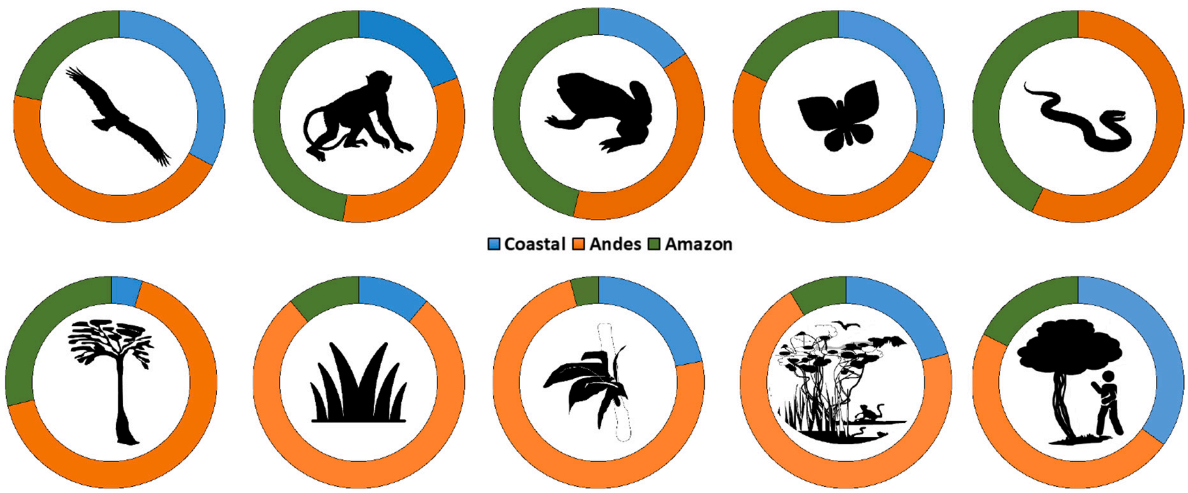

Fig. 2. Proportion of studies on micro and meso level per taxa investigating one of the three main biomes (Coast, Andes and Amazon) in Ecuador.

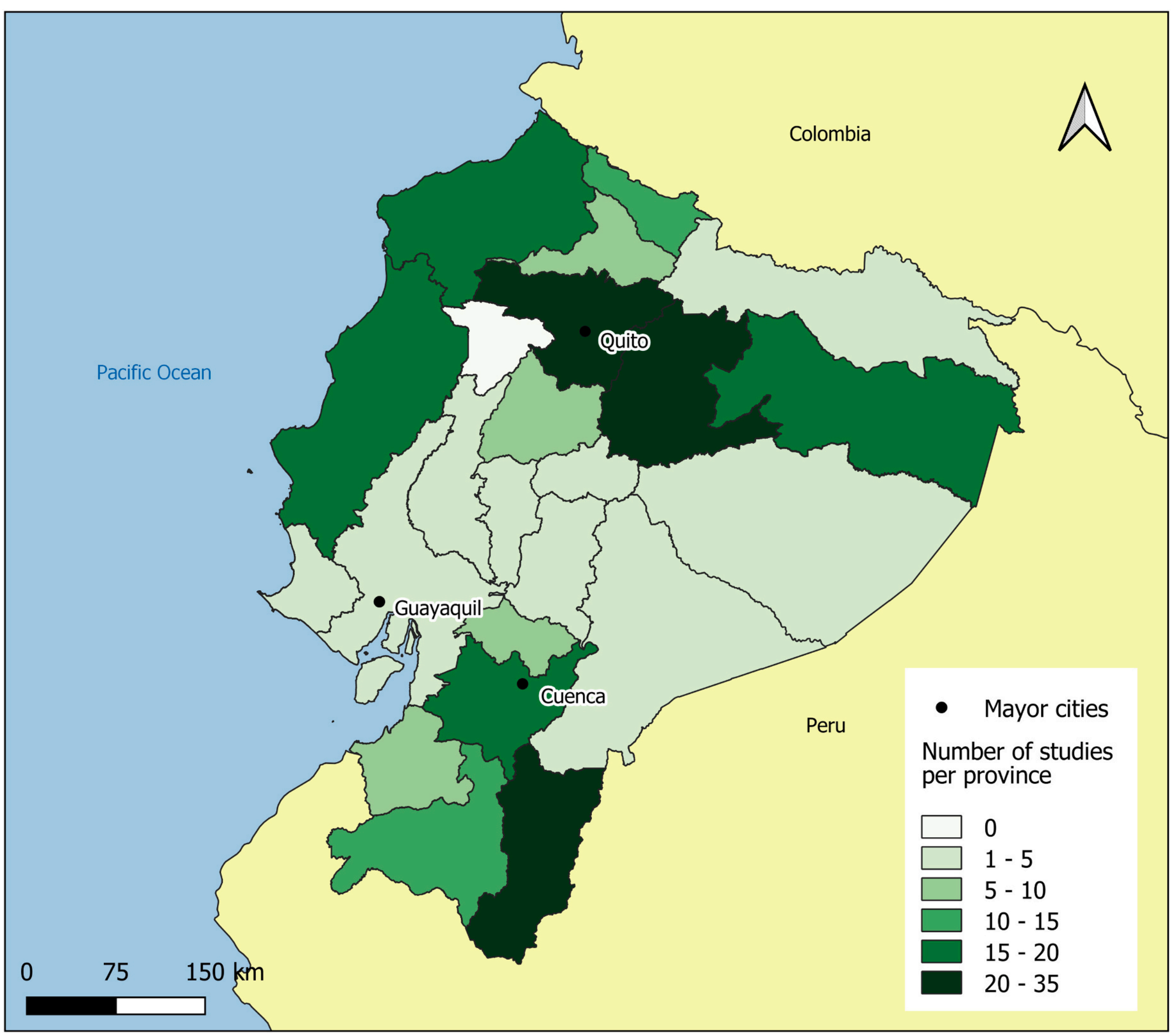

Fig. 3. Number of studies per province that analyzed the impact of human disturbance and climate change on biodiversity and ecosystem services in continental Ecuador. The names of the provinces are provided in Annex Fig. A.1.

central part of the Andes and for most regions of the Amazon, apart from Orellana and Zamora Chinchipe Province. The province Santo Domingo de los Tsachilas was not studied at all. For the Zamora Chinchipe Province, many studies in the Podocarpus National Park and San Francisco Reserve were responsible for the high representation of this province in the total assessment. For the Orellana Province, studies were most often conducted in Yasuni National Park. Interestingly, most parts of the Amazon are still white spots of BES studies, especially the indigenous territories in Pastaza and Morona Santiago Province. Coastal Ecuador is better represented than the Amazon even though it is considered to be "less diverse, more densely populated and disturbed" (De la Torre et al., 2012; p. 8) than the Amazon. Sucumbíos is an Amazon province where high pressure exists due to oil extraction but studies on impacts of human disturbance on BES are rare in this region. However, we did not consider renaturation studies which could play a role in Sucumbíos (e.g., Villacís et al., 2016).

3.2. Research trends per taxa, for ecosystems and ecosystem services

3.2.1. Birds

Considering the effects per taxon, several studies have analyzed the relationship between disturbed landscapes and species richness for birds (e.g., Mordecai et al., 2009; Santillán et al., 2020). Landscape heterogeneity was often positively associated with species richness. However, some studies on human disturbance reported trade-off effects (17%, 10 of 60 studies; see supplementary Table B.1) because other biodiversity metrics (e.g., functional diversity) showed a negative effect. Generalists may replace specialists in degraded habitats (Becker and Agreda, 2005) and heterogeneity had more effects on insectivorous than on frugivorous birds because insectivorous bird species are often more specialized in foraging (in Santillán et al., 2020 citing Pigot et al., 2016). Effects of climate change on bird biodiversity were more negative (67%, 12 of 18 studies) than effects of human disturbance (62%, 37 of 60 studies).

3.2.2. Mammals

Despite the limited number of studies on the biodiversity of mammals, human disturbance and climate change can certainly negatively affect mammal's abundance, behavior and their species richness. The majority of studies focused on the effects of human disturbance (87%, 26 of 30 studies; see supplementary Table B.2). These studies mainly investigated the effects on a micro scale on a few species in the Andes and Amazon, whereas the west of Ecuador seemed to be neglected, even though this region has been most severely impacted by deforestation and large-scale plantations (e.g., palm oil and eucalyptus plantations). Mining, hunting, and oil-related activity are, along with agriculture, the major threats for mammals in the Andes and Amazon, respectively. 19 out of 26 studies (73%) concluded a negative effect of human disturbance. In intact ecosystems such as Yasuni National Park, human activities (except hunting; Zapata-Ríos et al., 2009) seem to have no pressing impact on most species that were investigated (Blake and Loiselle, 2018; Salvador and Espinosa, 2016). Although effects of climate change on especially endangered mammals cannot be denied (5 out of 9 studies with negative effect), allowing free movement by providing sufficient protected areas and migration corridors can buffer these effects for many species.

3.2.3. Reptiles

There were only 11 studies in total investigating the impact of climate change and/or human disturbances on reptiles. Most of these studies (73%, 8 of 11 studies; see supplementary Table B.3) addressed the diversity of reptiles in all of Ecuador or in the Andes. In contrast, studies specifically focusing on reptiles in other Ecuadorian biomes, i.e. the Amazonian rainforest or coastal areas, were rare (3 in the Amazon region) or completely lacking (coast). Moreover, most of the studies (73%, 8 of 11 studies) did not investigate a specific group of reptiles but rather considered the whole vertebrate fauna or herpetofauna of the study area. Of the 5 studies investigating the effect of human disturbances (mainly habitat change and fragmentation) on Ecuadorian reptiles, three inferred a negative effect on the species richness, abundance or distribution, while two studies (Tolhurst et al., 2016; Vigle, 2008) found no or positive and negative effects on reptilian diversity estimates. The majority of studies investigating the impact of climate change on reptile diversity in Ecuador (5 of 6 studies) inferred negative effects such as an increasing extinction risk, a decreasing abundance and/or distribution range.

3.2.4. Amphibians

Most of the studies on the biodiversity of amphibians investigated either all of Ecuador or Ecuador as part of South America/ the Neotropis/ the Western Hemisphere/ the world (54%, 15 of 28 studies; see supplementary Table B.4) rather than focusing on a smaller spatial scale. Approximately half of these studies also concentrated on the entire amphibian fauna occurring within a study area rather than on a specific amphibian group. Considering taxon specific studies, harlequin toads (genus *Atelopus*) were the most frequently investigated group (5 studies). Nearly all of the studies addressing human disturbances, apart from Vigle (2008) and Menéndez-Guerrero and Graham (2013), found a negative effect of habitat loss, habitat change and/or fragmentation on amphibian diversity (88%, 14 of 16 studies), mainly measured as species richness or abundance. The effects of climate change on amphibian diversity often revealed a negative effect on amphibian distribution and/or abundance (75%, 11 of 15 studies). However, Menéndez-Guerrero et al. (2020) and Silva Vieira et al. (2018) suggested trade-off effects of climate change on amphibian diversity or their distribution and abundance. Interestingly, although climate change has previously been suggested to be linked to outbreaks of fungal diseases in amphibians, there is no direct evidence for Ecuadorian amphibians (Hof et al., 2011; Lips et al., 2008; Menéndez-Guerrero and Graham, 2013).

3.2.5. Arthropods

A variety of different families were represented for arthropods even though Dangles et al. (2009) mentioned that the current research focus is on a few groups (e.g., *Papilionoidea, Carabidae*). Studies on human disturbance reported mainly negative effects (38%, 9 of 24 studies; see supplementary Table B.5) and trade-offs (25%, 6 of 24 studies). Trade-offs were primarily related to different effects on biodiversity metrics, taxonomic groups or functional groups. Negative climate change effects were not found in many studies (36%, 4 of 11 studies on climate change) and the effects were also positive due to the expansion of pest species, e.g. mosquitos (Lippi et al., 2019) and the tropical fire ant (Byeon et al., 2020). Studies on functional diversity in arthropods along an elevational gradient in Ecuador exist (e.g., Brehm et al., 2005), but could not be considered in this study due to the missing direct analysis of effects of climate variability on species.

3.2.6. Epiphytes

According to Jørgensen and Léon-Yánez (1999), 3,953 vascular epiphytic species can be found in Ecuador. The majority of the studies of epiphytes were carried out at the micro scale (68%, 15 of 22 studies; see supplementary Table B.6). Similarly, there was a large geographical bias. Almost all of the micro and meso scale studies (77%, 17 of 22 studies) were conducted in the Andes. Although the majority of the studies found a negative effect of human disturbance on several biodiversity metrics (90%, 19 of 21 studies on disturbance), some found a trade-off between groups and metrics. For instance, disturbance benefited lichens but was harmful to bryophytes (non-vascular epiphytes; Noeske et al., 2008). Species richness sometimes increased with disturbance but species composition often reflected the negative or lack of effect (Larrea and Werner, 2010; Noeske et al., 2008). Only 5 studies indirectly assessed the impact of climate change on epiphytes, in conjunction with the impact of disturbance (e.g., Benitez et al., 2015; Koester et al., 2013; Werner and Gradstein, 2008), and found a negative effect overall. The effect was more pronounced on bryophytes. Surprisingly, not a single study directly assessed the possible impact of climate change on epiphytes.

3.2.7. Grasses and herbaceous species

There exist 5,752 herbaceous species in Ecuador. Grasses *(Poaceae)* belong to the most species-rich families of the Ecuadorian flora with about 450 species (Jørgensen and Léon-Yánez, 1999), but only 9 papers were found in total. Páramo vegetation was often mentioned (67%, 6 of 9 studies; see supplementary Table B.7) and the impact of human-induced fires was addressed as human disturbance. There was either no effect due to human disturbance or a positive effect because grasses expanded into agricultural areas and disturbed forest.

3.2.8. Trees and other woody species

Given the outstanding diversity of trees with about 2,736 species in Ecuador (Jørgensen and Léon-Yánez, 1999), it was surprising that only 31 papers dealt with the response of tree species to effects of climate change and/or human disturbance. Effects of climate change on tree species were mainly negative (10 out of 11 studies; see supplementary Table B.8) while studies with negative effects from human disturbance amounted to 71% (17 of 24 studies). The majority of studies used modeling approaches such as species distribution modeling or global vegetation models to analyze species present and future distributions (e.g., Aguirre et al., 2017; Cuesta et al., 2017; Ramirez-Villegas et al., 2014). In studies of human disturbance, some studies evaluated demography (e.g., fringe effects of the performance of juveniles versus adults) and reported negative effects (Anthelme et al., 2011; Browne and Karubian, 2016), but also positive responses such as palm species that benefitted from the environmental conditions of the disturbed forest (Rodríguez-Paredes et al., 2012). The Rosaceae *Polylepis* was the most investigated genus (5 studies) and, due to its location at higher elevations, the Andes biome was well represented (Fig. 2). Negative impacts of human disturbance on genetic diversity of *Polylepis* were reported by Aragundi et al. (2011, for *P. pauta*) and Hensen et al. (2012, for *P. incana*). Hensen et al. (2012) compared genetic diversity and structure of adult trees with those of seedlings in nine forest fragments and found that estimates of genetic diversity at the population level were significantly lower in seedlings than in adults. This pattern was confirmed by Browne et al. (2015) and Browne and Karubian (2018) for Neotropical palm species, implying that species' genetic diversity is not only affected by historic but also by recent fragmentation.

3.2.9. Ecosystems

The majority of the studies on biome level were conducted in the Andes (71%, 24 of 34 studies on biome level; see supplementary Table B.9), while fewer studies focused on the Amazon region (9%, 3 out of 34 studies). There were more studies which focused on the impact of human disturbance (76%, 32 out of 42 studies) than on the impact of climate change (26%, 11 out of 42 studies). Only one study addressed the impact of both aspects (Fremout et al., 2020). All studies relevant to human disturbance showed negative impacts on biodiversity, which specifically addressed forest fragmentation and degradation due to deforestation, as well as its resulting habitat fragmentation. The majority of the studies on ecosystems dealt with its importance as habitat for flora and fauna, and the impacts of human disturbance and climate change on the biodiversity of species in the respective ecosystem. Only a few studies focused on the responses of ecosystems and forests to climate change, which lead to changes in the composition of ecosystems (Esquivel-Muelbert et al., 2019; Fadrique et al., 2018). 6 of the 10 climate change related studies (60%) showed negative impacts on biodiversity by assessing the risk of species turnover and the displacement of species depending on climate change scenarios (e.g., Cheng et al., 2013; Fremout et al., 2020; Killeen and Solorzano, 2008). However, 4 studies showed mixed impacts of climate change on biodiversity (40%) which were defined as trade-offs (e.g., Aguirre et al., 2017; Esquivel-Muelbert et al., 2019; Fadrique et al., 2018).

3.2.10. Ecosystem services

Publications on ES were especially available for the Andes and coastal region (83%, 33 out of 40 studies on micro and meso scale). Regarding the ES types, provisioning (77%, 37 out of 48 studies; see supplementary Table B.10) and regulating (58%, 28 out of 48 studies) ES were mainly analyzed related to food and water provision, carbon sequestration and hydrological regulation. Water was interestingly quite often analyzed (60%, 29 out of 48 studies) as water quality, quantity, hydrological regulation, and water energy – especially Páramo as an important water supplier for the cities. For example, 85% of the surface water provision for Quito comes from the Páramo (Buytaert et al., 2006). All 3 ES types (provisioning, regulating and cultural) were only analyzed in 2 studies. A usual finding for ES was that studies showed trade-offs between different ES types and biodiversity under human disturbance (38%, 18 out of 48 studies; e.g., Quintana et al., 2019; Rodríguez et al., 2005). For example, hydropower dams provide energy but generate high ecological costs (Briones-Hidrovo et al., 2019). Climate change impacts were analyzed more often for ecosystems than for ES. Only 6 studies on climate change effects which showed mainly a negative impact (5 studies) were obtainable.

3.3. Priority areas for biodiversity conservation

Only 0.6% of the very high to medium priority areas for biodiversity conservation suggested by Cuesta et al. (2017), Lessmann et al. (2014), Noh et al. (2020), and Sierra et al. (2002) overlap. They are located in southern Ecuador in the semi-deciduous forest mountain foothills of Catamayo-Alamor in the province of Loja (Fig. 4). This biodiversity hotspot is on the fringes of the Bosque Seco Biosphere Reserve and threatened by human activity and population growth causing higher fragmentation (Tapia-Armijos et al., 2015). Loja and Zamora Chinchipe lost approx. 46% of their natural vegetation between 1976 and 2008 (ibid.). In the Cordillera Kutukú and Shaimi protective vegetation, small biodiversity hotspots are located. However, the protected areas (PAs) do not belong to the SNAP and have lower protection status (crosshatched in Fig. 4). For example, in the Tumbesian region of Ecuador, only 25% of the protected forests still have their original vegetation as it is densely populated (Rodas, 2004 in Bonaccorso et al., 2007). As shown in Fig. 4, many PAs with lower conservation status are located close to densely populated areas, e.g. Quito, Cuenca, and Guayaquil (see Annex Fig. A.1 for city locations) causing high pressure on the PAs (supported by Andrade-Núñez and Aide, 2020) and assuming a high risk of land conversion due to their lower protection status.

4. Discussion

4.1. Recommendations for research, conservation, and policy

As a result of our literature review and workshop conducted in Germany combined with online meetings with Ecuadorian partners, we developed recommendations for BES research, conservation, and policy.

4.1.1. Recommendations for research

4.1.1.1. Conduct more studies on potential threats and combined effects on BES. Even though the total amount of studies of effects of human disturbance and/or climate change is rather low, our review has revealed that there exist more studies on human disturbance than on climate change effects on BES. Furthermore, studies analyzing the effects of climate change in combination with human disturbance are rare. Climate change apparently increases the pressure on ecosystems that provide human benefits and habitats for species. There is a lack of relevant studies addressing climate change impacts on taxa overall; but also specific groups, such as epiphytes, terrestrial ferns, spiders, myriapods, and reptiles, seemed to be understudied. For example, although Ecuador has the highest number of reptile species per area worldwide (Torres-Carvajal et al., 2019) there is a large data deficit on the conservation status of Ecuadorian reptiles (Reyes-Puig et al., 2017; Torres-Carvaja et al., 2019) and potential threats such as climate change (Winter et al., 2016). Moreover, Roll et al. (2017) suggests that global conservation schemes represent birds and mammals better than reptiles

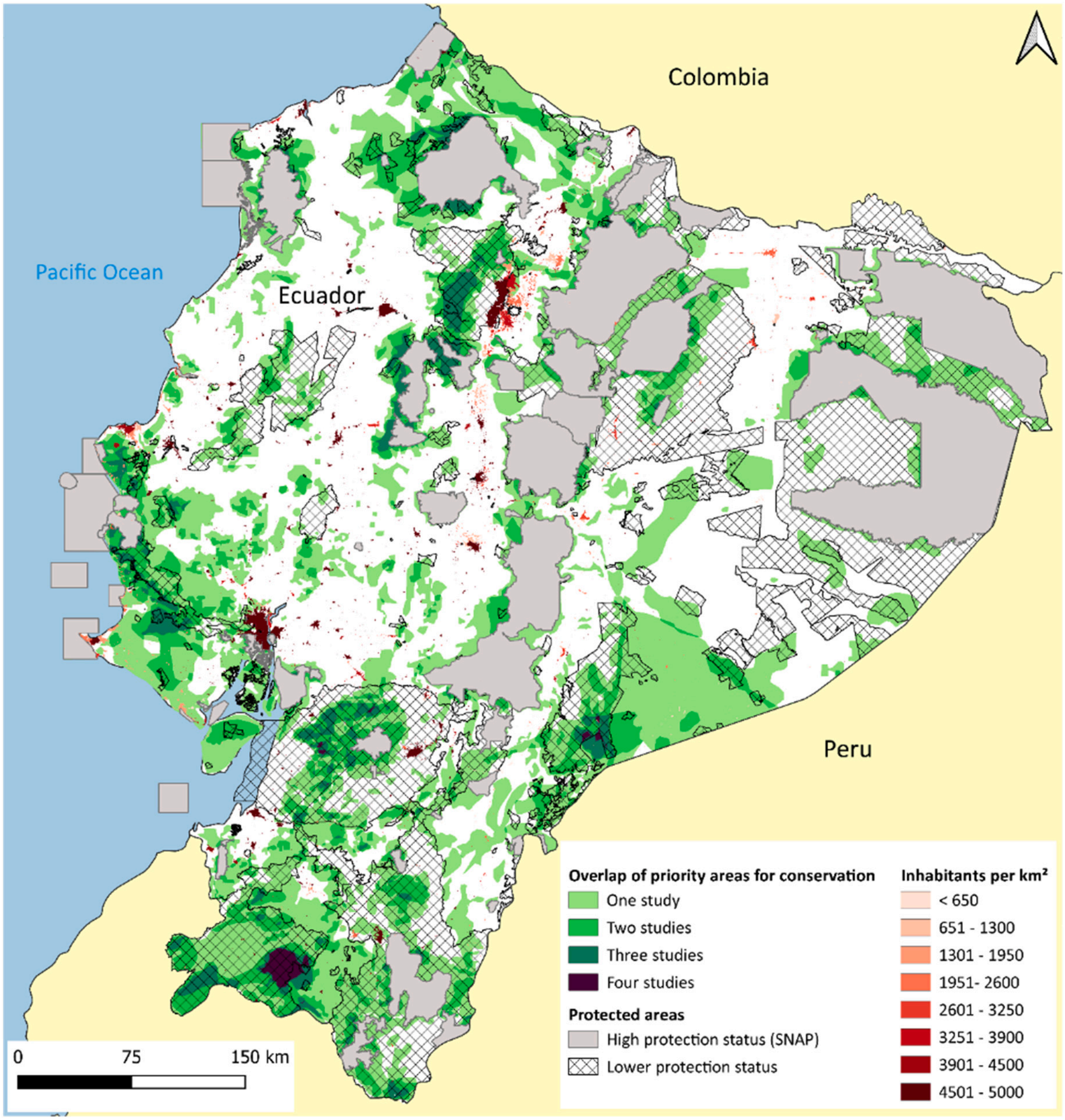

Fig. 4. Map showing the spatial overlap of the four studies by Cuesta et al. (2017), Lessmann et al. (2014), Noh et al. (2020), and Sierra et al. (2002) suggesting additional priority areas for biodiversity and ecosystem conservation in Ecuador. Grey areas: protected areas (PAs) with high protection status (Sistema Nacional de Areas Protegidas - SNAP), crosshatched area: PAs with lower conservation status, e.g. biosphere reserves, forest reserves, and private PAs. PAs smaller than 1000 ha are excluded from its representation on a national level. The delineation of PAs was taken from the website of the Ministry of Environment, Water and Ecological Transition (MAATE, 2021).

emphasizing the need for further studies addressing the effects of potential threats such as climate change and human disturbance on reptile diversity. In addition, there is a need to address combined effects of climate change and human disturbances but also other threats. For example, in amphibians, it has previously been hypothesized that climate change is positively correlated with the spread of the fatal fungal disease chytridiomycosis (e.g., Pounds et al., 2006), which is one of the major causes of amphibian decline (Voyles et al., 2009).

In addition, we identified more studies investigating the effects of climate change on fauna than on flora of Ecuador. This finding is in contrast to the argument from Báez et al. (2016) that studies on climate change impacts have been less researched for birds, mammals and reptiles than for plants. However, Báez et al. (2016) focused on studies in the whole neotropics rather than exclusively Ecuador. The necessity of climate change related studies has been emphasized as Ecuador hosts ecosystems that are most vulnerable to climate change (Eguiguren-Velepucha et al., 2016). This issue can be addressed by data with high resolution to analyze a long-term climate change trend and adaptive mechanism of ecosystems (Fernandez et al., 2015). Our literature search has also shown that 2/3 of all studies were conducted in protected areas. Future studies should also focus on potential trade-offs within taxa groups as several papers have outlined (e.g., Esquivel-Muelbert et al., 2019; Lippi et al., 2019; Menéndez-Guerrero et al., 2020), as well as between biodiversity measures of different taxa and ES (e.g., hunting as ES versus species loss; Franzen, 2006; Zapata-Ríos et al., 2009). This in-depth analysis of potential impacts should guide decision-making, priority settings for future conservation, and adapted planning.

4.1.1.2. Conduct more BES studies in the Amazon biome and coastal hinterland. The analysis at micro and meso scales showed that many BES studies were conducted in the Andes biome. This finding is in line with Campos (2014, in MAE, 2016a). Similarly, Báez et al. (2016) found more studies on the effects of climate change on the biodiversity in the Andean region of Ecuador than for the Andes in Argentina, Venezuela and Bolivia. The Amazon biome was surprisingly understudied, especially for epiphytes and ecosystems, even though the Amazon basin represents one of the most globally relevant ecosystems. The coast and coastal hinterland have higher human activity than other regions, but studies regarding the impact of human disturbance and climate change on BES have been less conducted than in the provinces around Quito. Biodiversity in the coastal hinterland is lower than in the Amazon but the appreciation of ES might be high due to high population densities (De la Torre et al., 2012). In contrast, the population density in the Amazon biome is low, nevertheless, human pressure is high. Oil extraction is causing irreversible damage in the Amazon that is furthermore an ecosystem highly vulnerable to climatic changes (Eguiguren-Velepucha et al., 2016; Malhi et al., 2020; Sales et al., 2017). Considering the incredible biodiversity value, analyses and action for nature conservation are required for the Amazon, especially where high pressure of oil fields exists, as in the Sucumbíos Province. Consequently, there should be more research activities in the Amazon and coastal hinterland.

4.1.2. Recommendations for conservation

4.1.2.1. Establish new reserves and expand existing protected areas. Even though many protected areas (PAs) exist in Ecuador, its protection status, connectivity and real conservation vary. Private reserves are especially small and isolated (MAATE, 2021). Cuesta et al. (2017) report that PAs were often designated based on other criteria than conservation due to the fact that many PAs are located at higher elevations, on steeper slopes, and in inaccessible or marginal areas. As seen from Section 3.3, one of the overlapping areas of priority for biodiversity conservation was in Loja Province where lowland dry forests are located. These ecosystem types are hardly protected by SNAP (Mestanza-Ramón et al., 2020), and they are in constant decline (Haro-Carrión and Southworth, 2018; Rivas et al., 2020). A vulnerable species inhabiting these threatened ecosystems, for example, is the Andean Bear (*Tremarctos ornatus;* Tapia-Armijos et al., 2015). Programs for the Andean Bear to collect more scientific data and develop movement corridors exist, but these programs focus on areas next to and inside PAs (e.g., Cleveland Zoological Society, 2021), or they are not located in Loja Province (e.g., Fondo Ambientale, 2019). Regarding amphibians, as an example of highly threatened taxa, specifically the Chocó area, Cayambe-Coca, Antisana, and Sumaco, and southern Ecuador would require more PAs. For reptiles, conservation priority areas that have been suggested include parts of the Northwestern slopes of the Andes, the Central-South Amazonian area, the Southwestern Andean slopes and adjacent lowlands and the Central Pacific coast (Reyes-Puig et al., 2017).

4.1.2.2. Improve the connection between protected areas. Ecuador belongs to the top global priority areas where more connectivity between PAs is needed to protect important ranges and ecoregions of vertebrates (Saura et al., 2018). Corridors become even more important in the context of climate change, where more species may spatially shift and migrate. For instance, Moret et al. (2016) found an upslope shift (ca. 300 m) in elevation for most specialized stenotopic ground beetles between 1880 and 1985. In contrast, generalists showed a wide spectrum of upward shift. Other studies also confirm species shifts to higher elevations (if geographically possible; Colwell et al., 2008; Thuiller et al., 2008). For mammals, climate change models by Iturralde-Pólit et al. (2017) predict a significant decrease in species richness for most groups, under a range of different climate change scenarios and dispersal assumptions. They argue that primates are most severely affected due to limited suitable and available habitat. Another study focusing on 80 Amazon primate species showed that dispersal corridors might be very effective in supporting most primate species to cope with climatic changes (Sales et al., 2019). Therefore, important biodiversity areas should be further expanded as corridors to maintain connectivity between habitats (Cuesta et al., 2017). There are several attempts to connect national parks in the Andes. For example, the Ministry of Environment, Water and Ecological Transition of Ecuador (MAATE) and the Water Fund for the Conservation of the Paute River Basin (FONAPA) discussed the development of a corridor between the Sangay and Podocarpus National Park (NCI, 2017) to connect habitats crucial for water provision.

4.1.2.3. Strengthen existing protected areas. More efficient control and monitoring mechanisms for PAs need to be developed, such as using drones, remote sensing, and apps. For example, in Brazil, a combination between control on site (patrol by boats and vehicles) and remote control (helicopters, planes and drones) is used to quickly identify small illegal deforestation patches (Chen et al., 2021). In addition, indicators such as carbon sequestration and avoided deforestation allow a periodic evaluation of PA effectiveness. On the other hand, strong conservation measures of PAs and their buffer zones could cause a leakage effect where people migrate to other areas to deforest (Ewers and Rodrigues, 2008). To counteract this process, it is crucial to improve ecotourism in buffer zones and to offer financial benefits that are sustainable and compatible to nature conservation. The Socio Bosque Program (SBP) seeks to reduce deforestation but also improves people's living conditions. Cuenca et al. (2018) identified that deforestation was reduced by 1.5% in forests that received the direct payment from the SBP. Private as well as communal lands are addressed by this program (de Koning et al., 2011) and Cuenca et al. (2018) reported that individual SBP beneficiaries made a more significant impact on avoided deforestation than community SBP beneficiaries. However, also the SBP needs to be enhanced by including incentives for actions that improve the connectivity between fragmented areas which contribute to the valuation of non-timber forest products, increase the quality and quantity of water, and increase the presence of wildlife in its forests.

4.1.2.4. Increase species-specific conservation programs. The National Policy for the Management of Wildlife promotes the in-situ and ex-situ conservation of species, among others (MAE, 2017). Zoos play a role in ex-situ conservation but they also support in-situ programs, e.g., the Cleveland Zoological Society (2021). For many species, ex-situ conservation is impossible or difficult (Michaels et al., 2014), for example, for harlequin toads (*Atelopus*; Coloma and Almeida-Reinoso, 2012). Therefore, we recommend prioritizing in-situ conservation – the maintenance of PAs for species. Wildlife refuges in Ecuador are specifically assigned to species conservation but they are rather small areas (MAE, 2015) and affected by edge effects (Fahrig, 2002). Specialists are more affected by environmental changes than generalists, as shown, for example, in small mammal communities in the *Polylepis* Andean forest (Ojala-Barbour et al., 2019). Considering our findings for birds, focus should be laid on specialists that are threatened and/or endemic, that have small population sizes and a limited geographical distribution such as the Black-breasted Pufleg (*Eriocnemis nigrivestis*), which can only be found in the Andes of Pichincha, Esmeraldas and Imbabura provinces (BirdLife International, 2020). In this case, habitat conservation strategies are very locally specific due to the small remnants (Guevara et al., 2015). In contrast, Puma (*Puma concolor)* or Mountain Tapir *(Tapirus pinchaque)* need huge undisturbed areas and have high demands on their environment (Ortega-Andrade et al., 2015; Tapia-Armijos et al., 2015) but secure habitats are becoming rare. For the Mountain Tapir, for example, it is hard to find any area "where they are not being over-hunted" (Lizcano et al., 2016, p.1). Therefore, priority should be given to the conservation of ecosystems in general to maintain habitats.

4.1.3. Recommendations for policy

4.1.3.1. Invest in documenting and publishing data. The amount of taxonomic studies is increasing but the amount of biodiversity conservation studies still has to be further developed (Campos, 2014 in MAE, 2016a; Dangles et al., 2009). Highly specialized taxonomists are still rare in Ecuador even though inventory studies are being conducted and students are being trained. Related to the need to do further research and improve knowledge about BES in Ecuador, data access needs to be improved. It could be the case that data are only stored in local libraries, that specimens are stored but not described (well) in the collections, or that data were not published. Even though there is a positive trend of publications by Ecuadorian scientists, they should be encouraged to publish more in internationally peer-reviewed scientific journals. Authorship of our analyzed papers was mainly from abroad which is also supported by Campos (2014), Titley et al. (2017), and Tydecks et al. (2018). In contrast, Jennifer Guevara from Ikiam, the Editor-in-Chief of the journal Neotropical Biodiversity, reported that the lack of a professional, scientific environment and the immense workload discourage Ecuadorian researchers - and especially women - from publishing their work (Guevara, 2019). The Secretariat of Higher Education, Science, and Technology of Ecuador (Senescyt) supported open access with no publishing costs for this journal. More initiatives of open access funds by governments or universities as well as higher awareness of the importance of publishing (legitimacy of spending more time in publishing) are needed to encourage national researchers to publish more.

4.1.3.2. Promote specimen collection and sharing. The CITES, the Nagoya Protocol and the CBD protect species from illegal trade. However, these regulations also hamper cross-border research collaborations. Collection and export permits for species and even herbarium materials are very difficult to get (Lawson et al., 2019). Outdated collections could be the consequence, although species protection from collection and trade is commendable. Meanwhile, some permits can be obtained online which is important for facilitating the research activities in the country. Also related to data access, specimens are held in local and international museums but restricted for access or rental. Systematic specimen collection is essential for monitoring biodiversity developments and identifying new species (Freile et al., 2014). One option to overcome the problem of access would require enormous effort and funding in building a digital collection.

4.1.3.3. Develop innovative research initiatives for BES protection. In order to ensure efficient control and monitoring mechanisms for the PAs, more financial and human resources are needed to quickly interpret ecosystem changes such as with remote sensing data for deforested areas. Modeling (for example, upscaling), spatial assessments and scenario development of BES can support future directions (Cheung et al., 2016). More inter- and transdisciplinary research should be conducted that analyzes the link between the ecological and social system – especially the consequences of habitat fragmentation and climate change for BES and the indirect effects on human health and well-being. A systematic approach to regional and national BES assessments with a standardized set of indicators would support the medium and long-term monitoring of BES.

4.1.3.4. Improve comparability between researches for up−/downscaling and (long-term) monitoring. Research of BES in Ecuador is scattered and conducted on different levels and with diverse scientific methods. Differences in the methodological approaches for the analysis of taxa can generate fundamentally different results (Carlton et al., 2004). Similar methodological approaches in field studies would enhance comparability (Souza and Hebert, 2018) and would allow a consistent upscaling to the regional level. Similarly, downscaling and feedback between the global, the regional and local level bear high uncertainties and do not allow reliable conclusions to be drawn at the local level (Klatt et al., 2018). More comparable studies would also support the long-term monitoring of changes in BES. Long-term datasets on biodiversity are needed for climate change analyses but still missing for the Southern Hemisphere; especially for mammals, amphibians, reptiles, fish and insects (Chambers et al., 2017). Similarly, long-term studies on the effects of climate change in the Neotropics seem to be rare for birds (Orihuela-Torres et al., 2020) even though research on bird species might be better documented for Ecuador than, for example, for Bolivia and Venezuela (Freile et al., 2014; supported by Campos, 2014, in MAE, 2016a). Ecuador is already part of the Red Gloria-Andes project (CONDESAN, 2020) which is comparable to TERENO and LTER sites where long-term research is standardized for specific biomes (TERENO, 2020; LTER, 2021). In the Red Gloria-Andes research network, the impact of climate change on the biodiversity of the high Andes is analyzed.

4.1.3.5. Support the national and international policy-science interface. Currently, research and scientific knowledge is fragmented in different research institutes and there are not many experts on national level. In addition, changes in executive positions of national institutions, e.g. due to elections, delay decision-making. Still, parameters and national priorities need to be defined based on national science and multi-criteria analysis with different stakeholders. Joint forces are needed for harmonized research in a national research network. National policy-science networks exist but need to be strengthened. For example, the RedBio Network is a good starting point for outreach and communicating research into policy. Research gaps can be identified and serve as feedback mechanisms for remedial policy. However, in RedBio, the communication with the government is slow. In a policy-science interface between researchers and national institutions, INABIO (Instituto Nacional de Biodiversidad), for example, could enable communication, while new policies could be generated and further funding provided. The network also improves the cooperation between research, policy, and the international community and facilitates the contribution to IPBES. Ecuador has nominated two experts to participate in the IPBES (IPBES, 2021a), however, better communication among the national and international levels still needs to be established.

4.1.3.6. Improve participatory approaches and environmental education. Ecuador is doing well in environmental education, for example, there exist good ecotourism concepts such as the Añangu Kichwa Community in the Yasuní National Park (Good Travel Guide, 2021). Furthermore, by 2021, one person in 8 of 10 households in Ecuador should know about good environmental practices (Aichi Goals target 1.1., CBD, 2020). The consultation of citizens in science is of great value, especially for the integration of indigenous, traditional and local knowledge. Citizen science can further reduce data gaps in Ecuador. For example, iNaturalist is running as a national initiative (iNaturalist, 2021) with almost half a million observations. By using the iNaturalist app on the cell phone, photos can be uploaded, shared and geotagged by citizens and tourists that can be checked by biologists to update species distribution maps. However, a study by Oldekop et al. (2011) showed that training of citizens might be necessary. They identified that the estimation of species richness of ferns in the Ecuadorian Amazon did not significantly differ between indigenous people/settlers and specialized biologists if laymen received either visual guides or hands-on training. Besides, training in analysis and modeling software should be moved forward. Universities in Ecuador have been established also in the remote regions like in the Amazon, for example Universidad Regional Amazónica (Ikiam) and Universidad Estatal Amazónica (UEA), where also indigenous people get the chance to study in proximity to their homes.

4.2. Uncertainty of data use, availability, and accessibility

The team of authors is experienced in this specific field of research for Ecuador and South America. With this non-exhaustive but structured literature review, it was our intention to provide an overview of the available international scientific publications on BES in Ecuador. Due to this approach, some uncertainty exists in the findings. For example, there are books, reports and many degree theses available in Spanish such as for the Cotacachi Cayapas Natural Reserve or El Oro. INABIO published a series of books on plants, animals, and ecosystems in El Oro Province and Quito Metropolitan District which are online but not yet listed in platforms of scientific publications such as Google Scholar. For some publications, full access was not possible even via the different universities involved. Studies assigned as trade-off effects might also be related to the amount of different species, taxa, and locations analyzed in one study. If the focus would have been on single species, potentially more clear statements regarding positive or negative effects of human disturbance and climate change could have been identified. For example, generalists and specialists were analyzed for birds in Becker and Agreda (2005), and we assigned trade-off effects for human disturbance. If the study would have focused only on specialists, negative effects would have been assigned. Furthermore, responses to climate change and human disturbance often differed between biodiversity metrics (between species richness and species composition, for example), where only trade-off effects could have been assigned. We could not prioritize our results according to the conservation status of the species, e.g. the IUCN Red List, because of missing information in some papers. In addition, the literature might be biased towards PAs (2/3 of the publications) even though it was not our focus and was not included as a search term. The recommendations for policy were developed based on the expertise from representatives of the environmental ministry in Ecuador and scientists who conduct research on BES in Ecuador. Therefore, the recommendations reflect a subjective assessment.

5. Conclusion

Ecuador is on track to identify, analyze, and assess the ecological richness of its country. Our review found a total of 266 international peer-reviewed papers examining the current impacts of human disturbance and climate change on BES in Ecuador. Studies on human disturbance were generally more available than studies on the impact of climate change, although there is still a great lack of knowledge regarding the effect of human disturbances on many taxa in Ecuador. Considering the incredible diversity of species and ecosystems in Ecuador, more joint research efforts are needed. Research on different species, ecosystems and ES remains scattered. We found that birds were the most studied taxon in Ecuador, while the number of scientific publications for other Ecuadorian plant and animal taxa was lower or nonexistent. No relevant studies were found for spiders, myriapods, and terrestrial ferns and very few for reptiles and grasses. Water supply, quality, and regulation were the most frequently studied ES. In addition, there seems to be spatial focus on the Pichincha, Napo and Zamora Chinchipe Provinces. The Amazon Provinces, apart from Orellana and Zamora Chinchipe, remain largely unexplored despite a rich biodiversity and potential threats from climate change, deforestation, hunting, and oil exploitation. Furthermore, the studies conducted on BES in Ecuador are hardly comparable due to different methodological approaches and spatial scales. There is a need for better scientific agreement in methods, approaches, locations, and scales for traceability and long-term monitoring. In addition, the majority of national research on BES is still conducted by international researchers who make a valuable contribution; however, scientists from Ecuador need to be more visible in the international arena. This paper should be taken as an inducement for Ecuador to become more active in the international science-policy interface.

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Declaration of competing interest

The authors of the manuscript "Priorities of action and research for biodiversity and ecosystem services in continental Ecuador" confirm that there is no conflict of interest.

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Glossary

BES: Biodiversity and ecosystem services (BES) are essential to support human health and human well-being (MEA, 2005). Ecosystem services (ES) provide food, water, pollination, water and air filtration, recreation, among other services (ibid.). Biodiversity plays an important role in the provision of ES by enabling structures that support ecosystem processes and functions (Naeem et al., 1995; Cardinale et al., 2012). Ecosystems can provide a better quality and more ES if the underlying ecological structures and functions are more diverse (Harrison et al., 2014). For example, a higher species richness increases ecosystem productivity (Schwartz et al., 2000), and a higher species abundance benefits particularly pest regulation, pollination and recreation (Harrison et al., 2014).:
Buen Vivir: The Andean concept of Good Living or Living Well ("Sumak Kawsay", in Kichwa), encompasses a set of ideas forged as a reaction and alternative to conventional concepts about development. As a "paradigm" that proposes to rethink development, it has been incorporated into the new constitutions of Ecuador and Bolivia (Acosta, 2013).:
CBD: The Convention on Biological Diversity (CBD) was the first global agreement to cover all aspects of biological diversity and aims to achieve the following: "the conservation of biological diversity, the sustainable use of its components and the fair and equitable sharing of benefits arising from the use of genetic resources" (CBD, n.d.). The CBD was ready for signatures at the Earth Summit in Rio de Janeiro in June 1992 and entered into force in December the following year. It has two supplementary agreements, the Cartagena Protocol and Nagoya Protocol.:
CICES: The Common International Classification of Ecosystem Services (CICES) is based on The Economics of Ecosystems and Biodiversity (TEEB, 2010) and the Millennium Ecosystem Assessment (MEA, 2005) and was further developed by Haines-Young and Potschin (2018). CICES provides an overview of ES on a hierarchical scale. There are three main categories: regulating, provisioning and cultural ES.:
CITES: The Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) is "an international agreement between governments. Its aim is to ensure that international trade in specimens of wild animals and plants does not threaten the survival of the species" (CITES, n.d.). It was drafted in 1963 after an IUCN meeting and came into force in 1975. It currently has 183 member states.:
ES: Ecosystem services are the various services that are provided by nature for humans. Biodiversity and ES are essential for supporting human health and human well-being (MEA, 2005). Regulating ES are, for example, water regulation, soil erosion control, pollination, and micro and macro climate regulation. Provisioning ES are, for example, wood, food, and water provision. Cultural ES are, for example, landscape aesthetics, spiritual values of nature, and environmental education. For more details, please take a look at Haines-Young and Potschin (2018).:
INABIO: The National Institute of Biodiversity (Instituto Nacional de Biodiversidad, in Spanish) is a public institution that provides access to information about biodiversity for the scientific community, decision makers and civil society. A database of biodiversity is the main strategy for the management and distribution of information (INABIO, n.d.).:
iNaturalist: This is a social network of naturalists, citizen scientists, and biologists built on the concept of mapping and sharing observations of biodiversity across the globe. iNaturalist may be accessed via its website or from its mobile applications (Van Horn et al., 2018).:
IUCN: The International Union for Conservation of Nature (IUCN) is a membership Union founded in 1948 and based on organizations from government and civil societies (IUCN, 2021). It is the global institution that deals with the status of the environment and the measures needed to protect it. Important are the IUCN Red List of Threatened Species and the Red List of Ecosystems.:
IPBES: The Intergovernmental Platform on Biodiversity and Ecosystem Services (IPBES) carried out the most recent global assessment of biodiversity and ecosystem services in 2019 which is based on an international policy-science collaboration. IPBES was founded in 2012 with the aim of regularly assessing the status, trend and impact of BES on global and regional levels (IPBES, 2021b).:
MAATE: Ministry of Environment, Water and Ecological Transition of Ecuador (MAATE) is the national ministry in Ecuador responsible for natural resource management, the national network of protected areas, and sustainable development. It was renamed in 2021 to the "Ministry of

Environment, Water and Ecological Transition of Ecuador" (MAAE).:
RedBio Network: The National Biodiversity Research Network (La Red Nacional de Investigación sobre Biodiversidad, in Spanish), was founded on May 22, 2017 with the support of some state entities, not only to become a platform for articulation between academia, society and the government, but also to make proposals based on research (RedBio, 2017).:
Red Gloria-Andes project: The GLORIA-Andes network is a regional long-term monitoring platform that studies the impacts of climate change on the biodiversity of high mountain ecosystems in the Andes. It is a consolidated and collaborative South-South cooperation initiative of Andean research centers and institutions that has been working for more than 10 years along the Andes from Venezuela to Chile and Argentina. This network generates and provides information based on quantifiable and standardized data on the vegetation of the high mountain summits in order to evaluate the impacts of climate change along the Andes. This project is covering areas of long-term research and is standardized for specific biomes (CONDESAN, 2020).:
SNAP: Ecuador has a national system of protected areas (Sistema Nacional de Areas Protegidas, SNAP; MAE, 2015). The categories with higher protection status without or with little human use are national parks (e.g., Yasuni), marine reserves (e.g., Galera San Francisco), ecological reserves (e.g. Antisana), biological reserves (e.g., El Condor), wildlife refuges (e.g., Esmeraldas Estuary), and geobotanical reserves (Pululahua). Lower protection is assigned to the Flora and Fauna Production Reserve (e.g., Chimborazo), and natural recreation areas (e.g., Los Samanes; for its names and location, please refer to Fig. 1 in Cuesta et al., 2017). Wildlife refuges are particularly small conservation areas for endangered species (ibid.). Comparing the locations of protected areas, there are more protected areas in the Andes biome than in the coastal and Amazon biome. The largest national park is the Yasuni National Park, located in the Amazon, and contains the highest density of reptile species, tree communities, bird species, and bat and insect communities in the Amazon (Bass et al., 2010).:
SBP: The Socio Bosque Program (SBP) is a national program of payments for biodiversity and ecosystem services that seeks to reduce deforestation, protect Ecuador's forest cover, and improve people's living conditions, thus mitigating climate change. The SBP was launched in 2008 as part of the Buen Vivir program (MAE, 2016).:
Senescyt: The Secretariat of Higher Education, Science, and Technology of Ecuador is the government technical body responsible for implementing policies for science, technology, and innovation in Ecuador. It is an autonomous agency of the Ministry of Planning and National Development to promote applied research (SENESCYT, 2009).:
Yasuni ITT-Initiative: The Yasuni-ITT Initiative (ITT: named after the three areas where oil was found) was established to protect the Amazon ecosystem and gained international media notoriety between 2007 and 2013 (Sovacool and Scarpaci, 2016). The proposed solution by the initiative in order to protect biodiversity while satisfying economic needs was to gather 3.6 billion US Dollars from the international community, which was considered to be half of the equivalent monetary value of the hydrocarbon reserves underground to keep them locked. However, only 0.36% of the requested value was collected, and the Ecuadorian government decided to start the extraction of oil and gas (ibid.).: