




Review

In-Situ and Ex-Situ Biodiversity Conservation in Ecuador: A Review of Policies, Actions and Challenges

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Abstract: Biodiversity is vital for the stability of the planet; its ecosystem services provide essential elements for our survival and well-being. This review analyzes the national biodiversity policies and describes the main strategies for biodiversity conservation in Ecuador, one of the “mega-diverse” countries in the world with the highest species density. It deepens an analysis of in-situ and ex-situ conservation processes. Ecuador has six clear policies for biodiversity conservation. These policies strengthen biodiversity conservation through mechanisms that improve the well-being of wildlife by ensuring human, wildlife and ecosystem health. It promotes actions for the welfare of wildlife, through technical, administrative and legal tools. The National System of Protected Areas, with 60 protected areas, is the most effective in-situ conservation instrument at the country level. Several ex-situ conservation and management means for the conservation of wild species are being utilized, including nurseries, botanical gardens, zoos, germplasm banks, aquariums, species reproduction and rehabilitation centers. Ecuador is making slow progress on ex-situ conservation despite the availability of a sound policy framework, possibly due to financial, infrastructural, and/or technological challenges, and knowledge gaps. We propose fostering international research collaborations and establishing fully funded small-scale captive breeding programs at zoos, aquariums and university research facilities to help recovery of at-risk species of reptiles, amphibians, fish and species beyond Galapagos region. We recommend utilizing citizen science programs to fill the gaps of biodiversity information and increasing efforts to revive the ex-situ conservation strategies in protecting the unique biodiversity of Ecuador.

Keywords: national system of protected areas; wildlife; strategies; policy; management

1. Introduction

The loss of biodiversity is rapid and continuous [1,2]. Over the past 50 years, high consumerism and atrophic pressures have changed ecosystems more rapidly and extensively than in any comparable period of human history [3]. The direct causes of biodiversity loss show no sign of abating. Humanity's ecological footprint exceeds the Earth's biological capacity to recover [2,4]. The human population increase brings an ever-increasing demand for exploitation of natural resources, agricultural and animal production, urban expansion, industrial processes and trade on a global scale. This in turn results in negative impacts and threats to biodiversity, such as habitat loss, overexploitation, pollution, invasive species and climate change [5]. The current human impact on biodiversity is unprecedented with a 47,000 species assessed, 36% of which are at risk of extinction [6–8]. It is estimated that the current rate of biodiversity extinction is 50 to 500 times greater than the background extinction rates. These evidence suggest that the planet Earth is going through a sixth mass extinction event, with a particularity, the first great extinction caused by man [1,2].

Biodiversity conservation aims to maintain the diversity of species, habitats and interrelationships in ecosystems including ecosystem services [9,10]. It is important to define and understand processes involved in biodiversity conservation in order to implement the best conservation strategies. There are two major conservation strategies (in-situ and ex-situ) with various possible techniques to be adopted [11, 12]. The ex-situ (off-site) conservation is a set of techniques applied outside the natural habitat of the target species, focusing on captive breeding in addition to sampling, transfer and storage of species (botanic or zoological gardens, seed/seed/ovule storage or gene banks maintained under special artificial conditions) [12,13]. The in-situ (on-site) strategies consist of techniques in which the natural habitat is protected, managed and monitored (wildlife reserves, on-farm and community-based) [14–16].

Although in-situ conservation strategies provide the best long-term options for biodiversity conservation, the short-term survival of many threatened species depend on ex-situ conservation strategies. For example, some threatened species may have enough secure habitat, but the survival of the species may be jeopardized by impacts associated with inbreeding depression, climate change, overexploitation and/or invasive species [17,18]. More importantly, the Convention of Biological Diversity (Article 9, CBD) recognizes the value of ex-situ conservation as a supplementary tool for in-situ conservation [19]. However, the role of ex-situ conservation in supplementing in-situ strategies were not clarified until the adoption of ex-situ management guidelines by the IUCN Species Survival Commission [20]. For many critically endangered (e.g., California condor) or extinct in wild species (e.g., Spix's Macaw), the only hedge against extinction is carefully implemented fast ex-situ conservation strategies, such as conservation breeding programs [17,18,21–24].

Since 1998, Ecuador has been part of the 17 “megadiverse” countries, with only 0.06% of the global land surface, but home to approximately 16% of the world's bird species, 8% of amphibians, 5% of reptiles and 8% of mammals (Table 1, [21,22]). The floral diversity is also unparalleled with more than 25,000 scientifically described plant species and many more to be discovered and described formally (Table 1, [25]). These characteristics make it the most biodiverse country per unit of surface area in the world [25]. The key to its immense biodiversity is due to factors such as being crossed by the equatorial line [26], the presence of the Andean mountain range, coastal and insular areas and its diverse climatic floors, resulting in four regions: Amazon, Andean, Coastal and Galapagos. Ecuador has 91 ecosystems with three hot spots for conservation: the Choco region, the Tumbesian region and the Eastern Andes [27–30]. The importance of Ecuador in global biodiversity is well reflected by designating seven UNESCO Man and the Biosphere Reserves in the country [31]. Additionally, Ramsar Convention has identified 19 sites in Ecuador as Wetlands of International Importance (Ramsar Sites), covering more than 1 million hectares [32].

Table 1. The species diversity of various taxonomic groups in Ecuador [25].

Taxonomic Group	Total Species	Endemic Species	Percent Endemism
Plants	25,560	5348	20.92%
Vertebrates	2794	436	15.60%
Mammals	362	30	8.28%
Birds	1616	52	3.21%
Reptiles	394	114	28.93%
Amphibians	422	240	56.87%

The objective of this review is to analyze national biodiversity policies and to describe the main strategies for biodiversity conservation in Ecuador by deepening an analysis on the processes of in-situ and ex-situ conservation. The study was carried out based via a bibliographic review of legal documents (Constitution, laws, regulations and strategies) related to biodiversity conservation in Ecuador, in addition to a thorough review of peer-reviewed publications and our personal experience on the topic. We wrap up the review with a discussion of challenges to conserve biodiversity in Ecuador.

2. National Policy for Wildlife Management (NPWM)

In 2007, Ecuador approved a new constitution under President Rafael Correa. The concepts of “Good Living” (*Sumak Kawsay*) and “Rights of Nature” were incorporated into the new Ecuadorian Constitution in 2008. The “Good Living” concept was derived from the traditional native beliefs of “Sumak Kawsay” which treats the Planet Earth as “Pachamama” (i.e., the Mother Earth), and promotes harmony between humans and nature promoting sustainable use of natural resources, such as forest products and petroleum, nature conservation and equity in accessing natural resources [33,34]. The “Rights of Nature” concept was derived from ideas presented by US jurists Christopher Stone in 1972 and nature has been recognized as a subject of rights. Article 71 of Chapter seven of the Ecuadorian Constitution (2008) recognizes that nature has right to exist, persist, maintain and regenerate its vital cycles, structure, functions and its processes in evolution. This provides a unique biocentric view with a recognition of the intrinsic value of nature [33,35]. The Environment Ministry of Ecuador, in accordance with the considerations established in the Ecuadorian Constitution on the protection of the country’s natural and cultural heritage, on 7 August 2017, through Ministerial Agreement 29, Official Registry 52, agreed to issue the National Policy for the Management of Wildlife (NPWM). This document is pivotal to establish guidelines for decentralized management of wildlife and coordination systems for policy implementation [36].

The main objective of NPWM (Table 2) is to establish guidelines at national and local levels that allow for the sustainable management of wildlife at different levels of government, according to their competences [37,38]. The central government is in charge of the national rectorship of environmental management in coordination with the decentralized autonomous governments, which adopt adequate mechanisms for the conservation of wildlife [20,23]. For the application of the NPWM, wildlife shall be understood as animal and plant species and other organisms not domesticated by human beings, which have originated and live freely in their natural environment, subject to the processes of natural evolution and which have ecological, social, cultural and/or economic importance including urban wildlife [39].

The Ministry of the Environment, as the National Environmental Authority, shall develop the guidelines for the exercise of the powers on wildlife granted to the provincial, municipal and metropolitan decentralized autonomous governments, in accordance with the present policies. The application of the policy is evaluated by the National Environmental Authority, through the Undersecretary of Natural Heritage in coordination with the National Directorate of Biodiversity, according to the monitoring and evaluation guidelines established by the Ministry of the Environment [36,37].

Table 2. Policies and corresponding objectives of the National Policy for the Management of Wildlife (NPMW), 2017, of Ecuador [36].

Policy	Objective
Promote the conservation, management and protection in-situ and ex-situ of wildlife at the national, regional and local levels	To conserve and protect wildlife throughout the national territory, in order to maintain natural habitats and healthy populations of wild species through the participatory management of decentralized autonomous governments and the citizens, academia, governmental and non-governmental organizations.
Promote the development of scientific research for the conservation and sustainable use of wildlife	Promote scientific research throughout the national territory aimed at generating, articulating, obtaining and disseminating information and knowledge for the conservation and sustainable use of wildlife, protected by the related environmental regulations.
Promote the management and sustainable use of wildlife and its derived products at the national, regional and local levels through technical and legal mechanisms, within the framework of nature's rights.	To develop mechanisms that allow the management, production and sustainable use of wildlife and/or its derived products, respecting the rights of nature as established in the related national and international regulations.
Strengthen national and local coordination activities and mechanisms to control and monitor the sustainable use, trafficking and illegal commercialization of wildlife.	To have guidelines that allow the different levels of government, the coordinated exercise of control and surveillance to the sustainable use, trafficking and illegal commercialization of wildlife at a national and local level.
Articulate the integrated management of wildlife at the different levels of government, considering the inter-institutional, sectoral, and decentralized powers.	Strengthen inter-institutional coordination between different levels of government to achieve integrated wildlife management in an articulated and coordinated manner in the territory.
Strengthen the conservation of biodiversity through mechanisms that improve the welfare of wildlife by ensuring human, animal and ecosystem health in articulation with the different levels of government, considering the competences and powers of institutions, sectors, and decentralized.	Promote actions for the welfare of in-situ and ex-situ wildlife, through technical, administrative and legal tools in coordination with the different levels of decentralized autonomous governments.

3. In-Situ and Ex-Situ Conservation Strategies in Ecuador

Biodiversity conservation is carried out by in-situ and/or ex-situ processes, depending on the ecological characteristics including nature and intensity of threats, levels of endemism or category of species threatened with extinction [9]. To safeguard the biological heritage from genetic erosion, in accordance with the policy formulated by the National Environmental Authority, the National System of Science, Technology, Innovation and Ancestral Knowledge promotes and regulates in-situ and ex-situ scientific research involving extraction, collection, importation, mobilization, transportation, exportation and temporary or final disposal of wildlife species. To this end, it is necessary to implement mechanisms for tracking and monitoring biodiversity, according to the guidelines of the competent authorities [40].

The first National Policy for Wildlife Management promotes in-situ and ex-situ conservation, management and protection of wildlife at the national, regional and local levels. It aims to conserve and protect wildlife throughout the national territory, in order to maintain natural habitats and healthy populations of wildlife species through the participatory management of decentralized autonomous governments, citizens, academia, governmental and non-governmental organizations [36]. The strategies of this policy are as follows:

- Promote in-situ conservation by consolidating the National System of Protected Areas and prioritizing fragile ecosystems and other forms of conservation as a guiding

mechanism for structuring the development and land management plans of decentralized autonomous governments.

- Evaluate and establish measures, to reduce the impact on wildlife, of activities generated by works and projects that generate environmental risk at national, regional and local levels.
- Strengthen ex-situ conservation through the creation and implementation of wildlife tenure and management centers, based on national and international guidelines, which contribute to the rehabilitation of wild species in support of in-situ conservation, and the promotion of an attitude of respect by humans for biodiversity and its components.
- To develop plans, programs and projects for the conservation, protection and management of wildlife throughout the national territory, for its management and execution, at the local level, with emphasis on threatened and endangered species.
- Implement permanent communication, education and participation actions at the national and local level on the importance of biodiversity, conservation and protection with emphasis on wildlife.
- Articulate and agree on planning for the conservation, protection, and management of wildlife by decentralized autonomous governments at all levels according to their scope and attribution with national planning.

National Biodiversity Strategy (NBS)

NBS is the management tool that guides the State's efforts to know, value, protect, restore and sustainably use its biodiversity. This is a response to international commitments and challenges linked to changing the production matrix, eradicating poverty and conserving the biocultural heritage of Ecuadorians [41]. It starts from the national planning frameworks and develops in greater depth the actions that should be implemented in the territories, to contribute to the innovation and systemic competitiveness of the country [40,42]. It defines 20 results to which Ecuador is committed until 2030 [38]. These definitions are based on national development frameworks and sectoral and intersectoral public policies established as part of the national participatory planning system. The NBS is managed by an intersectoral committee led by the Ministry of the Environment and made up of the Ministry of Coordination of Strategic Sectors, the Ministry of Coordination of Knowledge and Human Talent, the Ministry of Finance and the National Secretariat of Planning and Development [43].

4. In-Situ Conservation Strategies in Ecuador

The Convention on Biological Diversity (CBD) identifies a set of objectives for biodiversity conservation and determines that in-situ conservation is essential to achieve these goals. This refers to the preservation of areas with considerable local biodiversity, known as protected areas [44]. Ecuador has a National System of Natural Protected Areas [42]. In Ecuador, the mechanisms for in-situ conservation of biodiversity are The National System of Protected Areas, special areas for biodiversity conservation, management of natural landscapes and others determined by the National Environmental Authority [40]. The protected areas will be priority areas for conservation and sustainable development. The Decentralized Autonomous Governments must incorporate the protected areas into their territorial management tools [45].

The first conservation actions in Ecuador date back to 1936, when the country declared the Galapagos Archipelago a protected area. In 1976, the Ministry of Agriculture, through the National Forestry Program, proposed the Preliminary Strategy for the Conservation of Ecuador's Outstanding Wildlife Areas. This strategy marked the beginning of a series of processes and actions aimed at consolidating Ecuador's National System of Natural Protected Areas (NSNPA). The Ministry of the Environment is currently in charge of the NSNPA and defines the general guidelines and regulations in coordination with the different actors involved.

National System of Natural Protected Areas (NSNPA)

The NSNPA is divided into four subsystems (i.e., State, Municipal, Community and Private), which are classified into 10 management categories (Figure 1). It guarantees the conservation of biodiversity and the maintenance of ecological functions [36]. It is governed and regulated by the State. It allocates the economic resources necessary for the financial sustainability of the system and promotes the participation of the communities, people and nationalities that inhabit the protected areas in its administration and management [42]. The administration of the State’s Natural Areas Heritage is the responsibility of the Ministry of the Environment, while the administration of the other subsystems: sectional, community and private governments, will be carried out by the entities defined and organized for that purpose.

The NSNPA is the most effective in-situ conservation instrument at the country level, it is a strengthened governing institution with high management capacity [36]. Ecuador currently has 60 protected areas (Tables 3 and 4; Figures 1 and 2), distributed in 23 of its 24 provinces, and 20.3% of the continental territory and the 12.07% of the marine area is protected [41].

Table 3. National System of Natural Protected Areas (NSNPA) Management Categories.

Name	No.	Name	No.	Name	No.
National Park	13	National Recreation Areas	6	Community Reserve	2
Wildlife Refuge	10	Biological Reserve	5	Geobotanical Reserve	1
Ecological Reserve	8	Wildlife Reserve	4	Decentralized Autonomous Protected Area	1
Marine Reserve	6	Ecological Conservation Area	2	Private Protected Area	2

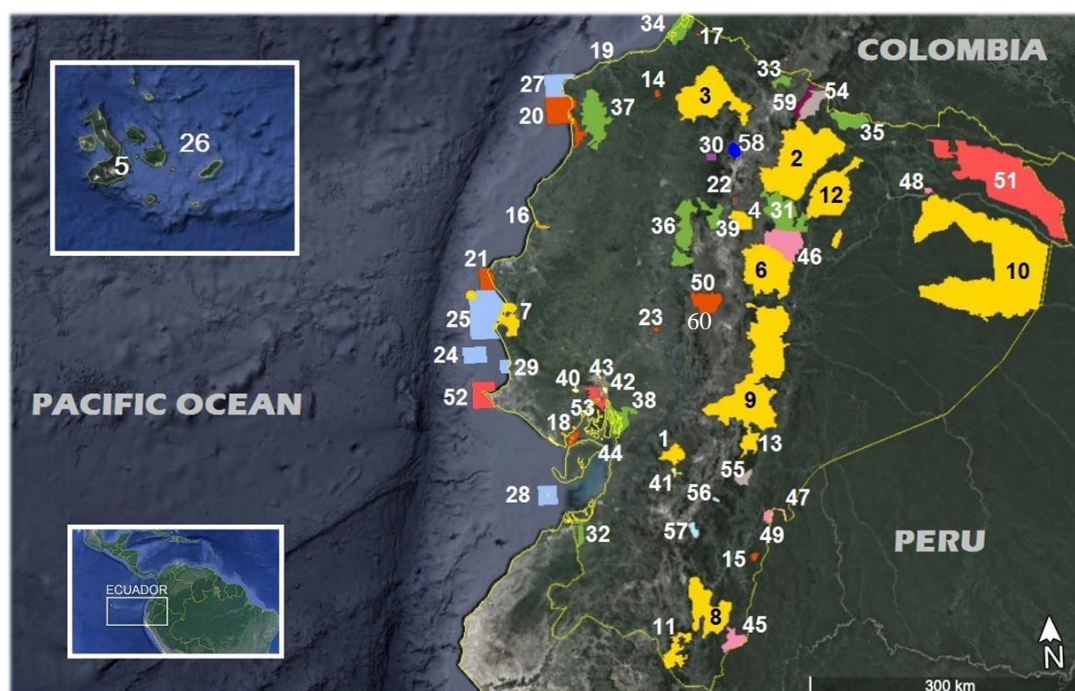


Figure 1. Distribution of Protected Areas under National System of Natural Protected Areas (NSNPA) in Ecuador by Management Category [41,46].

Table 4. The list of natural protected areas under National System of Natural Protected Areas (NSNPA) of Ecuador [41,42].

No.	Protected Area	No.	Protected Area
1	Cajas National Park ¹	31	Antisana Ecological Reserve ¹
2	Cayambe Coca National Park ¹	32	Arenillas Ecological Reserve ¹
3	Cotacachi Cayapas National Park ¹	33	Ángel Ecological Reserve ¹
4	Cotopaxi National Park ¹	34	Cayapas Mataje Mangroves Ecological Reserve ¹
5	Galápagos National Park ¹	35	Cofán Bermejo Ecological Reserve ¹
6	Llanganates National Park ¹	36	Illinizas Ecological Reserve ¹
7	Machalilla National Park ¹	37	Mache Chindul Ecological Reserve ¹
8	Podocarpus National Park ¹	38	Churute Mangroves Ecological Reserve ¹
9	Sangay National Park ¹	39	Boliche National Recreation Area ¹
10	Yasuní National Park ¹	40	Lago Park National Recreation Area ¹
11	Yacuri National Park ¹	41	Quimsacocha National Recreation Area ¹
12	Sumaco Napo Galeras National Park ¹	42	Samanes Park National Recreation Area ¹
13	Río Negro—Sopladora National Park ¹	43	Santay Island National Recreation Area ¹
14	Pambilar Wildlife Refuge ¹	44	Villamil Beach National Recreation Area ¹
15	Zarza Wildlife Refuge ¹	45	Cerro Plateado Biological Reserve ¹
16	Island Corazón and Fragatas Wildlife Refuge ¹	46	Colonso Chalupas Biological Reserve ¹
17	Chiquita Wildlife Refuge ¹	47	Cóndor Biological Reserve ¹
18	Morro Mangroves Wildlife Refuge ¹	48	Limoncocha Biological Reserve ¹
19	Esmeraldas River Mangroves Estuary Wildlife Refuge ¹	49	Quimi Biological Reserve ¹
20	Muisne River Mangroves Estuary Wildlife Refuge ¹	50	Chimborazo Wildlife Reserve ¹
21	Pacocha Wildlife Refuge ¹	51	Cuyabeno Wildlife Reserve ¹
22	Paschoa Wildlife Refuge ¹	52	Puntilla Santa Elena Wildlife Reserve ¹
23	Samama Mumbes Wildlife Refuge ¹	53	Salado Mangroves Wildlife Reserve ¹
24	Bajo Cope Marine Reserve ¹	54	Bonita—Cofanes—Chingual Ecological Conservation Area ²
25	Cantagallo Machalilla Marine Reserve ¹	55	Siete Iglesias Ecological Conservation Area ²
26	Galápagos Marine Reserve ¹	56	Tambillo Community Reserve ³
27	Galera San Francisco Marine Reserve ¹	57	Marcos Perez de Castilla Community Reserve ³
28	Island Santa Clara Marine Reserve ¹	58	Pululahua Geobotanical Reserve ¹
29	Pelado Marine Reserve ¹	59	Decentralized Autonomous Protected Area Cordillera Oriental del Carchi ²
30	Bellavista Private Protected Area ⁴	60	Ichubamba Yasepan Moors Private Protected Area ⁴

Subsystem: ¹ = State (53), ² = Municipal (3), ³ = Community (2), ⁴ = Private (2).

The NSNPA will guarantee the conservation of biodiversity and the maintenance of the ecological functions of the ecosystems [47,48]. The State shall allocate the economic resources necessary for the financial sustainability of the system, and shall promote the participation of the community, people and nationalities that have ancestrally inhabited the protected areas in their administration and

management. Protected areas are the most effective solution for in-situ conservation in Ecuador and allow for the counteraction of deforestation and land use changes [36].

Protected areas in Ecuador preserve zones with special ecological characteristics, which have become natural banks of biodiversity (Figure 2), sustaining life for present and future generations. In these areas, fragile ecosystems are conserved and populations of endangered species are preserved. Genetic resources are also conserved here, by maintaining wild relatives of cultivated species. The criteria for the establishment of these areas are: diversity, intrinsic fragility, vulnerability, endemism, current and potential use, among others [40,42].

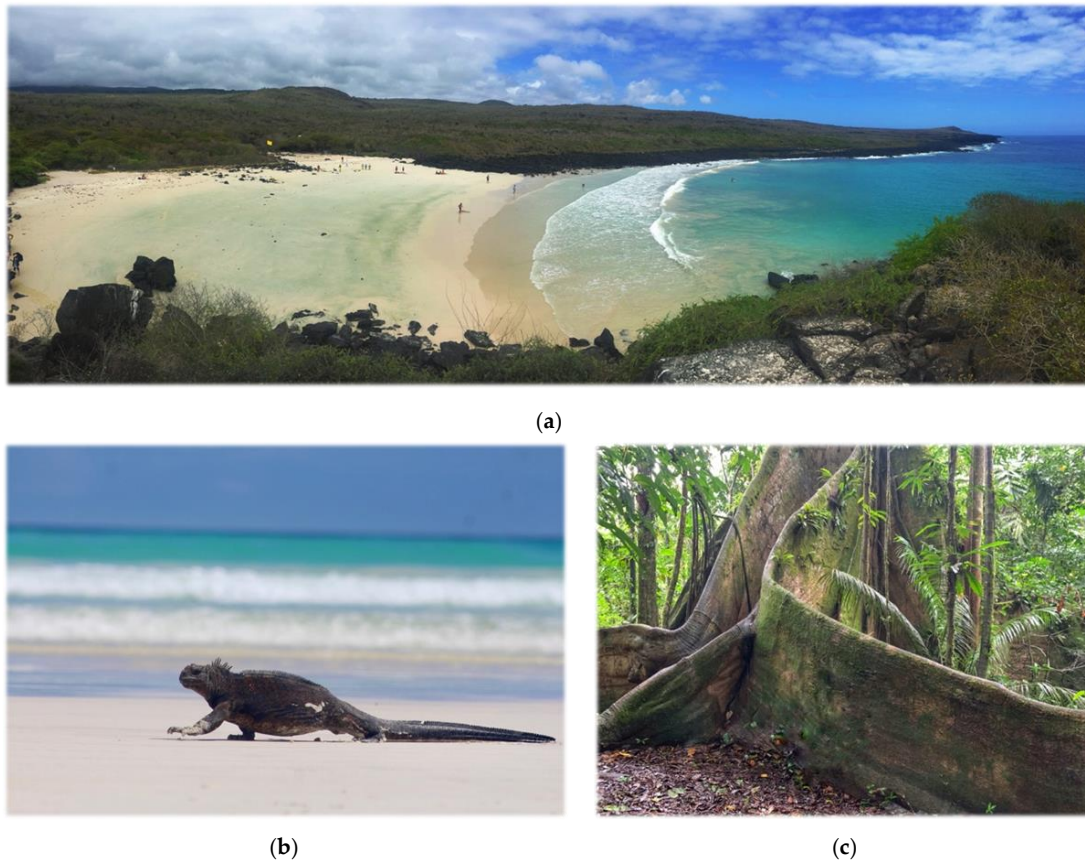


Figure 2. Protected areas in Ecuador: (a) Puerto Chino beach, San Cristobal Island, Galapagos National Park; (b) Galapagos Marine Iguana (*Amblyrhynchus cristatus*), Galapagos National Park; (c) Amazon Ceibo (*Ceiba pentandra*), Yasuní National Park.

5. Ex-Situ Conservation Strategies in Ecuador

The Organic Environmental Code of Ecuador (OECE), created through Official Registry Supplement 983 of 12 April 2017, aims to guarantee the right of people to live in a healthy and ecologically balanced environment, as well as to protect the rights of nature for the realization of good living. It establishes that ex-situ conservation will seek the protection, conservation, sustainable use and survival of wildlife species [37,49], in order to enhance opportunities for environmental education, scientific research and development, biotechnology development and commercialization of the components of biodiversity and their synthesized products [36,50]. Ex-situ conservation should also serve as a supplementary tool to in-situ conservation, and as an opportunity for public awareness of wildlife species [51]. A wild species must first qualify as a species susceptible to extinction according to specific conditions established (Table 5) [25] before executing a certain ex-situ conservation strategy.

Table 5. Conditions for ex-situ conservation processes.

Habitat	Species that are reduced or restricted in their population size or distribution, evidence of threat of extinction, erosion of the national genetic heritage or any other cause, and those that cannot be conserved in-situ.
Education	Species that have particular current or future importance for science, economy, food or medicine.
Food	Species suitable for breeding, cultivation or genetic improvement of their relatives.
Education and Food	Species that have been subject to breeding, selection, cultivation and domestication or that are in collections and gene banks.
Ecological	Species that play a key role in food chains.
Education	Species that cannot be reintroduced into the wild according to technical criteria.
Biological	Useful species for biological control.

Ecuador has established seven ex-situ conservation and management strategies (Table 6) for the conservation of wild species [36,49], which align with criteria specified in the Article 9 of CBD (CBD 1992). These ex-situ strategies are very valuable because they contain documentation and records of biodiversity important for education and research processes. These are administered and regulated by the Ministry of the Environment, except for the germplasm banks, which are administered and regulated by the Public Institute for Scientific Research on Biodiversity [36,37]. In order to ensure that species are properly managed in ex-situ conservation activities, the Ministry of the Environment is responsible for implementation and regular assessments of the sustainability of these activities. The provisions of the OECE are mandatory for all entities, agencies and departments that comprise the public sector, natural and legal persons, communes, communities, peoples, nationalities and groups, which are permanently or temporarily in the national territory.

These means are important for the recovery, use and sustainable management of biodiversity (Figure 3). Systems of traceability of wildlife species, chains of custody or certificates of origin of the authorized breeding and reproduction species are established [11,52]. Herbaria and museums will be considered as documentation and registration centers for biodiversity. In accordance with technical and veterinary criteria, ex-situ conservation centers for wildlife species include technical mechanisms necessary to maintain the animals under animal welfare conditions established in the Ecuadorian Environmental Code [45,49].

Table 6. The major ex-situ conservation strategies for biodiversity conservation in Ecuador [36].

Means of Conservation	Description
Nurseries	The nurseries are lands destined to receive and cultivate woody species from seedbeds, provide care and finally transplant them to a definitive habitat. The most relevant nurseries in Ecuador are Oro verde Caupichu and El Trébol
Botanical Gardens	The Botanical Gardens are areas managed by institutions with documented collections of living plant species, for conservation, research, exhibition and educational purposes [28]. The most relevant Botanical Gardens in Ecuador Quito, Guayaquil and Las Orquídeas
Zoos	It is a center for holding and managing wildlife for public and profit purposes, maintained in ex situ form, which aims at conservation, through education, research and recreation. The zoos Guayabamba in Quito, Pantanal in Guayaquil and Amaru in Cuenca, are the most relevant in Ecuador.
Breeding and Sustainable reproduction Centers	These are places where animals are bred by selective breeding for special genetic traits, to maintain or improve future genetic traits [29]. The Arnaldo Tupiza Breeding Center in Puerto Villamil, El Arca in Archidona and La Granja del Tío Mario in Quito are the main centers for sustainable breeding

Table 6. Cont.

Means of Conservation	Description
Rescue and Rehabilitation Centers	Center for the recovery of wild animals, where injured, sick or debilitated animals are treated for rehabilitation, with the aim of reintroducing them to their natural habitat. The main rescue and rehabilitation centers in Ecuador are Amazonico Animal Rescue Centre in Napo, YanaCocha and ZooRefugio Tarqui in Pastaza and Nueva Loja Tourist Park in Sucumbíos.
Germplasm Banks	They are places created with certain conditions for the conservation of genetic diversity in the form of seed, pollen or tissue culture [16]. The most important germplasm bank in Ecuador is held by the National Institute of Agricultural Research.
Aquariums	Useful species for biological control. The best-known aquarium in Ecuador is the Parque Marino Valdivia, located near the commune of Valdivia, in the parish of Manglaralto about 4 km from the city of Santa Elena, Ecuador.

The National Institute of Agricultural Research through the National Department of Plant Genetic Resources, is responsible for the conservation and use of Ecuadorian agrobiodiversity. Among its main activities aimed at the conservation and use of agrobiodiversity is the collection of germplasm and its conservation ex-situ in a germplasm bank [36,53]. It focuses its work on the characterization, evaluation, regeneration, multiplication, information and documentation of the phylogenetic resource. Currently, it maintains the largest germplasm bank in Ecuador with approximately 28,000 accessions of cultivated and wild species. The Institute is a focal point for FAO on plant genetic resources, the international treaty on plant genetic resources for food and agriculture. It maintains cooperation with several national and international universities and with farmers' organizations and local governments [53].

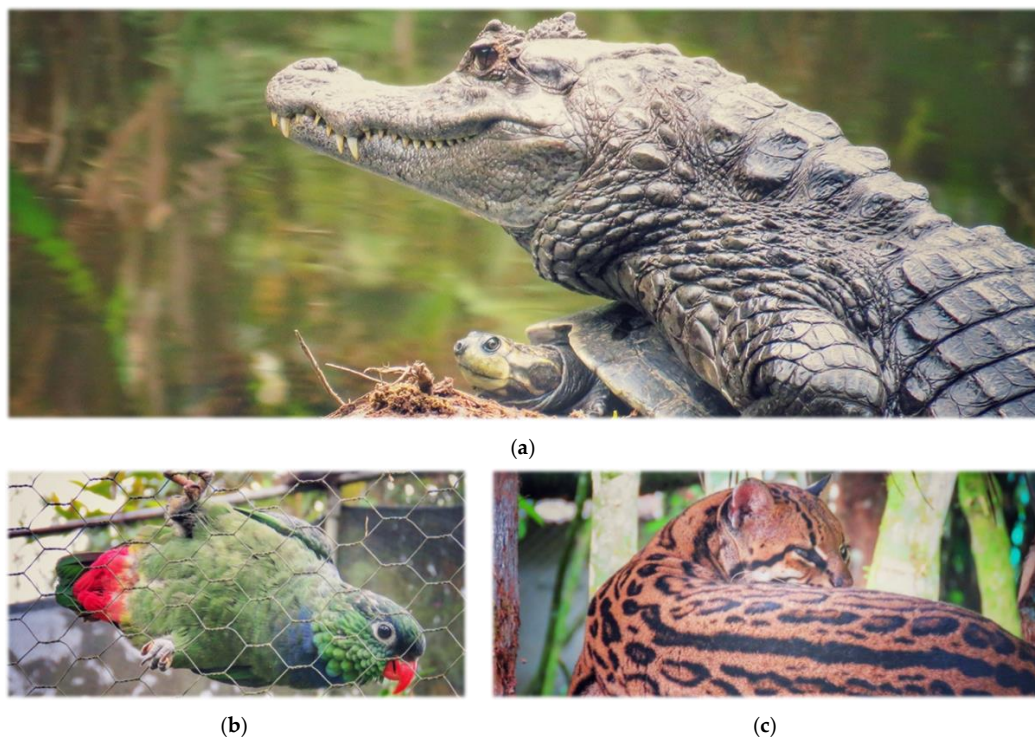


Figure 3. Tamandua Wildlife Sanctuary, YanaCocha Rescue Center, species in captive rehabilitation: (a) Spectacled caiman (*Caiman crocodilus*) and giant river turtle (*Podocnemus expansa*); (b) Red-billed parrot (*Pionus sordidus*). Parrots are one of the major targets of illegal pet trade in Ecuador; (c) Globally decreasing ocelot (*Leopardus pardalis*).

The processes and techniques in the ex-situ conservation must undergo evaluation to determine their effectiveness [41]. First, it is important to identify where there is a clear and explicit role of ex-situ conservation programs and mechanisms in biodiversity conservation [42]. Only then can their contribution to the achievement of the objectives of the CBD (Article 9, CBD 1992) and the improvement of the status of the most threatened species be demonstrated [43]. Ecuador needs to clearly and precisely apply its ex-situ conservation policies and strategies, otherwise the role of ex-situ management will continue to be questioned in terms of its value, viability and scope, as it is in other countries worldwide [44,45]. There is little commitment to ex-situ conservation strategies from State agencies. The National Institute of Agricultural Research has executed the most relevant programs and projects with an emphasis on agriculturally important species.

6. Challenges and Opportunities for Biodiversity Conservation in Ecuador

In 2019, the budget to support the NSNPA was reduced by 33.12%, compared to the average of the last 5 years [54]. This decrease affects the management of protected areas, and their control and surveillance are threatened. It is important to review these government decisions, considering the importance of protected areas to maintain the biodiversity and ecosystem services [55,56]. Additionally, it is fundamental to strengthen control and surveillance of diverse economic uses of protected areas (e.g., oil explorations, mining, tourism and fishing) with a budget increase, contrary to what has been happening in recent years. The decrease in budget is of greater concern to marine protected areas [4,57], since their control, monitoring and conservation entails higher costs than those of continental areas. Under these conditions, the National System of Protected Areas presents great challenges, especially in terms of guaranteeing effective controls on the use and exploitation of its protected areas. It is important to stop the overexploitation of its resources, since they are currently being used in an unsustainable way.

In the face of changing climate scenarios, Ecuador's protected areas are indispensable for the conservation of biological diversity and the provision of environmental services. For this reason, it is necessary to strengthen the NSNPA as a strategy that contributes to reducing the vulnerability of society and Ecuador's natural heritage [38]. The management of the four subsystems of the NSNPA has the opportunity and responsibility to articulate different types of conservation actions at different administrative levels that allow the application of a coordinated strategy to minimize the potential negative effects of climate change on this important strategic resource of Ecuador, its mega-biodiversity [47,58]. The care and protection of the forests, grasslands, wetlands and mangroves preserved in the NSNPA is fundamental in the mitigation and adaptation to climate change in the country because they capture greenhouse gases that regulate the provision of environmental services. It is necessary to manage the challenges of climate change in a timely manner, guaranteeing good living and the rights of nature. It is essential to ensure that the NSNPA contributes to increasing the capacity of species and ecosystems to respond to the impacts of climate change. It is necessary to project a comprehensive training through the development of formal education modules on climate change to be inserted in the regular study programs in all primary and secondary educational institutions. These measures will allow conservation practitioners to reach an adequate level of knowledge, valuation and awareness regarding the importance of biodiversity and implement actions for its conservation and sustainable use in the face of climate change. Under these scenarios, it is clear that apart from promoting successful management of protected areas requires think of complementary planning schemes of the territory. Aspects that will facilitate migratory processes and the displacement of biological entities that are intended to be maintained in existing reserves in the face of future effects of climate change.

The state shall promote the protection, permanence, integrity and functional connectivity of ecosystems relevant to carbon storage. It is essential to promote actions aimed at achieving eco-systemic connectivity, through the use of tools such as biological corridors, in the most vulnerable ecosystems to increase the capacity for mobility and adaptability of species to possible climate change scenarios.

These actions will contribute to the integrity and connectivity of relevant ecosystems for carbon capture and storage and sustainable ecosystem management [38].

Although more than 20.3% of land area in Ecuador is dedicated for protected areas, some critical ecosystems covering unique and threatened species are not under the protection of NSNPA. For example, lowland coastal dry shrub habitats receive very low to no protection from NSNPA [59,60]. Therefore, potential future expansion of NSNPA should include such high-priority areas to avoid loss and extirpation of unique species and ecosystems. Since 2017, 19 high-priority areas were incorporated into NSNPA to improve habitat and wildlife management (i.e., connectivity, conservation, operability and integration) and giving them specialized treatment [36,41]. These new protected areas are located in the provinces of Esmeraldas, Manabí, Guayas, Santa Elena, El Oro and Galapagos, and are part of the Network of Marine and Coastal Protected Areas. However, it does not represent a different administrative structure, but follows the same policies and guidelines as any other protected area in the state system. A differentiated, efficient and effective management is needed to achieve a sustainable management of the marine ecosystem and not just by areas. Coastal marine protected areas must work in an articulated manner to achieve large-scale changes considering the dynamics, size of coastal marine ecosystems and patterns of migratory species in the country and the world [61].

The Galapagos Island Region and the central-northern continental zone are characterized by the largest protected territory and a hotspot for biodiversity research. It is necessary to focus efforts to strengthen a plan for the declaration of new protected areas in the southern zone of the country with valuable unique ecosystems. Protected areas in Ecuador cover extensive territories, which are difficult to monitor due to the reduced number of personnel. These areas have historically been threatened by illegal logging, hunting and deforestation. For proper protection of protected areas, the government must focus efforts on increasing funding, technical personnel and providing technological equipment and tools.

Although Ecuador is a megadiversity country, there are gaps in biodiversity information such as species identity, species distribution ranges and complete species richness for given regions. This information is critical when planning for in-situ as well as ex-situ conservation programs, such as identification of priority areas and conservation status assessments of species [20]. Properly managed citizen science programs could be an effective tool in filling some of these gaps in biodiversity information [62,63] (Theobald et al. 2015; Ross and Henkanaththegeedara 2019). One such widespread and popular, web-based citizen science program is iNaturalist [64]. This smartphone app allows observers to take pictures of organisms and share as georeferenced observation in addition to suggestions for species identification. Even a novice can use this app fairly well to document a biodiversity observation with high accuracy [65]. Although there are several National level iNaturalist projects covering Ecuadorian biodiversity, the participation from public, naturalists, researchers, students, tourists etc. can be improved with some organized effort. Additionally, taxa specific web-based citizen science projects such as eBird (<https://ebird.org/>) [66] may provide a valuable tool in conservation of birds.

Ecuador is making slow progress on ex-situ conservation despite the availability of a sound policy framework. There are several ex-situ conservation projects at botanical gardens, but none with the right conditions for proper functioning. At the same time, there are some zoos in operation that present various problems, whether in terms of infrastructure, financing, or human resources. It seems that majority of these facilities do not pay particular attention to biodiversity conservation via ex-situ strategies such as captive breeding, possibly due to financial, infrastructural and/or technological challenges and knowledge gaps. Despite Ecuador's megadiversity of species, IUCN recognizes 338 Critically Endangered, 895 Endangered, 1239 Vulnerable and 497 Near Threatened plant and vertebrate species, in addition to 6 Extinct in Wild plant species (Table 7; IUCN 2020). This presents a dire need and opportunity for implementing ex-situ conservation strategies, such as conservation breeding programs for species with an increased risk of extinction.

Table 7. Number of threatened plants and vertebrate taxa in Ecuador according to IUCN threat categories (IUCN 2020).

Taxonomic Group	Critically Endangered (CE)	Endangered (EN)	Vulnerable (VU)	Near Threatened (NT)	Data Deficient (DD)
Plants	271	740	949	280	1949
Vertebrates					
Mammals	0	14	33	22	54
Birds	7	24	81	97	3
Reptiles	15	41	79	51	87
Amphibians	42	76	58	26	55
Ray-finned Fish	3	0	39	21	129
TOTAL	338	895	1239	497	2277

Although there are a few successful captive breeding programs targeting Galapagos species such as Giant tortoises (*Geochelone* spp.), Land iguana (*Conolophus subcristatus*) [67] and Mangrove finch (*Camarhynchus heliobates*) [68], we propose that Ecuador must prioritize implementing ex-situ conservation programs for at risk species on the mainland. For example, critically endangered Andean condor (*Vultur gryphus*) is a prime target. A recent survey [69] has estimated about 100 condors and questioned the contributions of the already established captive breeding program [70] for the recovery of the condors. Since there are well-established protocols for critically endangered California condor (*Gymnogyps californianus*) in the USA [71], we believe that it is reasonable and beneficial to adopt those protocols and collaborate with researchers in the USA in rejuvenating Andean condor captive breeding program. Establishing small-scale captive breeding programs at zoos, aquariums and university research facilities with funding from the government or international research collaborations would help the recovery of threatened species of reptiles, amphibians and fish. Additionally, we believe that well-established rescue and rehabilitation centers could play a more active role in ex-situ conservation in Ecuador. Currently, these facilities maintain captive populations of injured and legally confiscated animals from illegal wildlife trade aiming at providing local and international tourists to learn about biodiversity and rescue/rehabilitation activities, and internship opportunities for students. However, we emphasize that these facilities could play a key role in regional small-scale captive breeding and release efforts of threatened species. These facilities could adopt a working model similar to The Charles Darwin Research Station (CDRS) in Galapagos Islands and contribute for biodiversity research and ex-situ conservation in collaboration with local and international researchers. The government authority must regulate collection of source populations for such captive breeding programs from natural habitats as not to threaten ecosystems and/or in-situ populations as outlined in the Article 9 of CBD [19].

A great challenge for the Ecuadorian state is to develop an integrated plan for ex-situ conservation that allows for the timely identification of viable populations of species that require ex-situ attention [21]. The ex-situ conservation processes should be developed in spaces with environmental conditions similar to the habitat of target species. This is a serious problem in the country, since most sites such as zoos, aquariums and botanical gardens have been established near cities, characteristics that leave in doubt the true objective of their existence [72,73]. It is important to remind the control authorities, Ministry of the Environment, what is stated in their laws, such as the constitution, NPWM and OECE, whose objective and main purpose is the conservation and rehabilitation of biodiversity, but not economic interests that seek to profit from false processes of ex-situ conservation. We recommend that more attention should be given to revive the ex-situ conservation strategies in protecting the unique biodiversity of Ecuador. Finally, a challenge for Ecuador is to propose reforms to its policies and strategies on ex-situ conservation processes that will allow the prompt adoption of transparent and objective guidelines on how, which and when a species should be adopted for ex-situ conservation strategy according to the guidelines recommended by the IUCN/SSC [20].

7. Recommendations

Our analysis of conservation policy and practice in Ecuador has led us to identify gaps in the policy, challenges with application of the policy, and opportunities with biodiversity conservation. We propose following major recommendations to make biodiversity conservation practices timelier and more effective in Ecuador.

- Allocate dedicated and increased government funding to support NSNPA and enforce national law and policy on biodiversity conservation, in addition to other in-situ and ex-situ conservation practices.
- Expand the in-situ conservation network by creating new protected areas covering high-priority areas for biodiversity conservation with unique species and ecosystems and incorporate them into NSNPA.
- Increase public awareness of the biodiversity heritage and conservation by incorporating formal information into primary and secondary education curriculum and textbooks. This may include topics such as the megadiversity of the country, value of biodiversity, unique species and ecosystems, conservation strategies and how public can participate in conservation actions.
- Promote citizen science as a tool to fill the gaps of biodiversity information such as species occurrence, distribution and accurate taxonomic identity. Complete and accurate biodiversity information is critical in planning conservation projects and status assessments of species. Additionally, these programs promote active exploration and environmental stewardship among participants.
- Adopt IUCN/SSC Guidelines on the use of ex-situ management for species conservation [20] to providing clear, transparent and objective guidelines on how, which and when a species should be adopted for ex-situ conservation.
- Promote ex-situ conservation strategies such as captive breeding and release programs for threatened species at zoos, aquariums and university research facilities with funding, guidelines and technological support from the government and/or international research collaborations.

8. Conclusions

Ecuador has six clear policies for biodiversity conservation based on the concepts of “Good Living” and “The Rights of Nature”. These policies seek to strengthen biodiversity conservation through mechanisms that improve the well-being of wildlife by ensuring human, animal and ecosystem health. These policies support promoting in-situ and ex-situ conservation actions for the welfare of wildlife through technical, administrative and legal tools.

The National System of Protected Areas is the most effective in-situ conservation instrument at the country level, based on a strengthened governing institution with high management capacity. Ecuador, with 20.3% of its land area protected, is the second country in South America with the largest territory dedicated to in-situ conservation of biodiversity. It has 60 protected areas of which 53 belong to the State, 3 to decentralized municipal governments, 2 to communities and 2 privates.

Ecuador has defined seven ex-situ means of conservation and management for the conservation of wild species (Nurseries, Botanical Gardens, Zoos, Germplasm banks, Aquariums, Breeding and Rehabilitation centers). In order to execute ex-situ conservation processes in wild species, the species must be considered susceptible to extinction. They must comply with conditions such as strong habitat problems, key species of great ecological, biological, scientific, educational, food or medicinal importance. Despite the availability of these sound conservation policies, more attention should be given to strengthen these ex-situ strategies for biodiversity conservation of Ecuador in coming years and decades.

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