

Challenges for research on global change in mainland Ecuador

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1. Introduction

Ecuador is one of the first countries worldwide that set the environment as a national priority. The 2008 constitution established the concept of “Living Well” or “Buen Vivir” as a parameter of coexistence of the Ecuadorian society, and is based on equity and harmony with nature. The 2009–2013 [1] and 2013–2017 [2] National Plan for Good Living focused on conservation and sustainable management of natural heritage and biodiversity and mitigation and adaptation to climate change. These initiatives are internationally recognized for being at the forefront of socio-environmental rights [3,4]. One of the four principles of the “Plan Nacional para el Buen Vivir” was environmental sustainability, aiming to strengthen conservation, valorization and sustainable use of natural resources, ecosystem services and biodiversity [2]. The 2017–2021 National Development Plan [5] has been designed to further achieve environmental sustainability and territorial development.

To support such commitment, the Ministry of Environment of Ecuador launched the Socio Bosque Program in 2008 with the double objective of nature conservation and poverty alleviation [6]. Through the Socio Bosque Program, private and community land owners can benefit from a financial incentive in exchange for conservation of forests and native páramo grasslands [3,6]. Policy makers, stakeholders and funding agencies now raise the question to what extent market-based incentives, such as the Socio Bosque Program, are effective and efficient for enhancing carbon storage, biodiversity conservation and water regulation [7–9]. As conservation efforts continue to expand in the wider region, there is a need to evaluate the ability of conservation incentives to enhance ecosystems services’ supply and regulation. Evidence-based indicators and quantitative data are essential to measure the current state of supply and regulation of multiple goods and services by forest and páramo ecosystems, and then to evaluate their

dynamics after the implementation of conservation schemes [7,10].

Our present understanding of the landscape capacity to deliver essential ecosystem functions related to carbon, biodiversity and water limits an appropriate quantification of ecosystem services’ supply and regulation in wet and dry tropical forest and páramo ecosystems [11]. Limited information exists on the hydrological functioning of native forests and páramo grasslands in the tropics [12,13], their soil carbon and aboveground carbon storage [14], and native floristic biodiversity [15]. Furthermore, direct anthropogenic impact associated with land use change is rapidly transforming ecosystem functioning with direct and indirect consequences for multiple ecosystem services and goods [16–18].

Land-use change impacts are further exacerbated by change and variability in climatic conditions. Over the past few decades, a temperature increase of 0.5–1°C has been measured in the Tropical Andes, contributing to dramatic receding of glaciers [19]. Climate models predict a substantial warming of 5–6°C by the end of the century, with the largest increase occurring at high elevations [20,21]. Climate change is expected to have a direct impact on the provision and value of ecosystem goods and services, besides indirect impacts through adaptation and mitigation in agriculture and forestry [22–24].

A major concern for sustainable development in mainland Ecuador is the growing imbalance between ecosystem service supply and demand. While the capacity of the ecosystems to provide goods and services is already under pressure [16,25], the demand is rapidly increasing as a result of demographic growth, urbanization and evolving socioeconomic conditions [26–28]. In the Ecuadorian High Andes, this is epitomized by the rapid growth of megacities (e.g. Quito, Cuenca or Ambato), where requirement for essential ecosystem services ranging from provision of drinking water to water for

sanitation, irrigation and agriculture, mining operations and hydropower production will be higher in the near future [27,29]. In 2016, the total hydroelectric power potential in mainland Ecuador is assessed at about ~4445 MW, and is expected to increase with another 950 MW of installed capacity by 2020, when the 14 hydropower plants that are currently under construction will be operational [30]. This situation can lead to serious environmental conflicts between private companies, local peasants and public water companies [31,32].

2. Overview of papers in this special collection

In this special collection of papers, we compiled recent work on climate change and variability in mainland Ecuador. This compilation represents a selection of research projects that were presented in the national workshop on “Research on climate change and variability in Ecuador, and inter-institutional coordination of climate change research”, held in Quito in 2015. The workshop gathered 102 participants, and attracted researchers, policy makers, practitioners and professionals from government agencies, international organizations and NGOs. The special collection shows the diversity of topics within the study of climate change and variability in Ecuador. They represent the wide range of methodological approaches and spatial scales that are typically studied. A synopsis of the five papers follows.

Ecuador is home to high-biodiversity terrestrial ecosystems that exhibit very high levels of endemism in the tropics [33]. Land use has profoundly changed the natural habitats [34–36], and deforestation rates for the period 2008–2014 are estimated at 0.6% [6]. The principal driver of deforestation in Ecuador is the expanding agricultural frontier, followed by agroindustry, logging, mining and infrastructure. Van Der Hoek [37] has shown that governmentally protected areas can help to diminish deforestation. In the first paper of this special collection, Cuesta et al. [38] used ecosystem maps and species distribution models to identify priority areas for biodiversity conservation in mainland Ecuador. Their study complements current conservation efforts, and can contribute to guide land-use planning at local and national scales.

Global climate change will likely have a major effect on ecosystem functioning and biological diversity [39], and current diversity of mammals in Ecuador is expected to decrease significantly under climate change. Mountain ecosystems are particularly vulnerable to climate change, and will likely experience a significant decrease in the number of endemic species [39–41]. The consequences of climate change on Andean biodiversity remain unclear, given the high number of global climate change stressors, and variety of responses of climate change stressors on biological diversity. In their synthesis paper, Baez et al.

[42] critically reviewed published research investigating the effects of global climate change on the biodiversity of the Andean region up to 2015. Based on their synthesis, they concluded that observational data, modeling and experimental studies report negative impacts of global climate change on biological diversity of the Andean region. They suggested that networking, recovering historic field data and conducting large-scale ecosystem studies can contribute to improve our knowledge on past, present and future changes in biological diversity of the Andes.

Tropical dry forests are one of the most threatened tropical forest types in the Andes, and are largely understudied compared to wet tropical forests. The Tumbesian tropical dry forests of northwestern Peru and southwestern Ecuador are highly diverse ecosystems with intermediate endemism levels compared to other areas in South America [43,44]. Tapia-Armijos et al. [45] estimated that more than 50% of the area of dry forest ecosystems has disappeared because of anthropogenic activities. In their research paper, Aguirre et al. [41] analyzed the adaptive capacity of dry forest species with regard to anthropogenic (e.g. logging, agriculture, mining, fragmentation) and intrinsic (e.g. fire probability, water stress) stressors and climate change. The sensitivity and adaptive capacity data were combined with species distributions under the RCP 2.6 and RCP 8.5 future climate scenarios. Their results show that four of the five forest species are subject to a reduction of their future distribution area due to niche restriction: between 18% and 26% of their future distribution area is located in zones with high sensitivity, while 14–46% is corresponding to zones with potentially high adaptive capacity [41]. The authors concluded: “It is high priority to identify, preserve and, if possible, recover dry forest habitats”.

Tropical wet and dry forests have extensively been converted to agricultural land in Ecuador [6,16,34,45]. The expansion of commodity crops, such as palm oil and cocoa, in recent decades has increased the pressure on low-intensity agroforestry systems and forests [46]. Agricultural intensification is known to reduce the response capacity of the land-use systems to anthropogenic and intrinsic stressors and climate change. *Theobroma cocoa*, or cacao, is now grown throughout the Ecuadorian humid lowlands, and the commodity crop is rapidly gaining cultural, economic and ecological importance [47]. Cacao diseases like frosty pod, caused by *Moniliophthora roreri*, and witches’ broom, caused by *M. perniciosa*, can have severe impacts on crop production and yields [48,49]. Ortega-Andrade et al. [49] combined species potential distribution models with future climate scenarios from HADCM3 to assess the potential impacts of climate change on *M. roreri* and *T. cocoa* distribution in Latin America. Their results suggest that the precipitation during the wettest month is most influential variable for presence and proliferation of the fungus *M. roreri*. The authors recommend policy

makers to invest in a “monitoring system allowing early warning and control of incipient outbreaks” [49].

Climate-change-related planning and sustainable development in Ecuador critically hinges on the generation of scientific knowledge on climate variability and climate change. Rigorous and consistent procedures for data collection, reporting and analyses are necessary to understand climatic variability, climate change and its impacts, to assess future climate change, risks and impacts, and to provide tools and technologies to support climate change mitigation and adaptation management. In the last paper of this special collection, Cadilhac et al. [50] present a preliminary state-of-the-art of climate change research based on a review of climate-change-related projects realized by Ecuadorian public research institutions and higher education institutions. Their online survey shows that research topics related to vulnerability and adaptation to climate change are relatively well covered, with a considerable number of projects emphasizing the impact on ecosystem services [13,16], biodiversity [41,42], agriculture [49] and health [51]. From the interinstitutional dialogue with policy makers, practitioners and professionals from government agencies, international organizations and NGOs, future research needs were identified in the field of [1] metrics that support technical analysis on mitigation, adaptation and greenhouse gas inventories [2], social impacts of climate change, governance and institutionalism [3], replicability of climate change studies and [4] traditional knowledge.

3. Challenges for future research

Critical socio-environmental issues related to provisional ecosystem services' supply and demand, and the impact of climate change and variability, urban growth and continued socioeconomic development on ecosystem services, require rapid action involving the development and implementation of adaptation and mitigation strategies [52]. Robust evidence-based strategies on sustainable socio-ecosystem management are necessary to assist policy makers and stakeholders in their decisions. As such, for successfully developing, promoting and implementing effective and efficient adaptation and mitigation strategies, it is vital to enhance our understanding on the current provision and demand for ecosystem services, and their projected evolution under future global climate change and land-use change.

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