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Review

Monitoring ecological change during rapid socio-economic and political transitions: Colombian ecosystems in the post-conflict era

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ABSTRACT

After more than 50-years of armed conflict, Colombia is now transitioning to a more stable social and political climate due to a series of peace agreements between the government and different armed groups. Consequences of these socio-economic and political changes on ecosystems are largely uncertain, but there is growing concern about derived increases in environmental degradation. Here, we review the capacity of Colombia to monitor the state of its ecosystems and their rate of change over time. We found several important programs currently set in place by different institutions as well as by independent groups of scientists that address different aspects of environmental monitoring. However, most of the current initiatives could be improved in terms of data coverage, quality and access, and could be better articulated among each other. We propose a set of activities that would increase the capacity of Colombia to monitor its ecosystems, provide useful information to policy makers, and facilitate scientific research. These include: 1) the establishment of a national center for ecological synthesis that focuses on analyzing existing information; 2) the establishment of an ecological observatory system that collects new information, integrates remote sensing products, and produces near real-time products on key ecological variables; and 3) the creation of new platforms for dialog and action within existing scientific and policy groups.

1. Introduction

Monitoring ecosystem functions and services is a challenging task that only a few countries and regions with strong economies are starting to tackle through large scientific infrastructure programs. Some of those include NEON (National Ecological Observatory Network) in the USA,

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Table 1
Classification of main monitoring categories and examples of variables with existing monitoring/measuring programs.

Category	Variables	Existing programs
Climate and biogeochemistry	Meteorological variables: air temperature, precipitation, solar radiation, wind speed and direction, etc.	IDEAM station network
	Hydrology: stream and river stage, flow, and discharge	IDEAM network, Hydro-SIG software
	Land-atmosphere interactions: Ozone, UV radiation, aerosols, trace gases, particulate matter, greenhouse gas concentrations.	IDEAM, single investigators
	Carbon cycle: biomass and C stocks, primary production	National Forest Inventory, IGAC soil surveys, Rainfor and CTFS-ForestGEO plots, single-investigator projects
Biodiversity	Species inventories: specimen collections, species catalogs	Herbariums, Universities, SiB Colombia (IAvH)
	Biodiversity assessment: species distributions, diversity indexes	Biomodelos platform (IAvH), single-investigator projects
	Ecosystem assessment: vegetation distribution maps, land use, land-use-change maps	IDEAM, IAvH
Socio-economic variables	Demography: birth and mortality rates, life expectancy, migration	DANE
	National agricultural and livestock census	DANE
	Economy: gross domestic product, inflation, basic living costs, interest rates	DANE, Central Bank
	Social conflict: internal migration, violent deaths, human-right violations, peace processes	DANE, Planeación Nacional, Observatory of Peace and Conflict (Unal)

or ICOS (Integrated Carbon Observatory System) in Europe, among others. Monitoring ecosystems in countries experiencing fast socio-economic and environmental transitions and with much lower investments in science and education is a more challenging endeavor. This is the case of Colombia, which covers only 0.7% of the global land area, but hosts approximately 10% of all known species on Earth (up to date 56,343 species of animals, plants, fungi, algae, and lichens are registered for Colombia; (SiB-Colombia, 2017)). Despite its relatively small size compared to countries such as Brazil or China, Colombia is ranked first in terms of species richness of birds and orchids, second for plants, amphibians, freshwater fishes, and butterflies, third for reptiles and palms, and fourth for mammals (GBIF, 2017; SiB-Colombia, 2017). Colombia is thus one of the so-called megadiverse countries.

Colombia has also suffered one of the longest armed conflicts in the world, lasting for over 50 years. With more than 8 million victims (RUV, 2017) and nearly 6 million refugees, Colombia is currently the country with the second largest internally displaced population in the world after Syria (CODHES, 2014). This long-lasting internal conflict has significantly shaped rural landscapes and ecosystems through changes in livelihoods, modes of economic production, and land cover (Arias et al., 2014; Pinilla, 2013). Armed conflict and civil unrest have resulted in contrasting consequences for ecosystems and natural resources. In some cases, military hideout zones and buffers among territories in conflict regions have promoted the conservation of natural areas. In other contexts, war has increased pressure on natural resources leading to environmental deterioration (Álvarez, 2001; Dávalos, 2001; Etter et al., 2006a,b; Gaynor et al., 2016; Sánchez-Cuervo et al., 2012). Conflict is also associated with poor governance in many regions, which results in lack of commitment on long-term government-sponsored development programs, and subsequent increases in deforestation rates (Dávalos et al., 2016).

During the last decade, Colombia has experienced dramatic changes in the internal conflict as a consequence of both intense negotiations with armed actors and the increased military control of vast areas of the territory. Today, Colombia has been closer than ever to achieve peace. Unprecedented agreements have been reached with paramilitary groups and the FARC (Fuerzas Armadas Revolucionarias de Colombia), the largest guerrilla group, that are leading the country to transition toward the so-called “post-conflict” era. Central to this process is the implementation of a series of incentives to promote rural small-landowner development, land restitution, consolidation of ongoing and projected large investments on road development, large-scale energy projects (particularly dam construction), commodity agriculture, and mining (Clerici et al., 2016; Negret et al., 2017). The consequences of these rapid socio-economic and political changes on the state of natural ecosystems, their biodiversity, and services are not clearly known, but may include negative effects such as increased deforestation and degradation due to timber extraction, agricultural and industrial expansion, or positive effects such as better environmental governance. Our ability to assess these changes and facilitate environmental stewardship depends largely on the capacity of the country to monitor relevant ecosystem variables and their rate of change in near-real time, so actors can respond quickly (Baptiste et al., 2017).

In this manuscript, we assess the capacity and needs of Colombia to monitor ecosystem change during the rapid social, political, economic, and environmental changes that the country is currently facing. Therefore, we address the following two questions: *what is the current capacity of Colombia to monitor relevant ecosystem variables and their rate of change? What are cost-effective initiatives that can be implemented to improve this capacity?* To address these questions, we present an inventory of major initiatives for ecosystem monitoring in Colombia. We identify major gaps and issues with current programs, and recommend a set of actions that can serve as guidance for other countries under similar circumstances.

2. Assessment of ecosystem monitoring capacity

We consider of fundamental importance to monitor the state of Colombian ecosystems in three broad categories: 1) climate and biogeochemistry, 2) biodiversity, and 3) socio-economic variables (Table 1). Climate and biogeochemistry variables include: energy, water, carbon, and nutrient budgets and fluxes. Biodiversity variables include: composition, structure and functioning of plant, animal, fungi, and lichens, as well as information on diversity of genes and ecosystems from a multi-scale perspective (Noss, 1990; Pereira et al., 2013). Socio-economic variables include those related to the demand for ecosystem services, the governance mechanisms that modulate that demand, the effect of those demands and governance mechanisms on ecosystem biogeochemistry and biodiversity, and the relationship between ecosystem services and human well-being. In the following, we outline Colombia's capacity to measure and monitor some of these variables.

2.1. Climate and biogeochemistry variables

2.1.1. Hydro-meteorological network

Colombia has a well-established network of hydro-meteorological stations distributed across different bioclimatic zones. This network is managed by the “Instituto de Hidrología, Meteorología y Estudios Ambientales” (IDEAM, see Box 1 for other acronyms), which is the governmental institution in charge to produce hydrological, meteorological, and environmental information.

Although the network has a reasonable spatial and temporal