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Research article

Estimating and valuing the carbon release in scenarios of land-use and climate changes in a Brazilian coastal area

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ABSTRACT

Deforestation is a significant source of man-made carbon in the atmosphere, contributing to the greenhouse gas (GHG) effect. Although carbon releases are associated to the ecosystem functions of climate regulation and are essential ecological processes that sustain life, their incremental economic impact is difficult to estimate. Using the InVEST model, this work quantifies and assesses the value of the carbon balance generated by predictive land-use change (LUC) scenarios for the Northern Coast of São Paulo State, Brazil. In this case, carbon losses are explained by the suppression of natural vegetation and human intervention associated to global warming. We analyzed three scenarios: i) the more conservative "legal framework"; ii) the "status quo", which represents the current development level; and iii) the "new ventures", encompassing all new infrastructure projects in the region. The carbon losses in the "legal framework" and "status quo" scenarios are similar to those of past periods: around 3.7 million MgC in twenty years, pointing to net current values of US$ 47 million. However, carbon losses exceeded 7 million MgC when considering factors linked to the "new ventures" scenario, such as infrastructure logistics, oil-gas exploration and pressure on natural environments. In this case, monetary losses could amount to US$ 90 million in 20 years. Besides carbon release, results also highlight the large amount of carbon still stored in protected areas that is threatened by the regional economics dynamics and requires special attention from the public sector, management bodies and regulators.

1. Introduction

Evidence drawn from the earth's continents and oceans points to the fact that regional changes in climate, especially increases in temperature, affect many natural systems (IPCC, 2014). There is indication that droughts and floods have already affected some human systems. Furthermore, biological activities are vulnerable to climate change which sometimes causes irreversible damage. It can also cause direct economic losses, as well as social transformations (IPCC, 2007a,b; Marengo et al., 2009; Chou et al., 2014; NCA, 2014). There is increasing concern with climate change as it interferes in the decision-making process of public and private institutions. Some planning processes integrate adaptation, where the implementation of responses is somewhat restricted, (Van Der Werf et al., 2009; IPCC, 2014).

The Paris Agreement aims to strengthen the ability of countries to deal with the impacts of climate change by putting in place adequate financial flows, new technology frameworks and enhanced capacity-building, in order to keep global temperature rises well below 2 °C above pre-industrial levels and pursue efforts to limit temperature increases even further to 1.5 °C (UNFCCC, 2015).

Global climate change projections point to carbon sequestration as one of the most important ecosystem services (MA, 2005). Carbon storage and sequestration are linked to climate regulation functions which maintain the essential ecological processes that support life. Although there is a consensus regarding the fact that tropical forests contain the largest amounts of carbon stocks, there is still uncertainty as to their exact value for the global carbon cycle (Malhi et al., 1999; Chave et al., 2005). Thus, the need to conduct more studies on this topic.

Forests will only be maintained when the cost of deforestation or gains achieved through conservation are greater than potential gains through other land-uses (CGEE and IPAM, 2011). It is necessary,

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therefore, to include external costs to society in fossil fuel prices, especially the costs of climate change and air and water pollution, so that carbon-free energies and energy efficiency can supplant fossil fuels more rapidly (Ackerman and Stanton, 2012; Hansen and Sato, 2016).

This can justify the need to implement economic mechanisms that fund conservation policies for large forests. In this context, tropical countries claim that responsibility for stabilizing the global climate - through their forests and the costs of their maintenance - should be shared by all via financial compensation for reducing carbon emissions from deforestation.

To encourage actions that reduce anthropogenic interventions and stimulate global collaboration to combat climate change, projects to reduce greenhouse gas emissions and generate carbon credits (CGEE and IPAM, 2011) have been developed. The REDD+ Program (Reducing Emissions from Deforestation and Degradation) encourages developing countries to take actions and set up strategies to mitigate climate change voluntarily in return for financial compensation for reducing rates of deforestation and degradation (UN REDD+, 2016).

Deforestation and forest degradation are the second largest anthropogenic sources of carbon compounds in the atmosphere, corresponding to approximately 6–25% of global emissions (Van Der Werf et al., 2009; Baccini et al., 2012; Pearson et al., 2017). They contribute to atmospheric greenhouse gas (GHG) emissions through the combustion of forest biomass and decomposition of remaining plant material and soil carbon (Van Der Werf et al., 2009). According to the Joint Research Centre and the Netherlands Environmental Assessment Agency (2009), in developing countries such as Brazil, Bolivia, Indonesia, Myanmar and Zambia, a substantial amount of emissions is due to forest loss which is also the largest source of CO_2.

At national level, Brazil contains 35% of the total carbon stored in tropical forests, while 52% of GHG emissions originate from forest and grassland conversions (Baccini et al., 2012; Cerri et al., 2009). However, emission rates may be underestimated due to a lack of studies on land-use change (LUC) in Brazilian forest areas that have undergone major changes in recent years. It is, therefore, essential to study and tabulate data related to LUC activities to identify Brazil's exact contribution to GHG emissions. Zvoleff et al. (2014) and Dupin et al. (2018) highlight the importance of naturally regenerating forests to the maintenance of ecosystem integrity and its services, which are frequently neglected in conservation strategies.

Brazil's potential gains from the voluntary carbon market are enormous, particularly in the REDD+ market. Public policies that aim to reduce greenhouse gas emissions from deforestation and forest degradation are considered cost-effective mechanisms to mitigate other anthropogenic emissions (Gullison et al., 2007).

The Brazilian Atlantic Forest (Morellato and Haddad, 2000; Oliveira Filho and Fontes, 2000) is a South American tropical biome of immense structural complexity harboring some of the most diverse and biologically unique forest ecosystems on earth (Wilson, 1992; Davis et al., 1997; Myers et al., 2000). Its wealth in terms of species, extremely high levels of endemism and the small amounts left of original forest led it to be ranked among the top biodiversity hotspots (Myers et al., 2000; Mittermeier et al., 2004).

Global society also benefits from services provided by the Atlantic Forest, such as the protection of genetic resources, scenic beauty, endemic species and climate change mitigation. The range of benefits it provides led to the formation of markets for the payment of these services. In the case of climate change mitigation, for example, resources available in other countries may help to support climate regulation services provided by the Atlantic Forest.

Its history of degradation describes the fate experienced globally by tropical forests. After centuries of human expansion, most Brazilian Atlantic Forest landscapes are archipelagos of small forest fragments surrounded by open-habitat matrices such as pastures and agricultural fields (Ribeiro et al., 2009; Joly et al., 2014).

According to Law N. 11428/2006, the Atlantic Forest biome makes up 15% of the Brazilian territory. It considers the following native forest formations and associated ecosystems: Dense Ombrophylous Forest; Mixed Ombrophilous Forest, also called Araucaria Forest; Open Ombrophilous Forest; Seasonal Semideciduous Forest; and Deciduous Seasonal Forest, as well as mangroves, sandstone vegetation, altitude fields, inland swamps and forest entanglements in the Northeast (Brazil, 2006).

Although deforestation has been declining since the 1990s, currently, only 12.4% of Atlantic Forest is preserved, around 16 million ha. Less than 2% of the national territory is native forest, well below the 15% established by law (Fundação SOS Mata Atlântica/INPE, 2018). Forest remnants were able to survive because of the difficulty in accessing slopes and implementing agropastoral activities. They are often found in small degraded fragments within environments modified by human action (Hirota, 2003).

Of the 27 Federal Units in Brazil, 17 States are fully or partially inserted in the Atlantic Forest biome. Although more than 69% of São Paulo State is considered part of Atlantic Forest biome by law, only 13.9% of the original forest coverage remains, around 2.3 million ha (Fundação SOS Mata Atlântica/INPE, 2018).

It is important to be aware of the interventions that can aggravate the situation of coastal areas, where the interaction between the mainland and maritime environments is highly complex. In the case of the Northern Coast of São Paulo, although there has been a decrease in deforestation rates in local municipalities in recent years, the amount of remnant forest is very small in comparison to the size of the original biome.

Nevertheless, some studies indicate high levels of carbon stored in the natural vegetation of the Northern Coast of São Paulo, especially within the tropical forest (Chave et al., 2005; Alves et al., 2010; Assis et al., 2011; Vieira et al., 2011). Although the current extent of the forest is much smaller than the original coverage, its carbon storage potential is still extremely important to regional carbon budgets, considering its regeneration capacity.

This work supports the development of coastal management strategies by analyzing the carbon balance as a result of LUC for past and predictive scenarios in the Northern Coast of São Paulo. It highlights the amount of carbon released into the atmosphere due to changes in landscape dynamics suggested by the guidelines of current laws, the expansion of urban areas and global warming. Results also indicate the potential loss of resources for the REDD market.

2. Material and methods

2.1. Study area

The Northern Coast of São Paulo is an administrative boundary of coastal area, which covers the municipalities of Ubatuba, Caraguatatuba, São Sebastião and Ilhabela (Fig. 1). The area comprises diverse ecosystems, such as tropical forest, rocky shores, beaches, mangroves and coastal flooded forest (*restinga*). Each of these ecosystems has specific biotic communities that are specially adapted to the structure and physical dynamics of the environment (São Paulo, 2005; Vieira et al., 2011; Eisenlohr et al., 2013).

This coastal territory encompasses an area of 186,232 ha, which is almost fully protected by State Parks, totaling 86% of the region in preserved areas of Atlantic Forest. The considerable number of protected areas, in addition to the Serra do Mar escarpments, limit land use and, more specifically, the implementation of infrastructure (São Paulo, 2009). These limitations ensure the preservation of native vegetation that holds a supply of ecosystem services, such as large carbon stocks in the region. Nevertheless, these areas are still permanently threatened by infrastructure growth.

In the Northern Coast of São Paulo, tourism has been the main historical driver of growth and urbanization, comprising mainly urban areas of second homes (Silva, 1975). More recently, we have seen the