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Identifying driving forces of landscape changes: Historical relationships and the availability of ecosystem services in the Atlantic forest

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ABSTRACT

We argue that the history of a landscape and the driving forces acting in each of its sectors account for the recent condition of its structure and ecological functions, which, in turn, can be translated into the availability of ecosystem services. Therefore, the present study investigated the historical relationship between the forces that have induced changes in the use and settlement of the island of São Sebastião over five centuries, their resulting impacts and their influences on the availability of regulation, supply, recreation and cultural ecosystem services. We worked with a broad historical survey and maps of land use and natural vegetation from different time periods. Thus, although the historical data were not accurate about the exact areas used for agriculture or forest we could infer about losses and replacement of ecosystem services. Moreover, we observed the occurrence of three driving forces that alternated in intensity and importance over time, leading to forest gains and losses that especially led to the degradation of regulation services.

1. Introduction

Changes caused by the relationships between humans and nature over time and space leave traces that can be observed on a landscape scale (Bürgi et al., 2004). The current structure of a landscape is, therefore, a result of the history of the production, economic and social relationships of that place (Teklemburg et al., 1997; Echeverría et al., 2012). The lasting effects of historical events tend to be expressed in proportion to their transforming capacity, thus defining the environmental quality of the place. Therefore, to evaluate changes in a landscape is to know the past, allowing a better comprehension of the present, an enhanced understanding of the human pressures that have accumulated over time and a more accurate prediction of future scenarios (Terra and Santos, 2012; Estoque and Murayama, 2012).

Several studies in landscape ecology have sought to recognize key environmental transformations to identify the primary drivers responsible for the changes (Marcucci, 2000; Wood and Handley, 2001; Wu and Hobbs, 2002; Bürgi et al., 2004; Eetvelde and Antrop, 2004; Klijn, 2004; Huston, 2005; Geist et al., 2006; Scheneeberger et al., 2007; Campos et al., 2012). These drivers are usually termed driving forces (Scheneeberger et al., 2007) and are described as the influence that causes the type, intensity and direction of the change (Bürgi et al., 2004; Campos et al., 2012). The sequence, intensity and duration of the driving forces on a certain location depend on both the historical trajectory of the region and its natural characteristics (Huston, 2005; Geist et al., 2006).

The influences of driving forces and the resulting changes are not identical throughout the landscape. Therefore, each land fraction has a recognizable set of patches of natural systems and anthropic uses of different dimensions, forming distinct mosaics (Antrop, 2003; Valverde et al., 2008; Bertolo et al., 2010) with their own conditions of functional complexity and human interferences (Wang et al., 2006; Braat and Ten Brink, 2008). Furthermore, the history and driving forces acting on each fraction of the landscape are assumed to account for the recent condition of their structure and ecological functions, which, in turn, generate ecosystem

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services according to the benefits appropriated by humans (Hueting et al., 1997; de Groot et al., 2002; Andrade and Romeiro, 2009; Portman, 2013).

The identical driving force that changes the landscape also favors (or disfavors) the use of a particular set of ecosystem services to the detriment of other services, depending on their circumstances throughout history. Assuming that these theoretical premises are true, the current proposal to respond to the availability of ecosystem services when properly planning a landscape depends on the interpretation of the losses or gains in those services over time and the consequences of the actions of the driving forces on the structure of a landscape. Therefore, the present study aimed to identify the historical relationship between driving forces, changes in land use and settlement, and the effects and availability of several major ecosystem services throughout the history of a landscape. Thus, although the historical data were not accurate about the exact boundaries of the areas used for agriculture or forest, the purpose of this study was to show qualitatively that the landscape we have today and consequently ecosystem services are products of historical local trajectories.

To verify the applicability of the concepts and matters discussed, a case study was designed based on the island of São Sebastião (São Paulo, Brazil), the selection of which is justified by its well-documented historical trajectory dating to the beginning of colonization, its large area of preserved Atlantic forest, its high degree of urbanization and the possibility of studying a complete system of ecotonal gradients with an interdependence between functions and concentrated flows.

2. Material and methods

The construction of the historical context and the changes in the use and settlement of the coastal landscape that occurred from the sixteenth to the twenty-first century was conducted through the process of "mining", as described by Pimentel (2001) (Table 1). The bibliographic information on the territory was made spatially explicit using sketches. Surveys were conducted to identify the main outlines of the historical trajectory of the island and to recognize the key moments in the transformation of the island, thus enabling the identification of the driving forces that induced changes in the landscape.

A literature search was performed on a datasets of indexed scientific data as related in Table 1 using query selectors: "ilha de são sebastião" OR "são sebastião island" OR "ilhabela" AND "litoral norte" AND "são paulo" OR "história do brasil", always in Portuguese language. We searched for these terms in the titles, and/or as keywords, and/or in the abstracts of articles, in peer-reviewed scientific journals, books, book chapters, master's or doctoral thesis, extended abstracts and summaries of scientific events. The texts resulting from this research had focused on social relationships and the historical context which was related to a particular event or social group, with no interest in quantification of losses of forest or agriculture gains. Because of this, historical data on the amount of loss or replacement services are not accurate, and it has translated into difficulty in establishing the exact boundaries of the areas used for agriculture or the amount of coffee and sugar produced in the specific area and time. Maps of the land uses, settlements and vegetation on the island were created based on aerial photographs taken in 1962, Landsat 5 satellite images from 1987 and Landsat 7 images from 2001 (Table 1). These more modern maps were combined with a land use sketch made by França (1954) in the 1950 s and old photographs available in public archives (Table 1).

Mapping was performed through a visual interpretation and image digitization technique using the ArcGIS 9.2 software. Image coordinates were corrected using the Universal Transverse Mercator system (UTM Zone 23 S) and datum SAD-69 (South American Datum of 1969). The images LANDSAT 7 ETM and 5 TM were georeferenced in ArcGIS using at least 10 control points. Was applied a transformation of 1st order polynomial (affine), resulting in RMS error (root mean square) of 25 m, according to the Brazilian Map Accuracy Standards, is the maximum on the scale of 1: 50,000. The degree of reliability was performed by calculating the percentage concordance between the types of uses observed in the field and mapped, which led to a degree of 92% mapping reliability.

Graphic representations were generated based on maps and dated sketches to illustrate the action of the driving forces and the use of ecosystem services over the last five centuries of occupation of the island of São Sebastião.

The data clarified the relationships between the spatial patterns or measures of landscape change caused by the driving forces acting on the territory and developed the overall spatially explicit interpretation of the history of the island.

Each driving force identified within every time period was interpreted according to the intensity of its use of ecosystem services and, consequently, the degradation of the ecosystem. Due to

Table 1
Summary of the materials used for the spatial reconstruction of history.

Date	Material	Source
Pre – 1950 and between 1960 and 1990	Historical survey, figures and images obtained from old texts	Databases: Scielo, ATHENA (UNESP), SOPHIA (UNICAMP), DEDALUS (USP); Municipal Library of São Sebastião, Public Library "*Prefeita Nilce Signorini*" (Ilhabela), and the public agencies of the State of São Paulo (Environmental Sanitation Technology Company [Companhia de Tecnologia de Saneamento Ambiental – CETESB], Road Development S/A [Desenvolvimento Rodoviário – DERSA], Agronomy Institute of Campinas) and websites
1950 s	Collection of old photos of the island of São Sebastião	Department of Culture of the Municipality of Ilhabela
1954	Land use sketch of the island of São Sebastião	FRANÇA (1954)
1987	Image from the Landsat 5 ETM[1] satellite, 30 m resolution. 1:50,000 scale Bands 3, 4 and 5. Orbit/point 218/077	http://glcf.umiacs.umd.edu/data/landsat/
2001	Image from the Landsat 7 ETM^{+2} satellite, 30 m resolution. 1:50,000 scale Bands 3, 4 and 5. Orbit/point 218/077	Laboratory of Environmental Planning, State University of Campinas (Laboratório de Planejamento Ambiental da Universidade Estadual de Campinas - LAPLA/UNICAMP).
2010 s	Newspaper material and academic studies	Scielo, ATHENA (UNESP), SOPHIA (UNICAMP), DEDALUS (USP) and websites