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A century of change in coastal sedimentary landscapes in the Canary Islands (Spain) — Change, processes, and driving forces

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ABSTRACT

A global understanding of landscape dynamics, through local case studies, is a prime topic in land change science. Consequently, this approach should be urgently applied to changing and heavily transformed environments, such as coastal areas. The aim of this work is to study landscape changes, comparatively, by focusing on three coastal sedimentary landscapes in the Canary Islands (Spain). We examine changes in main land cover types and identify their driving forces, actors and institutions, analyze their inter-relationships, and match each case to a case-specific development model. The three landscapes reveal very different change processes with regard to population density, land cover, and major land change processes (i.e., resource extraction, urbanization, tourism, and nature protection). We found that socioeconomic, political, and natural/spatial driving force types are of highest importance, while the local level is dominant in all three cases. The findings of this study can be used to interpret other similar landscapes worldwide. Driving-force and organizational-level patterns may be expressed in a synthesized manner as we demonstrate in this paper.

1. Introduction

Land change research has become an important scientific field in the understanding of global environmental change (Turner et al., 2007). In addition to case studies that quantify landscape changes and characterize change processes (Geist and Lambin, 2002; Munteanu et al., 2014; Wu et al., 2015), and that subsequently perform *meta*-analyses (Rudel 2008; van Vliet et al., 2015), theoretical-conceptual frameworks have been proposed (Lambin et al., 2001; Rindfuss et al., 2004; Verburg et al., 2004; Turner, 2010; Verburg, 2014). Furthermore, in recent decades, the study and validation of general patterns and processes in landscape change has been attempted in an effort to develop a general theory of landscape change (Antrop 1998; Bergsten and Zetterberg, 2013).

To move beyond a merely descriptive approach, understanding the causes and consequences of landscape change constitutes a major objective for land change science (Magliocca et al., 2015). To study land change causes, various methodologies that enable the analysis of so-called driving forces of land use or landscape change have been proposed. These include the DPSIR (Drivers-Pressures-State-Impacts-Response) model, which is an extension of the PSR model by Anthony Friend, developed by the European Environmental Agency (EEA, 1999), and the driving forces approach described by Bürgi et al. (2004) and Geist and Lambin (2002). Both approaches have been applied successfully in a number of case studies (e.g., Lin et al., 2007, Hersperger and Bürgi, 2009).

Driving forces can be defined as “forces that cause observed landscape changes, i.e., they are influential processes in the evolutionary trajectory of the landscape” (Bürgi et al., 2004). Basically, five types of driving forces can be distinguished, namely, socioeconomic, political, technological, cultural, and natural/spatial. These are all scaled in character, i.e., they can be classified into four organizational levels: international, national, regional, and local (Hersperger and Bürgi, 2009).

Several studies of landscape change based on the driving forces approach have either encompassed all types (Schneeberger et al., 2007;

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Hersperger and Bürgi, 2009; Lieskovský et al., 2014), or focused on specific types of driving forces, such as technological (Domon and Bouchard, 2007; Hasselmann et al., 2010), political (Hersperger and Bürgi 2010), and social (Bičík et al., 2001) driving forces.

The present study comprehensively applies the driving forces approach to coastal environments. The global significance of coastal areas can be illustrated by the fact that 41% of the world's population lives in such environments, which have been heavily transformed by humans (Martínez et al., 2007). These areas provide a number of important ecosystem services that must be protected (Agardy and Alder, 2005). This is a great challenge given that coastal areas experience enormous natural and human pressures such as sea level rise, tourist activity, and sand extraction (Gormsen, 1997; Gössling, 2002; Jackson and Nordstrom, 2011), all of which clearly threaten their current functions. Sandy landscapes cover about 40% percent of the planet's coasts (Bird, 1996); they benefit local communities (Nordstrom et al. 1990; Carter, 1998; Martínez and Psuty, 2004; Miththapala, 2008) by: providing protection barriers against episodes of marine storms; supplying essential sand reserves to maintain the dynamic balance of the coasts; preventing sea water intrusions; and harboring communities of several specific plant and animal species. For these reasons, beaches and coastal dunes are considered fragile and sensitive to the human intervention (Paskoff, 1993) that has affected the natural state of coastal territories throughout history (Jackson and Nordstrom, 2011), especially in recent decades with the phenomenon of "littoralisation" (Bajocco et al., 2012).

Landscape change studies in coastal areas under similar conceptual frameworks and related methodologies to those described above can be found in the literature. For example, Napton et al. (2010) performed a study for the southeastern USA over different environments—from the coast to mountainous inland area—observing that commercial forestry, competition between forest and agriculture, and economic and population growth represent the main driving forces in land cover change. The study combined quantification of land cover changes with identification of driving forces, as well as their influence on each environment studied. In another study, Bertolo et al. (2012) conducted research at the island of São Sebastião (Brazil) and developed a methodology that enables identification of the structure of patterns that result from the relationships between driving forces, change vectors, and evolutive phases in coastal landscapes.

Given the widespread and varying nature of coastal sedimentary landscapes, a comparative approach is likely a rich source of data. To our knowledge this approach has not been previously implemented to date, at least under the driving forces approach. Thus, in the present paper we examine the landscape changes in three coastal sedimentary landscapes in the Canary Islands (Spain) from 1900 to 2010, focusing on changes, major land change processes, and driving forces. The study sites are the Guanarteme and Maspalomas dune fields (Gran Canaria), and the sedimentary systems of the island of La Graciosa. The main goal of the study is to understand the landscape changes in the study sites. This is achieved by:

(1) determination of shifts in the two main land cover types (i.e., the natural sedimentary system and areas of human occupation over the study period) and identification of the driving forces, actors and institutions, and major land change processes (i.e., human activities that have led to landscape change or persistence over landscape dynamics);
(2) analysis of the relationships between driving forces, institutions, and actors by linking them to each other and to the major land change processes for each study area; and
(3) examination of the relationships between landscape changes and site-specific development models.

2. Materials and methods

Following the procedure proposed by Bürgi et al. (2004), we executed three main steps:

(1) system definition, in which basic information about the study area (such as extent of study area, grain of the study, temporal resolution, etc.) is described;
(2) system analysis, which focuses on driving forces, actors and institutions, and change and persistence of physical landscape elements; and
(3) system synthesis, where actors, institutions, and driving forces are linked to each other and to the major land change processes, in order to understand the land cover changes in the study sites.

2.1. System definition

The Canary Islands is a volcanic archipelago, composed of seven islands and six islets. It is situated in the Atlantic Ocean, between 27° and 30° north latitude, and 13° and 19° west longitude. The Guanarteme and Maspalomas dune fields are located in Gran Canaria, while La Graciosa is a minor island situated at the northeastern part end of the archipelago (Fig. 1).

The formation of the archipelago dates back at least 20.6 million years BP (Carracedo et al., 1998). Due to their volcanic nature, sedimentary systems are not present on all islands and can only be found on the oldest ones (Lanzarote and its islets, including La Graciosa, Fuerteventura and Gran Canaria) (Hernández Calvento, 2006).

The socioeconomic system of the Canary Islands has changed during the 20th century from an agriculture to a service-based system, where tourism has played a central and dominant role. However, the impact of tourism on the islands has not been homogenous. It has been more focused on coastal areas, in particular in Gran Canaria and Tenerife. Although data on tourism are not available for the entire period of study, nor for all sites studied, the number of tourists that visited Gran Canaria from 1990 to 2010 was used as a proxy for overall touristic development. Thus, in 1990, 1,736,908 tourists visited Gran Canaria, reaching 3,136,262 in 1999 (peak), and decreasing to 2,481,672 in 2010 (AENA, 2015). Additionally, we know that in 1986 more than 15,000 tourists visited La Graciosa (Acosta Rodríguez and González, 1994). In addition to tourism, urban sprawl in particular, and other socioeconomic and cultural factors including population growth, all impacted on the study sites.

With regards to the political situation, the country has been subject to different political systems. Spain began the 20th century with the same political regime that existed at the end of the 19th, known as the *Restauración canovista*. This consisted of alternation between two main political parties − the liberal and the conservative − through electoral fraud. This continued until 1931, except for the period 1923–1930 when the military dictatorship of Primo de Rivera was established. In 1931, the Spanish Republic II was proclaimed that constituted the country's first democratic political system. However, General Franco reacted to this political system by instigating the Spanish Civil War in 1936. After his victory in 1939, he established the Franco dictatorship − that lasted until 1975, and was followed by the current democratic system. During the Franco regime, the country's international relationships suffered —with significant socioeconomic consequences—and hindering of the development of regional institutions to foster the establishment of more rational land policies.

Furthermore, sociopolitical movements such as increases in ecological awareness observed during the 20th century (Brito Díaz, 2015) exerted more influence on the above-mentioned land policies. Thus, developmentalist policies (e.g., the urbanization of Guanarteme) were

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