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Dynamic integration of sustainability indicators in insular socio-ecological systems

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ABSTRACT

The sustainability assessment on socio-ecological systems requires a systemic perspective in order to address the close relationships between the environmental and socio-economic processes. This need is especially urgent in the case of arid insular systems where limiting factors, as land and water resources, are more evident. The hyperarid island of Fuerteventura (The Canary Islands, Spain) represents a challenging case due to the need for compatibilizing the rising tourist development with the sustainable management of its natural resources, highly vulnerable due to processes such as the degradation of natural habitats – which hosts endemic and endangered species – or the high dependence of allocthonous energy sources for basic processes, including water supply.

In this work we present an integral dynamic model, the Fuerteventura sustainability model (FSM), tested and calibrated for 1996–2011 period. The FSM allows to understand the main components of this socio-ecological system and their changes along time, as well as the interaction between the included sustainability indicators and other factors within the system. Results have shown the existence of potential trade-offs not only between socioeconomic development and conservation options, but also between sustainability goals under different management options. The conservation of the Houbara habitat might require the elimination of traditional agro-systems restoration plans, although these agro-systems offer important environmental functions. Besides, a reduction of cattle herd in order to control the degradation of high quality vegetation might negatively affect the endangered population of scavengers on the island. The water–energy binomial offers another trade-off regarding sustainable development, due to the strong dependency of the water availability on energy consumption. In this sense, the FSM has shown to be a useful tool to improve the comprehensive diagnosis of the system and to identify trade-offs between sustainability indicators to orientate management policies for this insular socio-ecological system.

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1. Introduction

The analysis of a socio-ecological system (SES[1]) should be tackled from a holistic, systemic perspective that enables an integrated assessment of socioeconomic and ecological factors and the linear and nonlinear interactions and feedbacks, which characterize complex socio-ecological systems (Lacitignola et al., 2007; Halliday and Glaser, 2011).

The application of this systemic perspective for sustainability assessment on insular socio-ecological systems has an increasing interest (Patterson et al., 2004; Aretano et al., 2013), due to its large potential as observatories of sustainability, where the narrow interaction between ecological aspects and socioeconomic processes is explicitly acknowledged. Regarding sustainability analysis and modelling, two advantages have been identified in the case of insular systems (Jørgensen, 2013; Petrosillo et al., 2013): (i) an easier identification of flows, facilitating the quantification of sectors and variables and (ii) insular systems allow to visualize the existence of physical limits and carrying capacity and to set sustainability thresholds.

Indicators are an essential component of sustainability assessment. Despite of this potential, sustainable indicators have had a moderate influence on the adoption and assessment of sustainable policies and practices (Hukkinen, 2003; Levrel et al., 2009; Kajikawa et al., 2011). Among other reasons, the use of static catalogues

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[1] SES: socio-ecological systems.

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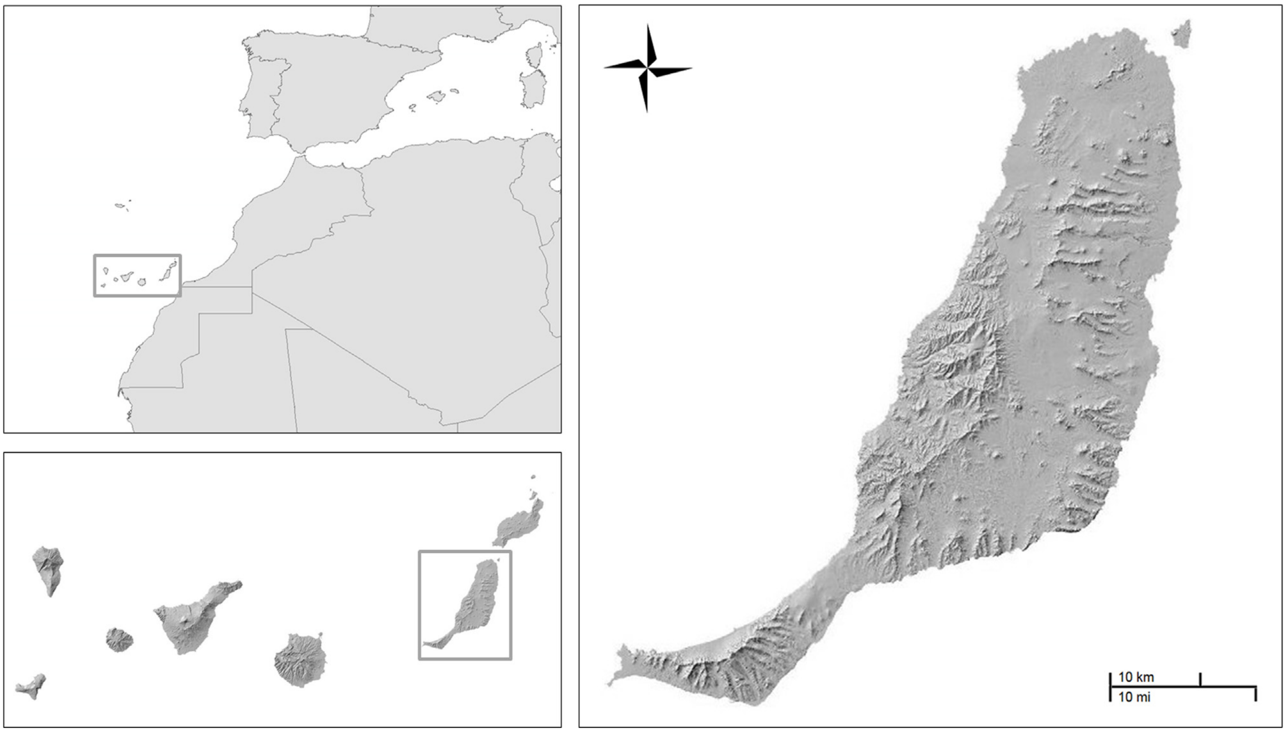

Fig. 1. Study area: Fuerteventura (Canary Islands, Spain).

of indicators, which do not consider the dynamic interrelations between the relevant processes, represents one of the most important limitations in their application.

In order to overcome some of these limitations, this work suggests the use of system dynamics modelling tools, since they provide a framework for the development of sustainability models, thanks to their capacity to conceptualize the complex interrelations of these SES (Bérard, 2010; Blanco, 2013; Wei et al., 2013). Moreover, the proposed methodological approach integrates the sustainable indicators into the system dynamic models (SDMs[2]) to visualize their change along time and to assess how any variation on one indicator may lead to a series of responses on other indicators (Lacitignola et al., 2007; Jin et al., 2009; Liu et al., 2014). Besides, SDMs represent useful learning tools that enhance system understanding and facilitate involvement of non-technical stakeholders in the decision making processes (Costanza and Ruth, 1998; Kelly et al., 2013).

In this work we present a dynamic model to contribute to a more balanced and multifunctional development of one insular SES: the Fuerteventura sustainability model (FSM[3]). Fuerteventura (The Canary Islands, Spain) represents one of the most arid environments in Europe, with a very low productivity and a particular fauna and flora with numerous endemic species, threatened by the recent tourist activities. This hyperarid and insular socio-ecological system represents a challenging case of study in order to compatibilize the tourist development with a sustainable management of its natural resources.

The specific aims of this work are: (i) to develop an integral dynamic model of Fuerteventura island, which collects the factors and key processes of the socio-ecological system; (ii) to include the most relevant sustainability indicators in the FSM and (iii) to analyze the main changes and interactions between those factors and indicators.

[2] SDMs: system dynamic models.
[3] FSM: Fuerteventura sustainability model.

1.1. Study case

Fuerteventura, situated in the Canary Islands, Spain (between 28°45′04″ and 28°02′16″ north latitude, and between 13°49′12″ and 14°30′24″ west longitude), has an area of 1655 km^2 (Fig. 1). It has a desertic hyperarid infra-thermomediterranean climate (Torres Cabrera, 1995), with an average annual rainfall of 120 mm.

The vegetation is dominated by xerophytic scrubs and annual grasslands frequently degraded due to goats overgrazing (Rodríguez-Rodríguez et al., 2005; Schuster et al., 2012). Nevertheless, the insular character favours a wide variety of endemic plant and animal species, with around a 5% of endemism (Arechavaleta et al., 2010; Scholz and Palacios, 2013).

The island is characterized by cultural landscapes marked by the aridity and the traditional management of water and land. In the last decades, the traditional productive activities (ranching, artisanal fishing and non irrigated land farming in *gavias*) have been mainly substituted by tourist and related activities. Therefore, tourism represents the main driving force of the socioeconomic and environmental changes in the island in the last years (Fernández-Palacios and Whittaker, 2008; Santana-Jiménez and Hernández, 2011), leading to the emergence of new socio-ecologic requirements, which should be addressed.

Fuerteventura was declared as Biosphere Reserve by UNESCO in 2009. The Action Plan of the Fuerteventura Biosphere Reserve (AP[4]) represents a guide to achieve a series of sustainability goals (AP, 2013) and constitutes one of the bases for this work.

2. Methodological approach

System dynamics models allow to understand the structure and behaviour of complex systems, by means of the causal relationships, feedback loops, delays and other processes of the system (Kampmann and Oliva, 2008; Li et al., 2012; Martínez-Moyano and

[4] AP: Action Plan of the Fuerteventura Biosphere Reserve.

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