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Environmental impacts on the Galapagos Islands: Identification of interactions, perceptions and steps ahead

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ABSTRACT

In the Galapagos Islands human activities such as fisheries and tourism, have boosted the islands' economy at the cost of ecological losses and constant pressures to the fragile insular ecosystems. Hence the evaluation of environmental impacts is essential and requires multiple indicators, appropriate for measuring the state and the interactions of the interrelated social and environmental variables and its relation to ecosystem services. The present research proposes a participatory approach to understand the perception of environmental impacts and its relation to ecosystem services to develop responsive impact mitigation strategies in the Galapagos Islands. The Drivers–Pressures–State–Impact–Responses (DPSIR) framework provided an analytical lens, while the Delphi method was chosen to involve selected Galapagos experts in the indicator selection process. The Delphi method consists of an iterative set of questionnaire surveys, interspersed with feedback from earlier response rounds. According to our results, 37/55 statistical consent indicators ($qi \geq 3.5$ and $Q \leq 0.5$) and 7/28 relevant interactions of environmental impacts (mean ≥ 0.5 and CV ≤ 0.5) explain a cascade of socio-ecological interconnectivity that generates environmental impacts on the Galapagos Islands. Hence, first the socio-economic-cultural and institutional forces (drivers) that include: the increase of tourism and migration, economic growth, continental lifestyles, lack of education and weak management of institutions. These drivers place stress on the environment (pressures). The pressures include: the importation of goods, land clearing for agriculture/abandonment and urban zone extension. Subsequently, these pressures generate changes in the environmental functions (impacts). The identification of impacts and their interactions indicate a close relationship between eight impacts in Galapagos: introduction of species, biodiversity loss, land use change, loss of biological resources, habitat fragmentation, landscape alterations, water basin overexploitation and decrease of water quality. Lastly, scientifically sound solutions and alternatives to deal with the Galapagos' social, economical, political, managerial and technical problems are also provided (responses). This study is an applicable useful systemic reference for Galapagos' decision makers to deliver policies in order to move towards proper conservation management.

1. Introduction

Since Charles Darwin visited the Galapagos Islands in 1835, this oceanic Pacific Ecuadorian archipelago has been at the focus of interest of many natural science and evolutionary researchers. However, rapid social development and the impacts of globalization have triggered complex social-ecological change (Gonzalez et al., 2008) that affect the island's ecosystem services (ES). ES are defined as "benefits that humans recognize as obtained from ecosystems that support, directly or indirectly, their survival and quality of life" (Harrington et al., 2010). Hence, Galapagos' human well-being depends on ES direct consumptive use values (i.e. fisheries) and non-consumptive values (i.e. tourism) (Goulder and Kennedy, 1997, 2011; Seddon et al., 2011).

Today more than 25,000 people inhabit four of the 19 largest islands Isabela (4670 km^2), Santa Cruz (986 km^2), San Cristobal (557 km^2) and Floreana (173 km^2) (INEC, 2010). Direct consumptive uses of land, removal of building materials such as sand, rock, and timber for use in housing and road construction are common; but, at the same time, generate related population demands for waste management, sewage disposal, water, electricity and goods to be transported to the island (Gonzalez et al., 2008; Kerr et al., 2004). These transported goods carry the risk of introduction of

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invasive species, today recognized as the largest single threat to Galapagos biodiversity in the short term (Gonzalez et al., 2008; Guézou et al., 2010).

As mentioned by Goulder and Kennedy (1997, 2011) the other direct consumptive use value corresponds to Galapagos' marine ecosystem. Since 1990 there has been a significant fishery for economically important trade species. The illegal fishing activities, mostly for shark fins (Reyes and Murillo, 2008), overexploitation of sea cucumbers especially *Isostichopus fuscus* (Hearn et al., 2005; Toral-Granda, 2008) and lobsters *Scyllarides astori*, *Panulirus penicillatus* and *Panulirus gracilis* (Hearn, 2006, 2008) are recognized as the major threats for these local marine resources and wildlife (Baine, 2007; Baine et al., 2007; Toral-Granda, 2008).

Against these direct consumptive use values is the non-consumptive value of tourism. In Galapagos there are 66 terrestrial visiting points distributed over 15 islands and 74 marine visiting sites distributed around 19 islands where certain activities such as scuba diving, snorkelling, kayak and panga rides are allowed (GNP, 2013). With more than 180,000 people visiting Galapagos (GNP, 2012), tourism is a cultural ecosystem service that can easily be captured in economic terms due to its iconic aesthetic measurable value (Satz et al., 2013). The revenues received from tourism generate more than 65% of Galapagos GDP with 85 million USD/year (Epler, 2007). Hence, tourism is the sector that provides the most employment (33%), followed by trade (21.5%), the public sector (11.6%), domestic jobs (8.7%), agriculture (5.9%) and construction (5.7%) (CGREG, 2010). Paradoxically, this process often poses a direct threat to the nature values that lie at the basis of tourism and economic prosperity itself (Samways et al., 2008) and makes Galapagos' economy crucially dependent on successful conservation strategies. The loss of wildlife would cause the loss of tourism and hence the rapid decline of the economy and vice versa. Ideally tourism brings money and could be invested in conservation efforts. In reality most revenues flow to tour operators, most of them non-Ecuadorian, and to other off-island entities; consequently, conflicts over resources (in particular of sea cucumber fisheries), the indirect use values of tourism by locals; and biodiversity conservation have arisen (Goulder and Kennedy, 2011).

Retrieving basic information on the dynamics of the interconnections between the social and ecological systems and the relationship of ecosystem services to human well-being is of sum importance (Carpenter et al., 2009). Sustainability is a concept that offers a solution to these problems by providing decision makers with strategies to guide their decisions so as to allow to present and future generations to meet their needs within the limits of the earth's carrying capacity (Rockstrom et al., 2009; Waas et al., 2011). However, in order to translate sustainability from a concept to a tangible strategy, indicators are key tools. Generically indicators could be defined as 'sign or signals that relay a complex message, from potentially numerous sources, in a simple and useful manner' (Kurtz et al., 2001) and are designed to communicate a property or trend of a system to decision makers (Bell and Morse, 2008; Hak et al., 2007; Miller, 2001). Hence when extended, sustainability indicators would be described as a set of indicators that measure characteristics or processes of the socio-ecological systems to ensure its continuity and functionality far into the future.

In the present research, the Drivers–Pressures–State–Impact–Responses (DPSIR) framework was used to structure our analysis and develop sustainability indicators. DPSIR is an approach that allows identifying the role of humans in nature by representing a system that includes societal (human) and ecological (biophysical) subsystems in mutual interactions (Elliott, 2002; Omann et al., 2009; Rogers and Greenaway, 2005; Scheren et al., 2004). The main goal of this paper is to identify and characterize environmental impacts and their interconnections associated with human activities and the ecosystem services on the Galapagos Islands. The DPSIR framework was used as an analytical lens to provide a sequential list of sustainability indicators, while the Delphi method was used to determine which indicators are perceived as more relevant according to a selected group of participants. Delphi is an iterative questionnaire designed to elicit expert's knowledge. The study also investigated whether crucial environmental information was lacking, how impacts interact with each other, the relation with ecosystem services, how multiple stakeholders in Galapagos perceive these impacts and what solutions they have to offer to further guide and facilitate a sustainable development and protection of the archipelago.

2. Materials and methods

Delphi is defined as 'a method of structuring a group communication process so that the process is effective in allowing a group of individuals as a whole to deal with a complex problems' (Hugé et al., 2010). It has been frequently used in many research areas ranging from medicine (Hwang et al., 2006; Thangaratinam and Redman, 2005) to environmental, scientific and policy evaluations and scenarios (Kuo et al., 2005; Miller, 2001; Nowack et al., 2011; Swor and Canter, 2011; Turoff and Linstone, 2002; Wright, 2006) and conservation management (Eycott et al., 2011; James et al., 2009; Mehnen et al., 2012).

The method is a structured and iterative survey of 'experts' or participants intended to generate unbiased opinions and transforming such opinions into one or more collective notion(s) through a feedback process. After completing the surveys each participant is given a communal feedback on the group responses. With this information in hand, the participants complete the survey form again. Then (s)he can change or not his opinion based on the information provided by the other participants. The process can be repeated several times in several rounds until consensus increases or is reached.

The reasons to use Delphi in this research were numerous but three were considered key: (1) *Rigorous for expert and stakeholder queries* (Dalal et al., 2011; Okoli and Pawlowski, 2004), (2) *flexible design* (Elmer et al., 2010); and (3) *anonymous survey* (Landeta and Barrutia, 2011). In the present study, the Delphi method was used in an online environment. The web-based survey tool used for this particular study was OSuCre online survey creator (see http://www.osucre.be/). The online-based Delphi was used to overcome limitations in the Delphi process using paper-based surveys and space limitations as observed on other Delphi studies (Cam et al., 2002; Steyaert and Lisoir, 2005).

2.1. Selection and identification of Delphi participants

Delphi is an expert elicitation method that has been used since the 1950s. An expert is a person who is particularly competent as authority on a certain matter of facts (Flick, 2009). However, defining what or who is an expert and the interrelated expertise and knowledge is challenging (Burgman et al., 2011; Failing et al., 2007). For instance, in the case of interactions with stakeholders that are designed to foster the acceptance of proposed actions, expertise should include the ability of an effective communication (Burgman et al., 2011). However, the separation of experts and stakeholders might be unrealistic and counter-productive as it can prevent the social capital resulting from co-generation of knowledge in a stakeholder group (Krueger et al., 2012). Moreover, knowledge is contextual and it depends on the interests it serves, the purpose for which it is harnessed, or the manner in which it is generated (Burgman et al., 2011). Thus, the selection of the participants in Delphi is critical and must be performed rigorously so that the group composition reflects the diversity of valuable knowledge (Okoli and