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Identifying management options for modified vegetation: Application of the novel ecosystems framework to a case study in the Galapagos Islands

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ABSTRACT

In highly modified, or 'novel', ecosystems it is often difficult to decide where limited conservation funds should be spent to reach management goals. We tested a recently-developed decision framework for novel ecosystems to help identify management options for modified native vegetation in the humid highlands of the Galapagos Islands. First, we conducted a data-based ecosystem assessment that compared contemporary vegetation to historical vegetation. This assessment characterised the biotic novelty of contemporary vegetation and resulted in a map of novelty over the landscape. Second, we considered processes affecting ecosystem change and barriers preventing the return to historical vegetation using state-and-transition models that incorporated the spatial extent of the contemporary vegetation states. Finally, we discussed options informed by our results that would address the management goals for our case study. Some of these options involve trade-offs between the goals of conserving biodiversity and maintaining ecosystem services, while other options address both goals in a win–win scenario. The novel ecosystems decision framework was a useful tool for identifying management options because it framed results that enabled a quantitative comparison of the degree of novelty of ecosystems across the landscape and also defined barriers to restoration. Tools that accounted for the spatial extent of the novel ecosystems complemented the framework, particularly for application at a landscape scale. Our approach could be broadly applied to the assessment and management of modified ecosystems, especially where historical data are available to calculate measures of biotic novelty.

1. Introduction

Human domination of the planet has resulted in highly modified ecosystems around the world (Vitousek et al., 1997; Ellis et al., 2010). There is global recognition that societies need to implement ecosystem restoration activities to curtail the loss of biodiversity and ecosystem services (Aronson and Alexander, 2013). However, any restoration project is presented with a myriad of constraints that can make conservation outcomes difficult to achieve. One major constraint is the finite resources for doing restoration. How should limited resources be used to achieve the best possible outcomes for biodiversity conservation and for people? To make effective decisions a way of conceptualising management options for human-modified landscapes is required.

There are many conceptual frameworks that could be applied to decision-making for management of modified landscapes. These include state-and-transition models (Briske et al., 2005), decision analysis (e.g. Cipollini et al., 2005), triage as in human health care (Hobbs and Kristjanson, 2003) and modelling based on end points and effort (Hyman and Leibowitz, 2000). There are also systematic approaches to conservation planning, including prioritizing restoration efforts (Wilson et al., 2011) that could be applied to modified landscapes. One framework that focuses specifically on modified landscapes is the *novel ecosystems* framework (Hobbs et al., 2009), which aims to "develop a management framework to address rapidly changing ecosystems in a way that benefits the well-being of both humans and other species" (Hobbs et al., 2013). Here, we aimed to test this new framework for its practical application using a case study in the Galapagos Islands. Specifically, we applied a novel ecosystems decision tool (Hulvey et al., 2013) to the management of the humid highlands within the National Park on Santa Cruz Island.

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Like many other parts of the world, the humid highlands of the inhabited islands of Galapagos have been modified by human activity (Watson et al., 2009). Clearing for agriculture and invasions by introduced plants have transformed some of the historic ecosystems into novel ecosystems such as communities of elephant grass (*Pennisetum purpureum*), quinine trees (*Cinchona pubescens*) and blackberry (*Rubus niveus*). These transformations have resulted in reductions in the abundance of native species (Wilkinson, 2002; Jäger et al., 2009; Rentería et al., 2012a) and altered seed dispersal and pollination (Heleno et al., 2013; Traveset et al., 2013). As a National Park with World Heritage status, the biodiversity values of this landscape are important both nationally and globally. However, the native ecosystems appear to be on a downwards trajectory – plant invasions are worsening as current problem species expand their ranges (e.g. Rentería et al., 2012b). Thus, a robust framework that takes account of ongoing degradation and barriers to restoration is needed to help identify management options for these modified, dynamic ecosystems. We test the ability of the novel ecosystems framework to meet this goal for this landscape and for modified landscapes more generally.

2. Methods

2.1. Theoretical foundation

The novel ecosystems conceptual framework is based on the idea that some human-modified ecosystems fall outside their historical range of variability in terms of their biotic and abiotic components (Hobbs et al., 2009). Ecosystems can be classified into one of three categories: historical – within historical range of variability, hybrid – dissimilar to historical ecosystem but with the potential for restoration, and novel – more dissimilar to historical and restoration prevented by the presence of potentially irreversible thresholds (Hobbs et al., 2009; Hallett et al., 2013). This classification requires an ecosystem assessment and consideration of ecological and social barriers to recovery, which then allows the identification of restoration options according to management goals (Fig. 1; Hulvey et al., 2013). Thus, the novel ecosystems framework can assist management decisions about potential interventions to achieve restoration goals.

The ecosystem assessment requires a comparison of contemporary, potentially novel, ecosystems with a historical reference (Hulvey et al., 2013). The historical reference can be characterised by survey of either unmodified vegetation at the same time but in a different place, or in the same place at an earlier time (Harris et al., 2013). We used the latter to characterise the historical references because historical data were available and because human modification to vegetation in our study site extends well beyond the known range of the historical vegetation types (Watson et al., 2009).

Another essential part of the framework is the identification of ecological and social barriers that prevent ecosystem restoration (Hulvey et al., 2013). The idea of ecological barriers is usually understood in terms of non-reversible thresholds that prevent an ecosystem from persisting within its historical range of variability (Suding and Hobbs, 2009). Thresholds can be caused by a global change, such as climate, a local change such as salinity or soil nutrients, a biological change such as the local extinction of a keystone species (Hallett et al., 2013), plant invasions (Richardson and Gaertner, 2013), or combinations of these. Social factors (such as limited budgets, conflicting values or knowledge gaps) can present significant barriers to ecosystem restoration too and therefore are just as important to ecosystem management as ecological barriers (Hulvey et al., 2013).

In Galapagos there are a number of factors associated with plant invasions that may be considered barriers to restoration (Gardener et al., 2013). However, the reversibility of barriers associated with plant invasions is difficult to determine (Richardson and Gaertner, 2013). Regardless of putative ecological barriers, in Galapagos social barriers, and particularly limited budgets, inhibit the possibility of eradication of widespread invasive species (see further discussion in Section 4.1). Thus for vegetation states dominated by one or more introduced species, we considered transformation to their respective historical vegetation states to be prevented by (currently) irreversible barriers, as discussed in Section 4.1.

2.2. Methodological outline

We followed the decision process (Fig. 1) for our case study in the Galapagos Islands, focusing on the biotic ecosystem components. The first step was to conduct an ecosystem assessment to characterise the contemporary vegetation of the study area (Fig. 1 part A), which we have done using data in Section 3. We compared the species composition and structure of the contemporary vegetation states (CVSs) with that of their historical vegetation types (HVTs). We evaluated the biotic novelty of the CVSs using the metrics detailed in Section 2.4.2. To assist management decisions we extrapolated one of these metrics to map the degree

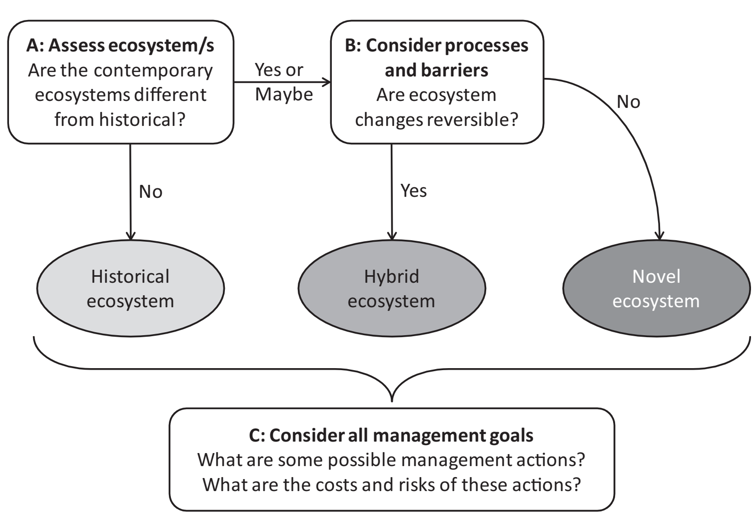

Fig. 1. Steps to identify management options under the novel ecosystems framework. Modified from Hobbs et al. (2013).