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Optimizing restoration of the degraded highlands of Galapagos: a conceptual framework

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Introduction

The highlands of the inhabited islands contain the most degraded ecosystems in Galapagos, with between 23 (Isabela) and 96% (San Cristóbal) altered by invasive species and agriculture (Table 1). On some islands this has resulted in the almost complete loss of unique communities; the highland *Scalesia* forests now cover less than 1% of their original range on Santa Cruz and 0.1% on Sierra Negra Volcano (Isabela) (see Mauchamp and Atkinson, this volume).

Table 1. Percentage of vegetation zones degraded by land clearing or invasive species in each of the four inhabited islands (adapted from Watson *et al.*, 2010); Very Humid and Humid categories have been grouped together under Humid.

Island	Vegetation Zone		
	Humid	Transition	Arid
San Cristóbal	96	23	2
Santa Cruz	86	25	0.4
Floreana	38	2	0.5
Southern Isabela	23	4	0.2

To date the goal of conservation action in these degraded areas has been to restore systems to a near pristine condition (Bensted Smith *et al.*, 2002). Despite numerous attempts and much investment, this approach has consistently failed to deliver widespread and long-term results. This failure is due to a lack of understanding of the holistic nature of degradation as well as a lack of shared vision among highland users. Unfortunately there is no magic wand for

restoration; changes in abiotic and biotic factors that occur as systems degrade may be difficult or impossible to reverse sufficiently so that systems can return to their pristine state (Hobbs *et al.*, 2009). It is increasingly understood among scientists that the maintenance or restoration of ecosystem function, which includes the plethora of interactions between biological and physical elements including the human element (often termed ecosystem services), should be the ultimate goal of conservation management (Hobbs and Norton, 1996). We suggest that this should also be the focus in Galapagos. However, systems can lose rarer components of their biodiversity and therefore resilience before function begins to be affected (Schwartz *et al.*, 2000), so the goal is considerably lower than maintaining all original biodiversity.

A goal based on functionality allows us to consider that some introduced species may play a neutral or even valued role in natural communities. This important paradigm shift (that introduced species are not always bad) opens the door to potential management solutions that maintain resilient systems composed of mixtures of native and exotic elements that would never have occurred naturally, rather than trying to return systems to their unaltered state. These novel or hybrid ecosystems (Hobbs *et al.*, 2006) may be more stable and resilient to new invasions than pristine systems, require lower inputs of resources enabling improved cost effectiveness of current management practices (Seastadt *et al.*, 2008), and thus a much needed extension of areas under active management.

The objective of this paper is to review current management for restoration in the highlands and propose ways in which the paradigm shift could help refine and optimize this action. However, there is very little understanding of the ecological processes in the highlands so that much of the basic information necessary to embrace the concept of novel ecosystems and help improve management is missing. We outline a conceptual framework for the degradation process in the inhabited highlands and use this to identify knowledge gaps and key studies that need to be carried out. Furthermore, it is hoped that this conceptual framework can be used as a first step to develop a shared and realistic vision among highland users.

Current management action to restore the Galapagos highlands

Highland restoration in Galapagos to date has focused on the eradication of single species already

having a significant ecological impact (e.g., vertebrates - Cruz *et al.*, 2005; Carrion *et al.*, 2007) or predicted to have future impact (e.g., plants - Buddenhagen, 2006). It has also addressed the control of widespread invasives in key areas (e.g., Buddenhagen *et al.*, 2004) and small-scale management of iconic endemic species, especially on private farmland (e.g., *Scalesia pedunculata*) (Table 2). While some of these projects have led to the successful natural regeneration of communities, especially on uninhabited and relatively pristine islands, results on the more degraded islands have been varied, with replacement of one invasive by another (e.g., Atkinson *et al.*, 2008), or simply with no positive long-term impact. This is often due to the small-scale and sporadic nature of the work, resulting from the high level of resources needed to carry out invasive species control. For example, projects such as the 200 ha Jatun Satcha on San Cristóbal, the use of *Scalesia pedunculata* as a cover crop for coffee in Santa Cruz, or weed control in critical areas of the National Park are only possible on a small scale because of the need for a continuous input of expensive labor to control key invasive weed species that transform the highlands into states that did not previously exist (including *Cedrela odorata*, *Cinchona pubescens*, *Lantana camara*, *Psidium guayaba*, *Rubus niveus*, *Syzygium jambos*, and several African grass species). These species have life history characteristics that readily out-compete indigenous Galapagos vegetation. Costs to remove invasive species from farmland range between US\$500 and US\$2500 per ha, with maintenance costs of about US\$500 to US\$1000 per ha per year depending on the land use (Scott Henderson and Jamie Recourse, pers. comms).

There are few agricultural activities that bring a high enough return to justify such an expense; potential examples include agro-tourism combined with high-value products such as coffee and bananas, or greenhouse-produced vegetable crops. This problem has led to the abandonment of about 60% of the agricultural land in Santa Cruz, land which now acts as a seed source of invasive species for the surrounding managed farms and the Galapagos National Park. A similar story is occurring in the National Park where almost all of the annual budget for weed control (estimated at US\$630,000 for 2007) was spent on the control of the most invasive species in an area of less than 200 ha (Figure 1). To put this in context, it is estimated that the introduced invasive *Psidium guayaba* covers at least 90,000 ha of National Park land. Very little of

Table 2. Examples of current management practices and how our proposed paradigm shift may result in a more optimized restoration.

Current management	Examples	Result	New direction
Priority area management: iconic or single species invasive focus	Los Gemelos (<i>Scalesia pedunculata</i> and <i>Rubus niveus</i>); Media Luna (<i>Miconia</i> and <i>Cinchona pubescens</i>)	Single species benefits; ecosystem function often degraded; long-term high cost to maintain	Use maintenance of whole ecosystem function and biodiversity maintenance as aims; management uses less energy and can target larger areas
Small scale eradication	Pilot plant eradication; fire ant control	Dependent on available methodology, prevention of reinvasion, and community involvement	Species need to be chosen based on potential impact; regular evaluation needed; needs community awareness and clear lines of authority
Whole island eradication: single invasive focus	Goat, pig, and donkey eradication: Project Isabela	Successful on uninhabited islands; some unexpected and negative ecosystem impacts	Whole ecosystem response needs to be considered to ensure resources available for emerging problems
Farmland restoration	Jatun Sacha; <i>Scalesia</i> on farms	Long-term high input required; necessary in seriously threatened habitats	Redefining objective to maintain functioning rather than native-only ecosystems will lower costs and increase size of area under management; need for spatial planning and community involvement
Education	Gardening program	Raises community awareness about Galapagos flora and threat of introduced species	Increase basic environmental awareness including understanding of precautionary principle; better quarantine; shared long-term vision

the weed control budget is spent on active restoration or early detection and eradication to solve emerging problems. However, whilst plant eradication seems an attractive goal, in theory a one-off injection of funds and the problem is solved, evidence shows that it is extremely difficult (Gardener et al., 2010).

A more mechanistic-based approach

A principle barrier in successful restoration both in Galapagos and the world at large has been the lack of

a mechanistic-based approach to understanding the degradation process. A better understanding of this process is the first step in the development of more efficient management practices. We can begin to define the fundamental elements of the degradation process by its representation as a state and transition model. A state is a definable type of community (e.g., pure *Scalesia* forest, mixed introduced and native forest, or introduced pasture), and a transition is the process by which the system moves from one state to another (e.g., land clearing or invasion of transformer species). Representation of the highlands in this way

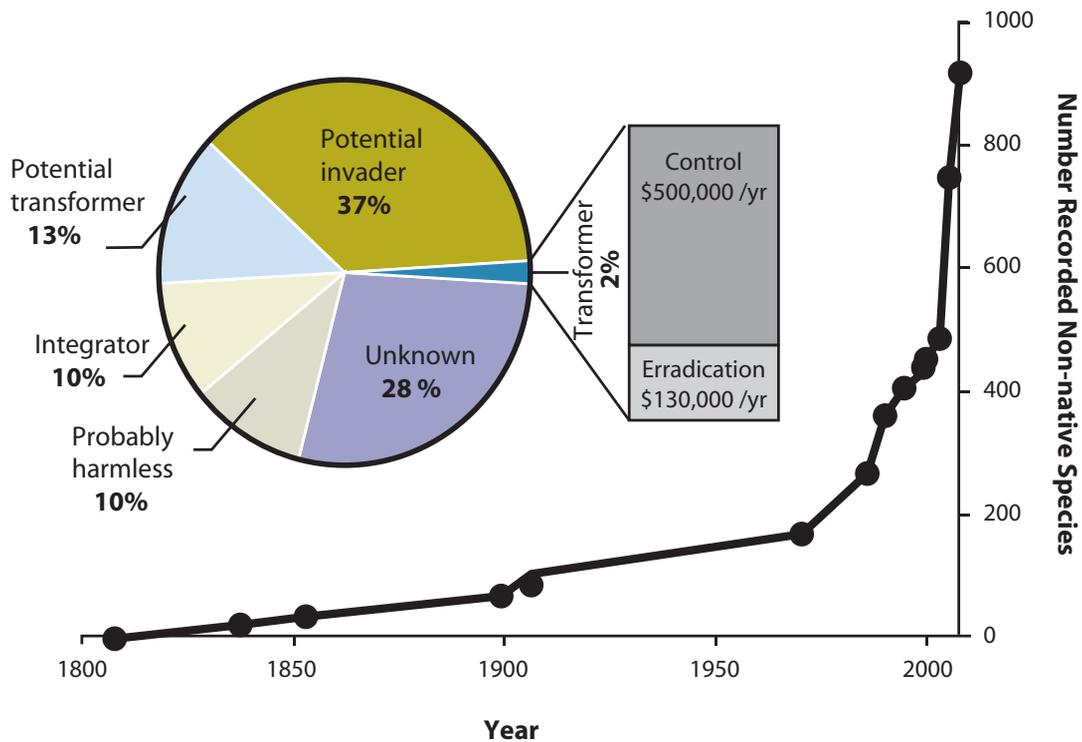


Figure 1. Numbers of non-native plant species recorded in Galapagos over the period 1800-2008. Inset: Categorization of the 919 non-native species in 2008 based on the Galapagos Weed Risk Assessment database. National Park allocation of resources for non-native plant species was US\$630,000 in 2007, with all of the expenditures targeting species defined as transformers (Galapagos National Park work plan 2007).

allows for the identification of desired goals in restoration, which, as discussed above, may include hybrid or novel systems (Hobbs *et al.*, 2006). It is study and understanding of the processes that drive transitions rather than of the states themselves that will allow for successful restoration management to be developed (Hulme, 2006).

We present a state and transition model that was developed using local and international knowledge at a workshop held in Santa Cruz in November 2008 (Figure 2). It builds upon that of Wilkinson *et al.* (2005), which specifically considered *Scalesia* forest and introduced pasture, to encompass the whole of the humid highlands. The workshop revealed significant information gaps that need to be filled in order to allow for a better understanding of the degradation process in the highlands. The information gaps were divided into three key themes. The first addresses spatial distribution, function, and value of different vegetation states (i.e., characterizing the states), the second determines the ecological and social processes driving degradation (i.e., characterizing the transitions), and the third theme helps to develop a novel tool box to aid restoration to functioning states. A total of thirteen research projects were proposed within the themes, each the size of a PhD study, to fill the necessary knowledge and research gaps.

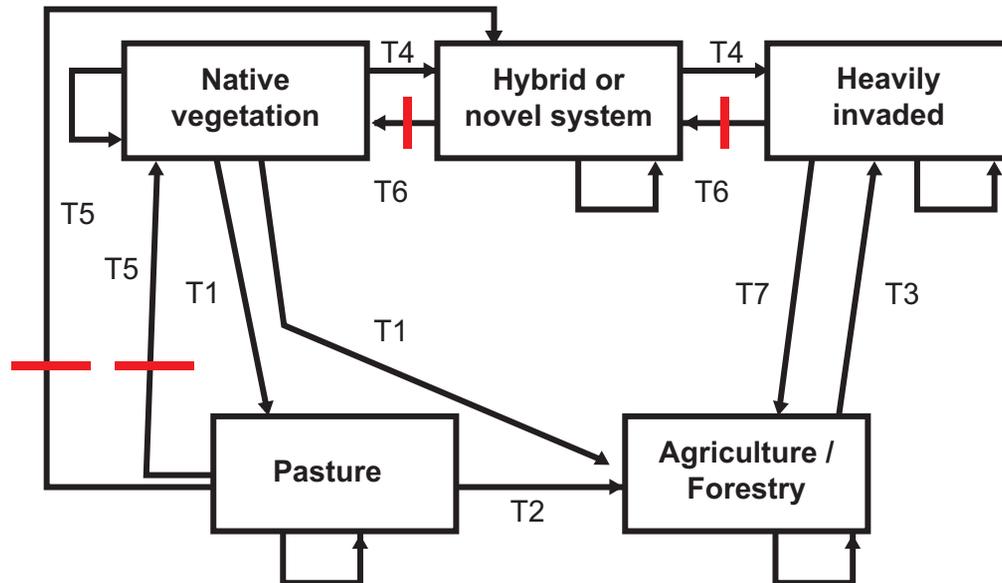
The three key themes identified in the workshop are detailed below.

a) Spatial distribution, function and value of different vegetation states

There has been no fine-scale mapping to determine what vegetation states are present in the highlands of Galapagos. At present it is assumed that states composed of introduced species have no inherent value. A crucial first step is to study their ecological function in order to determine the social, economic, and conservation value of each state. This is necessary in order to be able to identify which states can be considered as useful end points for restoration. This information can then be combined with mapping to develop a spatially explicit network of priority sites for conservation management and human livelihoods.

b) Ecological and social drivers of degradation

While we know the key invasive species in Galapagos, there has been little quantitative study on the impact they have on systems and how that impact drives degradation. An elegant exception is the work of Jäger *et al.* (2007; 2009) on the impact of the tree *Cinchona pubescens* on the treeless pampas in the highlands of Santa Cruz. Surprisingly they



T1: Clearing; **T2:** Intensive cultivation; **T3:** Abandonment; **T4:** invasion; **T5:** Removal of invasives + planting natives; **T6:** Removal of invasives; **T7:** Cultivation of crops, etc

Figure 2. A suggested state-transition model for the highlands of inhabited islands in Galapagos. Boxes represent main states and arrows represent transition or drivers between states. Red bars indicate possible biological or physical barriers preventing transitions to less degraded states.

showed that although an increase in tree density reduced abundance of native and endemic species, no extinctions occurred. Impacts of invasive species can include changes in abiotic or physical conditions (e.g., light, water, or nutrients) and changes in biotic components (e.g., vegetation structure, species composition, changes in pollination, and seed dispersal webs). In addition, changes in human land use that may be influenced by external economic pressures can also impact heavily on degradation processes. This information helps to identify barriers or thresholds to restoration and thus has important implications for successful management (Hobbs *et al.*, 2009).

c) A novel tool box to help in restoration

Currently tools used in restoration have focused on the eradication or long-term control of individual key species. The only example of an attempt to combine this with restoration has been the planting of young *Scalesia pedunculata* in areas freshly cleared of weeds. To date there is no evidence that this helps in developing resilience of the natural community to further invasion due to a lack of understanding of seedbank dynamics and the physical properties of vegetation required to control reinvasion of key weed species. Research is also required to develop new techniques to control some of the worst and most widespread

weeds using an integrated approach. Techniques include biological control, changes in land use, and use of herbivores, but it is also important to increase the effectiveness of current management techniques. In addition, it is essential to develop an understanding of the economic, policy, and social pressures that lead to current land use trends and identify strategies that allow for the incorporation of restoration into these processes.

The highland areas are inhabited; they are the focus of agriculture and are also used for leisure and tourism activities. Thus, social and economic aspirations of the community who live in and use the highlands are integral components in shaping the restoration vision, and must also be considered in all stages as important components in the state transition model.

Optimizing future restoration activities

The biodiversity vision for “Galapagos 2050” clearly points to the need for restoration of the highlands of the four inhabited islands (Bensted Smith *et al.*, 2002). However, the need for a paradigm shift is obvious if we wish to optimize the use of limited resources for both research and management to maintain bigger natural areas that retain ecological function into the future. Hence, we propose a shift in highland restoration that



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aims at managing much larger areas and requires fewer resources, with the endpoint being a functional and resilient system. However, at present there are significant knowledge gaps that prevent us proceeding effectively with this task. The projects discussed in this document form part of a new strategic plan for the restoration of the highlands and collaboration is actively sought in order to help us understand the degradation process.

If this scientifically led process is to produce better management options based on ecosystem function, which incorporate community aspirations and maximize biodiversity with low-cost solutions over larger areas, we need to use an adaptive management approach. This will require much tighter linking between scientists, managers, and the community in order to be able to respond quickly and effectively to results from the field, continually refining management action as a team in order to develop optimal solutions in a constantly changing world.

Acknowledgements

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