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Prioritising Invasive Species Control Actions: Evaluating Effectiveness, Costs, Willingness to Pay and Social Acceptance

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ABSTRACT

Island ecosystems are recognised as high priority for biodiversity conservation, with invasive species a significant threat. To investigate prioritisation invasive species control, we conducted cost-effectiveness analysis of donkey control on Bonaire, Caribbean Netherlands. Successful prioritisation must take account of ecological, economic and social aspects of conservation. Further improvements are possible where impacts are measured across ecosystem boundaries, and management is tied to funding. We modelled the expected ecological impacts of control options, estimated costs, and connected this to the willingness of beneficiaries to fund such projects. Finally we surveyed experts to understand the social acceptability of donkey control. Of the control options, eradication is predicted to have the highest ecological impacts across two ecosystems, and to be cost-effective over the long term. Costs of all control options were within user willingness to pay. Social acceptability was highest for fencing, and lowest for lethal control. Though eradication offers the highest ecological benefits, we suggest that lower initial costs and higher social acceptability make fencing the better choice for Bonaire in the immediate future. In this way we illustrate the importance of considering economic and social impacts alongside the ecological in environmental conservation, and present an integrated application for prioritising conservation choices.

1. Introduction

Invasive species present a significant threat to ecosystems worldwide. This is particularly the case on islands, where species have been isolated from competition or predation pressure, and thus are less able to withstand invasions when they occur (Dawson et al., 2015; Martins et al., 2006). Understanding the impacts of invasive species and the tools available for their control is important for prioritising environmental conservation actions. While evaluations of the cost-effectiveness and social acceptability of alternative control options are becoming more widespread, studies drawing these together with potential funding mechanisms remain scarce. Given the large impacts of invasive species on islands, further gains in environmental conservation may also be observed where such prioritisation is able to consider impacts across ecosystem boundaries (e.g. terrestrial to marine).

Prioritising actions to tackle ecological degradation caused by introduced species requires prediction of environmental states with and without action, to identify the additionality of proposed initiatives (Maron et al., 2013), though such estimates are often hampered by the long time scales involved with recovery (Shwiff et al., 2013). The highly specific spatial and temporal variation associated with costs and benefits of environmental conservation (Armsworth, 2014; Balmford et al., 2003; Cullen, 2013) also limits the spatial transfer of studies. Additionally economic costs are high, and vary between actions, while environmental management remains chronically underfunded (Armsworth, 2014; Boyd et al., 2015; Bruner et al., 2004). Prioritisation of environmental conservation has drawn upon risk analysis (Harwood, 2000), decision analysis (Maguire, 2004), adaptive management (McCarthy and Possingham, 2007) and return on investment analysis (Boyd et al., 2015), among others, to incorporate the multiple uncertainties, objectives and stakeholders involved in prioritising conservation actions. However the high data needs of such methods presents a barrier to many projects. As such we present here an initial step towards prioritisation of conservation actions, and the analysis presented in this paper may inform the basis of continued adaptive management and a more in-depth prioritisation plan.

This paper is the last in a series of papers investigating the impacts and control of invasive grazing species on the island of Bonaire, Caribbean Netherlands (12° 10′ N 68° 17′ W). Previous work has modelled the relationship between ecosystem characteristics and

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natural variation in invasive species densities, estimating a negative relationship between grazing pressure by donkeys and vegetation ground cover (Roberts, 2017). We demonstrate how these models can be utilised to estimate the impacts of alternative management strategies (in this case donkey control) on ecosystem characteristics. We draw on models developed in Roberts et al., 2017b, which estimate a positive relationship between terrestrial vegetation and coral reef health, to illustrate the impacts that invasive species control can have across ecosystem boundaries. Though estimating costs of invasive species control is fraught with difficultly (de Brooke et al., 2007; Donlan and Wilcox, 2007; Martins et al., 2006), inclusion of even broad cost estimates have been shown to be valuable to prioritising conservation actions (Boyd et al., 2015). We therefore estimate the costs of actions and relate these to predicted environmental impacts from Roberts, 2017 & Roberts et al., 2017bto assess the cost-effectiveness of each control option.

Conservation actions are limited by restricted funding (Bruner et al., 2004). Since the persistence of conservation programs is more likely where they are self-financed (Whitelaw et al., 2014), user fees have the potential to greatly improve conservation gains. As alternative conservation actions are expected to have varied environmental outcomes, user willingness to pay should vary across actions. In Roberts et al., 2017a we estimated willingness to pay of SCUBA divers for control of terrestrial invasive species, where this would be expected to improve reef health. In this paper we use those estimates to calculate willingness of SCUBA divers to pay for the coral reef improvements predicted to arise from the alternative donkey control strategies.

Finally, addressing social concerns has been recognised as of high importance for successful invasive species control (Guerrero et al., 2010; McLeod et al., 2015). Failing to account for social acceptability of actions can lead to unforeseen costs and delays, public opposition, and cancellations of management actions (Frank et al., 2015; Lodge and Shrader-Frechette, 2003; Moon et al., 2015). We therefore present an initial overview of the social acceptability of each donkey control strategy, and discuss further work needed before any action can be implemented.

2. Methods

Drawing together the four criterion needed for prioritising conservation actions (conservation effectiveness (Roberts, 2017; Roberts et al., 2017b); economic costs; willingness to pay of beneficiaries (Roberts et al., 2017a), and social acceptance), we analyse invasive species control options, and make recommendations for future management in our study site. This approach is particularly applicable to sites where data and expertise for formal risk analysis, feeding into multi-criteria analysis, are not available. The process followed in this paper is summarized in Fig. 1.

2.1. Study System

The island of Bonaire, Caribbean Netherlands, is a highly-regarded SCUBA diving destination, with an extensive marine conservation program (Steneck et al., 2015). However the island has a long history of terrestrial degradation, as invasive goats, donkeys and pigs were introduced for farming as early as the 16th Century (Westermann and Zonneveld, 1956). Today all three species have established feral populations (goats: 30,000 (Cado van der Lelij et al., 2013), donkeys: 1000 (unpublished data), pigs < 1000 (unpublished data)), while goats continue to be farmed. As a result, Bonaire's dry forest is now characterised by only a few surviving trees and by low levels of vegetation ground cover (De Freitas et al., 2005). Low vegetation cover is associated to increased sediment run-off, due to reduced root systems, which otherwise anchor soils (Álvarez-Romero et al., 2011; Maina et al., 2013; Mateos-Molina et al., 2015). Increased sediment levels adversely impact the coral reefs surrounding Bonaire. Increased suspended sediment is associated to reduced light levels, which slows coral growth rates (Pollock et al., 2014), reduces structural stability (Erftemeijer et al., 2012) and disrupts coral (Jones et al., 2015) and fish (Wenger et al., 2014; Wenger et al., 2011) development and recruitment. Nutrient levels are also increased, which promote macroalgal growth and smothers hard corals (De'Ath and Fabricius, 2010). Settling sediment can lead directly to coral mortality, as well as restricting feeding polyps, altering coral morphology (Erftemeijer et al., 2012), promoting disease (Weber et al., 2012) and disrupting fish communities (Goatley and Bellwood, 2012). Further disruption to recruitment is seen as juvenile corals struggle to establish on high sediment substrates (Jones et al., 2015). Such damage to coral reef system decreases its attractiveness to divers. Consequently, terrestrial degradation is recognised as threatening Bonaire's marine ecosystems (Slijkerman et al., 2011; Wosten, 2013), a situation which is common in coral reef systems worldwide.

2.2. Control Options

Options for mitigating the ecological damages due to over-grazing by donkeys, goats and pigs were identified through communication with local stakeholders (Bonaire Island Government; Bonaire conservation organisation, Echo; National Park Authority STINAPA). Three management strategies were considered:

1. Fencing of designated nature areas (Fig. 2);
2. Lethal control of feral donkey populations (reducing populations but not eliminating them);
3. Eradication of feral donkey populations.

Due to the high densities of goats recorded across the island it was not possible to model the impacts of goat control, as no variation in goat grazing pressure was observable. Conversely pig densities were too low across the island to enable modelling of pig impacts. For these reasons we have considered only donkey control within this study.

2.3. Quantifying Grazer Impacts on Vegetation Health

Vegetation characteristics anticipated to impact reef health were identified as tree biomass and percentage ground cover (Aguirre-Muñoz et al., 2008; Rojas-Sandoval et al., 2014). These characteristics were estimated within 101 quadrats of 100m^2, randomly located, stratified by landscape type. Due to low densities of donkeys point counts were not possible, therefore donkey densities were estimated from transect counts, with a density index calculated from the number of donkeys observed at a given location, divided by the number of visits to that location. Kernel density estimation was then used to extrapolate this data to create a density map across the island, from which estimated density at each point could be extracted. General linear models were used to estimate the relationship between donkey density and tree biomass (estimated from height and diameter, no attempt to estimate belowground biomass was made) or vegetation ground cover (data log transformed). Vegetation ground cover was estimated to be negatively impacted by dry season donkey density. Tree biomass did not show any variation with variables modelled (Appendix A).

We calculated the predicted impacts on ground cover of each grazer control strategy. To calculate ground cover for fencing estimates were first made for median and zero donkey density. Weighted means of these estimates were used to calculate ground cover for fencing from zero to 41% of island area (0 ha–1208 ha, area covered by nature areas which when fenced will have a donkey density of zero). Ground cover following donkey control and eradication was estimated from zero to maximum donkey density (max donkey density index = 18). Estimates of ground cover if no action were taken were estimated using median donkey density. Median density was used because grazer populations on Bonaire are well established, and therefore likely at equilibrium within the ecosystem. Sensitivity of models to errors associated with the