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A decision framework for management of conflicting production and biodiversity goals for a commercially valuable invasive species

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ABSTRACT

The management of introduced species that are both invasive and commercially valuable is contentious. While such species provide substantial economic benefits to some, they pose considerable costs to others due to negative impacts on ecosystems. We propose a decision framework to help balance conflicting objectives and support the management of commercially valuable invasive species. We illustrate our framework using the buffel grass (*Pennisetum ciliare* syn. *Cenchrus ciliaris* L.) invasion in Australia. In rangelands worldwide, buffel grass is amongst a suite of commercially valuable invasive species, highly valued by some graziers as a pasture species but widely unpopular among those concerned with the threat it poses for native biodiversity. The framework comprises four components. First we develop a state and transition model to represent the invasion dynamics of buffel grass and the effect of management actions. Second we construct utility functions to represent the relative values of buffel grass cover in terms of production and biodiversity utilities (indicative of grazier's and conservationist's relative 'happiness' regarding buffel grass cover). We draw on expert and empirical data for the construction of the model and utility functions. Third, we present management strategies that minimize losses in production and biodiversity utilities in the absence of budget constraints. We use stochastic dynamic programming and multi-criteria decision analysis which explicitly account for trade-offs between production and biodiversity conservation concerns. Finally, we conduct a sensitivity analysis to assess the impact of assumptions of the model and utility functions. Management complexity arises from biodiversity-production trade-off situations in which the desirable state of buffel grass cover and effective actions to achieve this state depend on the utility functions. Management solutions were particularly sensitive to the shape of the utility functions for biodiversity. Solutions were less sensitive to uncertainty surrounding the effectiveness of management actions. We found in most biodiversity-production trade-off situations a compromise solution led to management for an intermediate level (>0–50%) of buffel grass cover. However, when maximal values for both biodiversity and production are high, it may be more practical to manage for one value rather than find a compromise solution where concessions from both sides are high. Our decision framework does not attempt to optimize economic outcomes but provides a guide for formulating trade-offs between opposing views, something that is relevant to the management of any natural resource management problem where there are conflicting objectives.

1. Introduction

The management of economically valuable species that are also invasive is contentious. Conflict arises from the species' ability to provide considerable private and public financial benefits, while at the same time imposing substantial public costs through negative impacts on ecosystems. While debate continues on whether invasive species are drivers or passengers of ecological change,

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their dominance is associated with altered ecosystem structure and function and displacement of native species, and hence they are generally considered a threat to biodiversity (MacDougall and Turkington, 2005). Several of the ecological traits that make a plant commercially successful (e.g., fast growth rates, large reproductive output, ability to withstand biotic and abiotic stresses) are the same traits that enhance the species' invasiveness (McIntyre et al., 2005). A wide range of plants, with contrasting growth forms and commercial uses, fall into this category (Grice, 2006a). Trees such as *Olea europea* L. in horticulture and *Pinus radiata* D. Don in forestry (Grice, 2006a), ornamental shrubs e.g. *Rhododendron ponticum* L. (Dehnen-Schmutz and Williamson, 2006), pasture grasses e.g. *Cenchrus cililaris* L. (Lonsdale, 1994) and grasses used for biofuel production e.g., *Arundo donax* L. and *Panicum virgatum* L. (Barney and DiTomaso, 2008; Raghu et al., 2006) are all commercially valuable invasive plant species.

Natural resource management can involve making decisions about conflicting objectives. Typically, for valuable pasture species that are also invasive, producers are concerned with maximizing the productivity of their land by promoting the cultivation of the species, whereas conservation agencies are concerned with maintaining biodiversity value by avoiding adverse consequences associated with the spread of such species. Most decision analyses for managing invasive species focus on species which have only negative impacts, and hence impacts can be lessened by either reducing, containing or eradicating populations of the invader (Cacho et al., 2008; Sharov, 2004; Yokomizo et al., 2009). Invasion dynamics, cost of control efforts and monetary measures of invasion impact are three major components for determining which invasion management strategy is economically-optimal (Epanchin-Niell and Hastings, 2010; Cacho et al., 2008; Pichancourt et al., 2012; Sharov, 2004). However, to be relevant to invasive species that have both positive and negative impacts, a new component is required which enables managers to balance the divergent values associated with the invader (e.g. Yokomizo et al., 2012). Another challenge is placing a monetary value on the ecological costs or economic benefits of the invasive species (Sinden and Griffith, 2007). Given the difficulty this entails, it is possible to optimize alternative objectives which do not require the evaluation of the cost of damage associated with an invasion or the benefit of controlling an invasion. For example, Hauser et al. (2006) obtained optimal monitoring strategies for the management of wildlife species where conflict existed over the value of the species using a utility function that expressed the overall desirability of the species' densities without translating the utility into a monetary value.

In this study, we propose a decision framework to support the management of commercially valuable invasive plant species by providing management solutions over time that accommodate conflicting viewpoints. Our framework determines what management strategies are the most effective at minimizing overall losses in production and biodiversity utilities, given the characteristics of a site and the management objective, in the absence of budget constraints. Site characteristics include the level of invasive plant cover and the potential maximum biodiversity and production values. The management objective is to decide between production, biodiversity conservation or trade-offs between the two. Our framework takes into account the population dynamics of the invasive species by means of a state and transition model. Transition probabilities define the effect of possible management actions used to increase or decrease plant cover. The framework explicitly considers the trade-off between the benefits to production and costs to conservation assets of plant invasion without placing a monetary value on these benefits and costs. Utility functions are used to represent the value of increasing plant cover from production and biodiversity viewpoints. These functions represent a stakeholders' relative happiness with varying levels of cover of commercially valuable invasive species (Ng, 1996). We determine management schedules that minimize overall utility losses over time using stochastic dynamic programming (SDP; Bellman, 1957) in combination with multi-criteria decision analysis (Romero and Rehman, 2003) which explicitly accounts for trade-offs between production and biodiversity conservation concerns.

We illustrate the value of our framework by considering the management of a site threatened by buffel grass, (*Pennisetum ciliare* syn. *Cenchrus ciliaris* L.). Buffel grass is one of many exotic grasses deliberately introduced for livestock production and soil conservation and is now widely distributed in the United States, Mexico and Australia (Arriaga et al., 2004; Lawson et al., 2004; Martin et al., 2006). Because buffel grass provides both economic benefits and poses significant environmental threats, the management of buffel grass has been the source of considerable debate and conflict (Grice et al., 2012). Despite this conflict, Friedel et al. (2011) have found production and conservation stakeholders are willing to consider opposing views, providing a basis for examining biodiversity-production management trade-offs.

The negative impact of buffel grass cover on native biodiversity is now widely acknowledged (Clarke et al., 2005; Eyre et al., 2009; Fairfax and Fensham, 2000; Franks, 2002; Jackson, 2005; Miller et al., 2010; Smyth et al., 2009), but uncertainty remains around the magnitude of impact. The quantitative impact of buffel grass on biodiversity varies depending on which environmental and biodiversity indicators are measured and the temporal and spatial scales that are investigated (Jackson, 2005). The economic benefit of buffel grass for production is also subject to debate, particularly regarding the value of buffel grass dominance within a pasture. In monocultures for example, low species diversity could increase the vulnerability of the pasture to pests, diseases and unfavorable seasonal conditions. Given this uncertainty, we examine ways to account for variability in a species' behavior and the effectiveness of management actions depending on species- and site-specific conditions. We analyze how sensitive the minimal loss management strategies are to (i) differences in the utility functions for production and biodiversity, and (ii) the effectiveness of management actions. Finally, we assess the performance of the recommended management strategies through time. In summary, we demonstrate a decision framework that provides a transparent and repeatable means of formulating trade-offs between opposing views to support the management of commercially valuable invasive species.

2. Materials and methods

2.1. Study species

Buffel grass is a perennial species native to parts of Africa, Asia and the Middle East. The capacity of buffel grass to produce high forage yields, resist drought and heavy grazing, and respond well after fire makes it highly valued by some graziers in arid and semi-arid rangelands (McIvor, 2003). However, these same traits, coupled with a capacity for establishment in disturbed areas (McIvor, 2003), rapid growth, fast maturation, prolonged flowering/fruiting, prolific seed production, high seed dispersal (Franks, 2002) and potential for vegetative reproduction also make it a successful colonizer of non-targeted areas. Buffel grass can form dense single-species stands and out-compete native plant species, threatening native animal species through displacement of native vegetation (McIvor, 2003). Several studies have highlighted its negative impact on biodiversity within remnant vegetation, tropical forests and woodlands of Queensland (Eyre et al., 2009; Fairfax and Fensham, 2000; Franks, 2002; Jackson, 2005) and in the arid rangelands of central Australia (Clarke et al., 2005; Miller et al.,