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Review

A framework for sustainable invasive species management: Environmental, social, and economic objectives☆

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ABSTRACT

Applying the concept of sustainability to invasive species management (ISM) is challenging but necessary, given the increasing rates of invasion and the high costs of invasion impacts and control. To be sustainable, ISM must address environmental, social, and economic factors (or "pillars") that influence the causes, impacts, and control of invasive species across multiple spatial and temporal scales. Although these pillars are generally acknowledged, their implementation is often limited by insufficient control options and significant economic and political constraints. In this paper, we outline specific objectives in each of these three "pillars" that, if incorporated into a management plan, will improve the plan's likelihood of sustainability. We then examine three case studies that illustrate how these objectives can be effectively implemented. Each pillar reinforces the others, such that the inclusion of even a few of the outlined objectives will lead to more effective management that achieves ecological goals, while generating social support and long-term funding to maintain projects to completion. We encourage agency directors and policy-makers to consider sustainability principles when developing funding schemes, management agendas, and policy.

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1. Introduction

The prevention and control of invasive species has received considerable attention in recent years because of their demonstrated and potential ecological (Wilcove et al., 1998; Levine et al., 2003) and economic (Pimentel et al., 2005) impacts. However, our ability to effectively manage invasions is limited by the efficacy of available management tools and economic and political constraints (Hobbs and Humphries, 1995). Resource managers with limited funds and labor must often react to immediate threats, with few resources remaining for developing and implementing comprehensive long-term invasive species management plans. Funding for current invasive species management (ISM) is clearly insufficient, but given that rates of invasion are expected to accelerate (Lodge et al., 2006; Hellmann et al., 2008), it is increasingly important that we ask the question: is effective invasive species management sustainable?

The term "sustainable" has become something of a watchword for the 21st Century: more than 40,000 articles can be retrieved on Web of Science (a web-based bibliographic search application published by Thomson Reuters) using the keywords *sustainable* or *sustainability*, implying a rich literature surrounding the concept. Although The Oxford English Dictionary (1989) provides a deceptively straightforward definition: "Capable of being maintained at a certain rate or level", Meyer and Helfman (1993) note that the definition is context dependent. Often, the term is used in relation to extractive resource use and implies that natural resources should be used such that they remain available at comparable levels for future generations (Brundtland, 1987). However, sustainability can also be applied to resource management, including ISM. Given the high costs of ISM and increasing rates of invasion, we must aim to sustain management efforts into the future, without depleting financial and social capital.

We base our discussion on the idea that sustainability depends on three "pillars" (e.g., Pope et al., 2004): environmental, social, and economic. While specific management goals will be unique to

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projects, in general, sustainable management will minimize environmental, social, and economic costs while restoring resilience to ecosystems and creating robust social and economic supports for the implementation of management plans. Such a framework harks back to the underpinnings of integrated pest management (Kogan, 1998). Although the importance of the three pillars is generally acknowledged, their implementation is often weak or lacking. Social and economic principles in particular are often underrepresented in higher level policy. For example, the Nonindigenous Aquatic Nuisance Prevention and Control Act (1990) and its reauthorization, the National Invasive Species Act (1996), two federal policy instruments addressing invasive species in the United States, make only limited mention of the economic and social factors that we consider integral to ISM. To achieve sustainable ISM, we need to identify barriers to implementation of the pillars and develop specific ways that the pillars can be meaningfully integrated into long-term management plans. While attention to sustainability goals is critical at all levels, it is particularly important at the policy and upper-management levels, wherein lie the authority and power to broadly shape long-term planning and funding for ISM.

In this paper, we apply the three pillars of sustainability to ISM and present specific environmental, social, and economic objectives that can be included in management plans (Table 1). We discuss three case studies that illustrate how the three pillars work together toward sustainable ISM. We restrict our discussion to ISM as it applies to natural and semi-natural areas (e.g., parks, national forests, and rangeland), rather than to intensive agricultural systems (e.g., rowcrops and orchards) which have been discussed in detail elsewhere (see, for example, Van Cauwenbergh et al., 2007)). Also, while our frame of reference is largely North American, many of the objectives we present are relevant to ISM in the broader global context.

2. Management objectives

Clear and mutually agreed upon objectives at the outset of ISM programs are crucial and explicit consideration of each of the three pillars may increase the likelihood a program will be sustainable. We define objectives as measurable benchmarks by which progress toward a management goal will be assessed. For example, if the management goal is to increase the dominance of native species and thus improve ecosystem function in a desert riparian zone, objectives could include specific targets for (1) native dominance and invasive reduction, (2) improvement in water storage, including public outreach explaining the benefits to affected citizens, and (3) reduction in costs associated with water depletion by invasive species. In a sustainable framework, objectives should be measurable, meaningful, and understandable to all stakeholders. A benefit of clear objectives is the ability to demonstrate progress throughout the life of the management plan; success no longer hinges on one all-or-none endpoint. ISM objectives should be re-evaluated (as in adaptive management; see Evans et al. (2008) for a discussion of adaptive management and ISM), not only to assess progress, but also to determine whether objectives are still relevant, and when environmental, social and economic contexts change.

2.1. The environmental pillar

Of the three pillars of sustainable management, the environmental implications of ISM have likely received the most attention. Understanding the mechanisms that facilitate or inhibit invasion is crucial in assessing threats and defining control options (Valentine et al., 2007). Managers must consider the temporal and spatial scale of an invasion to develop management plans that are environmentally sustainable. Such management plans would consider the most effective control methods based on the stage of invasion and system invaded, while limiting non-target effects, and promoting the recovery and restoration of endangered species, native species diversity, and ecosystem processes (Denslow, 2007). Central to development of a management plan is the identification of the harm invasive species are causing (Evans et al., 2008); only by knowing this can benchmarks of recovery be established.

Environmental objectives of ISM reflect the stages of invasion. Prior to species introduction, a key objective is to *identify likely pathways of invasion* (Table 1). Scale and boundary characteristics of the managed area, as well as dispersal and life history attributes of the species of concern, will inform the search for pathways (Stokes et al., 2006; Hulme et al., 2008). Once identified, pathways can be targeted for monitoring.

Monitoring must occur at an intensity that will *allow early detection of invasive species* (Table 1). A lag phase is common in invasive species dynamics (Crooks, 2005), so apparently-benign exotic species should not be ignored. Because of the uncertainty regarding the likelihood species will arrive, establish, and cause harm, objectives should be frequently evaluated and revised as information becomes available. Risk assessments (Landis, 2004), although labor-intensive, provide a means by which managers can evaluate the likelihood of arrival and probable impacts, thus helping to prioritize management (Venette and Gould, 2006). This enables balance between too little effort (species invade without detection) and too much (detections are disproportionately few given the monetary input (Leung, 2002)). Species may also be ranked according to potential harm, helping to highlight species for which management is most critical. A broadly-available repository of risk assessments, organized by species and ecosystem, would be a useful tool for managers trying to manage invasive species.

Table 1
Objectives for achieving sustainable ISM. Management plans should include specific benchmarks within these categories to allow managers to measure progress toward the goal of sustainability.

Environmental	Social	Economic
Identify vulnerable pathways	Involve multiple stakeholders in the management planning process	Include non-market elements in cost-benefit analyses
Monitor to allow early detection of invasive species and eradicate when feasible	Communicate measurable progress	Expand temporal and spatial scales of cost-benefit analyses and planning
Contain spread of established invaders	Involve community members in project implementation	Incorporate principles of efficiency into project selection
Reduce or reverse effects of the invader on native species and ecosystems	Develop education and outreach programs	Consider efficiency when selecting management practices
Minimize non-target effects of the management plan on native species and ecosystems	Increase coordination of agencies and knowledge networks at all levels	Secure sufficient funding for project completion
Restore biodiversity and bolster resilience of native systems to prevent reinvasions	–	–