Broadening the Case for Invasive Species Management to Include Impacts on Ecosystem Services

JENNIFER L. FUNK, VIRGINIA MATZEK, MATTHEW BERNHARDT, AND DOUG JOHNSON

In addition to their negative impacts on biodiversity, alien plant species often affect ecosystem processes in ways that degrade ecosystem services for humans, resulting in economic losses. Timely intervention to control the spread of invaders can minimize economic and ecological damages, whereas lapses or delays in funding weed control can be extremely costly in the long run. Using recent decreases in funding for invasive plant management in California as an example, we argue that managers must make a broader case for investing in the control of invasive species to prevent the loss of ecosystem services. In particular, managers need to partner with academic scientists, private landowners, and the public sector to quantify the impact of invasive weeds on service provision, assess where services are most at risk and who benefits from the avoided cost of weed control, and create mechanisms to fund invasive species management through payment for ecosystem services.

Keywords: ecosystem services, restoration ecology, weed control, economics of invasive species

Invasive species are frequently classified among the major drivers of biodiversity loss around the globe (Pyšek and Richardson 2010). However, their impact on the provision of ecosystem services is also large, and our understanding of it is growing (Pejchar and Mooney 2009, Pyšek and Richardson 2010). In the United States, invasive plants are known to affect provisioning services (i.e., products obtained from ecosystems), regulating services (i.e., those that regulate ecosystem processes, such as climate and pollination), and cultural services (e.g., aesthetic values, recreation, religious values). Here, we call on land managers, conservationists, and researchers to broaden the scope of weed management by considering the benefits to human welfare of controlling the spread of invasive plants.

A well-known example of a plant invader affecting provisioning services is water consumption by salt cedar (*Tamarix* spp.), which occupies nearly every floodplain in the southwestern United States and consumes 3000–4600 cubic meters per hectare (ha) per year more water than does the native vegetation that it replaces (Zavaleta 2000). The increased water use depletes water supplies for municipalities, farmers, and hydropower generation—an estimated loss of $127 million to $291 million each year. Another plant species, yellow starthistle (*Centaurea solstitialis*), costs California ranchers upward of $17 million annually in lost forage and eradication expenses on public and private rangelands (Eagle et al. 2007), and water losses due to its late summer drawdown of soil moisture amount to as much as $75 million each year in the economically important agricultural region surrounding the Sacramento River (Gerlach 2004). As an example of the impacts of invasive plant species on regulating services, giant reed (*Arundo donax*) alters the hydrology of river channels and degrades the quality of litter inputs to riparian food webs (Going and Dudley 2008), consequently rendering California rivers less hospitable to salmonid fishes, a $1.2 million (annually) industry (CDFG 2011). In addition, studies show that nonnative vegetation in California does not support native pollinators as well as native vegetation does and that native pollinators provide important agricultural pollination services, estimated at $1 billion to $2.5 billion annually (e.g., Chaplin-Kramer et al. 2011). Finally, invasive plant species can influence a range of cultural services, which are more difficult to quantify. In a modeling study, Eiswerth and colleagues (2005) predicted that an infestation of exotic plant species in Nevada watersheds reduced recreation-related income by $6 million to $12 million annually. The invasive forb leafy spurge (*Euphorbia esula*) has caused losses of $2.4 million annually in wildlife-related recreation expenditures in Montana, North Dakota, South Dakota, and Wyoming, according to an estimate by Leitch and colleagues (1994).

In accounting for the negative impacts of exotic invaders on ecosystem services, it is important to consider that some invaders have positive or mixed impacts (Eviner et al. 2012).

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For example, lowland Hawaiian rainforests infested with exotic tree species are similarly productive (aboveground biomass) or more productive (litterfall, belowground carbon storage, nitrogen and phosphorus turnover) than forests dominated by native species (Mascaro et al. 2012). Kudzu (*Pueraria montana*) reduces forest biodiversity and increases air pollution in the southeastern United States (Forseth and Innis 2004, Hickman et al. 2010) but was initially introduced to provide erosion control. Exotic grass species from the Mediterranean basin reduce native biodiversity and increase the frequency of fire in California (Keeley et al. 2003) but provide forage for livestock.

How should we allocate resources to control invasive plants?

With such large impacts attributable to invaders, it is worth identifying management practices that prevent ecological and economic harm. We do know that early interventions are more cost effective than later ones and that consistent applications are more effective than inconsistent ones (Simberloff 2009). Economic risk analysis has demonstrated that, in most cases, it is more cost effective to prevent invasion than to control it (Leung et al. 2002), and infestations occupying a smaller area are easier to eradicate (i.e., permanent removal; Pluess et al. 2012). For example, an analysis of eradication attempts by the California Department of Food and Agriculture suggested that exotic plant eradication is possible for infestations of areas smaller than 1 ha, but the likelihood of eradication decreases as the area of infestation increases (Rejmánek and Pitcairn 2002). Furthermore, this study concluded that, even with ample resources, infestations larger than 1000 ha are unlikely to be eradicated. Several studies have shown that smaller populations can be eradicated because of Allee effects, by which reduced population growth can result from a number of density-dependent factors, including pollen limitation, inbreeding depression, or a lack of facultative systems (Tobin et al. 2011).

Consistent funding levels allow for more effective invasive species control. For example, Gardener and colleagues (2010) found that the primary reason for failed plant eradication projects in the Galápagos Archipelago was inconsistent funding (38% of failed projects). A simulation of *Acacia cyclops* and *Pinus pinaster* spread on the Cape Peninsula in South Africa showed that the budget for weed management was more important than any other factor—including the invader's rate of spread and the type of management strategy used—in reducing the total cost and time of the clearing operation, as well as the cumulative threat to rare and endemic plant species (Higgins et al. 2000). Through other spatial simulations, it has been concluded that eradication of invaders is possible on low annual budgets if priority is given to fast-growing low-density plants, but this strategy results in a higher total expenditure, a longer time to eradication, and an increased risk of reinvasion (Menz et al. 1980, Taylor and Hastings 2004). Consistent state funding facilitated the successful eradication of water hyacinth (*Eichhornia crassipes*) and Australian paperbark (*Melaleuca quinquenervia*) in Florida (Simberloff 2009). In addition, the Exotic Plant Management Team in Hawaii Volcanoes National Park has received consistent funding since its inception in 2005 and uses sophisticated detection and control techniques to thwart invasion attempts by new plant species, such as Koster's curse (*Clidemia hirta*), guineagrass (*Panicum maximum*), and silky oak (*Grevillea robusta*), and reinvasion by 13 previously eradicated species, including black wattle (*Acacia mearnsii*) (Benitez et al. 2012).

A different way to think about invasive plant management would be to apply the equimarginal principle, to make investments in invasive plant control commensurate with the economic harm done by the invader. Applied to invasive plant management, the principle would ensure that invasive plant species are controlled up to the point at which the cost of control is equal to the benefit (the avoided damage) that it secures (for a review, see Gren 2008). In this definition, *avoided damage* refers to the services that people obtain from invaded ecosystems. Many economic studies have evaluated the amount and timing of invasive species management to determine the optimal management protocol on the basis of the equimarginal principle (e.g., Eiswerth and Johnson 2002, Burnett et al. 2006, Finnoff et al. 2007). Optimal control (eradication, prevention, or accommodation) will depend on estimates of damage and management cost at different stages of invasion. Working in Hawaii, Burnett and colleagues (2006) found that the optimal management strategy for an invasive tree species (*Miconia calvescens*) was to control the population to roughly 31,000 trees, down from roughly 100 million. Below a population size of 31,000, trees become increasing difficult to find and the management costs exceed the benefits. In Idaho, researchers studying how best to allocate scarce resources to control cheatgrass (*Bromus tectorum*) invasion found that considering the provision of multiple ecosystem services, in concert with the likelihood of restoration achieving its goals, could improve the cost effectiveness of management actions (Wainger et al. 2010). A similar result emerged from decisionmaking tools with a hierarchical ranking of multiple criteria, including the potential for invasive species control to improve the provision of water in South Africa (Forsyth et al. 2012).

However, there is little evidence that US invasive species programs, even when they are motivated by an invader's potential for economic harm, obey the equimarginal principle. One reason is that, although the economic costs associated with a few species (e.g., *Miconia*, *Tamarisk*, zebra mussels [*Dreissena polymorpha*], the brown treesnake [*Boiga irregularis*]) are well established (Zavaleta 2000, Leung et al. 2002, Burnett et al. 2006), our ability to estimate avoided damage is lacking for many invaders. The second reason is that weed management funding has traditionally come from state and federal budgets that are on the decline and is therefore politically vulnerable—perhaps because conservation advocates have not made a sufficiently explicit case for the role of invasive species control in providing broader social benefits through ecosystem services.

During the recent economic downturn, funding for state-level programs, such as the Alabama Tropical Soda Apple Eradication Program, the Oregon Invasive Species Council, and the Florida Invasive Plant Management Program, has been reduced or cut entirely (Ruark Cleary, Fish and Wildlife Conservation Commission, personal communication, 28 January 2013; Lisa DeBruyckere, Oregon Invasive Species Council, personal communication, 30 January 2013; Stephen Enloe, Auburn University, personal communication, 30 January 2013). In addition, the Hawaiian Ecosystems at Risk project (*www.hear.org*), which has documented invasive species throughout the Pacific Islands, may be shut down in 2013 because of budget cuts. In 2012, the state of California eliminated financial support for its Weed Management Areas (WMA) program, which provided funding to coordinate invasive plant control among agencies at the county level and to help leverage additional funding from matching grants for invasive plant control.

The effects of budget cuts on invasive plant management in California

We find the California cuts especially interesting, for two reasons. First, as an arid western state with a large fraction of its area in working landscapes such as rangelands and timberlands and with more than 40% of its land in public ownership (NRCM 2000), California has an unusually large stake in preventing the spread of invasive species that affect ecosystem provisioning services. Second, both public and private organizations in California are currently experimenting with schemes for compensation for ecosystem services. In other words, California is a state in which investments in invasive plant management are likely to pay off in benefits to ecosystem services and in which mechanisms to make such investments exist or might soon exist. However, funding is still largely dependent on conventional budget allocations, which are shrinking. We sought to understand the funding landscape in California and its impact on invasive species control by surveying two sets of California land managers: heads of the WMA programs that were directly affected by the loss of funding in 2012 and a larger set of managers who deal with California invasive species management for federal, state, and local organizations throughout the state. Details of the survey questions and methodology are provided in the supplemental material.

We first asked the WMA directors to gauge the direct impacts of the funding cuts on their work in the short term. The results showed that the biggest declines would be felt in what are arguably the most important aspects of efficient invasive species management: the early detection of invaders (a decline of 60%) and on-the-ground invasive plant control (a decline of 63%). In addition, mapping and monitoring efforts, which might be expected to contribute to early detection, were anticipated to decrease by nearly half (table 1).

In the open-comment section of our survey, the directors expressed concern that breaks in on-the-ground treatment and detection would set them back years, as weed population sizes rebounded to precontrol levels. Indirect effects of the funding cuts were also anticipated through the loss of institutional memory caused by staff positions' being eliminated, the inability to coordinate with other managers, and the inability to keep up with current practice by attending symposia or workshops. More than 75% of the WMA directors were not confident that they could replace lost funding within 3 years. When asked to name specific sources from which they would seek alternative funds, only one manager (or 4.7% of the managers) mentioned pursuing programs that are intended to preserve ecosystem services (a Sierra Nevada Conservancy Proposition 84 grant).

Table 1. Survey results reflecting the expected average change in weed management area (WMA) annual budgets as a result of the California state budget cuts.

	Funding (in dollars)		
Budget category	**2011**	**2012**	**Percentage decline**
On-the-ground treatment	55,622	20,333	63.4
Mapping	11,851	6667	43.7
Education	5576	3833	31.2
Assessment	7126	3633	49.0
Regulation	7501	5967	20.5
Early detection or rapid response	5719	2300	59.8
Other	1875	1333	28.9
Total	95,269	44,067	53.7

Note: The largest decrease in funding will be for on-the-ground treatment of invasive plant species. The sample size was 21 WMA directors.

Our larger survey of managers from various agencies across the state revealed that 78% were confident that their current invasive plant control efforts were either reducing cover or controlling further spread of the most troublesome invasive plants, including yellow starthistle (*Centaurea solstitialis*) and giant reed (*A. donax*), although only 4% thought that total eradication of their most difficult invasive species was possible within a decade. The managers overwhelmingly (65%) identified the lack of funding, not a lack of information on invaders or control strategies (1%), as the largest obstacle to successful eradication of these invaders (table 2). However, when asked why invasive species should be controlled, these same managers ranked preserving ecosystem services as a distant third behind preventing harm to native species and avoiding the loss of ecosystem functions (table 3). So, although the managers believed that their invasive plant control was working and that it should be a bigger funding priority, they may not have been thinking in terms of making broader economic arguments to policymakers and the public in order to build support for invasive species control.

Integrating ecosystem services into invasive species management

We think the time is ripe for managers to make the case for funding to include recognition of the important impacts of wildland and agricultural invaders on ecosystem services. Emphasizing the return on investments in invasive plant control as benefits to social welfare and the economy is necessary to convince a skeptical public and legislators of the value of invasive species management during hard economic times. However, to effectively make this case, there are important information gaps that must be filled.

First, we need better information on the economic and ecological impacts of invasive species. As we discussed above, the economic impacts are well characterized for only a handful of species. The ecological and economic impacts of invaders are likely highly correlated within broad taxonomic groups and habitat types (Pyšek and Richardson 2010), but impacts at the local level may be challenging to measure directly (Eviner et al. 2012). Furthermore, some ecosystem processes, such as timber production or streamflow, can be directly measured, but others, such as carbon storage and flood control, are more difficult to quantify. Plant functional traits are increasingly used to predict the ecosystem impacts of invasive species (Drenovsky et al. 2012) and may constitute a shortcut to the quantification of these impacts. For example, species impacts on nitrogen cycling are driven by functional traits, such as nitrogen fixation, leaf chemistry, and phenology (Ehrenfeld 2003). However, understanding an invader's impact on ecosystem processes is not necessarily the same thing as predicting its impact on ecosystem services (Pejchar and Mooney 2009). For example, timber or crop production (an ecosystem service) may be influenced by a number of ecosystem processes, including net primary production, nutrient cycling, pollination, and soil water availability (Eviner et al. 2012).

Second, we need to know who benefits from avoided costs when invaders that threaten ecosystem services are controlled. If there are beneficiaries who stand to gain from invasive species control, it is reasonable to ask them to pay for those benefits. The best-studied cases have been focused on the impacts of exotic pests on productivity and pollination of timber and crop species. Using a bioeconomic model, Cook and colleagues (2007) estimated the avoided costs of preventing varroa mite infestation of honeybees in Australia, which provide valuable pollination services for a variety of crop species. Over 30 years, the economic damages avoided by controlling mite infestation would be $16.4 million to $38.8 million. Wang and colleagues (2012) determined that the control of Chinese tallow trees (*Triadica sebifera*) in southern US forests represents an avoided cost of $100 million to timber plantations over 20 years. Current funding mechanisms are sometimes based on such aggregate measures of harm when the impact can be isolated to a particular commodity, but most species' impacts are on general ecosystem services that affect a much wider segment of society.

Table 2. Managers' responses to the question, "What most limits your success against the most troublesome invasive species?"

Response	Percentage of responses
Insufficient funding	65
Insufficient information	1
Both factors are about equal	14
Neither is the most important factor	19

Note: The sample size was 207 respondents.

Table 3. Reasons to control invasive species from a survey of California resource managers.

Reasons to combat invaders	Rank	Weighted rank
To prevent impacts on native species	1	1.73
To preserve ecosystem function	2	1.80
To prevent the degradation of ecosystem services	3	3.12
To preserve aesthetics or historical value	4	3.86

Note: For the weighted ranks, a lower rank reflects greater importance. The participants chose whether a response was important enough to rank, then ordered their responses. The sample size was 201 respondents.

Third, we need to develop mechanisms that allow for control costs to be placed in the context of invader harm (e.g., payment for ecosystem services [PES]). There are several domestic and international examples that illustrate this approach. South Africa's Working for Water program maximizes water delivery by clearing water-demanding exotic plant species, which is more cost effective than other options, such as building dams. The program has coalesced into a PES system as water benefits have become more apparent: Water users pay for restoration in watersheds contracted out as jobs relief (Turpie et al. 2008). In the United States, there are several movements afoot to develop frameworks for PES that could potentially help control the spread of invaders. Oregon's Senate Bill 513 established a framework for statewide ecosystem service markets as a mechanism for achieving conservation and restoration goals in 2009. Some "forests to faucets" plans, which typically engage public water users in paying for upstream ecosystem preservation and restoration, have included invasive plant management in their project goals, such as that governing the Santa Fe Municipal Watershed, in New Mexico, and the Mokelumne Watershed, in California. The Mokelumne Watershed project is pioneering an assessment of the effects of changes in land use and stewardship (including restoration activities) on water supply and water quality, with the expectation that income from beneficiaries will eventually be used to compensate landowners in the watershed for making such improvements (Kelli McCune, Sustainable Conservation, personal communication, 13 August 2013). California also has a market system for compensating landowners for carbon sequestration through reforestation and improved forest management that could create incentives for restoring native forest cover and removing invaders that spread fire. California's 2006 Safe Drinking Water Act, funded by bonds, provides for weed management as a means of ensuring water supplies. Finally, in seeking additional efficiency in invasive plant control, managers could also focus on partnering with private landowners eligible for funding through conservation banking or wetland mitigation banking funds.

Although not an ecosystem service per se, unemployment relief is another social benefit that invasive plant control may provide. South Africa's Working for Water program seeks social equity through job creation and training tens of thousands of people while maximizing the delivery of water (van Wilgen et al. 2011). Although the Working for Water program has had both successes and failures in invasive plant management over its 15-year history (van Wilgen et al. 2012), the social welfare return on the investment is likely comparable to or exceeds the ecosystem service return. In California, a program to control the invasive reed *A. donax* recently won funding partly by emphasizing its economic benefits as a public works project. The contracting firm River Partners is tracking the economic benefits that the project provides to the adjacent community through increased employment and local spending (Julie Rentner, River Partners, personal communication, 13 August 2013). In another example, American Youth Works (*www.americanyouthworks.org*) provides education and green-job training for at-risk youth through native habitat restoration and invasive plant control on private and public lands.

In conclusion, we encourage managers, academic scientists, and conservationists to work together to more effectively assess and communicate the impacts that invasive plant species have on ecosystem services and to work toward incorporating these impacts into policy that supports invasive species control efforts. The current economic downturn has illustrated the vulnerability of budgets for invasive plant management. Because gaps in funding are likely to escalate the total costs of control, as well as the total economic losses from impacts on ecosystem services, the time is ripe to make a better case for the economic benefits of timely investment in weed control. More research to quantify the impacts of invasive plant species on ecosystem services is urgently needed. Land managers should advocate for invasive plant management on broader grounds, recognizing that investment in weed control can pay large dividends in social and economic benefits, including avoided damage costs. Conservationists need to identify opportunities to establish mechanisms for PES, which includes identifying the beneficiaries of invasive plant control and engaging with them directly.

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Supplemental material

The supplemental material is available online at *http://bioscience.oxfordjournals.org/lookup/suppl/doi:10.1093/biosci/bit004/-/DC1*.

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Jennifer L. Funk (jlfunk@chapman.edu) and Matthew Bernhardt are affiliated with the School of Earth and Environmental Sciences at Chapman University, in Orange, California. Virginia Matzek is affiliated with the Department of Environmental Studies and Sciences at Santa Clara University, in Santa Clara, California. Doug Johnson is affiliated with the California Invasive Plant Council, in Berkeley, California.