Chapter 6
The Ecosystem Service Impacts from Invasive Plants in Antietam National Battlefield

Todd R. Lookingbill, Emily S. Minor, and Lisa A. Wainger

Abstract Following their memorialization as protected landscapes, battlefield parks can provide a blend of cultural and other ecosystem services. Among the many threats to providing these services are non-native invasive plants. In this chapter, we assess the threats imposed by biological invasions of non-native plants in battlefield parks and discuss management strategies. We use evidence from the scientific and economic literature and the expert judgment of biologists, economists, and park managers to identify the harms caused by invasives and to characterize their effects on park ecosystem services. Based on this evidence, we propose four generic stressor-response relationships to describe the relationships between invasion extent and ecological endpoints such as park vegetation structure and diversity. Using Antietam National Battlefield as a case study, we tailor the general stressor-response curves to four specific species representing different functional groups of invasive plants: trees, shrubs, vines, and herbaceous forbs. We next link the ecological response of changes in vegetation structure and diversity to relevant ecosystem service impacts using interviews with national park service personnel and the economic literature. We identify four broad categories of parks users who might be affected by these losses of services: causal visitors, avid recreationalists, park neighbors, and non-use beneficiaries. Our findings reveal a general lack of experimental evidence quantifying the ecosystem service impacts of invasive plants. This lack of evidence, combined with the likely non-linear effects of non-native plant invasions on ecological endpoints, could catch managers unaware of dangerous thresholds in long-term resource management of battlefield landscapes.

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6.1 Introduction

Battlefield parks provide a blend of cultural and ecological benefits that can extend beyond their boundaries. These benefits can be considered *ecosystem services* (Costanza et al. 1997), which for battlefield parks include recreational opportunities, preservation of historic viewsheds, aesthetic enjoyment for visitors, conservation of biodiversity, and increases in neighboring property values (Wainger et al. 2012). Like most parks, battlefield parks face wide-ranging threats to these services, many of which are associated with their geography. For strategic reasons, battles have historically often been fought on the outskirts of cities. In the years following war, many of the landscapes surrounding these battlefield sites have experienced high rates of suburbanized development as nearby metropolitan centers expand (Lookingbill et al. 2014a). The expanding population can bring opportunities for increases in the ecosystem services provided by the park, but also increases in the anthropogenic impacts to the site.

This trajectory of landscape change is illustrated by Antietam National Battlefield. Located in the Appalachian Ridge and Valley province of western Maryland, USA (Fig. 6.1), Antietam was the site of the highest number of military casualties in a single day in U.S. history. On September 17, 1862, in one of the defining conflicts of the U.S. Civil War, a total of 23,000 soldiers were lost in the hostilities. A major turning point in the war, the outcome of the battle paved the way for the issuance of

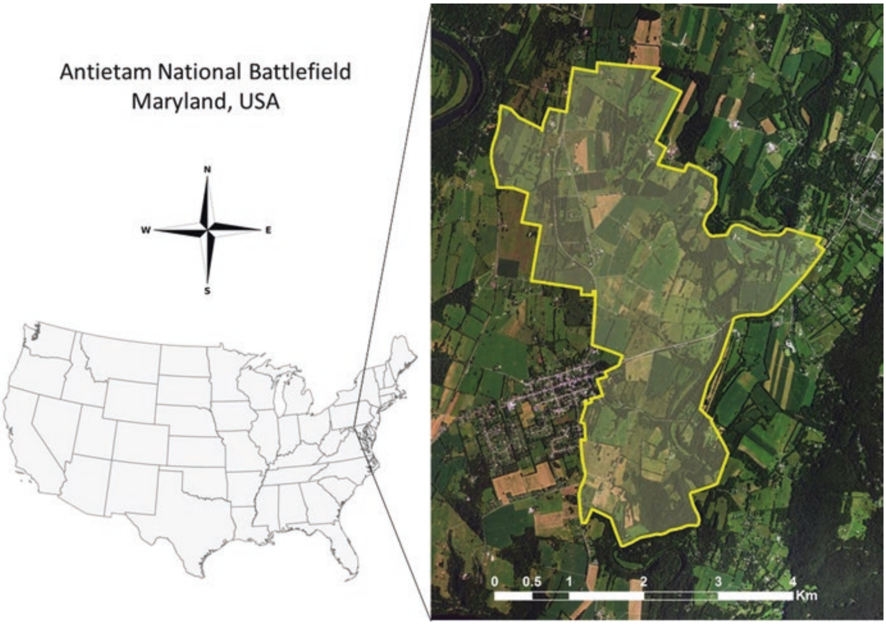


Fig. 6.1 Antietam National Battlefield located in the Mid-Atlantic region of the USA and surrounded by mixed forest, agriculture and urban development

the Emancipation Proclamation, making the eradication of slavery an explicit objective of the war (McPherson 2002).

The memorialization of the site began almost immediately following the Confederate retreat from the battlefield. A private cemetery was created on site within five years and was transferred to the U.S. War Department in 1879. As Congress turned its attention to preserving Civil War landscapes during the "Golden Age" of battlefield preservation, Antietam (along with Gettysburg, Chickamauga and Chattanooga, Shiloh, and Vicksburg) was one of the first Civil War parks to be established in 1890 (Smith 2008). In 1933, control of the 65 acres of park land was passed from the War Department to the National Park Service. The size of the park increased by an order of magnitude to 600 acres in the 1960s, as part of the Civil War Centennial commemoration. A series of additional acquisitions in the 1980s increased the acreage another fivefold to its current 3200 acres (Madron and Tilton, Chap. 2 of this book). The park today receives approximately 350,000 visitors per year, which comes in at the bottom of the list of the original five Civil War parks. However, the increase in visitation of over 75% in the past five decades tops the list for these parks (https://irma.nps.gov/Stats/Reports/Park).

Forest cover comprises approximately 14% of the park, mostly in small woodlots but also as contiguous corridors along Antietam Creek on the east side of the park, and the Potomac River, just to the west of the park (Table 6.1; Fig. 6.1). The remaining vegetation in the park is predominantly open fields and agricultural leases. Vegetation succession in the fields and other parts of the park requires constant and sometimes-extensive management to maintain the historical landscape. The land surrounding the park is a mixture of agricultural and urbanized areas (Fig. 6.1). The park is typical of Civil War battlefield parks of the Mid-Atlantic USA that are located in suburbanizing, mixed-use landscapes. As shown for Antietam, agricultural abandonment of small family farms has resulted in less agriculture and greater forest cover adjacent to the parks than in the parks themselves, where fields are preserved for their historical value (Table 6.1). However, these adjacent forests are being rapidly lost to suburban and exurban development (Suarez-Rubio et al. 2012).

Antietam National Battlefield is also demonstrative of regional environmental stressors in its invasive plants problems. Non-native invasive plants often accompany human encroachment around parks (Allen et al. 2009). These plants invade from surrounding homes and are carried into the parks by visitors, animals, and other vectors (Minor et al. 2009). As these parks mature, invasive plants can threaten the ecosystem functions and services that they provide. Once established, invasive plants can have negative ecological or cultural impacts on the landscape, including

Table 6.1 Percentage of dominant land cover classes in Antietam National Battlefield and in 5-km buffer surrounding the park (source: 2006 National Land Cover Dataset)

	Forest	Agriculture and Fields
Inside park	14.0%	75.5%
Within 5-km buffer of park	32.5%	55.7%

destroying historic structures (Celesti-Grapow and Blasi 2004), altering insect (Bezemer et al. 2014) and bird communities (Skórka et al. 2010), and degrading viewsheds and general sense of place (Barendse et al. 2016). These changes, in turn, affect park visitors, neighbors, and other stakeholders.

Managing invasive plants on historic battlefields is operationally challenging, as many of these undesirable species have become well-established, are likely to reinvade following treatment, and require ongoing control due to plant persistence and regional propagule pressure (Lookingbill et al. 2014b). The reduction of invasive plants must also be balanced against competing cultural and natural resource priorities. Understanding how to allocate management efforts is a multi-faceted problem that requires identifying the level of control effort that generates net benefits to the park.

The relationship between invasive plants and diminished ecosystem services is indirect and linked by the effect that invasive plants have on ecological endpoints. It is helpful to consider these relationships in two parts (Fig. 6.2). In the first part, changes in invasive species (for example, measured as spatial extent or density) generate changes to ecological endpoints. We call these relationships *stressor-response functions*. After determining stressor-response relationships, the changes in ecological endpoints must next be related to user preferences to quantify the economic value of affected ecosystem services. *Economic damage functions* are used to relate changes in one or more ecological endpoints to the benefits users derive from ecosystem services. Damage functions are created by quantifying how much people would be willing to trade off other goods and services to get more (quality or quantity) of a particular ecosystem service, usually by measuring willingness-to-pay.

In this analysis, we address the first half of this equation to build stressor-response functions for four plant species that are commonly invasive to battlefield parks within the Mid-Atlantic region of the United States. Of the multiple ecological endpoints identified in our earlier work (Wainger et al. 2012), we chose one type of ecological endpoint affected by invasive plants: impacts to vegetation structure and diversity. The remainder of this chapter describes a literature review and expert elicitation workshop conducted to build stressor-response functions for these impacts. We conclude with a summary of the ecosystem service users or beneficiaries likely to be affected by reducing vegetation quality in our focal park. However,

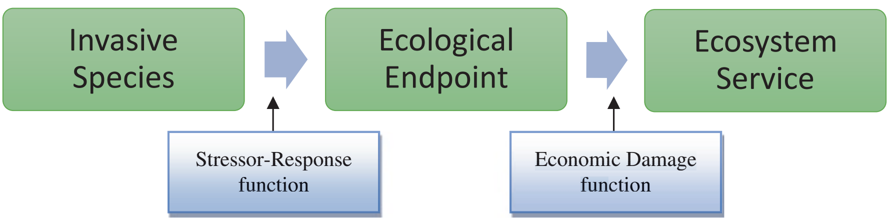


Fig. 6.2 Relationship between the spread of invasive plant species, ecological change, and associated impacts to ecosystem services

we do not generate quantitative economic damage functions here, which would be needed to value the economic impacts of changes in invasive species.

6.2 Stressor-Response Functions

In this chapter, we use changes in vegetation structure and diversity as the primary ecological endpoint of interest. Invasives also impact other ecological endpoints relevant to human well-being, including changes in insects, birds, water, air, or landscape features. We selected vegetation characteristics as our endpoint because of their pervasive effect on many other ecological conditions and observable ecosystem services. In this battlefield park, vegetation structure has a specific cultural interpretation because the park has an explicit mandate to maintain the landscape (including vegetation) to be consistent with the historical period of the Civil War. Therefore, changes to vegetation structure and diversity would lead to direct social harms for users who wish to experience historical accuracy, and these changes would be inconsistent with park management goals. Vegetation structure also influences other cultural and ecological properties of the park such as the overall aesthetics, wildlife viewing opportunities, and habitat quality.

To quantify the impact of invasive plants on vegetation structure and diversity, we surveyed the literature that demonstrated measurable effects of invasive presence or density on ecological endpoints. To fill the considerable data gaps that we found in the literature, we also consulted an expert panel of biologists, economists, and National Park Service management personnel with knowledge of Antietam National Battlefield. Our first goal was to develop a set of general curves depicting potential stressor-response relationships, where invasive plant abundance was the stress and an ecological endpoint relevant to ecosystem services was the response. The shape of these theoretical curves would then be refined on a case-by-case basis to describe specific stressor-response relationships within Antietam National Battlefield.

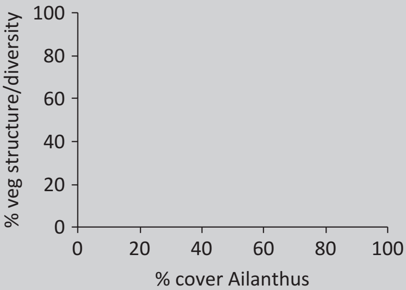
Briefing materials were made available via a website to participants in the expert panel workshop, including a project summary and supporting papers from the scientific literature (additional details in Wainger et al. 2012). Participants were asked to complete a questionnaire at the beginning of the workshop about the potential form of the stressor-response function for one or more species-endpoint combinations (Box 6.1). Then the group jointly discussed the evidence for different forms of the stressor-response functions. Thus, the workshop used both individual and group approaches to extract expert knowledge on impacts of invasive plants. The workshop was not aimed at achieving consensus but at eliciting expert judgment in unbiased ways to inform the eventual development of the generalized stressor-response functions.

The expert panel concurred with our finding that the empirical literature was inadequate to fully characterize stressor-response functions and suggested that the best approach to fill the data gap was to apply a family of theoretical curves. The

Box 6.1 Example questions from the expert workshop. These questions are intended to link changes in cover of a particular invasive species *(Ailanthus altissima)* to a change in an ecological endpoint (vegetation structure and diversity)

Question 1: What do you believe to be the major effects of Ailanthus on vegetation structure and diversity?
Question 2: What do you believe to be the causal mechanisms of those changes?
Question 3: Please use the table and/or chart below to fill in the relationship that you consider to be the most probable between % cover of Ailanthus and % of native vegetation structure and diversity.

% cover Ailanthus	% vegetation structure/diversity
0	
20	
40	
60	
80	
100	



Please list the assumptions/evidence supporting the relationships depicted:

curves could either be parameterized with data when available or applied as a general model of invasive plant impacts using qualitative information from the literature, when quantitative data were lacking. For example, the ecological endpoint affected by the increase in invasive species could be scaled along the y-axis to represent the best and worst-case conditions possible using a reference ecosystem to act as a benchmark for the non-degraded system. Similarly, the invasive abundance (or percent stressor) could be scaled from zero to a theoretical, maximum possible abundance along the x-axis.

We settled on four generalized, theoretical curves to represent the suite of species impacts (Fig. 6.3). Curve I represents a highly sensitive endpoint where low abundance of invasive plants has a large impact on the ecological endpoint. In contrast, curve IV represents a low-sensitivity endpoint where impact remains low until the invasive plant reaches high density. Curve II represents an endpoint with intermediate sensitivity, where invasive plants have minimal impact until an intermediate abundance level is reached, after which the impact increases rapidly. Curve III represents a linear relationship between density of the invasive plant and impact on the ecological endpoint.

We next considered the species-specific forms of these stressor-response relationships for four different invasive plants found within Antietam National Battlefield. The four species represent a mix of functional forms (tree, vine, shrub, and herb), and all have been labeled as species of concern to the park (Table 6.2).

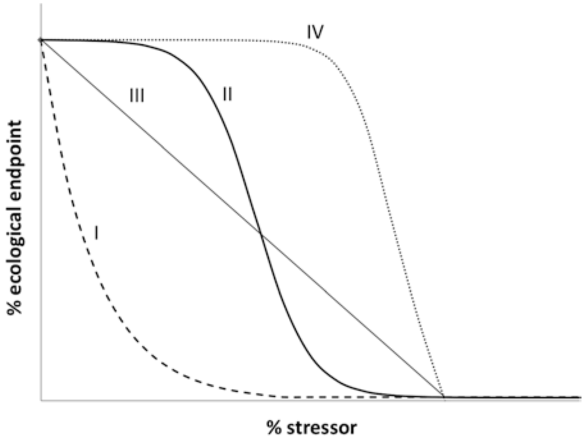


Fig. 6.3 Theoretical stressor-response curves (Adapted from Yokomizo et al. 2009)

Table 6.2 Case study species

Functional form	Common Name	Scientific Name
Tree	Tree-of-heaven	*Ailanthus altissima*
Shrub	Multiflora rose	*Rosa multiflora*
Vine	Oriental bittersweet	*Celastrus orbiculatus*
Herb	Garlic mustard	*Alliaria petiolata*

For each species, we searched the literature for information about its effect on ecosystems, focusing on potential impacts to vegetation structure and diversity as the ecological endpoint. In the following sections, we provide an overview of the relevant literature for each of the four focal invasive plant species. We use this information to select and apply appropriate theoretical stressor-response curves to depict the relationship between the percent cover of the invasive species and changes in the ecological endpoint of concern.

6.2.1 Ailanthus altissima

Ailanthus altissima, sometimes called "tree-of-heaven," is a common invasive tree in Antietam National Battlefield. Native to China, it has subsequently spread to all other continents except Antarctica (Kowarik and Säumel 2007). In its non-native range, tree-of-heaven can have major impacts on native vegetation structure and diversity.

Tree-of-heaven has several competitive advantages that alter its local environment and contribute to its success in invading new areas. Seeds are dispersed by wind but also are buoyant and remain viable after long-distance transport via water (Landenberger et al. 2007; Kowarik and Säumel 2008). Once established, individuals mature quickly, develop root networks that form dense clonal stands, and are able to resprout when cut (Miller 1990; Kowarik and Säumel 2007). The roots, leaves, and stems of tree-of-heaven exude chemicals that can negatively affect neighboring plants (Lawrence et al. 1991; Gómez-Aparicio and Canham 2008a; Heisey 1996). Greenhouse studies have shown that these allelopathic compounds reduce germination of seeds and damage or kill seedlings of multiple plant species (Heisey 1996). The impacts are greatest on heterospecific individuals previously unexposed to the species (Lawrence et al. 1991), suggesting that impacts of tree-of-heaven may be largest in newly invaded areas. Furthermore, its seedlings have fast-developing root systems and can be strong competitors for below-ground resources (Call and Nilsen 2005), altering the availability of soil resources in its proximity (Gómez-Aparicio and Canham 2008a; Vilá et al. 2006; Constán-Nava et al. 2015).

Together, tree-of-heaven's fast growth, allelopathy, and altered soil resources affect recruitment and growth of native plant species and often lead to changes in community composition and phylodiversity (Gómez-Aparicio and Canham 2008b; Vilá et al. 2006; Constán-Nava et al. 2015). Several field studies have shown a significant decrease in native plant species richness in areas invaded by tree-of-heaven. A field study near Paris, France, compared diversity under tree-of-heaven and native tree species in four different habitat types (Motard et al. 2011). In each habitat, understory vegetation under tree-of-heaven was significantly lower in species richness and species rarity than vegetation under native trees. The 15–30% loss of diversity under tree-of-heaven was linked to an increase in root suckers (Motard et al. 2011). Similarly, Vilá et al. (2006) found a 24% decrease in native plant species richness in invaded plots on Mediterranean islands compared to nearby non-invaded plots. These studies suggest that native vegetation structure and diversity may be relatively sensitive to tree-of-heaven invasion, perhaps resulting in a type I stressor-response curve (Fig. 6.4).

6.2.2 Rosa multiflora

Rosa multiflora, or multiflora rose, was intentionally introduced to the United States in the 1800s as a horticultural plant (Rehder 1936). The non-native shrub was further promoted in the mid-1900s as a way to reduce soil erosion and create living hedges for agriculture (Steavenson 1946; Reichard and White 2001). In subsequent years, multiflora rose has become an invasive species. In 2008, it was the most common introduced species in the Northeast and Midwest USA, found in over 27% of 1302 forest inventory plots (Schulz and Gray 2013). Today it is regulated or classified as a noxious weed in 12 states (USDA Federal and State Noxious Weeds; https://plants.usda.gov/java/noxiousDriver).

Multiflora rose spreads via a combination of sexual and clonal reproduction and can form large patches of monocultures up to 32 m in circumference (Jesse et al. 2010). It exhibits shade-avoiding traits (Dlugos et al. 2015) and is often most dense in successional habitats, open areas, and roadsides (Christen and Matlack 2009; Yates et al. 2004). However, multiflora rose also appears capable of establishing in a closed-canopy forest (Matlack and Schaub 2011) and can invade systems dominated by longer-lived species with slower turnover (Yurkonis et al. 2005). Its extended growing season allows understory shrubs to photosynthesize while canopy trees are bare (Dlugos et al. 2015).

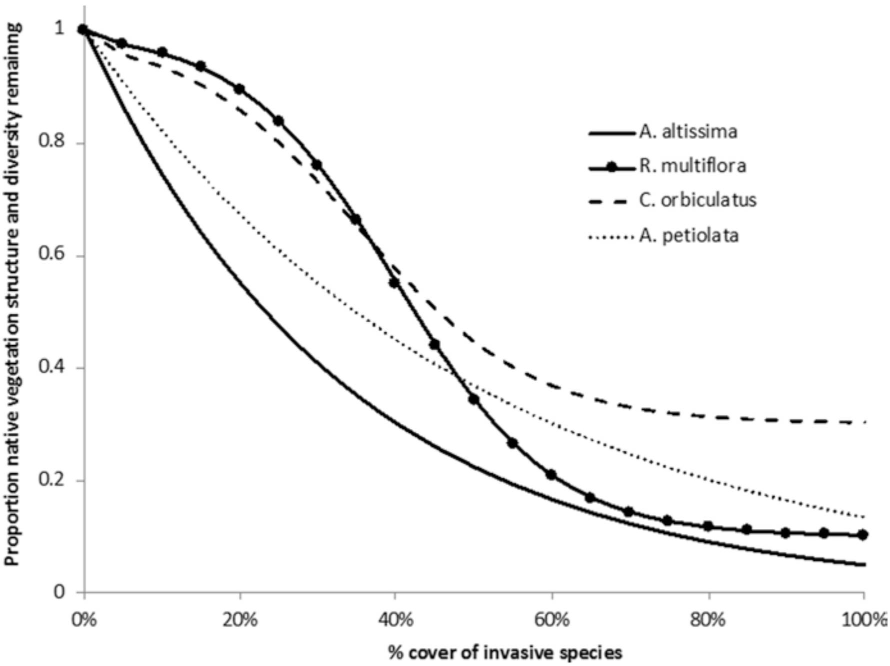


Fig. 6.4 Projected stressor-response curves for four case study species based on literature review and expert panel workshop

This large shrub can provide greater cover for foraging seed predators, therefore leading to greater discovery and removal of heterospecific seeds (Meiners and LoGiudice 2003; Meiners 2007), potentially leading to changes in community structure or species composition. A long-term study of abandoned agricultural land found that invasive shrub species, including multiflora rose, were associated with declines in both plant species richness (Meiners et al. 2001) and colonization of new species (Yurkonis et al. 2005). However, this negative impact was seen only at intermediate and high levels of invasion. Therefore, we expect vegetation structure and diversity to display a type II stressor-response curve to multiflora rose invasion (Fig. 6.4).

6.2.3 Celastrus orbiculatus

Celastrus orbiculatus, Oriental bittersweet, is a deciduous woody vine that was brought to the United States for cultivation as an ornamental species. Oriental bittersweet closely resembles a native con-generic species, *C. scandens*, but appears to outperform the native species across a broad range of light and temperature conditions (Leicht-Young et al. 2007). The congenerics also hybridize, which potentially contributes to the decline of the native species (Pooler et al. 2002; Zaya et al. 2015). Oriental bittersweet is commonly found in agricultural areas, natural forests, planted forests, grasslands, riparian zones, disturbed sites, and urban areas (Sundarapandian et al. 2015). Its range extends along the eastern seaboard from Maine to North Carolina, and west to Tennessee, Missouri, and Minnesota.

Traits leading to rapid colonization and spread of Oriental bittersweet include its high survivorship and ability to “sit and wait” for conditions that allow rapid growth (Greenberg et al. 2001). Oriental bittersweet apparently does not undergo density-dependent thinning under high densities (Leicht-Young et al. 2011). In full and partial sun, Oriental bittersweet grows quickly and may be able to overtop 1–2 m tall vegetation by the end of one growing season (Ellsworth et al. 2004). However, the plant is also tolerant of low light conditions (Leicht-Young et al. 2007), and seedlings can establish and survive under closed canopies at rates comparable to shade-tolerant trees (Ellsworth et al. 2004; Greenberg et al. 2001). Tolerance to low light probably explains why Oriental bittersweet colonized four different seral stages with equal frequency in the northern Piedmont of the United States (Robertson et al. 1994). Oriental bittersweet damages hardwood stands by stem girdling, increasing risk of ice damage, and eventually causing death by shading the crown foliage (McNab and Meeker 1987). Finally, Oriental bittersweet has alelopathic chemicals in its leaves that inhibit germination, for example of radish seeds (Pisula and Meiners 2010), and may also alter soil composition and soil processes in invaded areas, which could impact the re-introduction of native plants to these areas (Leicht-Young et al. 2009).

In their review of the top ten invasive climbing vines in the world, Sundarapandian et al. (2015) describe the primary ecosystem impact of Oriental bittersweet as overtopping native flora. This overtopping effect was seen in a four-decade study of old-field development in the northeastern United States when Oriental bittersweet invaded a portion of the field; two distinct plant communities developed based on the presence or absence of the invasive vine (Fike and Niering 2009). Bittersweet had much less of an effect in an established interior floodplain forest, where plots containing bittersweet had only slightly lower diversity, richness, and total abundance compared to plots without the invasive plant (Browder 2011). As much of Antietam National Battlefield consists of established floodplain forests, we expect that vegetation structure and diversity will show relatively low sensitivity to bittersweet invasion and follow a type II stressor-response (Fig. 6.4).

6.2.4 Alliaria petiolata

Alliaria petiolate, or garlic mustard, is a biennial plant in the Mustard family. The species is native to Europe and Asia and was introduced to North America in the mid-1800s as a culinary herb. It is currently listed as noxious in states throughout the eastern and mid-western United States. Garlic mustard is one of the few invaders that is able to grow in undisturbed woodland communities, where it is found in the understory of a variety of deciduous forests and woodlands (Munger 2001).

Garlic mustard has several traits that contribute to its success as an invader. Unlike many invasive species, garlic mustard can form dense monocultures in heavily shaded and semi-shaded habitats (Cavers et al. 1979). It produces allelopathic chemicals that suppress mycorrhizal fungi (Stinson et al. 2007), which subsequently decreases growth and survival of native mycorrhizal plants (Callaway et al. 2008). Garlic mustard tissues contain cyanide at levels considered toxic to many vertebrates (Cipollini and Gruner 2007), which probably explains why it is grazed little by mammalian or avian herbivores. In fact, in areas of high deer abundance, deer facilitate invasion by avoiding garlic mustard in favor of eating native plants instead (Knight et al. 2009). Additionally, research suggests that garlic mustard invasions may change soil nutrient availability in a way that promotes continued proliferation (Rodgers et al. 2008).

Impacts on native vegetation include mortality of existing trees and changes in understory composition. Several observational studies have shown a negative correlation between abundance of garlic mustard in the forest understory and diversity of native plant species (tree seedlings in particular), indicating that invasion by garlic mustard may lead to changes in native ecosystem structure and loss of canopy-forming trees (Stinson et al. 2007; Knight et al. 2009). In combination with deer browsing, garlic mustard can have particularly negative effects on growth of red oak (*Quercus rubra*) seedlings (Waller and Maas 2013). However, other studies show conflicting results (Rose et al. 2013; Davis et al. 2012), and some researchers suggest that garlic mustard invasion may be driven by native plant declines rather than the reverse (Phillips-Mao et al. 2014), or that the effects of garlic mustard at a site may change over time (Davis et al. 2012) or under different circumstances (Cipollini and Cipollini 2016). Therefore, while we expect garlic mustard invasion to have a relatively rapid effect on vegetation diversity because of attributes such as its allelopathy, we do not expect the final impact on the ecological endpoint to be as severe as for some other invasive species (Fig. 6.4).

It is worth noting that none of the four species are projected to have a linear stressor-response relationship. Tree-of-heaven and garlic mustard impacts are represented as type I curves, depicting their relatively large effects on vegetation at low abundance due to their fast growth, allelopathy, and ability to alter soil chemistry (especially for tree-of-heaven). There is less evidence of damages at low densities for the other two species, which follow type II theoretical curves. However, the available evidence indicates that multiflora rose can cause quite large impacts as it approaches its maximum possible abundance. From a management perspective, it would therefore be important to implement treatment for this species while it is still in its early phases of establishment before it can cause substantial harm. None of the curves were able to be parameterized from quantitative data. Instead all curves relied on qualitative evidence from the scientific literature and our expert panelists.

6.3 Ecosystem Services Impacted by Invasive Plants

The stressor-response functions are a step towards economic analyses of impacts on ecosystem services since they capture the degree to which invasives change ecosystem structure and function. These changes can be valued by translating them into ecosystem service benefits that affect people (the second step in Fig. 6.2). To value ecosystem services requires assessing people's degree of concern for any change in terms of what they would be willing to pay to avoid change (or accept change) (Freeman et al. 2014).

In the absence of the considerable work required to measure values of ecosystem service changes, ecological endpoints can be used as leading indicators of values. In this case, changes in vegetation structure and diversity can be related to their impact on the ecosystem services derived from battlefield landscapes. For example, the endpoint "vegetation structure" affects landscape character, length of views, light penetration below canopy, and habitat, which in turn affect aesthetic enjoyment of visitors interested in history, hiking, and birdwatching. Changes to ecological endpoints triggered by non-native plant invasions also can lead to changes in non-use values (Smith 1987), which affect people who never visit the park but who value preserving historic character, wildlife habitat, and biodiversity (Wainger et al. 2018).

From interviews and a review of recreational, social science, and economic literature, we identified the ecosystem services that we expected to be impacted by invasive plant-induced changes in vegetation structure and diversity. These ecosystem services are linked with four different groups of park users, each of which might differ in its sensitivity to ecological or physical changes (Table 6.3). For

Table 6.3 Ecosystem services influenced by changes in vegetation structure and diversity induced by invasive plants

Ecosystem services by user group
Casual visitors
Aesthetics of visitor experience
Convenient road/water access
Walking, hiking, biking opportunities
Safety of outdoor recreation
Avid recreationalists
Birdwatching
Native plant/wildflower viewing
Insect watching (e.g., butterflies)
Amphibian/reptile watching
Nature photography
Historic/cultural tourism
Neighbors
Safety and convenience of travel
Aesthetics from roads and viewpoints
Property values
Buffer incompatible uses
Maintenance costs (energy use, yard maintenance)
Distant and Non-use beneficiaries
Climate regulation
Native ecosystem preservation
Charismatic species preservation
Maintenance of significant natural areas

example, casual visitors might be less sensitive than avid recreationalists to visual aesthetics changes.

The set of ecosystem services that we identified emphasize the recreational benefits of battlefield parks. The services also recognize the benefits of battlefield parks on nearby property values and consider the collateral values associated with people knowing that natural areas are protected (i.e., non-uses). We recognize that parks provide a multitude of other services that are not quantified here. Further, we have not captured the values to scientific and educational user groups, even though we know that Antietam National Battlefield is well-used by both types of users. Instead, we focus on services for which there exists sufficient published literature to form the basis of a discussion.

6.3.1 Casual Visitors

Casual visitors, including joggers, hikers, dog-walkers, horse-back riders, and recreational drivers, tend to visit the park looking for exercise or relaxation. Users in this category are assumed to be less sensitive to changes in vegetation than avid recreationists but might still be affected by major changes in flora and fauna that could occur at high densities of invasive plants (Ioja et al. 2011; Zhang et al. 2015). In addition, at lower densities of invasive plants, their enjoyment might be affected by changes in aesthetic qualities, safety, or convenience. Invasive plants might affect their recreational experience by altering the character of the vegetation (e.g., making the understory more dense), reducing the probability of encounters with charismatic species such as birds and butterflies, increasing the probability of tree falls, and increasing health risks to people or pets from direct plant contact (e.g., cuts, skin irritations, and burns).

Driving for pleasure and recreation is one of the most common ways that casual visitors experience battlefield parks (NSRE n.d.). The value of this activity depends on the drivers' ability to enjoy scenic vistas and is enhanced by having well-maintained parking areas and pull-offs for enjoying the scenery and taking photographs (Hallo and Manning 2009). Some NPS units have explicit goals of offering recreational driving experiences. This service is sensitive to changes in vegetation structure that affect views and the risks to park users from tree falls.

6.3.2 Avid Recreationists

Avid recreationists include those who visit parks to experience specific species or ecosystems (i.e., nature viewers), or to experience the historical or cultural heritage of the park (i.e., historical and cultural tourists). This group is likely to be more sensitive to changes caused by invasive species than casual visitors.

Nature viewing includes birdwatching, native plant/wildflower viewing, insect watching (e.g., butterflies), amphibian/reptile watching, and nature photography.

Nature viewing will be affected if native plants induce changes in vegetation that ripple to higher trophic levels. For example, the introduction of garlic mustard is partially credited with decline of the rare West Virginia white butterfly (*Pieris virginiensis*) due to chemicals that appear to be toxic to the larval form (Davis et al. 2015). Richness of other arthropods may also be negatively affected by garlic mustard invasion (McCary 2016). Through impacts on insect communities and particularly on lepidopteran larvae, which are a disproportionately valuable source of food for multiple species of terrestrial birds (Tallamy 2004; Tallamy and Shropshire 2009), invasive plants can have indirect impacts on bird communities as well.

Invasive plants can also directly impact bird communities by changing vegetation structure and composition. In urbanizing landscapes, bird nests in exotic shrubs (including multiflora rose) experience higher daily mortality rates than those in native shrubs. This is likely due to reduced nest height and larger shrub volume surrounding the nests in exotic shrubs (Borgmann and Rodewald 2004). Furthermore, fruits of invasive shrubs like multiflora rose have been shown to be less appealing and less nutritious for migratory birds than fruits from native shrubs and thus may alter migratory stop-over dynamics (Bolser et al. 2013; Smith et al. 2013).

A sizable subset of recreationists visits parks, especially battlefield parks, with the primary goal of experiencing the historical or cultural heritage of the sites. The entire park can be a cultural or historical site, or components within the park may be the focus of the visit. For example, many Civil War battlefield parks aim to maintain vegetation appropriate to the period of conflict in the 1860s; this service would be threatened if invasive plants altered the historic vegetation. Similarly, invasive plants could threaten cultural tourism if vegetation damaged structures of cultural importance or significant aspects of historical vistas.

6.3.3 Neighbors

Battlefield parks provide amenities to neighbors because they provide open space, aesthetic benefits, and convenient recreational opportunities. Studies suggest that property adjacent to parks or other types of open space often has enhanced value relative to similar property not similarly situated (Crompton 2001; Geoghegan 2002; McConnell and Walls 2005). Hence, battlefield parks would be expected to have a positive effect on adjacent and nearby homes (Lutzenhiser and Netusil 2001). Due to their urban and suburban setting, battlefield parks often include major commuting roads for adjacent landowners that intersect or form park administrative boundaries.

However, with invasive plants, the value of this amenity can diminish if park aesthetics decline in the area adjacent to the property (Fox 1990) or if proximity becomes a “disamenity” due to threats of falling trees or a persistent source of noxious weeds. Large-scale changes in vegetation structure can further lead to changes in nearby heating and cooling cost (Nowak et al. 2006), although energy-saving benefits may already be captured in the property value premium.

6.3.4 Distant and Non-use Beneficiaries

Non-use or passive-use services are those associated with preserving a resource that will not be used in any tangible way. For example, people may value the existence of diverse vegetation communities even if they never plan to visit these communities. This service is associated with sense of place and intergenerational stewardship, which is the notion that people have an ethical responsibility to future generations to care for nature (Welburn 2014). Non-use services are typically divided into existence, option, and bequest values (Smith 1987), which correspond to benefits associated with knowing a resource exists, preserving the option to use it in the future, or providing the opportunity for future generations to use or enjoy that resource.

Non-use environmental values are generally underappreciated for battlefield landscapes. Non-use values for environmental preservation have the potential to outweigh those for cultural/historical preservation (Turner and Willmarth 2014), but may never be measured for parks that do not contain rare or endangered species. Nevertheless, more data on all types of non-use values, including cultural and historical services, provided by battlefield parks would be useful, as studies have shown that non-use values can greatly exceed use values (Grosclaude and Soguel 1993; Ruijgrok 2006).

6.4 Conclusions: Managing Biological Invasions to Promote Ecosystem Services in Battlefield Landscapes

Battlefield parks present an opportunity to provide numerous ecosystem services in close proximity to urban areas. However, as these parks mature, the management of their natural resources requires increasing attention. In particular, invasive plants represent a pervasive and costly challenge that will continue to grow over time. In this chapter, we presented a systematic approach to understanding how invasive plants can impact the ecosystem services provided by battlefield parks. This is a crucial step in identifying the level of control effort that will provide the greatest net benefits to the parks' diverse stakeholders.

Our approach starts by identifying stressor-response functions that connect invasion by non-native plants to ecological endpoints: here, changes in vegetation structure and diversity. We approached this task by conducting a literature review and a workshop to elicit expert opinion. This experience was illuminating in several ways. First, we quickly encountered limitations in terms of published literature about how invasive plants affect relevant ecological endpoints, such as native vegetation diversity and structure. Of the existing studies, which focus on a limited set of species (and are unevenly distributed across functional forms), the vast majority were observational rather than experimental, leaving uncertainty as to the potential causality of invasive-native plant relationships.

A second lesson learned was that while experts generally agreed that invasive plants have nonlinear effects on native vegetation, we found very little in the literature to either support or refute this idea. If our proposed stressor-response curves are reasonably accurate, lack of information combined with the nonlinear effects depicted by the curves could catch managers unaware of dangerous thresholds. Furthermore, these results would have implications for cost-effectiveness targeting of management actions. As one example, the existence of nonlinear relationships dictate that all restoration will not do the same amount of good. The magnitude of change in ecological endpoint is a function of the amount of change in invasive abundance as quantified by the slope of the stressor-response curve. The fact that the slope may differ at different invasive abundances dictates that restoration opportunities should be weighed carefully to target situations in which the greatest change in ecological endpoint is achieved per unit decrease in invasive abundance.

We offer a further caution that the impacts of non-native, invasive plants are not spatially uniform. First, the spread of invasive plants in these heterogeneous battlefield landscapes is highly variable depending on, among other factors, the location of introduction, the spatial patterning of the physical landscape, and the dispersal mode of the invading species (Holdenreider et al. 2004; Ferrari and Lookingbill 2009; Minor et al. 2009). In addition, the ecosystem services that are impacted are also spatially variable. For example, we would expect impacts to wildlife viewing to be concentrated in park management parcels of high habitat value for rare or charismatic species where wildlife viewers typically concentrate their activities (Fig. 6.5). The impact to historical visitors would spread along the main tour roads and trails of parks, as well as around park visitor centers. In light of this spatial variability, spatial targeting of management may be an approach to maximizing the benefits of management.

We see several potential next steps in this research. The stressor-response models developed in this chapter are only a first-cut and could be further refined with additional experimental data, for example. Lack of adequate information to better quantify these relationships is a common lament among invasive species managers. However, conceptual models like those presented here are valuable for prioritizing restoration activities and improving the return on investment from these actions, assuming they can approximate the shape of the function reasonably well.

An obvious omission from this chapter is the creation of damage functions — how do altered environmental endpoints quantitatively affect ecosystem service benefits? The evaluation of these functions requires consideration of how the biophysical changes in the environment influence the social or economic benefits that people derive from parks. For example, an invasive species may reduce the rate of groundwater recharge in a system – an ecological response. However, this change will create an economic harm only if the change in groundwater recharge rate is sufficient to reduce water levels where it is being pumped and may be a substantial harm only in areas where water is scarce and therefore valuable (e.g., Zavaleta 2000; Le Maitre et al. 2002). Assessments of the financial impacts and costs required to prevent and eradicate invasive plants are rare, but an important next step (Abella 2014). Based on general assumptions about the value premium associated with proximity to natural parks (e.g., Curtis 1993; Lutzenhiser and Netusil 2001), we might expect, for example, an overall invasive plant impact of nearly $500,000 to the 440 homes within the zone of influence of Antietam National Battlefield (Wainger et al. 2012).

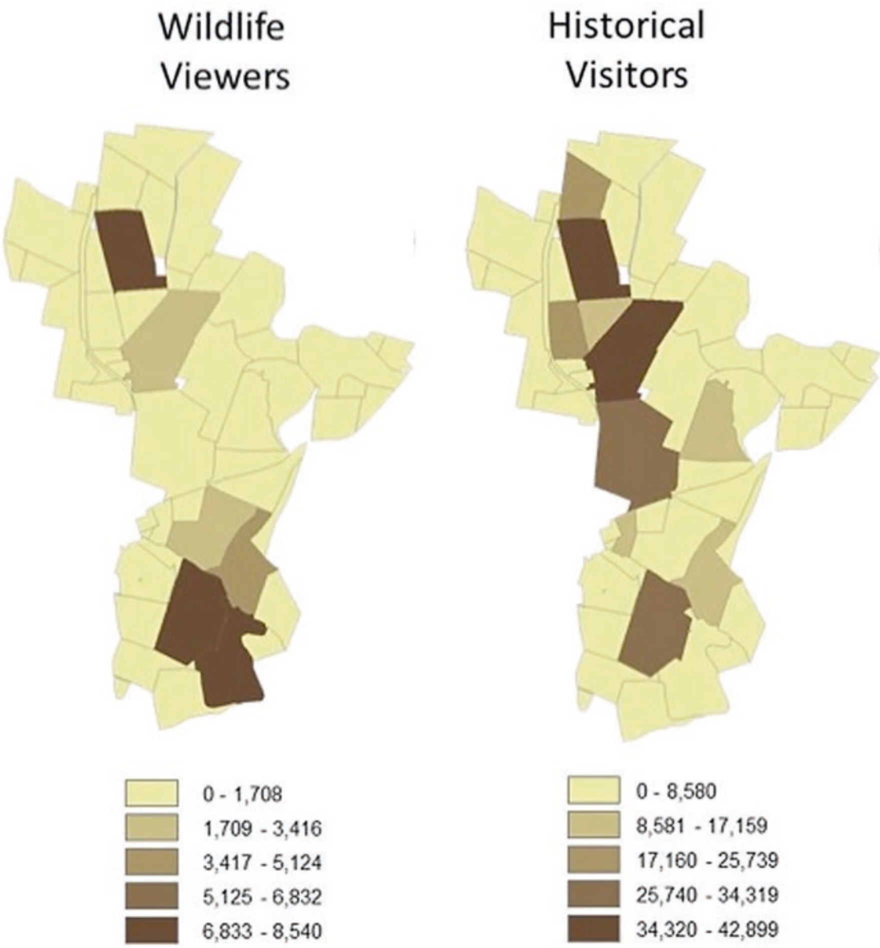


Fig. 6.5 Spatial patterning of two different ecosystem services at Antietam National Battlefield (annual number of users estimated per management unit)

Additional research is needed to examine effects of other invasive species and other ecological endpoints beyond vegetation structure and diversity. Invasive species are also certainly not the only threats to battlefield parks. New studies could consider the potential interactive effects of invasive plants with climate change, increasing isolation within an urbanizing matrix, and regional air-quality degradation. More detailed maps of the damages wrought by non-native, invasive plants also would be of great value to managers who must decide where to focus their eradication efforts.

We present this case study for Antietam National Battlefield, but the challenges are widespread for battlefield parks. For example, the cover of *Ligustrum sinense*, Chinese privet, increased five-fold from 1993 to 2008 in Chickamauga and Chattanooga National Military Park, contributing to a 70% decrease in native herbaceous plants, including rare and priority species (Sutter et al. 2011; Abella 2015).

National Park Service resources for managing non-native, invasive plants at most battlefield parks are scarce, often relying solely on one of the 16 Exotic Plant Management Teams spread throughout the country (Fraley et al. 2007). These management actions are expensive. A recent effort to reduce the density of *Lonicera morrowii*, Japanese honeysuckle, by half at Fort Necessity National Battlefield cost up to $9300/hectare for just the first treatment when plants were hand pulled (Love and Anderson 2009). However, these threats can not be ignored. Developing cost-effective strategies for treating invasive plants will be a priority for battlefield parks as they mature and embrace the ecosystem services provided by their natural resources as a complement to their historical and cultural missions.

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