National Park Service
U.S. Department of the Interior

Natural Resource Stewardship and Science

Invasive Plant Management Planning

Technical Considerations

Natural Resource Report NPS/NRSS/BRD/NRR—2018/1820

ON THE COVER
Yosemite weeds crew spraying yellow starthistle above Merced River.
Photograph by Sarah Hall

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The National Park Service, Natural Resource Stewardship and Science office in Fort Collins, Colorado, publishes a range of reports that address natural resource topics. These reports are of interest and applicability to a broad audience in the National Park Service and others in natural resource management, including scientists, conservation and environmental constituencies, and the public.

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All manuscripts in the series receive the appropriate level of peer review to ensure that the information is scientifically credible, technically accurate, appropriately written for the intended audience, and designed and published in a professional manner.

This report received formal peer review by subject-matter experts who were not directly involved in the collection, analysis, or reporting of the data, and whose background and expertise put them on par technically and scientifically with the authors of the information.

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Executive Summary

The National Park Service (NPS) manages non-native invasive plant species that impact the natural and cultural resources and visitor experience in parks. This document provides an overview of key technical concepts and critical information needed to develop the content of an effective invasive plant management plan. It does not address the specifics of the planning process and environmental compliance requirements as that guidance is provided by the NPS Environmental Quality Division.

Invasive plant management needs to be strategic and based on the best available science. Invasive plant management planning is critical for successful implementation of an invasive plant management program that serves to protect park values at risk from invasive plants. Each division within the park as well as park volunteers, partners, and neighbors plays a role in implementing a successful plan.

The plan must document what species are present, what species are likely to be present in the future, critical aspects of their biology and ecology, and what methods are available for their control. It must prioritize species and sites so that limited resources can be employed efficiently. The planning document is an opportunity to document compliance with law and policy or to serve as the foundation for that compliance. The frameworks of Adaptive Management and Integrated Pest Management are useful to ensure realistic goals are set and practices are safe.

Staff at park units without a current invasive plant management plan can use this guidance to help develop a robust plan that complies with law and policy and invests available resources efficiently to address invasive plant management needs on a programmatic basis. This document summarizes foundational information regarding laws and policies on which to build an invasive plant management plan, describes best practices for invasive plant management planning, and details technical considerations for the development of an invasive plant management plan.

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List of Acronyms

APCAM:	Alien Plant Control and Monitoring
APHIS:	Animal and Plant Health Inspection Service
BMP:	Best Management Practice
BRD:	Biological Resources Division of NPS-NRSS
CFR:	Code of Federal Regulations
DO:	Director's Order
EA:	Environmental Assessment
EO:	Executive Order
EPMT:	Exotic Plant Management Team
FIFRA:	Federal Insecticide, Fungicide, and Rodenticide Act
GAR:	Green-Amber-Red risk assessment model (for operational leadership)
GIS:	Geographic Information System
GPS:	Global Positioning System
IPM:	Integrated Pest Management
NEPA:	National Environmental Policy Act
NPS:	National Park Service
NRSS:	Natural Resources Stewardship and Science Directorate
RM:	Reference Manual
SOP:	Standard Operating Procedure
SPE:	Severity-Probability-Exposure risk assessment model (for operational leadership)
USC:	United States Code

Introduction

Scope of the Invasive Plant Issue for the National Park Service

It is the policy of the National Park Service (NPS) to manage invasive species that are interfering with natural processes, native species, native habitats, cultural resources, and the visitor experience. NPS manages approximately 84 million acres of land across a broad range of habitats. Invasive species negatively impact every park unit with natural resources and dominate millions of acres of park land and waters. Allen et al. (2009) used survey data from 2002 to conclude that the 216 parks surveyed contained 3756 non-native species covering 18 million acres. In 2014 the updated data set identified 4113 non-native taxa in national parks (NPS 2015). New plant species continue to be introduced over time and the rate of introduction is increasing (Stohlgren et al. 2013). Allen et al. (2009) also concluded that higher native richness, higher visitation, longer trail networks, and longer sections of rivers, are all positively correlated with higher non-native species richness.

NPS park units manage invasive plants with a variety of tools, including a portion of the parks receiving assistance from the Exotic Plant Management Team (EPMT) program. Although data are not available for the full scope of NPS activities controlling invasive plants, the EPMT program invests approximately $5 million per year to manage invasive plants. Since 1995 EPMT has inventoried millions of acres and treated 1000 invasive plant taxa over 130,000 acres.

Terminology

The terms weed, exotic, invasive, non-native, and alien can be confusing. Throughout this document the term “invasive” is used consistently with the following definition provided by the National Invasive Species Council (NISC 2006):

> An invasive species is a non-native species whose introduction does or is likely to cause economic or environmental harm or harm to human, animal, or plant health. Invasive species are species not native to the ecosystem being considered.

It is important to note that laws, executive orders, policies, programs, research reports, and existing plans have not always used the same definition and, in some cases, used the terms interchangeably. Where those pre-existing references are included in this document, their original word choice will be retained.

Relevant Laws and Policies

A number of laws and policies direct the NPS to manage or control invasive plant species. The major laws are described in more detail in Corn and Johnson (2013). The most broadly relevant laws and policies are summarized below.

NPS Policy

NPS Management Policies (2006) uses the term exotic rather than invasive. Section 4.4.1.3 defines exotic species as “those species that occupy or could occupy park lands directly or indirectly as a result of deliberate or accidental human activities. Exotic species are also commonly referred to as nonnative, alien, or invasive species. Because an exotic species did not evolve in concert with the species native to the place, the exotic species is not a natural component to the natural ecosystem at that place.” In section 4.4.4 the policy further defines the legal basis of an exotic plant management program by stating that “exotic species will not be allowed to displace native species if displacement can be prevented” and elaborates in section 4.4.4.2 that all exotic plant and animal species that are not maintained to meet an identified park purpose will be managed – up to and including eradication – if (1) control is prudent and feasible, and (2) the exotic species:

- interferes with natural processes and the perpetuation of natural features, native species or natural habitats, or
- disrupts the genetic integrity of native species, or
- disrupts the accurate presentation of a cultural landscape, or
- damages cultural resources, or
- significantly hampers the management of park or adjacent lands, or
- poses a public health hazard as advised by the U.S. Public Health Service, or
- creates a hazard to public safety.

Section 4.4.5.1 defines pests as living organisms that interfere with the purposes or management objectives of a specific site within a park or that jeopardize human health or safety. Section 4.4.5.2 prescribes that management of exotic species will be based on the use of an integrated pest management program to reduce risks to the public, park resources, and the environment from pests and pest-related management strategies. Integrated pest management is a decision-making process that coordinates knowledge of pest biology, the environment, and available technology to prevent unacceptable levels of pest damage by cost-effective means while posing the least possible risk to people, resources, and the environment. Specific policies exist regarding pesticide use approval, purchase and storage (NPS 2006, Section 4.4.5.5), and reporting as well as the use of biological control agents (NPS 2006, Section 4.4.5.5).

Director's Order/Reference Manual 12: Conservation Planning, Environmental Impact Analysis, and Decision-Making (NPS 2011, 2015) lays the groundwork for how the NPS complies with the National Environmental Policy Act (NEPA). The Order sets forth a planning process for incorporating scientific and technical information and establishing a solid administrative record for NPS projects and programmatic plans. The Order requires that impacts to park resources be analyzed in terms of their context, duration, and intensity. It is crucial for the public and decision makers to understand the implications of those impacts in the short and long term, cumulatively, and in context, based on an understanding and interpretation by resource professionals and specialists. The Order also requires that an analysis of impairment to park resources and values be made as part of the NEPA process.

Management of wilderness (under the Wilderness Act of 1964, described below) in the National Park Service is guided by NPS Management Policies (NPS 2006) and Director's Order/Reference Manual #41: Wilderness Preservation and Management (NPS 2013). The Order directs "Potential disruption of wilderness character and resources and applicable safety concerns would be considered before, and given significantly more weight than, economic efficiency and convenience. If a compromise of wilderness resources or character is unavoidable, only those actions that have localized, short term adverse impacts would be acceptable." Any prohibited use proposed in wilderness for non-emergency activities must be considered and documented with a wilderness minimum requirement analysis. The wilderness minimum requirement analysis will first include a determination of whether such use is necessary for the administration of the area as wilderness, and if so, would then determine the minimum method or tool that causes the least amount of impact to the physical resources and experiential qualities of wilderness as well as a discussion of alternatives considered. Additional wilderness considerations for invasive plant management planning are included in Appendix A.

Federal Laws

The stated purpose of the NPS (Organic Act of 1916) is to "conserve the scenery and the natural and historic objects and the wild life therein and to provide for the enjoyment of the same in such manner and by such means as will leave them unimpaired for the enjoyment of future generations." Each park was established by federal legislation or Presidential Proclamation and the specific direction provided in that legislation and/or the legislative history may give direction for the consideration of invasive plants. Many parks consider its native plant communities to be important features of the area (as may be reflected in the park Foundation Document as a fundamental resource or value or other important resource or value). Thus their preservation, including management of invasive plants that threaten native plant communities, may be consistent with the park's establishment as a unit of the National Park System.

The Plant Protection Act became law in June 2000 as part of the Agricultural Risk Protection Act. The Plant Protection Act consolidates all or part of 10 existing U.S. Department of Agriculture plant health laws into one comprehensive law, including the authority to regulate plants, plant products, certain biological control organisms, noxious weeds, and plant pests. The Plant Quarantine Act, the Federal Pest Act, and the Federal Noxious Weed Act are among the 10 statutes that the new act replaces. The Plant Protection Act is necessary because of the major impact plant pests could have or currently have on the agriculture, environment, economy, and commerce of the United States. The Plant Protection Act gives the Secretary of Agriculture (and through delegated authority, the Animal and Plant Health Inspection Service of the U.S. Department of Agriculture) the ability to prohibit or restrict the importation, exportation, and interstate movement of plants, plant products, certain biological control organisms, and noxious weeds, and plant pests. The act also authorizes the Animal and Plant Health Inspection Service to regulate "any enemy, antagonist, or competitor used to control a plant pest or noxious weed."

Although the Plant Protection Act of 2000 superseded and repealed most of the Federal Noxious Weed Act of 1974, section 15 (Management of Undesirable Plants on Federal Lands [7 USC 2814]) was retained. Section 15 requires federal land management agencies to develop and establish management programs to control undesirable plants on federal lands under the agencies' jurisdiction. Undesirable plants are those classified under state and federal law as undesirable, noxious, harmful, injurious, or poisonous. Under the authority of this Act the USDA Animal and

Plant Health Inspection Service periodically updates a listing of federal noxious weeds which is reflected in their status by species in the Plants database (http://plants.usda.gov). The act also requires that federal land management agencies enter into cooperative agreements to coordinate the management of undesirable plant species on federal lands where similar programs are being implemented on state and private lands in the same area. The Secretaries of Agriculture and the Interior must coordinate their respective control, research, and educational efforts relating to noxious weeds.

Executive Order 13751, Safeguarding the Nation From the Impacts of Invasive Species, signed on December 2016, amends Executive Order 13112. Section 2 of the Executive Order directs federal agencies to identify actions that may affect the status of invasive species and take action to: prevent the introduction of invasive species, detect and respond rapidly to eradicate or control populations of such species in a cost-effective and environmentally sound manner, monitor invasive species populations accurately and reliably, provide for restoration of native species and habitat conditions in ecosystems that have been invaded, conduct research on invasive species and develop technologies to prevent introduction and provide for environmentally sound control of invasive species, and promote public education on invasive species and the means to address them. The National Invasive Species Council Management Plan is an interagency document developed in support of EO 13751. The 2016-2018 Plan identifies six priority actions: provide institutional leadership and set priorities, facilitate effective coordination and cost-efficiencies, raise awareness and motivate high-impact actions, remove barriers, assess and strengthen federal capacities, and foster innovation.

Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA) and the regulation established by the U.S. Environmental Protection Agency (40 CFR 116-117,195,170-172) serve as primary guidance governing pesticide registration, pesticide use, the training and certification of pesticide applicators, and the criminal and civil penalties associated with misuse of pesticides. FIFRA defines the term "pesticide" as (1) any substance or mixture of substances intended for preventing, destroying, repelling, or mitigating any pests; (2) any substance or mixture of substances intended for use as a plant regulator, defoliant, or desiccant; and (3) any nitrogen stabilizer. Herbicide is a specific class of pesticide used to treat plants. All pesticides used in the United States must be registered by the U.S. Environmental Protection Agency. Registration ensures that pesticides will be properly labeled, and if used in accordance with specifications, will not cause unreasonable harm to the environment. Pesticide labels include direction for the protection of workers who apply the pesticide and direction for reducing exposure to non-applicators. Violation of these directions constitutes a violation of FIFRA. The storage and disposal of most pesticides are also regulated under the act, with specific direction provided on pesticide labels. Enforcement of the act is delegated to individual states. FIFRA also gives the U.S. Environmental Protection Agency review authority for biological control agents when they are used to control invasive pests.

The National Environmental Policy Act (NEPA) was enacted in 1969 for this reason: to make sure that agencies fully consider the environmental costs and benefits of their proposed actions before they make any decision to undertake those actions. The Act and subsequent regulations enacted by the Council on Environmental Quality establish two mechanisms to achieve this stated intent: (1) a requirement that all agencies make a careful, complete, and analytic study of the impacts of any proposal that has the potential to affect the environment, and alternatives to that proposal well before any decisions are made; and (2) the mandate that agencies be diligent in involving any interested or affected members of the public in the NEPA process. The National Park Service establishes agency policy and procedural requirements for compliance with NEPA in Directors Order/Reference Manual #12: Conservation Planning, Environmental Impact Analysis, and Decision-Making. Invasive Plant Management Plans are typically accompanied by or include an environmental assessment or environmental impact statement completed in compliance with NEPA.

The Wilderness Act of 1964 established a national wilderness preservation system "administered for the use and enjoyment of the American people in such manner as will leave them unimpaired for future use and enjoyment as wilderness, and so as to provide for the protection of these areas, the preservation of their wilderness character, and for the gathering and dissemination of information regarding their use and enjoyment as wilderness (16 USC 1131)." The act defines wilderness as "an area where the earth and its community of life are untrammeled by man, where man himself is a visitor who does not remain." Under Section 4(c) of the Wilderness Act, the following activities are generally prohibited in wilderness: commercial enterprises, permanent roads, temporary roads, use of motor vehicles, use of motorized equipment, use of motorboats, landing of aircraft, other forms of mechanical transport, structures or installations. Thus treatment of these invasive plants in wilderness is constrained by the requirements of this Act and the NPS policies that implement it.

Congress passed the National Historic Preservation Act of 1966 because "the historical and cultural foundations of the Nation should be preserved as a living part of our community life and development in order to give a sense of orientation to the American people" (16 USC 470b [2]). Section 106 of the Act requires that federal agencies consider the effects of their undertakings on historic properties; that is, those cultural resources eligible for the National Register of Historic Places. Treatment methods proposed to control invasive plants and the presence of invasive plants among historic structures and archaeological sites may have effects on historic properties in the Park and thus require consideration and consultation under this Act.

Section 7 of the Endangered Species Act of 1973 requires all federal agencies to ensure that any action authorized, funded, or carried out by the agency will not jeopardize the continued existence of any endangered or threatened species or adversely modify any critical habitat of these species (16 USC 1536[a][2]). Each federal agency must consult with the U.S. Fish and Wildlife Service (or the National Marine Fisheries Service for certain marine and anadromous species) regarding any federal action that may affect a listed species. Numerous endangered or threatened species as well as critical habitat for these species exist in many NPS units; pursuant to the Act, plans to control invasive plants must be consistent with the recovery plans for listed species.

State Laws

Every state has laws that govern invasive plants. Most states refer to a subset of invasive species as "noxious" and many states maintain a state noxious weed list that invokes specific regulations regarding lands that harbor those species and transport of those species. It is important to note that many noxious weed lists include both native and non-native species and the perception of the species as a "pest" or "weed" is often from an agricultural perspective and may not reflect the mission or values of the National Park Service. At a minimum all non-native noxious weeds listed in relevant states should be considered in a park's invasive plant management plan; however, native species listed as noxious weeds should be considered in light of NPS Management Policies. In addition, due consideration should be given to the fact that there are likely many other species that are highly invasive in park lands that are not listed in state noxious weed lists because they primarily affect natural ecosystems rather than agricultural values. These species should be considered in a park's invasive plant management plan regardless of their state status.

In some cases, local, county, or Tribal ordinances may also exist that deal with invasive or noxious plants. How binding these ordinances are on park land will vary by park based on the type of jurisdiction and land ownership the park has. Regardless, resource managers should be aware of these ordinances as part of the fabric of the park's physical and political landscape.

A summary of relevant state laws should be included in park invasive plant management plans and should be consulted periodically during implementation to assure continued compliance with state laws and regulations that may change over time. Pre-season work planning is a good opportunity to check for changes in state laws or regulations so that adjustments can be made if necessary prior to the next field season.

Best Practices for Invasive Plant Management Planning

This section summarizes some general concepts relevant to invasive plant management planning efforts, including understanding invasion ecology, understanding plant ecology, being forward thinking by preparing for future management actions, establishing realistic goals, ensuring that the planning process and actions laid out in the plan are legally defensible, managing risk, and incorporating adaptive management into the process. These topics are broad and are offered as concepts to consider in the development of an invasive plant management plan for lands and waters managed by the National Park Service. These topics should be considered in the pre-planning phase to set the context for development of a comprehensive and practical invasive plant management plan.

Understand Invasion Ecology

Invasion ecology is a rapidly evolving field of keen interest scientifically, economically, and for management of natural ecosystems including national parks. It deals with questions such as which species are most likely to be invasive and where, which habitats are most likely to be invaded (invasibility), how invasions proceed and factors regulating them, and how global policies and management intervention can limit the spread and impacts of invasive plant species. Lowry et al. (2013) recently conducted a systematic review of the invasion ecology literature. Their search returned over 2,398 research articles published between 1966 and 2011 dealing with invasion hypotheses and impacts of invasions. Even this enormous total represents only a fraction of knowledge in this rapidly expanding field that is producing major principles regarding invasions and their management. See Appendix B for recent research categorized by topics relevant to invasion ecology.

An understanding of invasion ecology is paramount to the development of effective invasive plant management strategies. Invasion ecology informs key management decisions in species and site prioritization, such as when to switch to or from early detection/treatment and reduction of established infestations, as well as the choice of the most effective treatment regimes (e.g., timing or duration). Some of the most management-relevant principles from invasion ecology relate to how invasive plants become established, timing of expansion of invasive plant populations, relationships of species traits and habitat invasibility, disturbance, and interactions of plant invasions with other agents of change (e.g., climate change).

Following is a summary of key principles of invasion ecology (synthesized from numerous references and summarized in books such as Davis 2009):

- Many introductions do fail; there are opportunities to stop invasions before they become well established.
- There is often a ‘lag phase’ between introduction and population explosion, providing another management window.
- Introduced species vary in their invasiveness, site preferences, impacts, and amenability to control.
- Habitats vary in their invasibility. Some habitats are readily invaded, while others better resist invasion. Unfortunately, no habitats are immune from invasion.
- Disturbance is often - but not always - correlated with range expansions of invasive plant species.
- Plant invasions interact with other biotic invasions (e.g., insects) and other agents of change (e.g., climate, fire).

The dynamics of plant introductions and establishment are initial determinants of if, where, and how a new species invades. A first principle of invasion ecology is that many intentional, or unintentional, introductions do fail (Davis 2009). Moreover, initial introductions may fail for numerous reasons (e.g., a species’ seed arriving on unsuitable habitat within a new continent), but a later introduction may succeed if conditions are favorable for the species.

A second principle is that there is often a lag time between initial establishment of an invading species and rapid population growth and distribution expansion (Crooks 2005). This lag time can be months to years to at least decades. Why this lag time occurs remains poorly understood, but may relate to factors such as attainment of critical population sizes needed for rapid growth, population sizes or time needed to improve adaptability to the new habitat, time for seed dispersal processes to create ‘satellite’ populations that then expand and coalesce, or coincidence of favorable conditions (e.g., wet periods, or disturbance) that promote invasion. Lag times complicate management of invasive plants. Some plant species may never become highly invasive and remain at low, innocuous levels for years or even centuries. On the other hand, other species may remain at seemingly innocuous levels before increasing exponentially to inflict great damage. These ‘lag’ species can be relatively easily managed initially, but difficult or nearly impossible once exponential population growth has begun.

One example of a species with a lag time is Sahara mustard (*Brassica tournefortii*) in the Mojave and Sonoran Deserts. First documented in California in the 1920's it was a pesky, local invader in disturbed soils for many decades slowly making its way eastward. In the 1990's land managers started becoming alarmed at its increasing presence in monocultures in flat, sandy desert lands but, as is true for many desert species, its population fluctuated dramatically from year to year. The winter of 2004-05 was unusually wet with perfect timing of precipitation for Sahara mustard germination. The population exploded and plants were soon found virtually everywhere, even in high densities in places where this species had not been seen before or at least was obscure or went unnoticed. Following the fuel loading associated with a wet winter, the summer of 2005 brought fire and almost 1 million acres burned in June and July. These large burned areas were readily invaded by the massive seed production of the tens of thousands of acres of Sahara mustard that had grown that spring prior to the fires. Thus Sahara mustard is now a ubiquitous species in much of the low to mid elevation desert lands, including millions of acres of NPS land.

A third key invasion ecology principle is that species vary in their invasiveness, site preferences, impacts, and amenability to control (Hulme 2012). Some species exhibit invasiveness quickly upon introduction, some only display their invasiveness after a long lag time, and others may always exhibit low invasiveness or be invasive only in certain habitats. Some invasive plant species do have site preferences that are broader than those of many native species and are able to infest numerous habitats. Even these species, however, usually are characterized by a certain range of site preferences in which they perform best. The key point is that basic principles of plant ecology, such as plants responding to their environment (e.g., nutrient and moisture availability), apply to invasive plants. This results in invasive plants performing best within particular ranges of conditions, akin to native species. Invasiveness, combined with site preferences and species traits, influences species impacts. Some invasive plant species minimally impact invaded ecosystems, whereas other invasive species severely impact ecosystems.

A fourth principle of invasion ecology is that habitats vary in their invasibility (Levine et al. 2004). Causal factors influencing invasibility can differ among ecosystems, time periods, and invading species. For example, moist, nutrient-rich habitats are often the most invasible because they offer environments favorable for plant growth. If these habitats are dominated by highly competitive (or allelopathic) native species, however, the native species can constitute a formidable impediment to establishment of some invasive plants. In some cases, dry or nutrient-poor habitats – including deserts – can also be highly invasible. Part of the reason for this can be that the habitats offer extensive soil area not already colonized by native plants. This sparsely vegetated soil is thus open to invasion by invasive plant species that use environmental resources differently than native species.

A fifth principle of invasion ecology is that disturbance is often, but not always, correlated with spread and abundance of invasive plants (Rew and Johnson 2010). Disturbance can promote plant invasions by dispersing seeds, reducing competition by native plants, creating bare soil surfaces, and releasing plant-available soil nutrients. Disturbances that remove plants, such as grazing or fire, can also reduce the biomass of invasive plants initially, though the reduction is usually short-lived as the disturbance mechanisms can make the landscape more vulnerable to future invasions. Moreover, some of the most damaging invaders in North America have no apparent inherent requirement for disturbance. Kudzu (*Pueraria montana*) and Chinese privet (*Ligustrum sinense*), for example, are two problematic species of eastern forests and have a demonstrated ability for expanding in minimally disturbed forests (Webster et al. 2007). Buffelgrass (*Cenchrus ciliaris*, common synonym *Pennisetum ciliare*) and red brome (*Bromus rubens*) are two of the most invasive plant species of southwestern arid lands and both can invade remote desert habitats rarely visited by humans. The key point is that it is important to understand and anticipate interactions between disturbance and invasive species that are particular to each park unit.

A sixth, and increasingly important, principle of invasion ecology is that plant invasions can interact with other biotic invasions and other agents of global change (Diez et al. 2012). For example, introduced forest insects can create forest die offs that, in turn, create conditions that promote invasive plants. Other agents of change, such as nitrogen deposition, changes in fire regimes, or hydrological alterations, also influence invasions through effects on habitat invasibility or invading species directly. Thus treating the invasive species may be only one part of the needed management response. Potential for climate change to influence invasions is high and warrants further research (Hellmann et al. 2008; Stohlgren et al. 2014). The current state of the science suggests that climate change may exacerbate some plant invasions, while actually reducing or forestalling others. For instance, droughts can promote invasions by weakening resident native vegetation, but droughts also can reduce or eliminate some invasive plant populations. This can create opportunities for native plant restoration. Responses to climate change will vary by species and plans should build in flexibility to accommodate potential changes in biotic invasions as climate continues to change.

Understand Plant Ecology

While species can behave quite differently in newly invaded habitats compared to their native habitat, their native habitat still provides some clues as to where a species might be found in the newly invaded habitat. For example, species invasive in southwestern U.S. parks tend to originate from comparably arid or semi-arid habitat on their native continents, while species invasive to temperate U.S. parks often hail from moister areas on other continents. Examining the ecology of a species in its native habitat can provide valuable insights for its management as an invasive species.

Similarly, a species in its invasive habitat still functions as a living organism that has environmental tolerances and responds to environmental stresses. While invasive species can have wider ranges of environmental tolerances than native species, or than the invasive species has in its native habitat, there often still are characteristic environments most preferred by the invader. Soil type, for instance, can constrain distribution of invasive plant species. Invasive plants can also influence soil properties around them. Moreover, invasive plants recruit using the same basic processes – via seed or vegetative propagation – that native plants do. Basic principles of plant ecology still apply to invasive plants, and these principles can reveal vulnerabilities in invasive plant traits that can be exploited by management.

Some of the key species traits to consider include the species' lifespan (annual or longer lived), growth form (e.g., woody plant, forb, or grass), ability to form soil seed banks (e.g., short-lived in soil, or longer lived-perhaps years to decades), mode of reproduction, ability to re-sprout from roots, seed dispersal mechanisms, and phenology or growth period. Numerous examples exist where considering these key traits results in effective treatments, and where not considering them results in increases of invasive species (Abella 2014). For example, if longevity of a species in the soil seed bank is known, this can provide clues as to how long treatments need to be sustained to exhaust the soil seed bank. Similarly, knowing a species' resprouting ability provides insight as to whether cutting or fire is viable for reducing the species. Cutting the invasive *Tamarix* spp., for example, simply stimulates sprouting, so cutting is usually followed by applying herbicide immediately to the cut stump to forestall sprouting and cause mortality. Marushia et al. (2010) provided an example where the phenology of invasive plant species could be exploited: treatments early in the year devastated invasive species that were actively growing, whereas these early treatments had little negative impact to native species because they were not yet growing. This type of knowledge can make the difference between successful and unsuccessful treatments. Some sources of species trait information – such as the U.S. Forest Service Fire Effects Information System – are discussed in the Situation Analysis section.

Understanding the traits and ecology of invasive plants can also help determine whether immediate action is needed. For example, many invasive species primarily found along roadsides are shade intolerant and only invade forest sites after canopy opening disturbances. If a new canopy is forming (i.e., native saplings are growing into the open canopy space), then these shade-intolerant invasive species may eventually die out as conditions become too shady. Such an ephemeral invasion may have lower management priority than other more persistent invaders.

Plant invasions may be symptoms of underlying problems and effective treatment may require a more holistic approach. For example changes in the hydrologic regime along streams, such as due to flood control structures, may enable flood-intolerant invasive species to establish. Invasive plant management in conjunction with restoration of the flooding regime may be the most effective strategy. Similarly, returning fire to landscapes where suppression activities have removed this natural process could help control some invasive species. Chronic nitrogen deposition, and thus an increase in soil nitrogen availability, may be facilitating invasion within otherwise nutrient poor sites. Efforts to ameliorate soil nutrient changes may be needed in conjunction with invasive plant management.

Be Forward-Thinking

Developing a comprehensive invasive plant management plan is not an easy undertaking, and it is likely that the plan will be out of date after 10-20 years. Therefore, it is important to use the planning effort to not just address the park's most immediate needs but to also proactively establish the programmatic framework for future management actions which will extend the usable life of the plan.

One way to be forward thinking in the plan is to commit to those actions that are needed to address short-term needs and establish the frameworks needed to address future needs, rather than locking into a rigid list of species and treatment options. In particular, apply an adaptive management framework that incorporates the range of management and restoration actions as well as new information to identify desired outcomes. The plan can prescribe a species prioritization scheme that meets certain criteria to prioritize work, and it can use the best available scheme to do the initial prioritization, but leave the door open for new and improved processes in the future. Initial treatment tactics can be included but leave room for new tactics in the future. For example, chemical X with application method Y may be the best available approach for a certain situation now, but leave the door open for new and improved technology to be used later on by laying out the criteria by which treatment options will be considered in the future.

The development of an invasive plant management plan will likely cause the resource managers to recognize that there are significant information gaps and that ideally other information would be available to inform decisions. While the plan will likely have to go forward based on existing information or new information that can be quickly obtained, the planning process presents an opportunity to establish monitoring systems and articulate research needs that can be used to systematically gather information needed to inform the next iteration of the plan.

Establish Goals

Fundamental resources and values within parks, for example as identified through a park's Foundation Document, can be protected and fostered through targeted management of invasive species within specific areas or around specific natural and cultural resources such as historic structures and exemplary natural communities. The focus is on not just what is being treated but rather on why it is being treated. In other words, what is the value at risk from the invasive species?

Accomplishing multiple goals through invasive plant management can be an effective and efficient use of resources and requires that we operate with intentionality when developing and carrying out invasive plant management. Reducing the size, density, and number of plant invasions is an essential activity within parks. Importantly, invasive plant management is also a vital tool to accomplish other conservation goals, including restoring local fire regimes, preserving unique resources, and adapting to climate change. Some invasive plants such as cheatgrass (*Bromus tectorum*) and red brome (*Bromus rubens*) increase continuity of fuels on the landscape and thus cause a shift in landscape-scale fire regimes (Brooks 1999). Invasive plant management can be used in this case, not only to control the extent of an invasive species, but also as a tool to specifically reinstate the spatial patterning of native vegetation and fuels.

Managing invasive plant species and populations is also a potent tool for climate change adaptation. Climate change adaptation is defined as an adjustment in natural or human systems in response to climate change and related effects, which moderates harm or exploits beneficial opportunities (NFWPCAP 2012). For example, targeted invasive plant management within specific areas of parks could be used to increase the resilience of native ecosystems to climate change. This is the 'reducing existing stressors' strategy of climate change adaptation (NFWPCAP 2012). Native populations that are not stressed by invasive plants will be better able to remain on the landscape within parks, such as within identified climate refugia, to shift their ranges to track changes in climate and to recover from disturbance events such as fire or pathogen outbreaks.

Be Realistic

While a programmatic invasive plant management plan provides an opportunity to look holistically at the entire program and its relationship to park-wide goals and desired conditions (typically articulated in a General Management Plan or the park's Resource Stewardship Strategy), it may be necessary to set more realistic interim goals that are priorities and achievable during the life of the plan. While desired conditions may be the ideal, such conditions may not be achievable in all situations. Therefore, focus the planning effort on affirming an ideal desired condition, but establish priorities and management actions that work toward that desired condition incrementally. For example, stating that the park will be free of invasive plants is in many cases unachievable, but you could use a combination of site-led and weed-led priorities (see section "Setting Priorities") to set an incremental goal of containing species X to area Y, and eradicating species X in a small area of endangered species habitat. This goal could then be reflected in a series of annual work plans where specific treatments are prescribed for specific areas with a target of containment in area Y and control or eradication in endangered species habitat.

Another strategy is to consider ecologically insidious but widespread species and determine where your efforts might be effective at achieving specific outcomes (see text box on novel ecosystems below). An example is red brome, an invasive annual grass that plagues much of the Mojave Desert. It is an annual grass that is widespread making it difficult to achieve long-term control, yet it is a known instigator of the grass-fire cycle whereby native desert shrublands are converted through frequent fire into non-native grasslands which are unsuitable habitat for many iconic desert species, including the federally listed desert tortoise (*Gopherus agassizii*). While park-wide control of red brome is ideal, it is generally infeasible. But rather than do nothing, an invasive plant management plan might establish a goal to consistently reduce the abundance and density of red brome within critical tortoise habitat and in areas that historically have high ignition rates, such as along roadside pullouts where human caused fires are frequent. In this example the goal is not eradication or even control of the invasive species on a park-wide landscape but rather a more narrowly focused effort to control red brome in specific locations in order to delay or prevent the onset of a grass-fire cycle in tortoise habitat.

Novel Ecosystems

Some landscapes are irretrievably altered by human actions, such that their structure and function are changed. Seastaedt et al. (2008) and others argue that such novel ecosystems require a new approach to resource management. In some cases, attempts to return systems to their prior biotic and abiotic characteristics and processes may not be possible and activities such as invasive plant control aimed at removing undesirable features of the novel ecosystem may exacerbate the problem. In such cases, the management action should be re-focused on desired outcomes or trajectories, such as maintaining genetic and species diversity and supporting the biogeochemical characteristics that favor desirable species.

Likewise, the actions outlined in an invasive plant management plan should be realistic given the organizational capacity and fiscal constraints under which it will be implemented. However, the plan should take into account the 20 year planning horizon and provide scalability to expand or contract effort depending on the human and fiscal resources available for implementation as well as any opportunities or limitations that might be imposed by environmental factors (e.g., extreme weather events) that vary over time.

Be Legally Defensible

Many environmental compliance laws are largely procedural in nature, thus most successful legal challenges arise from discrepancies in process or procedure, rather than actual end products of the planning process. As a programmatic invasive plant management plan is meant to serve the park for a relatively long period, it is a wise investment to make sure the planning process is consistent with law and policy and uses the best available science to inform the decision. Park and/or regional environmental compliance specialists should be consulted routinely throughout the planning process to ensure that the end product will be legally defensible if challenged. Care should be taken to ensure compliance with all federal laws but these are particularly relevant to invasive plant management: National Environmental Policy Act, National Historic Preservation Act, Endangered Species Act, Wilderness Act, and the Clean Water Act. For additional information, see guidance issued by the Environmental Quality Division regarding planning processes for invasive plant management plans. A diligent effort toward maintaining the administrative record for the planning process (as prescribed by other guidance issued by the Environmental Quality Division), is also an important consideration of the planning process.

Manage Risk

There are two types of risk to keep in mind with invasive plant management: 1) risk to park resources, values (as articulated in the Park Foundation document) and/or visitors posed by invading species, both directly (e.g., boat motor damage due to invasive aquatic plants) or indirectly (e.g., increase in fire hazard due to fuel loading of invasive plants) and 2) risk to people and resources by undertaking treatment. It is important to consider both types of risk in relation to each other and to continually seek ways to minimize those risks.

Operational leadership is a component of the NPS Safety System and it provides a framework by which to consider risk in all work activities. At a strategic level undertaken during a planning process, the Severity-Probability-Exposure (SPE) risk assessment model may be a good approach to consider severity, probability, and exposure incurred with proposed actions considered in each alternative. The SPE model and worksheets are available in the NPS Operational Leadership toolbox (accessible from the InsideNPS intranet site or from the park or regional safety officer) and should be used to analyze the treatments and identify ways to mitigate risks to the extent possible so that an informed decision can be made. This may be particularly useful in selecting herbicides and application methods because it provides a way to relate herbicide toxicology to the decision of whether or not, or how to use a given herbicide or class of herbicides, as the exposure limits vary widely by chemical. In general, the value of the benefit of treatment should exceed the risk incurred in undertaking the treatment. This analysis can be undertaken as part of the impact analysis process during planning and the conclusions drawn from this analysis can be incorporated into the final decision document. Where mitigation measures are identified to reduce severity, probability, or exposure to risk, those mitigation measures should be incorporated into the mitigation requirements for the plan.

At an operational level, the Green-Amber-Red (GAR) model may be useful to analyze and minimize risk in the context of a specific treatment undertaken in specific environmental conditions with a known group of workers. However, the details necessary to use a GAR model are not generally known at the programmatic planning level and factors like weather conditions and team fitness will vary over time, and thus it is not likely to be useful in developing an invasive plant management plan, but may be very useful in implementing specific treatments prescribed in the plan. GAR tools are available in the NPS Operational Leadership toolbox. After-action reviews can also be useful following treatments to identify operational issues that could be improved, addressing some of those operational issues will also serve to further minimize or mitigate risk. Likewise, analysis of "near miss" incidents can also be very useful in improving the safety of invasive plant management operations over time. Tools and templates for analyzing and reporting such events can be found in the toolbox as well.

Adaptive Management

The Department of the Interior has provided the following official definition of adaptive management:

> *A system of management practices based on clearly identified outcomes and monitoring to determine whether management actions are meeting desired outcomes; and, if not, facilitating management changes that will best ensure that outcomes are met or re-evaluated. Adaptive management recognizes that knowledge about natural resource systems is sometimes uncertain. (43 CFR Subtitle A [10-1-11 Edition] §46.30)*

The Department of the Interior Technical Guide further describes adaptive management as follows:

> *Adaptive management is a decision process that promotes flexible decision making that can be adjusted in the face of uncertainties as outcomes from management actions and other events become better understood. Careful monitoring of these outcomes both advances scientific understanding and helps adjust policies or operations as part of an iterative learning process. Adaptive management also recognizes the importance of natural variability in contributing to ecological resilience and productivity. It is not a 'trial and error process,' but rather emphasizes learning while doing. Adaptive management does not represent an end in itself, but rather a means to more effective decision and enhanced benefits. Its true measure is in how well it helps meet environmental, social, and economic goals, increases scientific knowledge, and reduces tensions among stakeholders. (Williams et al. 2007)*

Adaptive management is especially important in light of global climate change. Changes in the earth's temperature are now detectable on land, in the atmosphere, and in our seas. Alterations in the abiotic components of ecosystems have dramatic effects on habitats as well as on plant and animal distributions and plant-animal interactions. A landscape of shifting climates and habitats may offer new opportunities for invasive plants to invade. Although, complex and interacting factors make it impossible to predict with certainty how species' distributions will change and whether they are likely to be successful under future conditions. Some species may become increasingly invasive and rapidly expand on the landscape while others may experience new stressors and become easier to control. Adaptive management allows for flexibility in the way invasive plants are controlled, which will be necessary as scientists and managers expand their understanding of climate change patterns and their effects on plant communities.

Adaptive management can be incorporated into many aspects of the invasive plant management programs as illustrated in Appendix C. The basic adaptive management process is six steps which must be completed sequentially as shown in Figure 1. Throughout this document, where the adaptive management steps align with the information

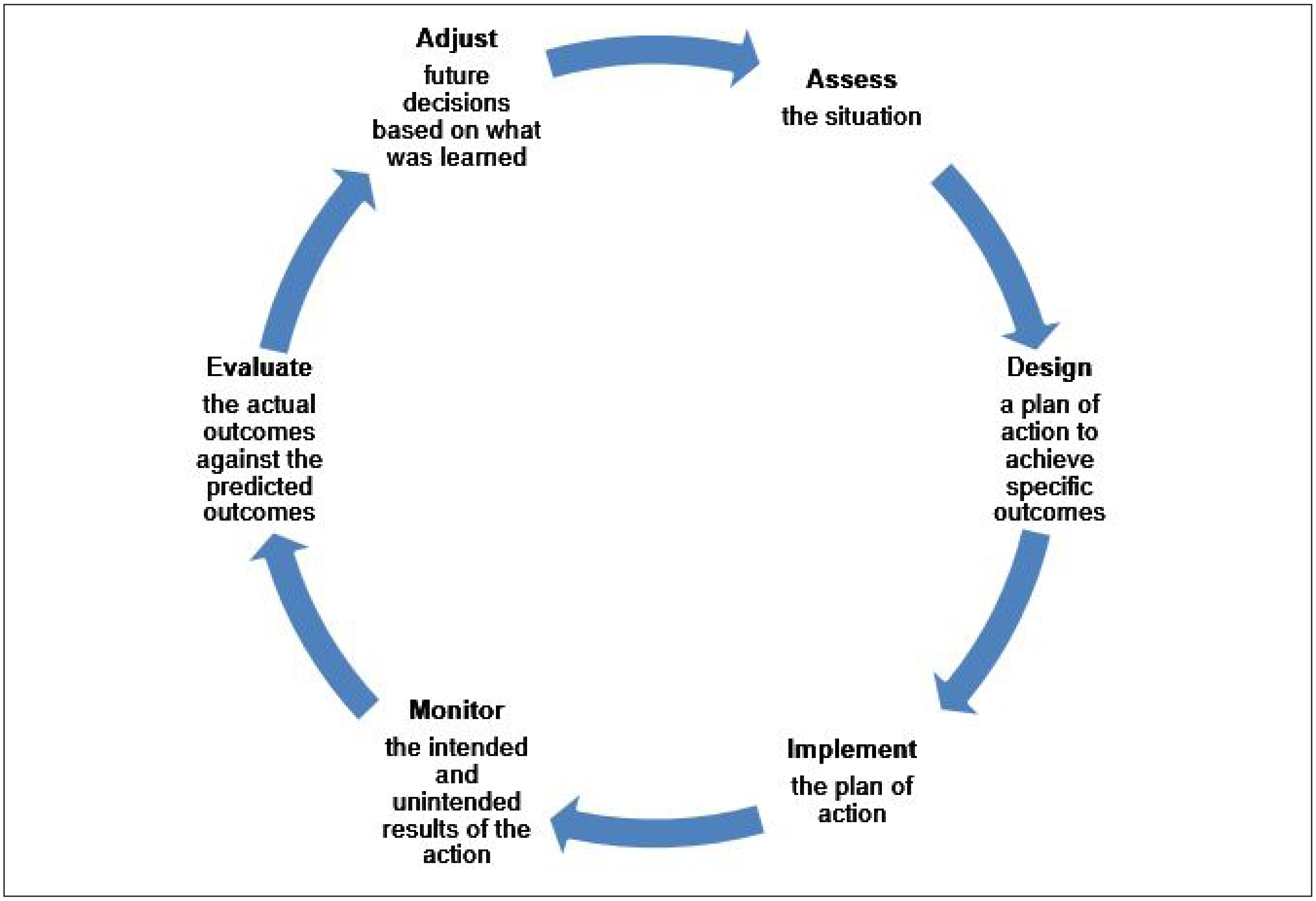

Figure 1. Adaptive management process.

presented, the adaptive management step will be noted. However, the information presented will be relevant to invasive plant management planning even if there is no effort to use an adaptive management framework. It is also important to note that adaptive management operates on multiple timescales, thus there can be some aspect of adaptive management that applies to routine actions that can be adjusted every time they are performed, or annually to update protocols based on the experiences of the prior season, or over multiple years to update the invasive plant management plan based on multiple years of implementation.

Examples of Recent NPS Invasive Plant Management Plans

As of January 2017, the National Park Service had completed Environmental Assessments or Environmental Impact Statements for contemporary (since 2005) invasive plant management plans for 78 parks (Table 1). These existing plans provide examples for management planning in a variety of ecosystems and park contexts. These plans are available from the National Park Service's Planning, Environment, and Public Comment (PEPC) website. Early in the development of a new invasive plant management plan it is recommended that recent examples be reviewed in order to learn from the experiences of other parks.

Table 1. Summary of existing invasive plant management Environmental Assessments (EA) and Environmental Impact Statements (EIS) since 2005 for 78 National Park Service units as of July 2018. Links included if documents reside on the NPS Integrated Resource Management Applications (IRMA) portal.

Year	No. Parks	Title
2005	1	Dinosaur National Monument Invasive Plant Mgt. Plan and EA
2006	1	Blue Ridge Parkway Exotic Plant Mgt. Plan (EA)
2006	2	Mesa Verde National Park and Yucca House National Monument: Invasive Exotic Plant Mgt. Plan EA
2009	1	EA for an Exotic Plant Mgt. Plan: Lake Mead National Recreation Area
2009	4	Exotic Plant Mgt. Plan EA: Southeast Utah Group (Arches, Canyonlands, Hovenweep, Natural Bridges)
2009	3	Flagstaff Area National Monuments Invasive Plant Mgt. Plan and EA (Wupatki, Walnut, Sunset Crater)
2009	1	Grand Canyon Exotic Plant Mgt. Plan and EA
2010	1	Bryce Canyon Vegetation Mgt. Plan and EA
2010	9	South Florida and Caribbean Parks Exotic Plant Mgt. Plan and EIS (includes 9 parks)
2010	1	Yosemite National Park Invasive Plant Mgt. Plan Update EA
2011	9	Northern Rocky Mountains Invasive Plant Mgt. Plan (includes 9 northern Rocky Mtns. Parks) (https://irma.nps.gov/DataStore/Reference/Profile/2195341)
2012	10	Great Lakes Invasive Plant Mgt. Plan EA (includes 10 parks)
2013	1	Great Basin National Park Invasive Plant Mgt. Plan EA
2013	15	Heartland Invasive Plant Mgt. Plan and EA (includes 15 Heartland Network parks)
2013	1	Yellowstone National Park Invasive Vegetation Mgt. Plan EA
2015	2	Mesa Verde National Park and Yucca House National Monument: Invasive Exotic Plant Mgt. Plan EA
2015	15	National Capital Region Invasive Plant Mgt. Plan and EA
2017	1	Crater Lake Invasive Vegetation Mgt. Plan

Technical Considerations for Invasive Plant Management Planning

This section details some of the biological and operational technical aspects to consider during an invasive plant management planning effort. Technical aspects of the planning process itself (e.g., compliance steps for the National Environmental Policy Act, Endangered Species Act, etc.) are omitted as that guidance is provided in other publications.

Each invasive plant management planning effort is somewhat unique, and some sections may not be applicable to a given park or planning effort. The sequence presented represents a typical progression; however, there may be compelling reasons for a park's invasive plant management planning process to proceed in a different order or to incorporate different considerations not mentioned here. For example, some management plans span across multiple federal jurisdictions and will require different technical considerations than those presented here. Likewise, some park units allow for non-traditional park uses, such as mining, grazing, and oil and gas development, which will likewise require unique considerations. So this section is presented in a modular fashion, leaving it to the park managers to determine what applies to their park and in what order.

Legal Foundations

Numerous federal laws apply to invasive plant management and the National Park Service has policy guidance related to invasive plant management, some of which are elaborated in the previous section of this document. At the initiation of an invasive plant management planning effort, these primary documents related to invasive plants should be reviewed (in order of priority) by the planning team:

1. NPS Policies (NPS 2006), Chapter 4, Section 4
2. NPS Natural Resource Management Reference Manual #77 (formerly known as NPS-77 Natural Resources Management Guideline available in hardcopy in most park resource management offices), chapters on Integrated Pest Management, Nonnative Species Management, and Vegetation Management:
3. NPS Integrated Pest Management Guidelines Reference Manual 77-7 (in development as of 07/19/2018, see Integrated Pest Management below):
4. Your Park Enabling Legislation. This may or may not address invasive plant management but may provide specific direction for restoring or preserving natural processes. There are also cases where other resources or values are identified in enabling legislation that may be impacted by invasive species or that deliberately include invasive species (e.g., cultural landscapes). Check before establishing your strategy for control.

Integrated Pest Management Framework

National Park Service policy (NPS 2006) requires the use of an integrated pest management (IPM) approach when managing pest organisms. Pests are defined as organisms interfering with the site management objective. Invasive plants are considered pest organisms. The concept of IPM is defined in policy as follows: "4.4.5.2. Integrated pest management is a decision making process that coordinates knowledge of pest biology, the environment, and available technology to prevent unacceptable levels of pest damage by cost-effective means while posing the least possible risk to people, resources, and the environment."

The NPS IPM Program uses this prescribed Process:

- Identification of the pest
- Monitoring pest populations and damage levels
- Establishing injury and threshold/action levels
  - Injury level is the population size at which the pest causes unacceptable damage
  - Threshold or Action level is the population size at which some management action must be taken to prevent the population from reaching the injury level
- Implementing treatments
- Indirect Suppression such as habitat modification, modifying human activities
- Direct Suppression such as physical or mechanical removal, biological control, or chemical treatment
- Evaluation of treatment results
- Education of staff and others regarding pest identification and prevention

IPM often employs a combination of treatment strategies specific to the species and location, focusing on those that are: least disruptive of natural controls; least hazardous to human health; least toxic to non-target organisms; least damaging to the general environment; most likely to produce permanent reduction in the pest; easiest to carry out effectively; and most cost effective in both the short- and long-term. For example, it is common to implement cultural practices (i.e., flooding or drying out an area) to prevent the spread of invasive plant seeds along with use of manual and chemical treatment of incipient and established populations.

Situation Analysis

In the context of invasive plant management planning, situation analysis is a scoping and analysis of the context in which the invasive plant management program or individual projects might operate. This is essentially the "assess" step of the adaptive management cycle. The basic steps are:

1. Define the geographic and political boundaries to be included in the planning effort.
2. Research and describe the current state and condition of the resources within the planning area.
3. Identify trends in conditions, the pressures being exerted, and the underlying forces driving the pressures (if applicable).
4. Identify significant issues to be addressed or resolved.
5. Identify key stakeholders and/or partners in the planning effort and in the implementation of the plan.
6. Establish the budget and timeline for completion of the plan using the appropriate NEPA pathway (see other guidance published by NPS Environmental Quality Division for more details regarding environmental compliance processes and requirements).

These information sources should be informed by considering park-specific information and reviewing other information sources as described below.

Park-Specific Information

The park's existing invasive plant management program and legacy data (or for a new park unit, what might have been inherited from the previous land manager or has been gathered since the park's creation) should be considered in detail. First, it provides an opportunity to learn from past experience so that the planning process serves to formally establish aspects of the program that work well, provides a means to reconsider aspects of the program that need to be improved. This is a reasonable point in time to undertake file organization and meta-analysis of legacy data to inform the new planning effort. Second, as a required component of the Environmental Assessment or Environmental Impact Statement, continuation of the park's existing program will be the no-action alternative in an invasive plant management plan. Thus the existing program must be summarized in any case. Not all of the details revealed by the questions below will necessarily be a part of the description of the no-action alternative, but collection of as much information as possible will be useful to informing the entire planning process and some of the information will be directly incorporated in the plan. By looking at the existing program as a whole, and considering what is working well and what might be improved, a thorough description of the no-action alternative provides a logical starting point to craft action alternatives in the plan.

While each invasive plant management program is different, below are some questions to start the evaluation process. Don't forget to use the invasive plant inventory and treatment data, pesticide use proposals, pesticide use reports, and other park-specific data sources!

1. What prevention efforts are currently in place?
    - A. What park-wide standard operating procedures (SOPs) related to invasive plant prevention are currently in place?
    - B. What staff and public education programs are in place to reinforce prevention practices?
2. What early detection and rapid response efforts are currently in place?
    - A. Are target areas identified for early detection survey? Are phenological windows identified for each target area and species? How were those targets selected and are those criteria still appropriate?
    - B. Are event triggers identified for increased early detection efforts (e.g., burned areas, flood areas, precipitation thresholds, etc.)? Is the list of event triggers still valid and is it complete?
    - C. What tools are available to quickly ramp up staffing levels to undertake a rapid response treatment to an incipient population? For example, do you have access to an NPS Exotic Plant Management Team or to a contract labor force by way of an existing agreement?
3. What control and containment efforts are currently in place?
    - A. What species are being treated and with what methods? What are the critical aspects of the species biology that influenced selection of treatment priorities and methods? How were those species selected?
    - B. What sites are being treated and why were they selected for treatment?

C. What herbicides are used on what species/sites and with what application methods? What manual, mechanical, and/or cultural treatments are used?

D. What is the best method or suite of methods for treating each target species? How effective is the treatment, both initially, as well as at intervals over time?

E. What is the effect of that treatment on non-target species?

F. Where are those species being treated and where are they left untreated? Why? Consider creating a series of maps for each species if possible, to better understand both the spatial distribution of the species, its habitat, and the treatment locations.

G. What biocontrols are currently in use and for what target invasive plant species? How is biocontrol effectiveness monitored? What other biocontrols have been considered but not implemented? Why?

4. What post-treatment restoration techniques are currently in use?

A. What restoration techniques are used, where, and for what intended outcome?

B. What was the effect of the restoration treatment? Initially, as well as at intervals over time.

C. What are your estimated costs for various restoration methods and what factors are most influential to those costs (e.g., cost of seed, labor, site accessibility, etc.)?

5. What is the current status of administrative and operational aspects of invasive plant management?

A. How is the existing program funded and staffed? Is it sustainable? Is it adequate?

B. How are invasive plant "projects" identified and funded?

C. How are pesticide use proposals, pesticide use logs, and chemical inventories accomplished? On what schedule?

D. Is there an established annual work cycle? Are annual work plans prepared for each calendar or fiscal year? With whom are they shared?

E. How are annual accomplishments summarized and to whom are they reported?

F. Is the park engaged with collaborative efforts such as interagency invasive plant working groups or public/private weed management area(s)? How might those relationships be incorporated into the planning effort?

G. What invasive plant monitoring program is currently in place? How might it be improved?

H. What do monitoring results reveal about species distributions and abundance over time, relationships to the environment (including stressors), and treatment effectiveness?

I. What invasive plant related research projects have been completed? What were their findings?

J. How are research questions related to invasive plants identified and communicated to potential research partners?

Legal requirements and constraints should also be well understood. State and local noxious weed lists relevant to park lands (often organized on county or 7.5' topo quads) as well as the federal noxious weed list should be compiled so that they can be incorporated into prioritization schemes. Critical habitat maps and locations of state or federally listed sensitive species should be known as they may influence the priority of sites or the feasibility of certain treatments. Consultation with cultural resource staff may also be pertinent to identify where invasive plants are affecting cultural resources (especially cultural landscapes) and to identify any invasive plant species that are part of cultural landscapes.

Existing Information Sources

Several sources of information exist on species-specific autecology, distribution, and management for invasive plants (Table 2). The U.S. Forest Service Fire Effects Information System provides searchable reviews on ecology and management of a small portion of invasive species in parks. The Canadian Journal of Plant Science, which is traditionally open access, provides a search function for locating review articles in their Biology of Canadian Weeds and Biology of Invasive Alien Species series. Taxonomic information, distribution maps, and links to further information are provided in the PLANTS Database of the U.S. Natural Resources Conservation Service. Similar information can be found on the University of Georgia's Early Detection & Distribution Mapping System (EDDMapS) web site. NatureServe, through its data explorer, provides summary information on species ecology and management, plus NatureServe's I-rank species impact prioritization. The Center for Invasive Species and Ecosystem Health also has useful information about a wide range of species.

Table 2. Summary of some major sources of information on invasive plant species, distribution, and management.

Source	Developer	Contains
Fire Effects Information System	U.S. Forest Service	Species autecology reviews
Canadian Journal of Plant Science	Agricultural Institute of Canada	Biology of Canadian weeds; Biology of invasive alien species
PLANTS Database	U.S. Nat. Resources Con. Serv.	Species taxonomy, links to further information, federal noxious weed list
Early Detection & Distribution Mapping System (EDDMapS)	The University of Georgia – Center for Invasive Species and Ecosystem Health	Species information, national and state-level distributions, library of identification and management information.
NatureServe Explorer	NatureServe	Use data explorer to find species ecology and I-ranks
GoogleScholar	Google	Search tool; subscriptions needed for some located articles
JSTOR	ITHAKA	Digital library of journals, primary sources, and books
California Invasive Plant Council	Cal-IPC	Species summaries, mgt. info.
State and Regional Invasive Plant Councils and Exotic Pest Plant Councils	Non-government agencies	Species summaries, mgt. info., training opportunities (Accessible National Association of Exotic Pest Plant Councils)
State noxious weed lists	State agencies	Species information, often state-level distributions and status for species of concern to agriculture
State natural heritage programs	State agencies	Species information, often state-level distributions and status
Inventory and Analysis Program	U.S. Forest Service	Vegetation plot data for forested landscapes, requires special access
IRMA	National Park Service	Digital data store for national parks
NPS vegetation inventory	National Park Service	Vegetation plot data, including invasives, within parks
NPS treatment synthesis	Abella (2014)	Synthesis of publications on treatments on NPS lands
NPS National Invasive Species Management System	National Park Service	Web accessible geospatial tool that is the NPS standard

GoogleScholar is a general search engine for articles and identifies freely available articles as well as articles that require subscription. Regional information sources including state and regional invasive plant councils and exotic pest plant councils, such as the California Invasive Plant Council, often provide ecological, management, and distribution summaries for key invasive plants in the region as well as best management practices and training videos. State noxious weed programs and state natural heritage programs can also supply useful information on invasive plants, recognizing that not all invasive plant species of interest to natural areas management are designated as noxious weeds under state law.

The National Park Service's Vegetation Inventory Program produces vegetation maps and can also provide site photos, lists of species on plots, and some information on distribution and abundance of invasive plants (see *Case Study: Using NPS vegetation inventory data to understand invasive plant dynamics at Bryce Canyon National Park, Abella and Tendick 2013*). Many of these products are available on the IRMA portal. A 2014 synthesis of treatment effectiveness reported in all known publications of projects conducted on National Park Service lands also is available (Abella 2014). This synthesis included 56 projects, 35 parks, and 157 invasive plant species. In addition to these information sources, park-specific botanical surveys and vegetation studies are also often available from park archives, with varying utility for understanding invasive plant species.

The NPS National Invasive Species Information Management System (NISIMS) was adapted from the Bureau of Land Management in 2014. The NPS system was designed to standardize the collection of infestation and treatment data.

The Exotic Plant Management Teams, some Inventory and Monitoring Networks, and some parks report invasive plant management and restoration data within this system. Online reports are also available summarizing treatment data.

Some parks may have very useful information included in their own datasets and reports, such as the Natural Resource Condition Assessment, Resource Stewardship Strategy, Vegetation Map, Fire Effects Monitoring Plan, Safeguarding America's Lands and Waters from Invasive Species A National Framework for Early Detection and Rapid Response, and the National Invasive Species Council Management Plan. In some cases such reports include plot data. Both the reports and the plot data should be accessible in the NPS IRMA datastore.

In addition to park resources, partner organizations and neighbors may have useful information on species occurrence, ecology, and control.

Completeness of information varies greatly among species, with extensive information available for some well-studied species and little to virtually no information available for poorly known species. This challenges management because extensive information often is only available for species that have already become major problems, whereas often less information is known for uncommon species that could be treated early to forestall invasion. Effective treatments are often poorly understood for these species, and extensive experimentation might be needed to identify effective treatments that also do not negatively impact park resources (Abella 2014).

Case Study: Using NPS vegetation inventory data to understand invasive plant dynamics at Bryce Canyon National Park

The Vegetation Inventory Program of the National Park Service has completed vegetation sampling and mapping for 250 of the 417 parks as of 2013. At a minimum, the resulting products provide photos of plant communities and species lists (often including exotic plants) at particular sites within parks. If plot sizes are kept consistent across the landscape, which is a recommended practice in vegetation investigations, and if plots are located in some useful fashion (ideally often stratified-random, such as among vegetation types or environmental gradients), the vegetation inventory data can have a much broader use in exotic plant management. Such an opportunity was provided at Bryce Canyon National Park, where 406 vegetation inventory plots were used to compare exotic plant abundance, composition, and distribution among vegetation map units across the landscape. Moreover, vegetation units were analyzed at three different resolutions (coarse, intermediate, and fine), all of which might have different strengths for management planning.

The analysis identified which exotic plant species were most prevalent and where they were distributed, as well as which vegetation units across the landscape were most invaded. The highest elevation forests, such as those dominated by white fir (*Abies concolor*) or bristlecone pine (*Pinus longaeva*), and lower elevation woodlands were generally least invaded. Wet meadows and some shrublands were generally most invaded, including by species such as rip gut brome (*Bromus inermis*) that are difficult to treat. More generally, vegetation mapping might 'capture' variation in numerous factors (e.g., native vegetation, environmental factors) related to exotic plant distribution and thus be a general tool useful in exotic plant management. This approach is fundamentally different than mapping exotic plants themselves, but represents an existing data source that may be useful to park managers. If plot sizes have varied among vegetation types or there are other reasons not to use the data (e.g., season of sampling did not capture exotic annual plants), then the data should not be used for these purposes. The Bryce Canyon project provides an illustration for the potential application that National Park Service vegetation inventory data could have for exotic plant management planning.

Source: Abella, S.R., and A. Tendick. 2013. Distribution of exotic plant species and relationship to vegetation type at Bryce Canyon National Park, USA. *Landscape and Urban Planning* 120:48-58.

Setting Priorities

Financial, labor, and time resources for treatment are limited. This necessitates prioritization of species and sites for treatment. Invasive plant management priorities can generally be classified as either site-led or weed-led; however the two are often used concurrently. The term weed-led is used because the program is defined by what is needed to manage the spread of a specified weed species (Owen 1998). Each invasive plant species known to occur, or likely to occur, in the park is evaluated and ranked according to some standard and documented method. Such rankings then focus invasive plant management actions on specific species that pose the greatest ecological threat. A site-led program aims to protect the quality or integrity of the natural values within a particular place (Owen 1998). Within the NPS protection of cultural values is also a priority. Its focus is a management unit with high natural ecological value; such as desert springs or rare plant habitat. Distinguishing between weed-led and site-led programs keeps attention focused on why time and effort are spent to manage invasive plants. A weed-led program is a proactive strategy to minimize future risks – it focuses not on the needs of a specific place, but rather on what is required to eradicate or contain a specific invasive plant species in the region. In contrast, site-led programs always focus on a specific place and what is required to protect the values of that place (Owen 1998). Prioritization, coupled with well-articulated goals and objectives, is the *design* step of the adaptive management cycle.

Species prioritization

Within the scope of weed-led management priorities, there are several methods by which individual plant species may be evaluated and ranked or prioritized for management purposes. Such efforts may be based entirely on expert opinion or may use systematic evaluation schemes that consider such characteristics as species biology, tendency to naturalize or invade undisturbed sites, feasibility of control, and impacts to other species and/or ecosystem processes. This section highlights a few existing ranking systems, some additional considerations, and opportunities to customize prioritization schemes to better meet park needs.

Several different systems and protocols exist for prioritizing species for treatment. For example, in a National Park Service technical report, Hiebert and Stubbendieck (1993) provided an early framework for prioritizing species. Their prioritization was based on a species' current perceived impact (in turn based on a species' abundance, ability to be invasive, and threat to park resources), feasibility of management (in turn based on abundance, ability to form a soil seed bank or to resprout, and amenability to treatment), and urgency of treatment (in turn based on consequences of delay). The authors further provided an example in Pipestone National Monument, where surveys were first conducted from 1989-1991 to survey species present in the park and their abundance, then information on species characteristics was gleaned from the literature to rank the species. Based on the rankings, each species was placed into one of four categories: lesser threat/easy to control, lesser threat/hard to control, serious threat/easy to control (none of the 70 species were in this category), and serious threat/hard to control. Managers might thus make decisions to allocate resources to the serious threats even though difficult to treat, or to treat the lesser threats that are easy to control, or a combination.

Another ranking system is NatureServe's I-rank (Randall et al. 2008; and search for particular species in their 'Data Search' box). This is a nation-wide system that ranks species as high, medium, low, or insignificant for priority for treatment based on ecological impact, current distribution and abundance, trend in population size and spread, and management difficulty. NatureServe staff and collaborators have gleaned information on the species from literature to input into the system to produce the rankings.

Two examples of regional ranking systems include the California Invasive Plant Council system (Cal-IPC) and the Alaska Natural Heritage Program-Alaska Exotic Plants Information Clearinghouse. The Cal-IPC system ranks species based on impact, invasiveness, and distribution, so management difficulty is not part of the ranking. The Alaska system ranks species based on perceived impacts, species traits (e.g., ability to form seed banks or be allelopathic), distribution, and management difficulty (Carlson et al. 2008).

Users should be aware that existing species ranking systems are useful resources, starting points and frameworks for identifying key characteristics related to assessing which invasive plants to treat on a landscape. However, ranking systems are currently limited by being incomplete (geographically, and also not all species are included in even regional ranking systems) and they are also only as good as the available information on a species and ecological knowledge of the people doing the rankings (Hiebert and Stubbendieck 1993). The sheer number of invasive plant species in the U.S. (thousands) and variation among an array of geographic areas complicates development of comprehensive rankings, and the detailed life-history information needed for effective ranking simply does not exist for many species. This information, such as seed bank formation, often needs to be determined through individual research projects on the species. Aspects of invasion ecology itself further complicate prioritization, as simple models of species traits that predict invasiveness remain elusive, and the frequent lag times between introduction and exponential population growth can result in erroneous assessments of which species are invasive. Additionally, the fact that a species can cause problems in one region of the U.S. but not another, further complicates rankings.

Another challenge with some prioritization systems is that they are often poorly suited to capture site specific detail that might be important to park managers. For example, it is appropriate to consider the species not only in the context of its known distribution but also to specifically consider the status of a species within the park relative to neighboring lands. If a species is common on neighboring lands, but has not yet established itself within the park, the park manager might designate this a zero tolerance species to ensure the species does not invade the park. Any report of that species found in the park would receive a rapid response or treatment.

Given these considerations, prioritization schemes could be viewed as tools available for managers but should not necessarily be viewed 'off the shelf' as final ways to rank species in any given park as each has its own strengths, weaknesses, and biases (see *Case Study: Comparison of species ranking results in southwestern desert parks*). Some managers use two or more ranking systems and compare the output, or they use the framework of a ranking system to develop their own customized rankings or rankings for species not yet 'officially' ranked by systems. In fact, experiences of park managers can be crucial for helping to refine ranking systems based on invasive behavior and impacts of particular species in different parks. Many of the invasive plants of park wildlands are not necessarily noxious weeds for agricultural purposes and may not be included in 'off the shelf' ranking systems. However these species may have negative impacts on federal wildlands and be important to include in park-specific ranking systems. Finally, it is important to note that this process should be revisited every year or few years to make sure that it remains current and reflects new invasions, new species of concern and other new information.

Case Study: Comparison of species ranking results in southwestern desert parks

Vegetation plot sampling at 1662 sites in Death Valley National Park, Mojave National Preserve, and Lake Mead National Recreation Area detected 28 exotic plant species on plots in 2010-2011. Nineteen of these species had impact/prioritization rankings available from the Cal-IPC system and 17 species had rankings available from the NatureServe I-rank system. There were six species not ranked by either system for which managers have no 'off the shelf' rankings available and would need to customize their own. Of the 9 species ranked by both systems, there were some similarities and differences in the rankings. This situation is not uncommon, because different ranking systems emphasize different criteria in their rankings and the invasibility of some species may vary across its range. Ranking was consistent for cheatgrass (*Bromus tectorum*) and tamarisk (*Tamarix ramosissima*), both scoring in the category of highest priority species capable of negatively impacting native ecosystems for both ranking systems. Ranking also was consistent for barbwire Russian thistle (*Salsola paulsenii*; limited impact or low priority) and Bermudagrass (*Cynodon dactylon*; moderate ranking). However, the two systems returned opposite rankings for *Schismus* spp.: Cal-IPC ranked the species as 'low', while NatureServe ranked the species as 'high' priority. The other 4 species differed by at least one category.

This case study illustrated that: 1) not all species of management interest will necessarily have 'off the shelf' rankings available, necessitating local managers forming their own rankings if desired; 2) comparing different ranking systems, when available, can be useful in evaluating consistency of rankings; 3) species prioritization schemes can be a useful starting point and generate ideas on what might be important factors in ranking species for treatment, but they are not necessarily the final 'answer'; and 4) ongoing evaluations of treatments at parks likely have much to contribute to a broader understanding of how to more effectively prioritize species and sites for treatment to make the most of limited treatment resources.

Source: Abella, S.R., N.A. Fisichelli, S.M. Schmid, T.M. Embrey, D.L. Hughson, and J. Cipra. 2014. Status and management of non-native plant invasion in three of the largest national parks in the United States. Journal for Nature Conservation (under review).

Consideration of Listed Noxious Weeds

All state and federally listed noxious weeds that occur in or near the park should be covered in the park's Invasive Plant Management Plan in recognition of the agency's legal responsibilities under state laws. However it is important to recognize that many state noxious weed lists include both native and non-native species and the perception of the species as a "pest" or "weed" is often from an agricultural perspective and may not reflect the mission or values of the National Park Service. Because not all noxious weeds pose significant threats to natural areas, it is helpful to consider them species by species in a species prioritization scheme so that they are given the same considerations as other invasive plant species and are ranked relative to all other species under consideration. Thus a common cropland pest that does not readily invade natural areas might be reasonably ranked as a low priority even though it is a state listed noxious weed. Also note that some states list native species as noxious weeds but that NPS Management Policies Chapter 4 provides specific guidance for the consideration of native species. Thus, it may be appropriate to evaluate all state and federally listed noxious weeds, but your final prioritization may result in some species listed as a no priority where the species is native.

Consideration of New or Novel Species

Sometimes new invasive species arrive and flourish in a short period of time, particularly in parks located near urban areas where many invasive cultivars are planted that may naturalize in the park through natural or human augmented dispersal. As many of these species are new to natural resource managers, they likely have not been previously evaluated using existing species prioritization schemes and, in some cases, there may be a lack of ecological information about the species in general. We recommend gathering information about these species and incorporating them into the park-wide prioritization as soon as possible. In such situations where a full evaluation of the species is not possible using an existing prioritization scheme, you may consider designating a special category of "urgent" priority to indicate the need to take immediate and aggressive action against these new and novel species regardless of the lack of complete information. This should certainly be a consideration in establishing the initial prioritization for an invasive plant management plan, but could also be undertaken on a scheduled update basis (e.g., annually revisit the species prioritization) or as soon as a new species is identified in the park. State, regional, and national Invasive Plant Councils or Agricultural Extension Agents are good sources of information on species new to a state. Some states maintain a red alert species list for just these types of new invaders. In such cases, it may be helpful to query the horticultural literature and gardening websites for information about how to cultivate the species, then use some "reverse engineering" to determine how big of a threat it likely poses to a wildland environment (e.g., many cultivars have environmental limitations likely to be exceeded in a natural setting and thus they are not likely to persist) and, if warranted, exploit the species' natural weaknesses to devise a treatment.

Consideration of Cultural Plants

National Parks protect both natural and cultural resources. Some of the cultural resources we protect are cultural landscapes. Rehabilitating cultural landscapes requires a complex analysis to identify what currently exists at the site and what was there historically. Retaining existing plants is the preference but additional plants may be required to rehabilitate the look and feel of the landscape. Plants that the park wishes to retain and plants the park wishes to plant should be evaluated for invasiveness. If a native species of local or suitable genotype is available that can fulfill the role in the landscape, then the native should be used. Various factors should be considered in deciding whether or not it is acceptable to plant a non-native species in a cultural setting. Considerations may include: 1) does a suitable native alternative exists, 2) is the non-native species hard to maintain, 3) does the non-native species pose a genetic contamination risk, or 4) is the non-native species invasive. NPS Management Policies Section 4.4.2.5 outlines the use of non-invasive species in this context (NPS 2006). In these cases, a species that has similar form may be chosen as a substitute. Many cultural landscapes were created over time without specific planting plans so NPS has some latitude to select plants that fit our modern day restrictions and then arrange them in a manner that is both within the guidelines of rehabilitation and consistent with any restrictions and desires for the site.

Whenever possible, native species should be used in any NPS setting. On those rare occasions when a non-native species must be used, known non-invasive species that are already present should be used. On very rare occasions new non-native species may be proposed. In those cases a weed risk assessment must be done. Predicting invasiveness is challenging but has been attempted with some success across the world including Australia (Pheloung et al. 1999, Gordon et al. 2010), Hawaii (Daehler et al. 2004), Florida (Gordon et al. 2008), the tropics (Chong et al. 2011) and the Mediterranean (Gasso et al. 2010). The science of weed risk assessment became established in the 1980s (Forcella et al. 1986, Gaudet and Keddy 1988, Newsome and Noble 1986, Williamson and Brown 1986, Westbrooks 1981) but assessment techniques have become more sophisticated over the last 25 years (e.g., Gasso et al.2010). These assessments evaluate traits of the potential invader (Gaudet and Keddy 1988), characteristics of the recipient habitat, climate matching (Thuiller et al. 2005), and information on whether the species has been recorded elsewhere as an invasive species (Westbrooks 1981, Rejmánek 2000, Thuiller et al. 2005, Richardson and Thuiller 2007). Inclusion of all of these factors helps to predict invasiveness, but the factor that is most predictive is whether or not the species is invasive in another region (Gordon et al. 2008, Kolar and Lodge 2001, Mack 1996, Reichard and Hamilton 1997). If the region where the species is already invasive has a climate similar to the recipient region, the risk of invasion increases (Thuiller et al. 2005).

The Presidio of San Francisco, a part of Golden Gate National Recreation Area, has developed a system (Frey 2012) that not only evaluates a species for invasiveness but evaluates a host of other factors including potential to cross pollinate with native and non-native plants, maintenance needs, and historic compatibility. The system used in the Presidio is a simplified approach that primarily focuses on the relationship between invasive plants and cultural landscapes, and so is not as protective of natural areas as evaluations in other parks might be.

Site prioritization

Numerous considerations can facilitate site-led prioritization of treatments. There are three broad categories of elements for site-led prioritization: resource protection, characteristics of the invasion, and human considerations. Identifying critical elements within a park for resource protection (and thus highest priority for treatment) could include identifying biodiversity hotspots, unique or rare native species habitats, cultural resource sites and/or cultural landscapes, or state or globally rare natural community locations. Maps of wetlands, for example, could assist with identifying biodiversity hotspots. As another example, endangered species habitat could be considered a priority site for resource protection, with the focus on those invasive species that directly or indirectly reduce the quality of the habitat or where the invasive species directly impacts the listed species (e.g., an invasive plant that competes with a listed plant). The "G-ranks" obtained from NatureServe species lists can also be useful in identifying rare or declining species or ecosystems that may be of conservation interest.

Characteristics of the invasion might be useful in prioritization, such as size of infestations, rate of spatial change, and invasive plant abundance within infestations. Especially when they are isolated or occur in new areas, eradicating small infestations – to prevent them from expanding – can result in large returns on the investment. Based on evaluating infestations in California, for example, Rejmánek and Pitcairn (2002) reported that about two-thirds of infestations ≤ 1 ha in size could be successfully eradicated by expending an average of < 180 work hours. Success declined sharply, while work time increased sharply, for infestations > 1 ha in size. If findings are similar elsewhere, then a rule of thumb is that full eradication can be quite successful for infestations smaller than 1 ha, whereas where infestations are larger than 1 ha, eradication is much less feasible and much more costly to achieve (see Table 3). In some situations, it could be that prioritizing treatment on small, 'satellite' infestations and simply 'holding the line' on the larger infestations produces the greatest treatment benefit for the least resources. It may then be possible to attack these large infestations when resources for treatment are most plentiful, or when an infestation is potentially weakened, such as during drought.

Infestation characteristics other than size, such as infestations which are a seed source that chronically cause new infestations, also can be important. An example of using this knowledge would be identifying upstream areas in riparian corridors to treat in order to curtail seed dispersal to downstream areas. Geographic location can also be important for prioritizing treatments. For example, treatment of 'satellite' populations that have 'jumped' some type of barrier to invasion (e.g., mountain range) might receive high priority in order to contain the invasion.

A third element of site prioritization – the human element – can inform prioritization in numerous ways. If an area is known to be highly visited by humans and a source population for subsequent seed dispersal, this and similar areas might be prioritized for treatment. As one example, even though they are chronically disturbed, areas near visitor centers, trailheads, or similar areas might be considered the highest priority to keep free of invasive plant species because seeds present at these areas can be readily transported throughout the park. Many park visitors first stop at visitor centers or main attractions and then disperse throughout parks, so those areas should be monitored frequently and treated promptly as new invasive species populations are found. A recent study at Yosemite National Park found that park operations, stock use, roads, and concessionaire buildings are more closely linked to invasive plant infestations than visitor activities (Dickman 2015). Therefore, park operations areas, such as the maintenance yards, borrow pits, and parking areas for government vehicles, should be monitored frequently and treated promptly before propagules are inadvertently spread to other areas through routine park operations. Areas used as incident command posts for extended periods of time, and other major incident operations areas such as staging areas and base camps, often experience a large volume of vehicle traffic, including vehicles that come from outside the immediate area. Many incident response vehicles travel to and from remote areas and recently disturbed sites (e.g., post-fire and post-flood landscapes). In some parks, good incident command post sites are re-used as future incident command post sites. Thus it is good practice to monitor (and treat as necessary) former incident command posts several times following a major incident and ideally prior to each use based on the life history of the invasive plant species likely to be found there. Prioritizing treatments in areas that become unsafe for human visitors when invaded can also be important. For example, invasive grasses in western parks can create hazardous fuels and extreme fire danger in some locations. Treatments in these situations where humans visit can be wise for numerous reasons, including ameliorating fuels in areas where human fire ignition sources are omnipresent.

Feasibility of treatment is another important human element and illustrates tradeoffs. For example, given an accessible infestation (e.g., near a road) versus one far in the backcountry, the accessible infestation could be prioritized because it can be treated more easily. On the other hand, the backcountry infestation could be prioritized to protect backcountry resources and forestall further invasion, despite the greater effort required to treat the infestation.

'Off the shelf' site-led prioritization schemes are currently limited and most extant agency examples were the result of park-specific effort. It is possible that some other conservation programs, such as Marxan developed by the University of Queensland (Australia), could be tailored for use in identifying critical sites for treatment in parks for invasive plant management. One example in use in the United States is "Weed Heuristics: Invasive Population Prioritization for Eradication Tool" that prioritizes invasive plant infestations for eradication based on potential impact, potential spread, and feasibility of control. In most situations, development of effective site-led planning for treatment likely hinges upon well-articulated desired conditions and/or goals, a good understanding of current local park conditions, coupled with conditions surrounding parks that can be seed sources, and is as much art as it is science. It requires skillfully balancing tradeoffs in treating one area but not another and minimizing risk/consequences of areas left untreated, while maximizing benefit to treated areas. Other resources discussed in this document, such as use of National Park Service vegetation inventory maps to identify biodiversity hotspots, may assist with this process. Moreover, research and monitoring of National Park Service treatment efforts themselves can likely enhance knowledge for how best to prioritize sites within parks for treatments.

In some cases it may be appropriate to combine both species-led and site-led prioritization schemes. For one recent example, see the Lake Mead National Recreation Area Exotic Plant Management Plan (NPS 2010) where species were first prioritized on a park-wide basis, then a site-led prioritization was used to focus on specific areas where values were most at risk. The site-led priorities were overlaid on the species-led priorities in GIS, which provided a mechanism to "over-ride" the park-wide prioritization of species. Thus in areas where endemic psammophilic rare plants were found, some low and medium priority invasive plant species were treated due to their ability to stabilize the sand-dune habitat to the detriment of the rare plants. Likewise, in some high use recreational beach sites, low and medium priority thorn-bearing species were treated due to their impact on bare feet and visitor enjoyment.

Development of an Invasive Plant Management Program

After the prioritization is complete, those priorities need to be translated into management actions. This is the *implement* step of the adaptive management cycle and is largely the proposed management actions to be evaluated in the invasive plant management plan and environmental document.

Major components of the invasive plant management program should be detailed in an invasive plant management plan, including prevention, early detection and rapid response, treatment of established populations, revegetation after invasive plant control, and monitoring of treatment effectiveness and ecological response. The results of these evaluations are then used to inform subsequent treatment decisions, thus completing one adaptive management cycle and initiating the next iteration. Each of these major components is detailed below.

Prevention

The development of a programmatic invasive plant management plan is an opportunity to integrate invasive plant prevention into park operations. Many parks maintain a system of Standard Operating Procedures (SOPs) and the invasive plant planning process is a prime opportunity to review the existing SOPs and then propose revisions and/or new SOPs to create a comprehensive system of SOPs that serve to operationalize measures to prevent the introduction and/or spread of invasive plant species through routine park operations. See the plans listed on Table 1 for examples of SOPs included in other NPS invasive plant management plans.

Invasive Plant Prevention Goals and Guiding Principles

When designing invasive plant prevention programs, there are eight over-arching goals to consider (adapted from Haultain et al. 2008). These are:

1. Avoid introducing invasive plant species seeds and propagules,
2. Avoid moving invasive plant species from infested areas into uninfested areas,
3. Avoid creating soil conditions that promote establishment of invasive plant species (e.g., unnecessary disturbance),
4. Avoid creating canopy conditions that promote establishment of invasive plant species (i.e., maintain natural levels of canopy closure whenever possible),
5. Establish and maintain the framework for early detection of invasive plant species introductions and rapid response to control them,
6. Increase awareness of invasive plant prevention practices in all park programs,
7. Be prepared to adapt management to changes in expectations and conditions, and
8. Strive for new levels of cooperation, communication, and information-sharing.

Early Detection and Rapid Response to Incipient Populations

Early detection and treatment of invasive plant species when their populations are small is more cost-effective and successful than treating large infestations of firmly established species. Completely eradicating an invader from a park, or even the entire U.S., is possible and has already been done in several U.S. national parks (Abella 2014). The importance of having an effective early detection and treatment system built into invasive plant management plans and successfully implementing it cannot be overemphasized. Early detection can include surveying for new species not yet in parks and treating them as soon as they may arrive in parks, treating species established at one or more locations within parks but not yet abundant or widespread, and identifying and treating small populations of either new species or firmly established species that might be expanding into new areas.

Based on analyzing outcomes of treating 53 infestations of various sizes in California, Rejmánek and Pitcairn (2002) developed a rule of thumb that infestations < 0.1 ha in size can be quite readily (and relatively cheaply) eradicated (Table 3). The table shows the number of eradicated infestations and the number of infestations still being treated as ongoing projects, according to infestation size. Note how work hours increase and success decreases as the size of infestations increase. Infestations < 1 ha in size also can often be successfully eradicated. Once infestations exceed 1 ha in size, and especially 100 ha in size, treatment difficulty and cost escalate. Thus, managers might consider prioritizing early detection to infestations < 0.1 or 1 ha in size. Infestations larger than this size are considered beyond the early detection and treatment phase and represent treating or simply containing a full-blown invasion.

Table 3. Example of the importance of treating infestations when still small, adapted from Rejmánek and Pitcairn (2002) from 53 separate infestations of 18 noxious species in California.

Category	Eradication Level	Initial Infestation (ha)				
		<0.1	0.1-1	1.1-100	101-1000	>1000
No. of eradicated infestations	NA	13	3	5	3	0
No. of ongoing projects	NA	2	4	9	10	4
Mean eradication effort per infestation (work hours)	Eradicated	63	180	1496	1845	–
	Ongoing	174	277	1577	17194	42751
Mean eradication effort per hectare (work hours)	Eradicated	NA	807	103	6	–
	Ongoing	NA	792	648	26	16

Early detection and treatment systems need not be complex, but must at least contain the elements to record new locations of invasive plant species, treatments, and ongoing evaluation of treatments. The agency data minimum standard and platform is the National Invasive Species Information Management System (NISIMS), which is a geospatial tool that is web-accessible through the Integrated Resource Management Applications (IRMA) portal. Early detection is often prioritized along perceived seed-dispersal vectors (e.g., roads, trails, waterways), but it should be recognized that not all invasive plant species show relationships to these perceived vectors (Craig et al. 2010). Thus, including a backcountry component to early detection is a cautious strategy enabling managers to 'see' beyond easily accessible areas. Early detection can occur via three main ways: by park visitors or even as 'citizen science' projects, by park staff during routine activities, or as more formal surveys (or a combination of all). Systems using smart-phone technology, websites where people can upload GPS coordinates of infestations, or simpler strategies such as comment cards at trailheads can engage park visitors and staff to assist with identifying infestations (Crall et al. 2012). Photos and guides to identify major invasive plant species of concern are becoming increasingly common. A system should then be in place for these plants to be treated.

More formal early detection systems can involve systematic searches along travel routes, such as driving roads and recording infestations in segments along roads. Over 3,000 km of travel corridors within federal lands were surveyed in this manner for 43 priority invasive plant species in Nevada (Abella et al. 2009). Backcountry routes also can be systematically traversed and monitored for invasive species on regular time intervals or opportunistically while other work is completed (e.g., train trail crew to recognize and report high priority invasive species, particularly along routes that experience a lot of stock use). A challenging aspect to recording infestations is determining whether to record them as point data, polygons, or as 'cells' representing systematic segments that have been surveyed. Each of these has advantages or disadvantages, but the key is to be able to relocate infestations whether they are treated at the time of identification or later. Note that NISIMS records as polygons which is considered to be the NPS standard. It is important to re-survey areas to ensure that the eradication has been successful.

Sometimes invasive species are deliberately planted in developed areas in parks, inholdings, or on neighboring lands. Early detection and rapid response to remove incipient populations as they invade the natural landscapes in the park, and cooperative work with facilities staff and/or adjacent land owners to eventually remove the seed source, can be very effective in mitigating the risk posed by these species before they become widely established in the park's natural areas (see *Case Study: Successful Invasive Plant Eradication through Cooperation at Death Valley National Park*).

It should be further emphasized that even species firmly established within a park can and often should be part of early detection systems. For example, even cheatgrass, a species widespread across much of the western U.S., often is most abundant only in certain areas within parks (Ransom et al. 2012). Early detection and treatment can be used to detect a species as it expands into new areas, following quickly with treatment to potentially contain the invasion. Thus, early detection and treatment is a critical tool for the invasive plant manager to both eradicate new species before they become problems and to limit expansion of more abundant species. Developing effective strategies and tools for early detection and treatment warrants considerable attention when developing invasive plant management plans.

Case Study: Successful Invasive Plant Eradication through Cooperation at Death Valley National Park

Thanks to early detection, friendly cooperation and aggressive control, the highly invasive fountain grass (*Cenchrus setaceus*, common synonym *Pennisetum setaceum*) has been successfully eradicated from Death Valley National Park. Fountain grass is an ornamental perennial bunchgrass from Africa that has become popular in desert landscaping throughout the southwest. Unfortunately its fluffy seeds are carried on the winds into neighboring wild lands, colonizing both rocky slopes and sensitive spring areas. Fountain grass has already invaded 540 acres in Joshua Tree National Park and over 1,800 acres in Lake Mead National Recreation Area including 20 miles of Lake Mohave shoreline. Park staff at both Lake Mead and Joshua Tree actively control fountain grass that has drifted into native ecosystems from nearby urban landscaping. Fountain grass is extremely flammable causing wildfires in areas where it may not have historically occurred.

In Death Valley National Park, fountain grass was introduced into landscaping at the Furnace Creek Inn (a private historic resort that pre-dates the park establishment) and also the Park residential area. The NPS removed the fountain grass in the park's residential area in 1998 and with continued monitoring and re-treatment it has been kept under control. Although fountain grass had been present at the Inn for several years, only a few individuals had escaped into nearby Texas Springs. The two invaders in Texas Springs were eradicated in 2007 by the Lake Mead Exotic Plant Management team while working on palms in the area, but the original seed source at Furnace Creek Inn remained, and so re-invasion was likely. In 2010, the Death Valley National Park Botanist contacted the Regional General Manager for the Xanterra Resort at Furnace Creek, and alerted him of the danger posed by this attractive grass. Xanterra, who operates the Furnace Creek Inn as a private resort and is also a park concessioner for the park's Furnace Creek Ranch Resort, was enthusiastic to cooperate with the Park to protect the natural ecosystems of Death Valley. Park staff worked together with the Landscape Manager at the Furnace Creek Inn to remove over 100 mature fountain grass plants in 2010. Since that time, some seedlings have returned, but the landscape staff at Furnace Creek Inn has been vigilant and thorough in preventing their reestablishment. A few seeds may still germinate in the coming years, but with awareness and rapid response, it is safe to say this invasion has been stopped in its tracks.

Provided by Jane Cipra, (former) Botanist, Death Valley National Park

Treatment of Established Populations

Control Strategies

Treatment of invasive species often includes multiple strategies, frequently used in coordination with each other. Control strategies are generally focused on the long-term reduction in density and/or abundance of a given population and are often measured against a defined threshold below which the presence of an invasive species may be acceptable to managers. The threshold is generally designed to represent a population level that does not interfere with natural processes or important park resources or visitor experiences. In some cases, any population is unacceptable and the concept of a lower threshold is meaningless so eradication may be the only desired outcome of a control effort. In some cases the strategy is to contain an invasive species by limiting its spread from a source population(s) into new habitats. In many cases, the two strategies are used in concert with each other so that there is an effort to aggressively treat outlying populations (which is a containment strategy) while simultaneously reducing the density or abundance of the source population (which is a control strategy) year after year so that the propagule pressure is reduced over time.

Almost any treatment method can be used with either strategy, though the typically slow acting nature of most biological controls generally makes them more suitable for control rather than containment strategies. Manual, mechanical, and chemical treatments can be used in containment strategies when they are applied selectively to outlying populations where individual plants are often the target of treatment or as part of control strategies where they are applied more broadly to a population of plants, often using broadcast application methods to treat relatively large areas.

Manual and Mechanical Treatments

Manual and mechanical treatments involve physical damage to, or removal of, part or all of the plant. Both manual and mechanical treatments may involve the use of tools. Examples of manual treatments include hand pulling, using cutting tools (shovels and clippers), pulling tools (such as weed wrenches™), and power tools (such as string trimmers). Examples of tools used in mechanical treatment may include cutting tools (chainsaw, riding mower) and tools that disturb the soil (bulldozer, disk, plow). Some manual and mechanical methods are highly selective for individual plants, thus these are a good choice to minimize disturbance to adjacent plants and surrounding habitat

Hand pulling can be used in any area and is most effective for shallow-rooted, non-rhizomatous species. Hand pulling is conducted by removing as much of the root as possible while minimizing soil disturbance. This method is generally not appropriate for rhizomatous species because the root fragments left behind will regenerate into many new plants where there was formerly only one, thus increasing the invasive plant population.

Hand cutting tools are a treatment option for removing the above ground portions of annual or biennial plants. Hand tools, such as trowels, shovels, and pulaskis can be used to remove a larger portion of the root system or to sever the plant's taproot below the point where adventitious roots develop. In some cases, manual and mechanical treatment may be used to simply remove the seed heads of the plants prior to seed set to prevent seed dispersal that growing season. This is particularly appropriate for some biennial species with a large tap root where it would take a substantial amount of effort to remove the entire plant and no additional invasive plant reduction would be realized from the effort (e.g., common mullein). Similarly, removal of seed heads of second year plants prior to natural mortality is also appropriate. Where treatment is used to remove only seeds, special effort must be made to contain the seeds to prevent accidental dispersal during the removal process, and the population needs to be monitored frequently throughout the remainder of the growing season to be sure that the plants do not produce new seeds prior to senescence.

Pulling tools are a treatment option for removing individual plants that are deep-rooted. Pulling tools can be used to control small infestations, such as when an invasive plant is first identified in an area. These tools grip the stem and remove the root by providing leverage. Pulling tools are most effective on firm ground rather than soft, sandy, or muddy substrate (Tu et al. 2001), but they can exacerbate erosion in some cases if the root systems are substantial.

Power tools can be used to treat small to large infestations. Power cutting tools, like hand cutting tools, are used to remove aboveground biomass, reduce seed production, and reduce plant growth, but can be used on larger plants and woody species that exceed the capacity of hand tools. Power tools are useful for controlling annual plants before they set seed. Power tools can also be used with other treatments, such as chemicals or prescribed fire, to treat perennial invasive plants. Resprouting after removal of aboveground biomass depletes nutrient reserves that are stored in root or rhizome systems. Once nutrient reserves are depleted, some invasive plants become more susceptible to subsequent chemical or fire treatments, particularly the tender growth of re-sprouts. This method often takes more than one treatment to achieve mortality of the target plant or population. Chainsaws are a power tool that may be used to remove aboveground biomass of shrubs and trees. Following biomass removal, chemicals are often applied directly to the stumps to prevent suckering.

Chemical Treatments

Chemical treatments involve applying herbicides as prescribed by their labels. A variety of application methods are available. Herbicides are most effective for treating dense stands of invasive plant species in areas where desirable plants are scarce or absent and where manual and mechanical methods are not feasible. However, highly selective application methods combined with thoughtful herbicide selection and careful application may also be used to treat individual plants interspersed with desirable species. As the scope of this document is limited to plants, the term herbicide is generally used except in reference to the NPS pesticide use program.

The appropriate herbicide, with consideration of active ingredient(s) and mode of action, should be selected for each target species and habitat. A toxicological analysis of the proposed herbicides should also be reviewed to determine if the level of risk posed to humans and the environment is commensurate with the impact of the invasive plant species. The NPS also provides a process to help park staff identify, understand, and define risk(s) associated with the use of proposed pesticides via the document 'Parameters for Pesticide Review' that is web-accessible through the IRMA portal. It is likely that new formulations of herbicides will become available in the future, thus the plan should be written with this in mind and not commit to any one specific herbicide formulation. Herbicides can be post-emergent, pre-emergent, or both; they can also be selective or non-selective; soil active or soil inactive. Special considerations and application requirements apply to aquatic label and restricted use herbicides. All herbicides must be proposed for use in a pesticide use proposal and approved by the regional IPM specialist. Each herbicide use must be recorded on a pesticide use log and reported annually to the regional IPM specialist. An invasive plant management plan need not describe these internal administrative processes in detail but should include such requirements as mitigation measures to demonstrate a level of agency review and shared accountability for herbicide selection and use.

An adjuvant is a substance added to an herbicide that has no herbicide action by itself. Some herbicides require the addition of an adjuvant to work effectively. Surfactants are adjuvants used in conjunction with herbicides to increase absorption of the chemical by the plant. Another adjuvant commonly used with herbicide is a dye product that turns the chemical mixture a specific color, usually blue, so that treated plants (or portions of plants) are easily recognized to aid the herbicide applicator in assuring a thorough application of the chemical to the targeted plant and to avoid missing or respraying plants. Typically herbicide labels direct that plants should be sprayed until wet but not to the point of excessive run-off. The plan should consider outlining the conditions under which adjuvants will be used with herbicide application and commit to following label restrictions and MSDS safety information, but should generally avoid committing to specific adjuvants in order to provide flexibility for use of new products in the future.

Safety procedures must be adhered to when applying herbicides. Label restrictions and Safety Data Sheets (SDS) must be kept on site for all adjuvants and herbicides used. Pesticide applications will only be performed by or under the supervision of certified or registered applicators licensed under the procedures of a federal or state certification system (NPS 2006, Section 4.4.5.3). NPS staff must adhere to certification requirements of the state within which they work.

Herbicides can be applied using one of several application methods. The most appropriate application method is determined by the invasive plant species being treated, size of plants, density of plants, the herbicide being applied, the skills of the applicator, and the application site (Tu et al. 2001). Methods of application can be broadly described as follows:

- Foliar application where herbicide is applied to intact, green leaves
  - Spot application using a precise tool such as a backpack applicator or spray bottle
  - Wick application where the herbicide is physically wiped onto the leaf surface
  - Broadcast application using boom or boomless sprayers to distribute herbicide over a relatively large area depending on the swath width and equipment used
- Basal bark application where herbicide is applied to intact bark around the circumference of the trunk
- Frill or “hack and squirt” methods where the trunk or stem is first cut into the cambium layer then herbicide is applied to the cut
- Injection where herbicide is injected through the bark into the cambium layer
- Cut stump treatment where the tree or stem is first cut straight across then the herbicide is applied to the freshly cut stump for transport to the root system
- Pelletized treatment where herbicide is made into a pellet that is implanted at the plant’s base
- Pre-emergent where the herbicide is applied to the soil before seeds of the target species germinate and emerge

It is also helpful to consider whether standing dead plants will be a hazard, and if so, consider if there are application methods that can minimize or mitigate that hazard or if follow up work will be necessary. For example, basal bark, frill, and injection methods can be used to kill standing trees but will leave a dead standing tree which in some locations will become a hazard tree, while cut stump treatments remove the hazard by laying the tree on the ground at the time of treatment. Thus, in locations where there is nothing to fall on, the basal bark, frill, and injection methods would be a good choice because they are relatively fast, while in areas adjacent to buildings, campgrounds, parking lots, and trails, the cut stump treatment might be a better choice to both kill the tree and to remove the hazard at the same time.

Plans that call for chemical treatment should incorporate best management practices to ensure that the overall effectiveness of herbicides is maximized and the potential for impacts is minimized. These can be articulated in the plan as mitigation measures if necessary. While best management practices (BMPs) can be tailored for each park, these general BMPs provide a starting point:

- Read and follow all product labels. It is a violation of federal law to use an herbicide in a manner that is inconsistent with its label.
- Obtain and maintain any certifications or licenses required by the state and/or county.
- Apply herbicides as near to the target plant as possible to avoid drift onto non-target plants and organisms.

- When planning to apply herbicides, account for environmental conditions such as wind speed, wind direction, inversions, humidity, and precipitation in relation to the presence of sensitive resources near the treatment area and direction provided on labels. Only apply herbicides when environmental conditions at the treatment site allow for complete and even coverage and no drifting of spray onto non-target sensitive resources or areas used by humans.
- Apply herbicides only during periods of suitable environmental conditions as indicated on the herbicide label.
- Herbicides should be applied using large droplet size (coarse sprays) to minimize the potential for drift. Avoid combinations of pressure and nozzle type that result in fine particles (mist). Add thickeners if the product label and application equipment permits.
- Apply herbicides at the appropriate time of day or season based on the herbicide's mode of action. Poor timing of application can reduce the effectiveness of herbicides and can increase the impact on non-target plants.
- Apply herbicides according to application rates specified on the product label.
- In areas where there is the potential to affect surface water or ground water resources, consider herbicide pH and soil pH to select the herbicide with the lowest leaching potential.
- Do not use highly water-soluble herbicides in areas where there is potential to affect surface water or ground water resources.
- Do not use herbicides with high volatility to treat areas located adjacent to sensitive areas because of the potential for unwanted movement of herbicides to these areas.
- Use herbicides with high soil retention in areas where there is potential to affect surface water or ground water resources.
- Apply herbicides with longer persistence at the lower concentration rates prescribed by the label and/or with less frequency to limit the potential for accumulation of herbicides in soils.
- Do not apply soil active herbicides near sensitive (desirable) species.
- As needed to protect the efficacy of the herbicide, water used in chemical dilution should be buffered, depending on hardness, pH, and other factors.
- Establish, document, and follow at all times safety protocols for storing, mixing, transporting, handling spills, and disposing of unused herbicides and containers. Establish and educate herbicide applicators on plans for emergency spills.
- Follow all pertinent federal, state, and local regulations regarding herbicide use.
- To maintain herbicide efficacy, only herbicide amounts that are expected to be used in a 1 year period should be purchased, as per NPS policy (NPS 2006).
- Maintain and calibrate equipment prior to each application of herbicides. If necessary, dedicate some spray equipment to specific herbicides to prevent chemical contamination.
- Use only herbicides that are registered for use in aquatic habitats in or near surface water (including reservoirs, rivers, springs, and seeps, but not including dry washes where no hydrophytic vegetation is present).
- Use only those herbicides that have a low potential toxicity in areas with a high leaching potential.
- Avoid applications of herbicides when precipitation is likely to wash residual herbicides into waterways.
- Applications of herbicides within 50 feet of surface water bodies (including streams, rivers, lakes, and waterways) should be done by hand or with vehicle mounted ground equipment to minimize the potential impacts to surface waters.

Herbicide applications can be implemented by using either ground-based or aerial delivery methods. Due to the density of vegetation, designation as wilderness, or the potential for damage to cultural resources, ground-based application using motorized equipment (e.g., ATVs) may not be suitable in some locations. Instead, ground based delivery is done by backpack spraying where the applicator wears a backpack containing the herbicide mix and uses an applicator wand to spot spray the herbicide on individual plants with minimal risk to adjacent non-target species. In difficult to access locations, particularly in wilderness, horse-mounted sprayer systems may also be considered for the delivery of larger volumes of herbicide into remote areas. In horse mounted sprayer systems, the herbicide is packed on horseback and applied with a wand applicator by a technician.

Aerial delivery can be done with either helicopters or fixed wing aircraft, though helicopter is preferable due to their superior maneuverability and precision in delivery. There are several types of equipment to administer herbicide from a helicopter including booms of various widths and precision delivery devices, informally referred to as spray balls which are suspended from a helicopter on a cable. The spray ball is able to come within 6 feet of the ground and spray an area as small as 12 feet in diameter. The spray ball method is preferred where terrain is difficult, non-target species density is high, and/or invasive plant distribution is patchy. Aerial broadcast spraying with herbicide using a helicopter fitted with a boom sprayer is most suitable for relatively large areas where invasive plants are dense or evenly distributed and native species are absent, sparse or dormant. If aerial delivery of herbicide is to be considered in the invasive plant management plan, careful consideration should be given to defining the conditions under which it would be used. Mitigation measures to minimize drift should also be incorporated into the environmental assessment.

Biological Treatments

Biological treatments are commonly referred to as biological control or biocontrol and rely on the use of other biological organisms to maintain pest populations below the action thresholds. Biological treatments involve the use of "natural enemies" to reduce the abundance of an invasive plant. Natural enemies include insects, mites, or pathogens that are imported from areas where the target invasive plant occurs as a native plant and are deliberately released into areas where the plant is invasive. These natural enemies limit the growth or reproduction of invasive plants or in some cases may damage the plant in ways that make it susceptible to other pathogens. Biological control may be a long-term solution for controlling some invasive species that are too widespread for control by other means. Biological control is best suited for infestations of a single, dominant invasive plant species that is not closely related to other native plant species. In the United States, biological control agents are identified, tested, and regulated by the U.S. Department of Agriculture Animal and Plant Health Inspection Service (APHIS).

Release of biological control agents on NPS lands should incorporate the following best management practices:

- Only those biological control agents approved by APHIS are allowed for use on NPS lands.
- Biological agents are also subject to a site based analysis by the NPS with due consideration of indirect effects.
- Prior to release, an implementation plan must be written to include: a summary of species biology and effectiveness of control, establishment of population and/or control thresholds, acquisition of biocontrol agents, strategy for actual release of organisms, and a strategy for monitoring the success of the release and indirect effects of the biocontrol agent. It is also helpful to include contingency plans for host shifts should they occur after release and an estimate of how much residual population of the host plant is acceptable (if any) to keep the biocontrol population viable for control of future invasions. The implementation plan should be peer reviewed by at least three people, one of whom should be experienced in the use of that specific biocontrol agent and pest plant.
- Before a biological control agent is released on NPS land, park staff responsible for invasive plant management must submit the implementation plan and receive approval from the National IPM Coordinator to release the agent.
- If biological control agents are to be obtained from another state, a permit which has been reviewed by the State Entomologist must also be obtained from APHIS. The transport, handling, and release of biological control agents must be in accordance with all permit conditions.
- Biological control agents should be released in each climatic zone that is occupied by the host so that the natural enemy has a chance to develop in all areas where the host occurs.
- The number of biological control agents released should reflect the size and density of the treatment area and the number of agents required to maintain a viable biological control agent population.
- More than one release in an area may be necessary for successful establishment. Multiple releases may occur in different locations at the same time or at the same location over multiple times, depending on the biology of the biological control agent and the distribution of the targeted invasive plant population.
- Releases should be synchronized with the time period when the host plant is present.
- Biological control agents should be released at times of the day when they will not disperse from the treatment area.
- Biological control populations should be monitored according to the strategy identified in the implementation plan. Monitoring should occur annually at a minimum.

Post-Treatment Revegetation

This section focuses on considerations of re-establishing desirable plant communities following invasive plant treatments. It is divided into a generalized two-step process that should be undertaken during development of an invasive plant management plan and prior to implementation: 1) Analyze site and select revegetation strategy, and 2) Develop treatment prescription for revegetation.

Post-treatment revegetation should be a consideration in all invasive plant management efforts though implementation may not be appropriate in all situations. Thus it is helpful if invasive plant management plans include a general framework by which revegetation decisions will be made on a site by site basis during plan implementation, taking into consideration the common practices and risks associated with restoring that specific vegetation community or biome. For example, arid lands often have a large percentage of land cover that is naturally unvegetated, so removal of an invasive plant does not necessarily mean a native one should be planted if the natural condition should be bare ground. However, in some verdant landscapes a gap caused by invasive plant removal may be an invitation for a new invader and so it may be appropriate to revegetate with desirable plant species.

A generalized two-step approach to post-treatment revegetation is presented here as a starting point, but it may or may not be applicable to a given situation. First, analyze site-specific factors to determine which revegetation strategy is appropriate: passive, facilitated, or active. Then consider various techniques for invasive plant control and/or revegetation within each of those strategies, based on site-specific constraints and opportunities for successful development of a treatment prescription to restore natural conditions to the site.

Step 1: Analyze site and select revegetation strategy

Factors to consider when selecting the optimal strategy for revegetation at a given site:

1. Invasive plants: The pre-treatment density and abundance of invasive plants is estimated based on pre-treatment data and local knowledge. Some of the details to be considered include:
   - A. How long has the invasive species been present in this site? This gives an indication of how abundant seed or rhizomes may be in the soil seed bank and how long the invasive species has been competing with native plants. If the invasive species has been on the site for a relatively short time, much of the native seed bank may still be viable and much of the native species richness will remain. Presumably the longer the site has been invaded the less resilient the native plant community may be.
   - B. What other invasive species are present on the site? Some other species may amplify or confound impacts of the target invasive species.
   - C. What is the response of invasive plants to treatment?
   - D. What is the proximity to vectors and pathways for new post-treatment invasions?
2. Pre-treatment native plant communities: The pre-treatment community composition and relative health is estimated based on pre-treatment data, and local knowledge. Some of the details to consider are:
   - A. What is the size and age class distribution of key species?
   - B. What are the seed bank characteristics? The presence of a robust native seed bank is a prerequisite for post-treatment germination of desired species.
   - C. What is the health and condition of the native plant community due to the presence of other stressors? Consider stressors of natural origin such as fire, persistent drought, freezes, or disease as well as stressors of anthropogenic origin such as other invasive plant or animal species, off-highway vehicle trespass, trespass or permitted livestock grazing, air pollution damage, persistent human disturbance, etc.
3. Post-treatment native plant communities (where applicable): The post-treatment mortality and vegetative response is estimated as a function of pre-treatment conditions, post-treatment site inspection, and local knowledge. Of particular interest is the likelihood of post-treatment re-sprout and/or germination of desired perennial plant species. There is likely to be a high degree of spatial variability within the treated area, and the vegetative response will likely vary depending on the type of treatment applied (e.g., broadcast treatments will have more widespread effects on site condition than spot treatments, pre-emergent herbicides will have more persistent effects on a broader range of species than most post-emergent herbicides). Some of the details to consider are:
   - A. What amount of bare ground is visible after treatment that was not visible before treatment?
   - B. What is the differential response of size/age classes of key plant species?

C. What is the differential response by species?

D. Are the invasive plants sufficiently under control?

E. Is treatment of re-sprouts and/or new seedlings of invasive plants anticipated?

Based on the outcome of the site analysis, the recommended revegetation strategy may be active, facilitated, or passive (Figure 2 and Table 4).

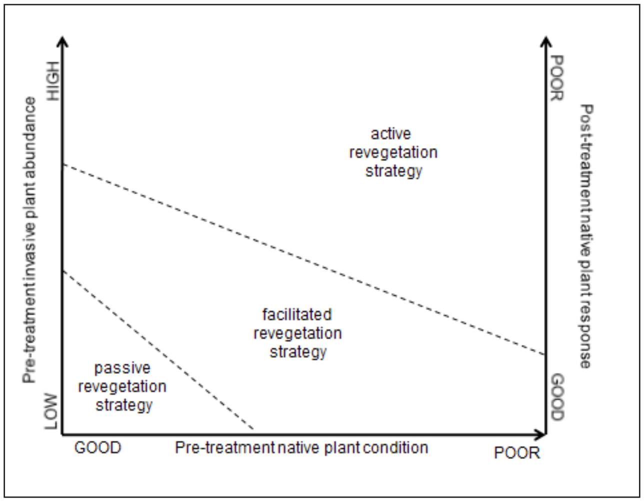

Figure 2. Recommended revegetation strategy.

Passive revegetation is the recommended strategy where the pre-treatment abundance of invasive species was low, pre-treatment native plant condition was good, and post-treatment plant response is expected to be good. These are the necessary conditions that increase the likelihood of successful natural recovery. In this strategy, the focus is on monitoring natural recovery and intervening in narrowly focused ways only when necessary. Such interventions may involve invasive plant control using selective methods (e.g., hand pulling or spot application of herbicide) on small insipient populations of invasive plants, particularly along pathways for invasion (e.g., roadsides and trail corridors). If the native plant response is poor after the first or second growing seasons, there were probably miscalculations in analyzing the site conditions and the selection of the revegetation strategy should be reconsidered and transitioned to either facilitated or active revegetation.

Facilitated revegetation is the recommended strategy where pre-treatment abundance of invasive plant species was moderate, pre-treatment native plant conditions were poor to moderate, and post-treatment native plant response is expected to be good. These are the conditions typical of sites that are recently invaded, where native plant communities may be showing signs of decline pre-treatment but the remaining native plant species continue to persist and reproduce. In this case, the invasive plant species seed bank is likely to be abundant and the re-sprouting and/or germination of invasive plant species will be problematic post-treatment. There may be some need for seed bank augmentation to facilitate the re-establishment of species that had already been lost on the site before the treatment. Interventions for this strategy will likely focus heavily on invasive plant control using a wide variety of methods, including both selective and less selective methods in variable densities for invasive plants, and seeding and/or planting of native species in small areas or with a relatively small mix of species.

Active revegetation is the recommended strategy where pre-treatment invasive plants were abundant and post-treatment native response is expected to be poor to moderate. Pre-treatment native plant community condition could range from poor to good, but is somewhat irrelevant due to the sheer abundance of invasive plant seeds and propagules on the site. Such revegetation treatments will likely include continued aggressive invasive plant control using

Table 4. Post-treatment revegetation strategies and their relationship to invasive plant control and revegetation techniques.

Strategy	Continued Invasive Plant Control	Revegetation techniques
Passive	Monitor for insipient invasions and control using selective methods.	Monitor natural recovery and protect site from other stressors (e.g., ORV trespass, repeat fire, etc.)
Facilitated	Invasive plant control using selective methods where densities are low and less selective methods where densities are high.	Seed bank augmentation with seeds of native plant species in small areas. Planting if necessary.
Active	Aggressive invasive plant control using broad range of methods	Seeding native species and planting (from plugs or nursery grown seedlings) native species appropriate to the microsite and soil conditions. Amend soil if needed to ameliorate conditions that would inhibit out planting success.

a wide range of methods, re-establishment of native plant communities via seeding and/or planting, and perhaps soil amendments if the invasive plant is allelopathic or known to alter soil chemistry.

Step 2: Develop treatment prescription for revegetation

Review NPS Management Policies (Chapter 4) regarding use of native and non-native plant materials and carefully consider the origin of native plant materials that will be used for revegetation efforts. Plan ahead to secure plants and/or seeds collected locally if possible recognizing that ecological seed zones will likely vary by species. Ecological seed zones are defined as areas within which movement of plant materials presents little risk of their being poorly adapted to their new location. Consider using existing agreements or entering into new agreements with conservation partners to increase seed availability through cultivated production off site so that the park can have sufficient quantities for a successful revegetation project.

The exact species mix and proportions used for any particular post-treatment revegetation effort should largely be determined by the strategy selected, the species that are appropriate and desirable on that site as well as the cost and availability of suitable plant materials. Below are some considerations to use in writing a project-specific revegetation prescription.

Seeding Treatments:

- Seeding native species may have potential as a revegetation tool in some landscapes but many variables can affect seeding success, such as species selection, genetic stock and germinability, associated treatments and their effects on site condition (such as mulching and invasive plant control), environmental site conditions, timing of seeding, precipitation, and seed depredation.
- Seed application methods should be considered based on site location, conditions and species requirements, and may include drilling, broadcast, seedballs, hydroseeding, mulching or other bioregional approaches. An example of a bioregional approach used in deserts is stockpiling for natural dispersal. In this approach, seed is placed in small piles in multiple places around the desired seeding area and native granivores (mostly rodents and ants) and wind disperse the seed throughout the landscape in a short period of time. Some seeding methods, particularly those that involve soil disturbance may increase the potential for new invasions. Research the pros and cons of different application methods to select the most appropriate method for the situation.

Live Plant Treatments:

- Planting of live plants should be considered for reestablishment of those species that do not readily establish from seeding into natural landscapes. For example, cactus is typically re-established from cuttings, willow and cottonwood are typically re-established from poles, perennial grasses are typically re-established from plugs. Where suitable containerized seedlings or bare-root seedlings are available from local partners or vendors, they may be used to re-establish a more diverse age and size class structure for long-lived perennial species or for the creation of a more diverse planting in high profile areas (e.g., visitor use areas, endangered species habitat, etc). Carefully consider, and mitigate to the extent possible, the potential for plantings to introduce new soil and plant pathogens as well as other invasive species.
- Planting of live plant materials should be considered on a site by site basis based on anticipated post-treatment native plant response, typical propagation techniques used for establishment of desired species (e.g., propagation using poles, plugs, containerized, bare root, etc.), and accessibility of the site for post-planting care and maintenance. Cost-benefit evaluation is an important consideration as such planting can be quite expensive and planted sites will often require long-term maintenance and continued investment over time to be successful.
- Planting may be locally suitable in high value locations where the site has limited native seed banks and is not likely to be re-colonized by desirable species (e.g., where pre-treatment invasion had depleted or suppressed desired plant species in the seed bank).

Post-Planting Treatments:

- Post-planting establishment success may be increased by the application of supplemental water and/or mulch. Such measures should be short-term, localized, and typically confined to areas that are relatively accessible. Loss of out-planted species to drought is a major concern in arid landscapes, and can be partially mitigated by supplying supplemental water via hand watering or a time-release water gel applied directly to the root zone (e.g., Dri-Water™). Some species also may benefit from the application of mulch composed of weed-free organic materials to reduce soil evaporation near the root zone of the plant.

- Post-planting success may be increased with the use of protective measures to reduce herbivory. Such treatments might include chemical controls (e.g., Critter Out™) or mechanical controls (e.g., herbivory cages above and/or below ground). Such measures should be short-term, localized, typically confined to areas that are relatively accessible, tested to ensure they do not negatively impact wildlife, particularly threatened and endangered species, through entrapment, entanglement or collision.

Monitoring

This section focuses primarily on treatment effectiveness monitoring as a minimum standard for invasive plant management programs, but briefly touches on other aspects of data collection that may be relevant to some invasive plant management programs. This is the *monitor* step of the adaptive management cycle.

Monitoring is the collection of repeated observations through time to evaluate the condition of some entity (Elzinga et al. 1998). Monitoring should not be confused with other types of data collection, such as surveys, retrospective condition assessments, experiments, or others. Surveys differ from monitoring because surveys are typically a one-time data collection to evaluate the distribution and abundance of species, and do not enable identification of temporal population trends (though surveys can become monitoring if they are repeated in time). Retrospective condition assessments also are not monitoring but they can be quite valuable for evaluating current condition of areas that were treated in the past. Saguaro National Park, for example, supported a condition assessment of areas treated during the previous five years for the invasive perennial buffelgrass. The condition assessment rapidly provided information on the current abundance of buffelgrass as well as the condition of the native plant community following several previous years of treatment (Abella et al. 2013). Experiments involve active manipulation of one or more factors, such as applying different concentrations of herbicide and measuring plant responses (which can then be monitored through time as part of the experiment). A key distinction is that monitoring can determine trends in populations, but not causes behind those trends. Experiments provide such cause-effect information and have been critical to formulating treatment protocols for numerous species, including those on National Park Service lands (Abella 2014).

It is important to recognize that different types of study designs and data collection, such as surveys, monitoring, and experiments, provide different types of information. They are usually complementary. Effective invasive plant management uses all of these information sources in different and complementary ways. For example, surveys might be used to identify sites across the landscape that are minimally or heavily invaded. This information then might inform monitoring, where a range of sites invaded to different extents are selected for monitoring to evaluate population trends in the many invasion situations confronting managers. A retrospective condition assessment might then be employed to evaluate ecological condition of areas that have been treated in the past as an assessment of what treatments seem to have worked (and where), or what species seem to have been effectively (or not) controlled. For species ineffectively controlled by existing treatments, research experiments might be planned to rigorously compare a range of possible treatments.

Unfortunately, there are rarely ‘shortcuts' in effective data gathering, but carefully thinking about multiple uses of the data can greatly expand the information gained for the effort expended. For example, a well-designed survey could also be a retrospective condition assessment, and vice versa. In this scenario, information could be generated both on distribution of target invasive plants and how abundant they are in areas that were treated and not treated. Further, sampling units installed for surveys or condition assessments could become long-term monitoring plots, if they are re-measured repeatedly through time. A key is to use consistently good methods (e.g., not varying sample plot sizes between treated and untreated areas, as varying sample size precludes comparison) and to identify the key questions and desired end-user information prior to initiating the invasive plant assessment. Data gathering should be designed with appropriate statistical power to assess progress toward stated goals and should be factored into the planning process early before any treatment is actually implemented.

A good resource on study design for vegetation measurements is Elzinga et al. (1998). It also is important to keep in mind that appropriate sample sizes (e.g., number of plots or transects) can be determined (as discussed in Elzinga et al. [1998]) through various equations that identify minimum sample sizes needed to achieve statistical significance. In practice, resources, or site availability (e.g., number of treated sites) often limit sample sizes, so a good rule of thumb is to sample as many areas as feasible given time and cost limitations while maintaining effective methods. It is usually better to sample fewer areas effectively than many areas with methods so coarse that they preclude detection of any trends. Above all, consistency is critical. Switching methods (unless there is a compelling reason to do so) between years, or using varying plot sizes or cover classes between sites, often frustrate efforts to reliably learn anything from the sampling data. Giving careful attention to objectives and methods at the onset of an investigation, and making any needed adjustments early on from pilot testing, are good practices for making the most of data collection efforts.

Elzinga et al. (1998) further distinguish types of monitoring as species, habitat, or implementation monitoring. In species monitoring, population trends (increase, decrease, or no change) of target species are measured. In habitat monitoring, characteristics of the habitat are measured, such as changes in diversity or cover of native plant species in treated and untreated areas. Implementation monitoring, referred to here as treatment effectiveness monitoring, measures how effectively a management intervention itself was implemented. An example of implementation monitoring could be tracking off-site condition of native plants when herbicide 'drift' is a concern, ideally with a finding of minimal damage on native plants. In a park context, habitat monitoring often is just as useful as species monitoring.

Some special challenges in invasive plant management should be kept in mind when developing information-gathering strategies. First, it may not always be possible or desirable to leave areas untreated as 'controls.' This makes before/after and invaded-treated/uninvaded comparisons especially valuable. It simply needs to be recognized that cause-effect of treatments is impossible to establish in this circumstance, as it cannot be ruled out that an infestation might have become reduced (or increase) on its own, such as transitions with climate changes. Managers may be comfortable simply knowing correlation in this case; however, because the desired outcome is to have infestations reduced, and if reductions are correlated with treatments, continuing this strategy would follow the precautionary principle. Given that it is rare that all infestations of a firmly established species can be treated, it often is possible and desirable to designate some areas as untreated controls (which would not be treated anyway at a particular time due to factors such as limited treatment resources). These untreated areas provide useful benchmarks against which to compare treated areas. Second, at a landscape scale, a monitoring outcome of 'no change' might actually be highly successful in invasive plant management because it means infestations have not expanded. Third, monitoring treatment outcomes at specific sites can be difficult, but monitoring overall changes on a park-scale is even harder. However, moving toward monitoring at a park scale is important, because treatment success at a few sites does not necessarily mean that invasive plants are in remission in the rest of a park.

A common statement is that allocation of any resources to treatment effectiveness monitoring (or surveys, condition assessments, or research), rather than allocating 100% of available resources to treatment, will result in expansion of invasive plant populations. However, even with 100% allocation to treatment, the number of invasive plants and their distribution overall has likely continued to increase in parks (Allen et al. 2009). Effective information gathering is important because it leads to improved treatment efficiency and thus can substantially increase benefits of treatments per unit expenditure. For example, Maxwell et al. (2009) concluded that allocating even up to 50% of available resources to careful monitoring and assessment would not result in expansion of invasive plant populations, because of gains in treatment effectiveness as a result of the information gathered.

Building monitoring and assessment into invasive plant management plans is the main way that management plans and strategies can be adaptive to changing conditions. Without strategies for gathering new information, it is difficult to portray that plans involve adaptive management. Monitoring schemes need not be complex. At a minimum, plans should have a strategy to support treatment effectiveness monitoring by systematically tracking where treatments have been implemented, what treatments have been done, and when. Efficiencies can be built in, such as collecting monitoring data before treatment and then treating sites immediately thereafter to save travel costs. Photo documentation can be readily performed with today's technologies and requires only the discipline to carefully record where photos were taken, re-take photos from those same locations and angles in the future, and maintain the photo files and associated information such as treatment type. Using plots, transects, or other types of sampling units (Elzinga et al. 1998) for treatment effectiveness monitoring, comparisons as simple as treated versus untreated (ideally with multiple sites of each), or before/after treatment at the same site, can generate extremely valuable information to inform the next generation of treatments. Moreover, this information can be extremely valuable to new managers arriving at a park, given high staff turnover.

Research

This section highlights some of the aspects of empirical and applied research that might be considered for inclusion in an invasive plant management plan. Research can be a part of the monitor or the evaluate step of the adaptive management cycle.

By definition, adaptive management includes use of existing information and incorporation of new information in management planning (Williams et al. 2007). Assessment, monitoring, and research are essential components of adaptive management. Some of the numerous examples of uses of research in invasive plant management include:

- Identification of species whose invasiveness might be changing, such as seemingly innocuous species that might be emerging from their lag phase to become highly damaging.
- Development of management strategies appropriate to broad-scale infestations – such as those exceeding thousands of acres and including the National Park Service's 'mega-parks' such as Alaska parks and Death Valley National Park. These large parks require techniques across scales far larger than most National Park Service personnel are accustomed.
- Species-specific and multi-species control techniques that are as long-lasting as possible and minimize any unintended damage to indigenous resources.
- Improving ability to predict when and where 'secondary invasion' (other invasive species simply replacing a treated, focal invader) is a potential problem requiring attention in management planning.
- Assessment of when and where active ecosystem restoration is most appropriate as part of invasive plant management. Similarly, assessment for how agents of global change (e.g., climate change, nitrogen deposition, altered fire regimes, forest die offs) should be accommodated in invasive plant management to achieve desired outcomes.

Managers can incorporate existing and propose new research in their planning through: 1) performing a situation analysis (such as existing or ongoing research in their specific parks, similar parks, or other lands), as previously described in this document; 2) employing freely available literature databases such as GoogleScholar, which allows customized searches of new literature by years and by specific search terms, and systems such as the U.S. Forest Service's Fire Effects System which periodically updates available species-specific accounts; 3) learning from projects conducted in other parks (e.g., synthesis of 56 invasive plant management projects conducted on national park lands; Abella 2014); 4) funding or facilitating research on key information needs within their parks; and 5) conducting some of their own monitoring and assessment, such as on treatment effectiveness and responses of native species (see preceding section on Monitoring).

It is informative to consider how invasive plant management would stagnate without development of new research, monitoring, and assessment. Promising techniques, such as carbon addition and native species selection, would cease to be developed. Existing techniques may or may not adequately control evolving invaders in present, future, or different ecosystems. Potential future ecological changes, including climate change and altered fire regimes, could only be incorporated in management planning based on today's projections. This is extremely problematic. For example, our comprehension of contemporary fire regimes in the U.S. has drastically changed in just the past 10 years with beginning of the 'mega-fire' era (Adams 2013). In western parks, these mega-fires are likely to be a driver of invasive plant management due to changes within parks as well as on surrounding lands. The future is difficult to predict, and we do not know what new challenges may confront invasive plant managers.

For these reasons, new research is likely to be an essential component of 21st century invasive plant management on National Park Service lands. For example, new research in Lake Mead National Recreation Area illuminated the scale of invasion across 3,000 km of transportation corridors (Abella et al. 2009). Before these surveys, only a general sense of invasion across the park was available. This new knowledge was directly incorporated into the park's 2010 invasive plant management plan. Of the invasive plant species that have invaded national parks only 4% of these species have documented control techniques developed for them on park lands (Allen et al. 2009, Abella 2014). While it is true that research on other lands can be extrapolated to park lands, parks can have unique contexts that make understanding a range of management options on park lands valuable. Moreover, given that invasive plant species in wildlands are not necessarily all agricultural or ornamental pests, the National Park Service cannot necessarily rely on other agencies to cover information needs. Instead, the Park Service may need to be a leader in developing effective, low-cost management techniques that maintain native species and cultural resources on park lands and beyond.

Secondary invasion and invasive species management using a restoration approach are two of numerous examples of topics warranting further research. Secondary invasion occurred in 44% of 16 documented invasive plant management projects that evaluated secondary invasion on park lands (Abella 2014). Why did secondary invasion occur in some projects but not others? If we could predict when secondary invasion may most likely occur, could initial or follow-up management activities reduce chances or seriousness of secondary invasion? In returning to Figure 2, are there reliable indicators of native plant community condition that can enable managers to anticipate restoration needs (if any)? What treatment types might both reduce invasive species while promoting or maintaining native species? Of 30 documented invasive plant management projects on park lands, 53% found that natives increased after invasive plant management, 40% reported no change to native species, and 7% that natives declined (Abella 2014). What factors influenced these responses, and can we improve identification of circumstances in which native species are desired to increase but will not without assistance or on a desired time frame? Answers to these types of questions may help managers better identify situations where coupling restoration with invasive plant management will improve outcomes. Knowing this from the start with a certain level of confidence could greatly help project planning.

While research funding opportunities are scarce for NPS directed research needs, thousands of researchers utilize NPS lands for research purposes every year and the parks can take a proactive role in attracting outside research interest to address NPS applied research needs. One relatively easy approach is to publish a list of research needs (and keep it updated) on the park's Research Permit and Reporting System (RPRS) website as well as the park's own website. Such lists can also be shared opportunistically at professional meetings where graduate students and their advisors may be looking for research opportunities. In many cases, interested parties can be attracted to perform research on park lands at little or no cost to the agency or support can be provided "in-kind" by allowing use of NPS owned facilities to support research of mutual interest (e.g., native plant nursery space was used to support a Joint Fire Sciences collaboration with University of Nevada-Las Vegas at Lake Mead National Recreation Area).

Development of an invasive plant management plan is likely to make park managers acutely aware of existing deficits in knowledge about park resources including autecology of key species, ecological interactions, and indirect effects of invasive plant treatments. Thus it is a great opportunity to identify those research needs within the invasive plant management plan and share them with the larger scientific community in order to address them prior to the next plan revision.

Administration and Implementation

The invasive plant management planning process provides an opportunity to identify programmatic administrative requirements and set the stage for consistent implementation. The topics presented below are a good starting point to clarify administrative requirements within the plan but the plan need not go into great detail or commit unnecessarily to software or technologies that will likely change over the life of the plan. This is part of the implement step of the adaptive management cycle and can also be useful for informing the monitor, evaluate and adjust steps.

Data Management

Detailed and accurate record keeping are a fundamental part of an invasive plant management program. Record keeping provides an historical record of activities and provides a means to compare results and improve future invasive plant management efforts.

Electronic and paper documents should be maintained according to the standards established in the park's Records Plan, and future updated versions thereof. Most parks follow the NPS DO-19, *Records Disposition Schedule*, as well as the *NPS Museum Handbook* chapter on *Archives*. Resource archives are retained in perpetuity in order to maintain an administrative history to document decisions that have been made regarding stewardship of resources. At least annually, important paper and electronic records should be identified by the park staff responsible for the invasive plant management program for inclusion in the Park Archive. After discussion with the Park's Archivist or Cultural Resource Manager, the records should be submitted for accession to the archive.

In compliance with the Federal Geographic Data Committee (FGDC) metadata standards, GIS and GPS data files should include metadata. Note that the agency data minimum standard and platform is the National Invasive Species Information Management System (NISIMS), which is a geospatial tool that is web-accessible through the IRMA portal. Parks are strongly encouraged to use NISIMS to manage their data. Geospatial data managed outside of NISIMS should be made available as requested to local cooperators and distributed through the NPS Data Store, as well as other federally sponsored geospatial data sharing programs developed under the auspices of the National Spatial Data Infrastructure program. Data collected under specific task agreements and/or supported by various funding sources may have additional reporting standards that are required. The invasive plant management plan should commit to these requirements and identify how these tasks will be carried out within that park.

An inventory of invasive plant distribution and abundance should be maintained as part of the park's invasive plant management program. In some cases, the NPS inventory and monitoring program may serve this need. In other cases, parks will need to develop their own mapping effort. A widely used invasive plant mapping standard is provided by the North American Invasive Species Management Association (formerly known as the North American Weed Management Association) and the latest version is generally available from their website.

All invasive plant treatments in an NPS unit, regardless of who undertakes the treatment, should be documented. The agency data minimum standard and platform has shifted from Alien Plant Control and Management Database (APCAM) to National Invasive Species Information Management System (NISIMS), adapted by NPS from the Bureau of Land Management. This geospatial database tracks acres treated as well as the specifics of control methods used on a per species basis. Although, some parks have developed their own data standards, NISIMS will be made available throughout the NPS. It is hoped that NISIMS will be widely adopted throughout the Service. Regardless of which data management system is used to record data, the invasive plant management plan should clearly describe the data standard that will be used.

Annual reports are also prepared and submitted according to NPS procedures, including annual reporting requirements for each park on the DOI performance measurements under the Government Performance and Results Act. Currently, the following reporting requirements are in effect throughout the National Park Service for biological and chemical control implemented as part of an invasive plant management program:

- Biological Control: An annual report will be submitted to the Regional IPM Coordinator as per agency requirements. The report will typically include:
    - Biological control agent common name and scientific name
    - Permit # (if transported across state lines)
    - Target invasive plant common name and scientific name
    - Date and time of release
    - Weather conditions during release
    - Description and location of release site
    - Estimated size of invasive plant infestation
    - Number of biological control agents released
- Chemical Control: The pesticide use logs maintained throughout the year will be compiled annually and submitted in the NPS pesticide use reporting system annually as per agency requirements. Pesticide use logs should include the following information for each approved herbicide:
    - Date and time of application
    - Name, location, and estimated area of treatment site
    - Brand and common name of the material or materials used, including formulation
    - USEPA registration number of materials used
    - The mix rate of material used
    - The amount of material used
    - Pest treated
    - Acres treated
    - Amount of water
    - Additives (surfactant, dye)
    - Name(s) of herbicide applicator(s)
    - General weather conditions, including wind direction and speed and air temperature

Operational Procedures

The operational standards and legal requirements of the invasive plant management program should be described in the invasive plant management plan. In some cases mitigation requirements may be developed based on these requirements in order to avoid, minimize, or mitigate potential negative impacts to humans and the environment. Topics to consider for inclusion or inclusion by reference are listed below:

- Operational risk management
- Training and certification requirements for field personnel as required by state law
- Herbicide use, storage, and inventory (including worker access to SDS and labels)

- Personal protective equipment as required by SDS or label
- Emergency response and reporting
- Job hazard analyses

Work Planning

There are numerous operational and administrative tasks to be completed monthly in order to implement invasive plant management, including mitigation requirements identified during impact analysis and/or agency consultations. It may be helpful to organize these tasks into an annual work cycle for ease of reference by those who will have responsibilities for implementation but may not have been part of the planning process. An example of the annual work cycle included in the Lake Mead National Recreation Area Invasive Plant Management Plan is provided below in Table 5.

An annual work plan will likely need to be prepared by the park personnel responsible for the park's invasive plant management program. The plan should include input from cooperators (e.g., the Exotic Plant Management Team) to identify and schedule invasive plant management tasks for the upcoming field season in order to maximize the opportunity for successful implementation of the invasive plant management plan. Small adjustments can be made each year to the invasive plant program by using post-season reviews and pre-season planning to compile the monitoring results and make minor adjustments to the treatment protocols or priorities prior to the upcoming field season. This is part of the adjust step of the adaptive management cycle and can be used to effectively extend the shelf-life of a completed invasive plant management plan provided the annual adjustments stay within the actions described and analyzed in the original plan and environmental document.

Examples of adjustments to invasive plant management programs

This is a sampling of some of the adjustments that might need to be made on an annual basis as a result of evaluating treatment effectiveness data.

- Plots treated with herbicide when temperatures were approaching the label limit were less effective at damaging the target species than those implemented at other temperatures. Adjustments can be made to the treatment protocol to impose a lower temperature threshold, or another chemical might be used, or staffing might be adjusted to allow for an earlier start time, or a combination of these and other adjustments.
- Small droplet size used in herbicide application is correlated with damage to adjacent non-target plants. Adjustments can be made to the treatment protocol to use a larger droplet size or a different application method or a different surfactant to minimize the potential for drift.
- The phenological stage for effective treatment of targeted species is a window that is too short for the existing field crew to hit all locations. Adjust budget and staffing to bring on extra help during critical windows for treatment, such as putting year end funds into a cooperative agreement for a youth labor corps for the following field season to augment the park's own field crew, or work with the EPMT to schedule their crew at times when park needs exceed capacity.
- The phenological window for treatment of target species is shifting over time due to climate influences, such as timing of snow melt. Adjust seasonal staffing schedules and priorities to better match the optimal window for treatment, which might require different recruitment practices (e.g., if college students are not typically available for your new window, then work with Human Resources Office to recruit from the local community).

Table 5. Example of an annual work cycle (adapted from NPS 2010).

Month	Task Category	Task	Responsible Party
January	Administrative	Depending on weed conditions and funding availability, hire SCA's for peak winter annual weed control or 2 seasonal park employees for a seasonal appointment (October to April)	Invasive Plant Manager
	Administrative	Prepare and submit NPS Pesticide Use Proposals for the year	Invasive Plant Manager
	Operational	Winter annual weed control - primarily *Brassica tournefortii* control	biotechs, contractors
	Operational	Monitor and evaluate any weed control for effectiveness	Invasive Plant Manager
	Operational	Early detection surveys	Invasive Plant Manager
February	Administrative	Prepare educational materials on weeds found at the park for the National Invasive Weed Awareness Week, distribute educational materials to park employees, volunteers, and cooperators	Invasive Plant Manager
	Operational	Winter annual weed control - primarily *Brassica tournefortii* control	Invasive Plant Manager, biotechs, contractors
	Operational	Monitor and evaluate any weed control for effectiveness	Invasive Plant Manager
	Operational	Early detection surveys	Invasive Plant Manager
March	Administrative	Prepare 2nd quarterly report, due at the end of the month	Invasive Plant Manager
	Operational	Perennial weed control on shorelines – primarily *Washingtonia filifera*, *Parkinsonia aculeata*, and *Cenchrus setaceus* (common synonym *Pennisetum setaceum*)	Invasive Plant Manager, biotechs, contractors
	Operational	Winter annual weed control - primarily *Brassica tournefortii* control	biotechs, contractors
	Operational	Monitor and evaluate any weed control for effectiveness	Invasive Plant Manager
	Operational	Early detection surveys	Invasive Plant Manager
April	Operational	Perennial weed control on Lake Mead and Mohave shorelines – primarily *Nerium oleander*, *Washingtonia filifera*, *Parkinsonia aculeata*, and *Cenchrus setaceus*	Invasive Plant Manager, biotechs, contractors, cooperators
	Operational	Control work on perennial rhizomatous weeds – primarily *Lepidium latifolium* at Las Vegas Wash and Willow Beach Fish Hatchery and *Alhagi maurorum* (common synonym, *Alhagi pseudalhagi*) control at Grand Wash Bay	Invasive Plant Manager, biotechs, contractors, cooperators
	Operational	Winter annual weed control - primarily Brassica tournefortii control in site-led priority areas	Invasive Plant Manager, biotechs, contractors, cooperators
	Operational	Monitor and evaluate any weed control for effectiveness	Invasive Plant Manager
	Operational	Early detection surveys	Invasive Plant Manager, biotechs, volunteers
May	Operational	Perennial weed control on Lake Mead and Mohave shorelines – primarily *Nerium oleander*, *Washingtonia filifera*, *Parkinsonia aculeata*, and *Cenchrus setaceus*	Invasive Plant Manager, biotechs, contractors, cooperators
	Operational	Monitor and evaluate any weed control for effectiveness	Invasive Plant Manager

Month	Task Category	Task	Responsible Party
June	Administrative	Prepare 3rd quarterly report, due at the end of the month	Invasive Plant Manager
	Administrative	CEU's for Arizona Pesticide Applicators Certification	Invasive Plant Manager
	Administrative	Schedule work crews for winter annual weed control (Nevada Conservation Corp)	Invasive Plant Manager
	Operational	Survey riparian areas for weeds, work to be completed in the fall or winter by Invasive Plant Manager or Lake Mead EPMT	Invasive Plant Manager
July	Administrative	Trainings/Conferences	Invasive Plant Manager
	Administrative	Develop work priorities for upcoming field season	Invasive Plant Manager
	Administrative	Annual Lake Mead work plan meeting with Lake Mead EPMT and other cooperators	Invasive Plant Manager, cooperators
	Operational	Survey any areas that recently burned	Invasive Plant Manager
August	Administrative	Trainings/Conferences	Invasive Plant Manager
	Administrative	Evaluate any new potential weeds using the Cal-IPC criteria	Invasive Plant Manager
	Administrative	Update priority list of weeds	Invasive Plant Manager
	Administrative	Inventory herbicide and application equipment	Invasive Plant Manager
	Administrative	Purchase herbicide and equipment needed for upcoming field season	Invasive Plant Manager
	Administrative	Inventory and update MSDS and Labels for herbicides	Invasive Plant Manager
	Operational	Survey target areas for summer annual weeds	Invasive Plant Manager
	Operational	Survey any areas that recently burned	Invasive Plant Manager
September	Administrative	Prepare 4th quarterly report, due at the end of the month	Invasive Plant Manager
	Administrative	Trainings/Conferences (Cal-IPC Symposium)	Invasive Plant Manager
	Administrative	Review new literature on existing weeds and update priority list if necessary	Invasive Plant Manager
	Administrative	Provide Lake Mead EPMT with treatment needs within the park for their annual work plan	Invasive Plant Manager
	Operational	Survey washes for annual weed emergence after monsoon season	Invasive Plant Manager
	Operational	Generate priority areas for Weed Sentry to focus on next fiscal year	Invasive Plant Manager

Month	Task Category	Task	Responsible Party
October	Administrative	Inventory and order personal protective equipment (Nitrile gloves, heavy duty garbage bags, any tools needed) if necessary	Invasive Plant Manager
	Administrative	Nevada Pesticide Certification or Recertification (if needed)	Invasive Plant Manager, biotechs
	Administrative	Arizona Pesticide Certification (if needed)	Invasive Plant Manager, biotechs
	Administrative	Conduct weed awareness training for new employees and cooperators	Invasive Plant Manager
	Operational	Control work on perennial rhizomatous weeds – primarily *Lepidium latifolium* - at Las Vegas Wash and Willow Beach Fish Hatchery.	Invasive Plant Manager
	Operational	Nevada Conservation Corp starts project work in the park	Invasive Plant Manager, cooperators
November	Operational	Perennial weed control on Lake Mead and Mohave shorelines, primarily *Tamarix ramosissima*, *Tamarix aphylla*, and *Nicotiana glauca*	Invasive Plant Manager
	Operational	Monitor infestations of perennial rhizomatous weeds, primarily *Alhagi maurorum*, at the Hoover Dam checkpoint (Nevada side) and Grand Wash Bay	Invasive Plant Manager
December	Administrative	Prepare 1st quarterly report, due at the end of the month	Invasive Plant Manager
	Administrative	Pesticide Use Report forms due	Invasive Plant Manager
	Operational	Possible winter annual weed control if there was a wet year, primarily *Brassica tournefortii* control	Invasive Plant Manager
	Operational	Early detection surveys	Invasive Plant Manager, biotechs, volunteers

A rolling five-year work plan may be useful to identify longer-term projects and/or invasive plant management efforts that build upon each other (e.g., treatment, site restoration, monitoring, etc.). The five-year plan can "roll-forward" each year so that there is always a plan that covers the next five fiscal years. The five-year plan can be used to prioritize and strategize funding proposals for out-years, but should remain flexible enough to accommodate short-notice funding opportunities and management needs. It may be helpful to include the first five-year work plan as an appendix to the Invasive Plant Management Plan in order to clarify how the management actions in the preferred alternative would be implemented over time.

Preparing for the next major revision to the invasive plant management plan is also an important part of the adaptive management cycle. Each new or revised plan is a substantial investment in time and money to write a new plan and environmental document and so periodically thought should be given to what it needs to include, what issues have arisen that were not addressed in the previous plan, what new treatment options are available that are currently outside the scope of the existing plan, etc. As these issues, needs, and tools arise that are not covered in the existing plan, they should be recorded for consideration by the future planning team that will revise the invasive plant management plan. This information should be maintained as part of the record keeping of the invasive plant management program and passed along to future invasive plant managers. This is also a part of the adjust step of the adaptive management cycle, but is implemented over a longer time frame than the routine minor adjustments that are included in the annual and five-year work plans.

Conclusion

Invasive plant management is a complex undertaking. Developing a plan for such an undertaking requires an intimate understanding of park resources, collaboration with park staff and neighbors, and an understanding of a broad range of scientific concepts. There are many places to go to find help in developing an invasive plant management plan. Park volunteers and employees from all divisions can provide valuable information and input into the planning process. Regional collaborations such as Cooperative Weed Management Areas as well as NPS staff in the Exotic Plant Management Team program and regional office can assist in providing landscape context. If local and regional support is not available for certain aspects of the planning process, the specialized expertise of the Natural Resource Stewardship and Science Directorate may also be able to assist. Academic cooperators, such as those facilitated by the Cooperative Ecosystem Studies Units (CESUs), can also provide valuable assistance in synthesizing relevant literature and analyzing legacy data to inform programmatic invasive plant management decisions made by park managers.

The benefits of completing a programmatic invasive plant management plan include improved operational efficiencies, expanded capacity for proactive response to new invaders or new situations, well considered priorities for investment of effort and staff time in all aspects of invasive plant management, and an alignment of organization goals to assure that the invasive plant management program is appropriately contributing to park-wide resource stewardship and visitor experience goals.

Literature Cited

Abella, S. R. 2014. Effectiveness of exotic plant treatments on National Park Service lands in the United States. Invasive Plant Science and Management 7(1):147-163.

Abella, S. R., L. P. Chiquoine, and D. M. Backer. 2013. Soil, vegetation, and seed bank of a Sonoran Desert ecosystem along an exotic plant (Pennisetum ciliare) treatment gradient. Environmental Management 52:946-957.

Abella, S. R., N. A. Fisichelli, S. M. Schmid, T. M. Embrey, D. L. Hughson, and J. Cipra. 2014. Status and management of non-native plant invasion in three of the largest national parks in the United States. National Park Service Unpublished Report, Boulder City, Nevada.

Abella, S. R., and A. Tendick. 2013. Distribution of exotic plant species and relationship to vegetation type at Bryce Canyon National Park, USA. Landscape and Urban Planning 120:48-58.

Abella, S. R., J. E. Spencer, J. Hoines, and C. Nazarchyk. 2009. Assessing an exotic plant surveying program in the Mojave Desert, Clark County, Nevada, USA. Environmental Monitoring and Assessment 151:221-230.

Adams, M. A. 2013. Mega-fires, tipping points and ecosystem services: managing forests and woodlands in an uncertain future. Forest Ecology and Management 294:250-261.

Allen, J. A., C. S. Brown, and T. J. Stohlgren. 2009. Non-native plant invasions of United States national parks. Biological Invasions 11:2195-2207.

Brooks, M. L. 1999. Alien annual grasses and fire in the Mojave Desert. Madroño 46(1):13-19.

Carlson, M. L., I. V. Lapina, M. Shephard, J. S. Conn, R. Densmore, P. Spencer, J. Heys, J. Riley, and J. Nielsen. 2008. Invasiveness ranking system for non-native plants of Alaska. R10-TP-143. U.S. Department of Agriculture, U.S. Forest Service, Alaska Region. 218 pp.

Chong K. Y., R. T. Corlett, D. C. J. Yeo and H. T. W. Tan 2011 Towards a global database of weed risk assessments: a test of transferability for the tropics. Biological Invasions Volume 13, Number 7, 1571-1577.

Corn, M. L., and R. Johnson. 2013. Invasive Species: Major Laws and the Role of Selected Federal Agencies. Congressional Research Service. 7-5700, R43258.

Craig, D. J., J. E. Craig, S. R. Abella, and C. H. Vanier. 2010. Factors affecting exotic annual plant cover and richness along roadsides in the eastern Mojave Desert, USA. Journal of Arid Environments 74:702-707.

Crall, A. W., M. Renz, B. J. Panke, G. J. Newman, C. Chapin, J. Graham, and C. Bargeron. 2012. Developing cost-effective early detection networks for regional invasions. Biological Invasions 14:2461-2469.

Crooks, J. A. 2005. Lag times and exotic species: the ecology and management of biological invasions in slow-motion. Ecoscience 12:316-329.

Daehler, C. C., S. J. Denslow, S. Ansari, and H. Kuo. 2004. A risk-assessment system for screening out invasive pest plants from Hawaii and other Pacific islands. Conservation Biology 18:360-368.

Davis, M.A. 2009. Invasion Biology. Oxford University Press, New York. 244 pp.

Dickman, G. 2015. Sources of invasive plant introductions in Yosemite: When 4 million visitors are not the problem. 2015 George Wright Society Conference on Parks, Protected Areas, and Cultural Sites. Oakland, CA.

Diez, J. M., C. M. D'Antonio, J. S. Dukes, E. D. Grosholz, J. D. Olden, C. J. B. Sorte, D. M. Blumenthal, B. A. Bradley, R. Early, I. Ibáñez, S. J. Jones, J. J. Lawler, and L. P. Miller. 2012. Will extreme climatic events facilitate biological invasions? Frontiers in Ecology and the Environment 10:249-257.

Dingman, S., A. C. Newton, and C. Norman. 2010. Adaptive Management and Exotic Plant Management at Lake Mead National Recreation Area in Weber, Samantha, editor. Rethinking Protected Areas in a Changing World. George Wright Society Biennial Conference on Parks, Protected Areas, and Cultural Sites, Hancock, Michigan.

Elzinga, C. L., D. W. Salzer, and J. W. Willoughby. 1998. Measuring and monitoring plant populations. Technical Reference 1730-1. Bureau of Land Management, Denver, CO.

Forcella, F., Wood, T. J. and Dillon, S. P. 1986. Characteristics distinguishing invasive weeds within Echium (Bugloss). Weed Research 26:351–364.

Frey, M. 2012. Developing a Landscape Plant Selection list for the Presidio of San Francisco, The George Wright Forum 29(3):362-370.

Gasso, N., C. Basnou, and M. Vilà. 2010. Predicting plant invaders in the Mediterranean through a weed risk assessment system. Biological Invasions 12:463 - 476.

Gaudet, C. L. and P. A. Keddy. 1988. Predicting competitive ability from plant traits: A comparative approach. Nature 334:242 243.

Gordon D. R., B. Riddle, P. Pheloung, S. Ansari, C. Buddenhagen, C. Chimera, C. C. Daehler, W. Dawson, J. S. Denslow, T. N. Jaqualine, A. LaRosa, T. Nishida, D. A. Onderdonk, F. D. Panetta, P. Pyšek, R. P. Randall, D. M. Richardson, J. G. Virtue, and P. A. Williams. 2010. Guidance for addressing the Australian Weed Risk Assessment questions. Plant Protection Quarterly 25:56–74.

Gordon D. R., D. A. Onderdonk, A. M. Fox, R. K. Stocker, and C. Gantz. 2008. Predicting Invasive Plants in Florida Using the Australian Weed Risk Assessment. Invasive Plant Science and Management 1:178–195.

Hellmann, J. J., J. E. Byers, B. G. Bierwagen, and J. S. Dukes. 2008. Five potential consequences of climate change for invasive species. Conservation Biology 22:534-543.

Hiebert, R. D., and J. Stubbendieck. 1993. Handbook for ranking exotic plants for management and control. Natural Resources Report. NPS/NRMWRO/NRR-93/08. National Park Service, Midwest Regional Office, Omaha, Nebraska.

Haultain, S., M. Cox, J. Rodgers, and J. Goldsmith. 2008. Workshop Results and Final Report: Working Together Against Weeds. National Park Service Unpublished Report, Pacific West Region.

Hulme, P. E. 2012. Weed risk assessment: A way forward or a waste of time? Journal of Applied Ecology 49:10-19.

Kolar, C. S., and D. M. Lodge. 2001. Progress in invasion biology: Predicting invaders. Trends in Ecology and Evolution 16:199 204.

Landres, P., C. Barns, J. G. Dennis, T. Devine, P. Geissler, C. S. McCasland, L. Merigliano, J. Seastrand, and R. Swain. 2008. Keeping It Wild: An Interagency Strategy to Monitor Trends in Wilderness Character across the National Wilderness Preservation System. General Technical Report RMRS-GTR-212. U.S. Forest Service, Rocky Mountain Research Station, Fort Collins, CO.

Levine, J. M., P. B. Adler, and S. G. Yelenik. 2004. A meta-analysis of biotic resistance to exotic plant invasions. Ecology Letters 7:975-989.

Lowry, E., E. J. Rollinson, A. J. Laybourn, T. E. Scott, M. E. Aiello-Lammens, S. M. Gray, J. Mickley, and J. Gurevitch. 2013. Biological invasions: a field synopsis, systematic review, and database of the literature. Ecology and Evolution 3:182-196.

Mack, R. N. 1996. Predicting the identity and fate of plant invaders: Emergent and emerging approaches. Biological Conservation 78:107-121.

Marushia, R. G., M. W. Cadotte, and J. S. Holt. 2010. Phenology as a basis for management of exotic annual plants in desert invasions. Journal of Applied Ecology 47:1290-1299.

Maxwell, B. D., E. Lehnhoff, and L. J. Rew. 2009. The rationale for monitoring invasive plant populations as a crucial step for management. Invasive Plant Science and Management 2:1-9.

Newsome, A. E., and I. R. Noble. 1986. Ecological and physiological characters of invading species, Pages 1-20 in R. H. Groves & J. J. Burdon, editors. Ecology of biological invasions. Cambridge University Press.

National Fish, Wildlife and Plants Climate Adaptation Partnership (NFWPCAP). 2012. National Fish, Wildlife and Plants Climate Adaptation Strategy. Association of Fish and Wildlife Agencies, Council on Environmental Quality, Great Lakes Indian Fish and Wildlife Commission, National Oceanic and Atmospheric Administration, and U.S. Fish and Wildlife Service., Washington, DC.

National Invasive Species Council. 2006. Invasive Species Definition Clarification and Guidance White Paper. Submitted by the Definitions subcommittee of the Invasive Species Advisory Committee, approved April 27, 2006.

National Park Service. 2011. Director's Order/Reference Manual 12: Conservation Planning, Environmental Impact Analysis, and Decision-Making.

National Park Service. 2006. Management Policies. National Park Service, Washington, D.C. pp. 168.

National Park Service. 2010. Lake Mead National Recreation Area Exotic Plant Management Plan. National Park Service, Boulder City, Nevada.

National Park Service. 2013. Director's Order/Reference Manual #41: Wilderness Stewardship.

National Park Service. 2014. Keeping It Wild in the National Park Service: A User Guide to Integrating Wilderness Character into Park Planning, Management, and Monitoring. Office of Wilderness Stewardship, Washington, D.C.

National Park Service. 2015. National Park Service NEPA Handbook.

National Park Service. 2015. NPSpecies: The National Park Service biodiversity database. IRMA Portal version. https://irma.nps.gov/npspecies/ (accessed 2 June 2015).

Owen, S. J. 1998. Department of Conservation strategic plan for managing invasive weeds. Department of Conservation Report, Wellington, New Zealand.

Pheloung, P. C., P. A. Williams, and S. R. Halloy. 1999. A weed risk assessment model for use as a biosecurity tool evaluating plant introductions. Journal of Environmental Management 57:239-251.

Randall, J. M., L. E. Morse, N. Benton, R. Hiebert, S. Lu, and T. Killeffer. 2008. The Invasive Species Assessment Protocol: A tool for creating regional and national lists of invasive nonnative plants that negatively impact biodiversity. Invasive Plant Science and Management 1:36-49.

Ransom, C. V., S. D. Christensen, K. A. Edvarchuk, and T. Naumann. 2012. A reinventory of invasive weed species in Dinosaur National Monument to determine management effectiveness. Invasive Plant Science and Management 5:300-309.

Reichard, S. H. and C. W. Hamilton. 1997. Predicting invasions of woody plants introduced into North America. Conservation Biology 11:193–203.

Rejmánek M. 2000. Invasive plants: approaches and predictions. Australian Ecology 25:497–506.

Rejmánek, M., and M. J. Pitcairn. 2002. When is eradication of pest plants a realistic goal? Pages 249-253 in C. R. Veitch and M.N. Clout, editors. Turning the tide: The eradication of invasive species. IUCN SSC Invasive Species Specialist Group. IUCN, Gland, Switzerland, and Cambridge, UK. 414 pp.

Rew, L. J. and M. P. Johnson. 2010. Reviewing the role of wildfire on the occurrence and spread of invasive plant species in wildland areas of the Intermountain western United States. Invasive Plant Science and Management 3:347-364.

Richardson, D. M., and W. Thuiller. 2007. Home away from home—objective mapping of high-risk source areas for plant introductions. Diversity and Distributions 13:299–312.

Seastedt, T. R., R. J. Hobbs, and K. N. Suding. 2008. Management of novel ecosystems: Are novel approaches required? Frontiers in Ecology and the Environment 6:547-553.

Stohlgren T. J., L. L. Loope, and L. J. Makarick. 2013. Plant Species Invasions in the United States National Parks. Pages 267-283 in L. Foxcroft, D. Richardson, P. Pyšek, and L. Genovesi, editors. Alien Plant Invasions in Protected Areas: A Global Assessment. Springer. New York.

Stohlgren, T., J. Resnik and G. E. Plumb. 2014. Climate Change and Alien Species in National Parks: Revisited. in L. H. Ziska and J. S. Dukes, eidtors, Invasive Species and Climate Change. Centre for Agricultural Bioscience International Publishing, UK. In Press.

Thuiller, W, D. M. Richardson, P. Pyšek, G. F. Midgley, G. O. Hughes, and M. Rouget. 2005. Niche-based modelling as a tool for predicting the risk of alien plant invasions at a global scale. Global Change Biology 11:2234–2250.

Tu, M., C. Hurd, and J. M. Randall. 2001. Weed Control Methods Handbook. The Nature Conservancy. Available at: http://www.invasive.org/gist/control.html (accessed 18 May 2015).

Webster, C. R., M. A. Jenkins, and S. Jose. 2007. Invasion biology and control of invasive woody plants in eastern forests. Native Plants Journal 8:97-106.

Westbrooks, R. 1981. Introduction of foreign noxious plants into the United States. Weeds Today 14:16-17.

Williams, B. K., R. C. Szaro, and C. D. Shapiro. 2007. Adaptive Management: The U.S. Department of the Interior Technical Guide. Adaptive Management Working Group, U.S. Department of the Interior, Washington, DC.

Williamson, M. H. and K. C Brown. 1986. The analysis and modelling of British invasions. Philosophical Transactions of the Royal Society of London B 314: 505-522.

Appendix A: Wilderness Considerations in Invasive Plant Management Plans

This appendix introduces some considerations for invasive plant management plans that address wilderness. This section is excerpted from NPS 2014, a component of NPS Reference Manual #41: Wilderness Stewardship. The term nonnative is used deliberately to refer to plants that do not belong in a given location, regardless of whether or not they are invasive.

Activities to address nonnative species that could affect wilderness character include accessing backcountry work locations; a range of treatment methods, including manual and chemical methods; and the manipulation of plants, an inherent characteristic of nonnative plant management. Outcomes of an invasive plant management plan should relate directly to the qualities, indicators, and measures in the wilderness character monitoring framework as described in Keeping It Wild (Landres et al. 2008). Steps for developing an exotic plant management plan that considers effects to wilderness character include:

Determine the scope of necessary action

Considering current policy and practices, discuss whether invasive plant treatments should be implemented in wilderness. Management action in wilderness should never be a foregone conclusion.

Analyze tradeoffs—Identify the range of actions required for a particular invasive plant treatment in terms of the effects on the qualities of wilderness character and the resulting tradeoffs of different management actions. For example, the action to control invasive plants in wilderness degrades the untrammeled quality and use of motorized tools required by some treatment methods degrades the undeveloped quality; however, these actions may improve the natural quality. Consider the means of access to treatment areas and use this analysis to inform decisions regarding nonnative plant management.

Identify logical connections between an exotic plant management plan and wilderness character—Determine the relative priority of wilderness lands, or specific locations within wilderness, when assessing the overall goals of wilderness stewardship and nonnative plant management. In a wilderness with very few invasive plant populations, there might be a high priority for early detection and eradication of incipient populations. Integrated pest management is an approach that inherently considers site characteristics in determining the most appropriate tool(s) for invasive plant control, and recognizes that multiple tools may be needed at different locations to achieve desired results.

Provide specific mitigation measures—When developing alternative mitigation measures, be sure to consider their impacts on wilderness character within the plan, rather than solely within a minimum requirements analysis, often included as an appendix to the plan. For example, management alternatives could be developed that do not allow motorized access or mechanical equipment in wilderness, but instead focus on manual control methods. These might include tools that have been specifically developed for use in wilderness, such as horse-mounted herbicide sprayer systems.

Use a minimum requirements analysis—When a park is conducting nonnative plant management in wilderness, potential actions must be analyzed either through a programmatic minimum requirements analysis developed for nonnative treatments, or individual minimum requirements analyses developed for individual actions, or a combination of the two.

Indicators and Measures

The exotic plant management plan can provide direction for monitoring wilderness character trends by identifying appropriate measures and potential sources of data. If staff have not yet identified measures or developed monitoring protocols for invasive species management and its effect on wilderness character, the plan can also help determine standards by which to assess these effects. If a wilderness stewardship plan and wilderness character monitoring measures have been developed, the exotic plant management plan can be designed to integrate the content of these plans, and to formulate management actions that have the least detrimental effect to wilderness character, and also provide data for wilderness character monitoring. Additional guidance and suggestions for data sources and applications are in table A1 below.

Table A1. Indicators and measures related to invasive and exotic species management plans (not all wilderness character indicators are included).

Quality	Indicator	Measure	Discussion	Data Suggestions
Untrammeled	Actions authorized by the Federal land manager that manipulate the biophysical environment	Number of actions to manage plants, animals, pathogens, soil, water, or fire	Generally these plans manipulate exotic plants to move toward restoration of native plant communities with no further manipulation or control after an exotic plant population is treated successfully.	An annual work plan component could be incorporated to provide better resolution regarding anticipated actions.
Natural	Plant and animal species and communities	Number of nonnative species	Reduction of non-native species would directly benefit this measure. Non-native plant management in itself is a form of conservation of native plant species and supports native ecosystems.	Provide a mechanism by which the list of species is updated periodically in NPSpecies web-based application.
		Abundance, distribution, or number of invasive nonnative species	Reduction of non-native species would directly benefit this measure. Exotic plant management in itself is a form of conservation of native plant species and supports native ecosystems.	Actual invasive plant treatments in the NPS are typically recorded in the Alien Plant Control and Management Database, and can be used to query abundance and distribution of species that are targeted for control.
	Biophysical processes	Area and magnitude of pathways for movement of non-native species into wilderness	Consistent with interagency thinking about examining entry points within and outside parks and managing invasive species at multiple scales.	Primary vectors and pathways for invasion are sometimes included in the EPMP, but typically are presented as a park-wide analysis. Additional refinements would usually be needed to use this data to inform wilderness character monitoring.
Undeveloped	Use of motor vehicles, motorized equipment, or mechanical transport	Type and amount of administrative and non-emergency use of motor vehicles, motorized equipment, or mechanical transport	Use of motorized equipment and transport may have short term adverse effects on the landscape and visitor experience.	The decision to allow motorized equipment is often included in the EPMP, but the details of planned uses are usually found in MRDA documents. In many cases, these are done on an annual basis for routine or recurring activities, such as exotic plant management. In those cases, it will be necessary to collect actual use data after the fact (e.g., days or hours of chainsaw use).
Solitude	Remoteness from sights and sounds of people inside the wilderness	Number of trail contacts visitors have with work crews (through the presence of the crews or visibility of management actions)	Although generally short-term and minimally adverse, visitors may experience impacts from the presence and visibility of crews and their actions.	Record cards from staff and volunteers help track encounter rates.
	Remoteness from occupied and modified areas outside of wilderness	Extent and magnitude of intrusions on the natural soundscape	When motorized equipment is determined necessary to meet the goals of the EPMP, consider the intensity, frequency, and duration of soundscape intrusion.	It may not be possible to determine actual impact to park visitors unless visitor use data is also analyzed to determine if visitors were in aural proximity of the noise.
Other features of value	Deterioration or loss of cultural resources integral to wilderness character	Number of authorized actions that result in disturbances to cultural resources (visitor and commercial use [e.g., catholes, trampling, hearths, aircraft landings]; findings of adverse effect for projects and operations)	Cultural landscapes may contain invasive non-native species that can naturalize and spread; or cultural landscapes may be impacted by the invasion of nonnative species; or cultural landscapes may contain historic noninvasive exotics that need to be preserved.	Work closely with the cultural resources staff to determine which elements of the landscape are significant (generally described in a cultural landscape inventory) and what nonnative planttreatments may be used in the cultural landscape and under what conditions.
	Other features locally defined			

Appendix B: Relevant Research on Invasive Plants

A sampling of some research articles as of January 2014 demonstrating the breadth of the field is listed below for ease of reference. Note that numerous other papers are available in each category than cited here; citations in the table are shown as examples and are not intended to be exhaustive. It is also important to keep in mind that such research is ever evolving and thus the sources listed below will eventually be out of date, so practitioners are encouraged to use tools such as JSTOR and GoogleScholar to query and review additional literature.

Spread dynamics and U.S. policy

Lodge, D.M., S. Williams, H.J. MacIsaac, K.R. Hayes, B. Leung, S. Reichard, R.N. Mack, P.B. Moyle, M. Smith, D.A. Andow, J.T. Carlton, and A. McMichael. 2006. Biological invasions: recommendations for US policy and management. Ecological Applications 16:2035-2054.

Impacts to native biodiversity and ecosystems

Gaertner, M., A. Den Breeyan, C. Hui, and D. M. Richardson. 2009. Impacts of alien plant invasions on species richness in Mediterranean-type ecosystems: A meta-analysis. Progress in Physical Geography 33:319-338.

Gilbert, B., and J. M. Levine. 2013. Plant invasions and extinction debts. Proceedings of the National Academy of Sciences (USA) 110:1744-1749.

Hejda, M., P. Pyšek, and V. Jarošik. 2009. Impact of invasive plants on the species richness, diversity and composition of invaded communities. Journal of Ecology 97:393-403.

Morales, C. L., and A. Traveset. 2009. A meta-analysis of impacts of alien vs. native plants on pollinator visitation and reproductive success of co-flowering native plants. Ecology Letters 12:716-728.

Pyšek, P., V. Jarošík, P. E. Hulme, J. Pergl, M. Hejda, U. Schaffner, and M. Vilà. 2012. A global assessment of invasive plant impacts on resident species, communities and ecosystems: the interaction of impact measures, invading species' traits and environment. Global Change Biology 18:1725-1737.

Vilà, M., J. L. Espinar, M. Hejda, P. E. Hulme, V. Jarošík, J. L. Maron, J. Pergl, U. Schaffner, Y. Sun, and P. Pyšek. 2011. Ecological impacts of invasive alien plants: a meta-analysis of their effects on species, communities and ecosystems. Ecology Letters 14:702-708.

Economic impacts to the U.S.

Pimental, D., R. Zuniga, and D. Monison. 2005. Update on the environmental and economic costs associated with alien-invasive species in the United States. Ecological Economics 52:273-288.

Species risk assessment

Hulme, P. E. 2012. Weed risk assessment: a way forward or a waste of time? Journal of Applied Ecology 49:10-19.

Ability of indigenous ecosystems to resist invasion

Levine, J. M., P. B. Adler, and S. G. Yelenik. 2004. A meta-analysis of biotic resistance to exotic plant invasions. Ecology Letters 7:975-989.

Climate change and exotic plants

Diez, J. M., C. M. D'Antonio, J. S. Dukes, E. D. Grosholz, J. D. Olden, C. J. B. Sorte, D. M. Blumenthal, B. A. Bradley, R. Early, I. Ibáñez, S. J. Jones, J. J. Lawler, and L. P. Miller. 2012. Will extreme climatic events facilitate biological invasions? Frontiers in Ecology and the Environment 10:249-257.

Hellmann, J. J., J. E. Byers, B. G. Bierwagen, and J. S. Dukes. 2008. Five potential consequences of climate change for invasive species. Conservation Biology 22:534-543.

Invasive plant mapping

Barnett, D. T., T. J. Stohlgren, C. S. Jarnevich, G. W. Chong, J. A. Ericson, T. R. Davern, and S. E. Simonson. 2007. The art and science of weed mapping. Environmental Monitoring and Assessment 132:235-252.

Christensen, S.D., C.V. Ransom, K.A. Edvarchuk, and V.P. Rasmussen. 2011. Efficiency and accuracy of wildland weed mapping methods. Invasive Plant Science and Management 4:458-465.

Management practices and benefits

Abella, S.R. 2014. Effectiveness of exotic plant treatments on National Park Service lands in the United States. Invasive Plant Science and Management 7:147-163.Brown, C.S., V.J. Anderson, V.P. Claassen, M.E. Stannard, L.M. Wilson, S.Y. Atkinson, J.E. Bromberg, T.A. Grant, and M.D. Munis. 2008. Restoration ecology and invasive plants in the semiarid West. Invasive Plant Science and Management 1:399-413.

Rew, L.J., and M.P. Johnson. 2010. Reviewing the role of wildfire on the occurrence and spread of invasive plant species in wildland areas of the Intermountain western United States. Invasive Plant Science and Management 3:347-364.

Sheley, R.L., J.J. James, M.J. Rinella, D. Blumenthal, and J.M. DiTomaso. 2011. Invasive plant management on anticipated conservation benefits: a scientific assessment. Pp. 291-336 in Briske, D.D. (ed.). Conservation benefits of rangeland practices: assessment, recommendations, and knowledge gaps. U.S. Department of Agriculture, Natural Resources Conservation Service. Allen Press, Inc., Lawrence, Kansas. 429 pp.

Webster, C.R., M.A. Jenkins, and S. Jose. 2007. Invasion biology and control of invasive woody plants in eastern forests. Native Plants Journal 8:97-106.

Herbicide ecology and practices

Norsworthy, J.K., S.M. Ward, D.R. Shaw, R.S. Llewellyn, R.L. Nichols, T.M. Webster, K.W. Bradley, G. Frisvold, S.B. Powles, N.R. Burgos, W.W. Witt, and M. Barrett. 2012. Reducing the risks of herbicide resistance: best management practices and recommendations. Weed Science Special Issue:31-62.

Appendix C: Adaptive Management in Invasive Plant Management Planning

Adaptive management is an applicable concept to many aspects of invasive plant management. Figure C1 shows flowchart symbols while the remaining flowcharts illustrate adaptively managed decision making processes that may be used for:

- Situation Evaluation Process (Figure C2)
- Site-led Treatment Process (Figure C3)
- Incipient Population Treatment Process (Figure C4)
- Established Population Treatment Process (Figure C5)
- Detail Chemical Treatment Flowchart to confirm compliance (Figure C6)
- Detail Biocontrol Treatment Flowchart to confirm compliance (Figure C7)

These flow charts are adapted from Dingman et al. 2010 and NPS 2010.

Figure C1 shows key symbols used in following flowcharts. Symbols represent a variety of indicators, as follows:

- Process, indicates any processing function
- Predefined process, indicates a subroutine or a module
- Decision, indicates a decision point between two or more paths in a flowchart
- Data, can represent any type of data or data collection needs in a flowchart
- Document, indicates documenting results of a process and evaluating opportunities for improving the process
- Off-page Connector, indicates an inspection point with a cross-reference from a process on one page to a process on another page
- Terminator, indicates the beginning or end of a program flow in the diagram
- Arrows connecting flowchart elements
- Dashed arrows indicating optional connections

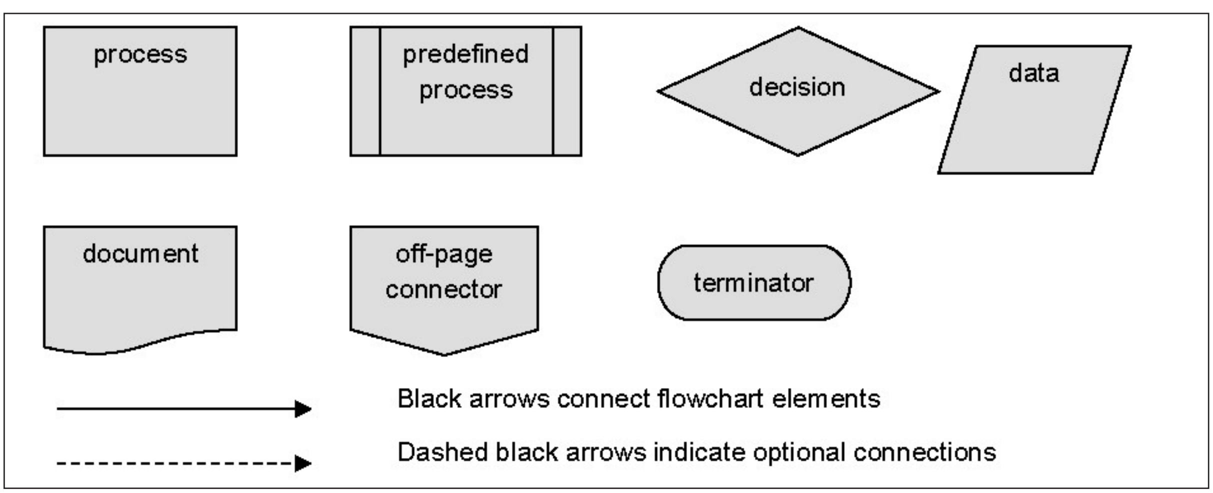

Figure C1. Key to symbols used in flowcharts.

Figure C2 shows the flowchart of a Situation Evaluation Process. The following steps represent routes through flowchart.

1. Process: “Confirm presence of exotic species in Park.”
2. Then, decision: “Evaluate site where it occurs. Is it a park Priority Site?”
   - A. If “No”, decision: “Is species a state listed noxious weed in the state where it occurs?”
     - i. If “No”, predefined process: “Evaluate species and determine rank using a well-defined prioritization scheme.” Then, decision: “Is it an incipient population?”
       - a. If “Yes”, off-page connector: “Go to flowchart for Incipient Population Treatment Process” (Figure C4).
       - b. If “No”, off-page connector: “Go to flowchart for Established Population Treatment Process” (Figure C5).
     - ii. If “Yes”, decision: “Is it an incipient population?”
       - a. If “Yes”, off-page connector: “Go to flowchart for Incipient Population Treatment Process” (Figure C4).
       - b. If “No”, off-page connector: “Go to flowchart for Established Population Treatment Process” (Figure C5).
   - B. If ‘Yes”, decision: “Is species a state listed noxious weed in the state where it occurs?”
     - i. If “No”, off-page connector: “Go to flowchart for Site-led Treatment Process” (Figure C3).
     - ii. If “Yes”, predefined process: “Evaluate species and determine rank using a well-defined prioritization scheme.” Then, decision: “Is it an incipient population?”
       - a. If “Yes”, off-page connector: “Go to flowchart for Incipient Population Treatment Process” (Figure C4).
       - b. If “No”, off-page connector: “Go to flowchart for Established Population Treatment Process” (Figure C5).

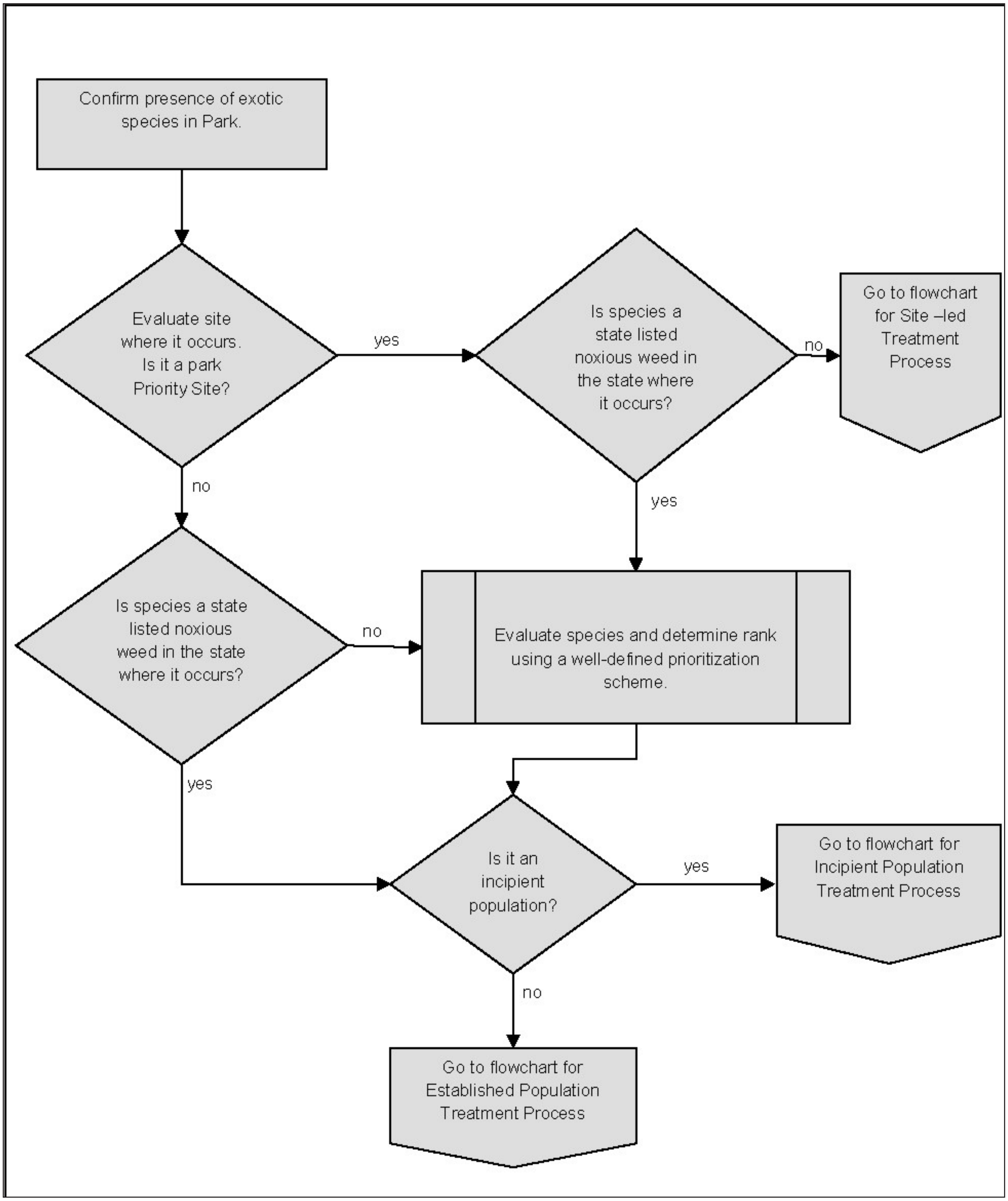

Figure C2. Flowchart of Situation Evaluation Process.

Figure C3 shows the two flowcharts for Site-led Treatment Process. The following steps represent routes through flowchart page 1.

1. Off-page connector: "From Situation Evaluation Process flowchart"
2. Then, decision: "Is the site in rare plant habitat?"
    A. If "No", decision: "Is the site near water?"
        i. If "No", off-page connector: "Go to Site-led Treatment Process (page 2 of 2)".
        ii. If "Yes", process: "Consult with Park Hydrologist or other experts regarding water quality and flow characteristics of the site."
            a. Then, process: "Develop weed treatment strategy using methods that best protect the water."
            b. Then, process: "Implement weed treatment strategy as well as site specific mitigation measures."
            c. Then, data: "Monitor results of weed treatment strategy on both weed and water resources."
            d. Then, document: "Document results and evaluate opportunities for improvement for re-treatment of this site or use in similar sites."
                1. Optional connector back to "Develop weed treatment strategy using methods that best protect the water."
    B. If "Yes", process: "Consult with Park Botanist or other experts regarding population status, species biology, and conservation needs of rare plant species at the site."
        i. Then, process: "Develop weed treatment strategy using method that bets protects conservation species at the site."
        ii. Then, process: "Implement weed treatment strategy as well as site specific mitigation measures."
        iii. Then, data: "Monitor results of weed treatment strategy on both weeds and conservation species."
        iv. Then, document: "Document results and evaluate opportunities for improvement for re-treatment of this site or use in similar sites."
            a. Optional connector back to "Develop weed treatment strategy using methods that best protect conservation species at the site."

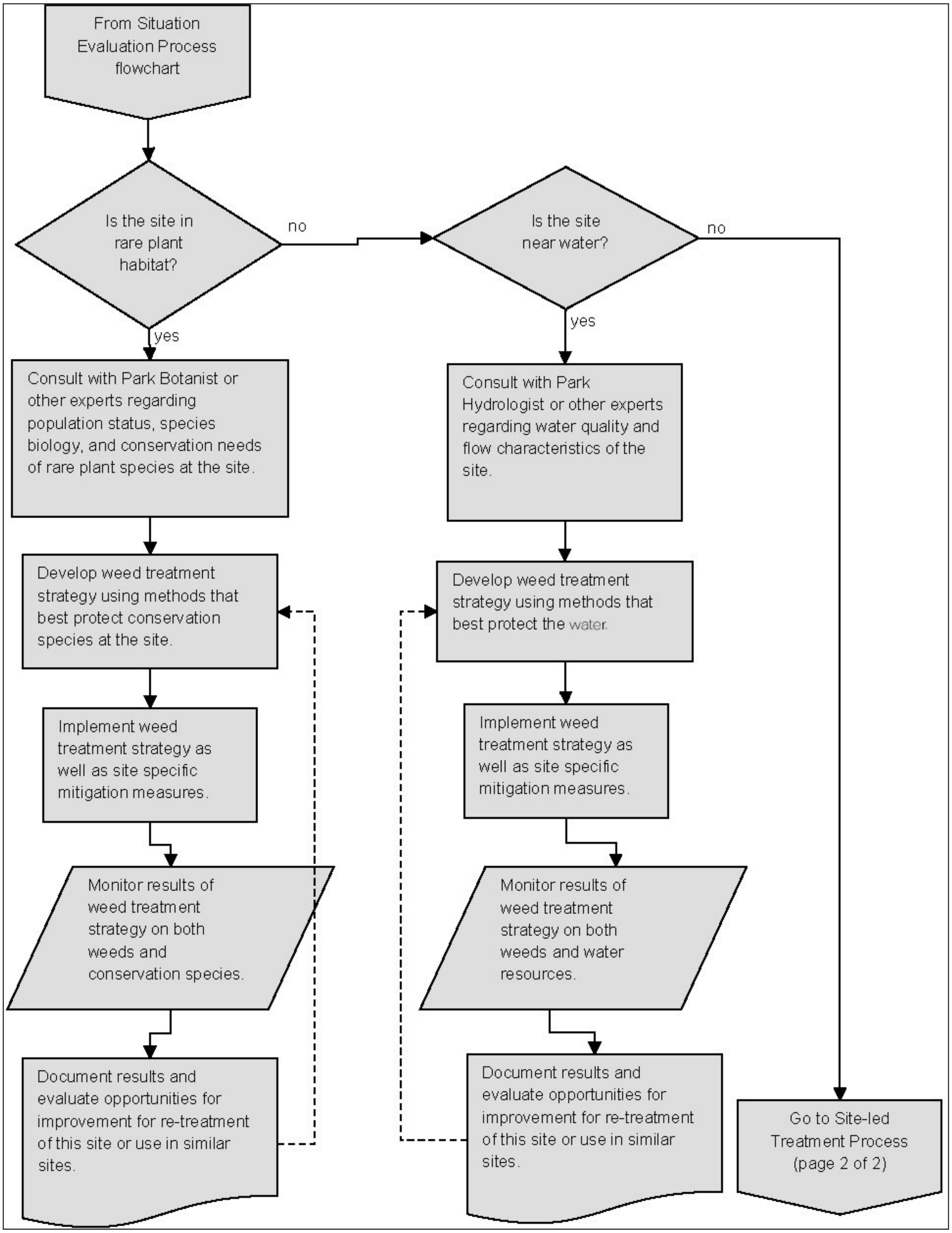

Figure C3. Flowchart for Site-led Treatment Process (page 1 of 2).

Figure C3 shows the two flowcharts for Site-led Treatment Process. The following steps represent routes through flowchart page 2.

1. Off-page connector: "From Site-led Treatment Process (page 2 of 2)"
2. Then, decision: "Is the site a cultural landscape?"
    A. If "No", decision: "Is the site a high use recreation area?"
        i. If "No", process: "Develop weed treatment strategy to prevent spread of seed or veg. propagules along vector."
            a. Then, process: "Implement weed treatment strategy."
            b. Then, data: "Monitor results of weed treatment strategy on weed spread."
            c. Then, document: "Document results and evaluate opportunities for improvement for re-treatment of this site or use in similar sites."
                1. Optional connector back to "Develop weed treatment strategy to prevent spread of seed or veg. propagules along vector."
        ii. If "Yes", process: "Consult with Park Mgmt Team regarding specific weed impacts on visitor use or safety and the typical visitor use patterns of the site."
            a. Then, process: "Develop weed treatment strategy using methods that best protect the visitors."
            b. Then, process: "Implement weed treatment strategy as well as site specific mitigation measures."
            c. Then, data: "Monitor results of weed treatment strategy on both weeds and visitor use/safety."
            d. Then, document: "Document results and evaluate opportunities for improvement for re-treatment of this site or in similar sites."
                1. Optional connector back to "Develop weed treatment strategy using methods that best protect the visitors."
    B. If "Yes", process: "Consult with Cultural Resource Manager regarding specific weed impacts on cultural landscape elements."
        i. Then, process: "Develop weed treatment strategy using methods that best protect the cultural landscape."
        ii. Then, process: "Implement weed treatment strategy as well as site specific mitigation measures."
        iii. Then, data: "Monitor results of weed treatment strategy on both weeds and visitor use/strategy."
        iv. Then, document: "Document results and evaluate opportunities for improvements for re-treatment of this site or use in similar sites."
            a. Optional connector back to "Develop weed treatment strategy using methods that best protect the cultural landscape."

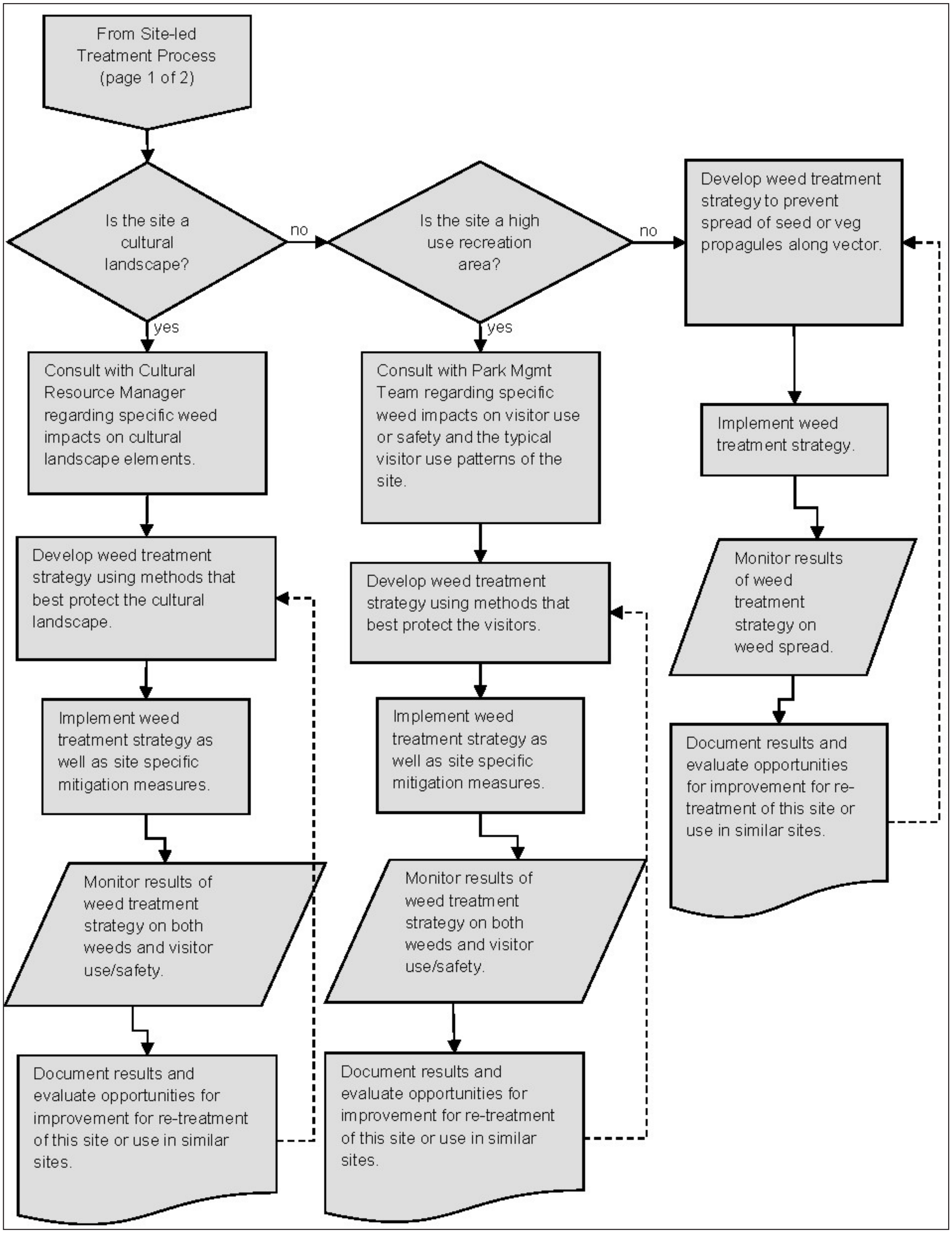

Figure C3. Flowchart for Site-led Treatment Process (page 2 of 2).

Figure C4 shows flowchart for Incipient Population Treatment Process. The following steps represent routes through flowchart.

1. Off-page connector: “From Situation Evaluation Process flowchart”
2. Then, process: “Evaluate other values at risk at the site, weed species biology, and range of treatment options for eradication.”
3. Then, decision, “Is the weed species rhizomatous or capable of re-sprouting?”
   - A. If “No”, decision: ‘Is it possible to remove all flowering plants before seed matures?”
     - i. If “Yes”, process: “Develop weed treatment strategy using mechanical or manual removal.”
       - a. Then, process: “Implement mechanical or manual weed treatment strategy.”
       - b. Then, data: “Monitor results of manual or mechanical weed treatment strategy.”
       - c. Then, document: “Document results and evaluate opportunities for improvement for re-treatment of this population or use in similar populations. If manual or mechanical treatment failed, consider use of chemical treatment.”
         - 1. Optional connector back to ‘”Develop weed treatment strategy using mechanical or manual removal.”
         - 2. Optional connector to “Develop weed treatment strategy using chemical methods. Confirm treatment strategy is in compliance with laws, policies, and regulations (see detail chemical treatment flowchart).”
       - d. Then, decision: “Was eradication successful?”
         - 1. If “No”, off-page connector: “Retry eradication or go to Established Populations Treatment Flowchart (Figure C5)”
         - 2. If “Yes”, terminator: “Success!”
     - ii. If “No”, process: “Develop weed treatment strategy using chemical methods. Confirm treatment strategy is in compliance with laws, policies, and regulations (see detail chemical treatment flowchart).”
       - a. Then, process: “Implement chemical weed treatment strategy.”
       - b. Then, data: “Monitor results of chemical weed treatment strategy.”
       - c. Then, document: “Document results and evaluate opportunities for improvement for re-treatment of this population or use for similar populations.”
         - 1. Optional connector back to “Develop weed treatment strategy using chemical methods. Confirm treatment strategy is in compliance with laws, policies, and regulations (see detail chemical treatment flowchart).”
       - d. Then, decision: “Was eradication successful?”
         - 1. If “Yes”, terminator: “Success!”
         - 2. If “No”, off-page connector: “Retry eradication or go to Established Populations Treatment Flowchart”
           - A. Optional connector back to “Evaluate other values at risk at the site, weed species biology, and range of treatment options for eradication.”

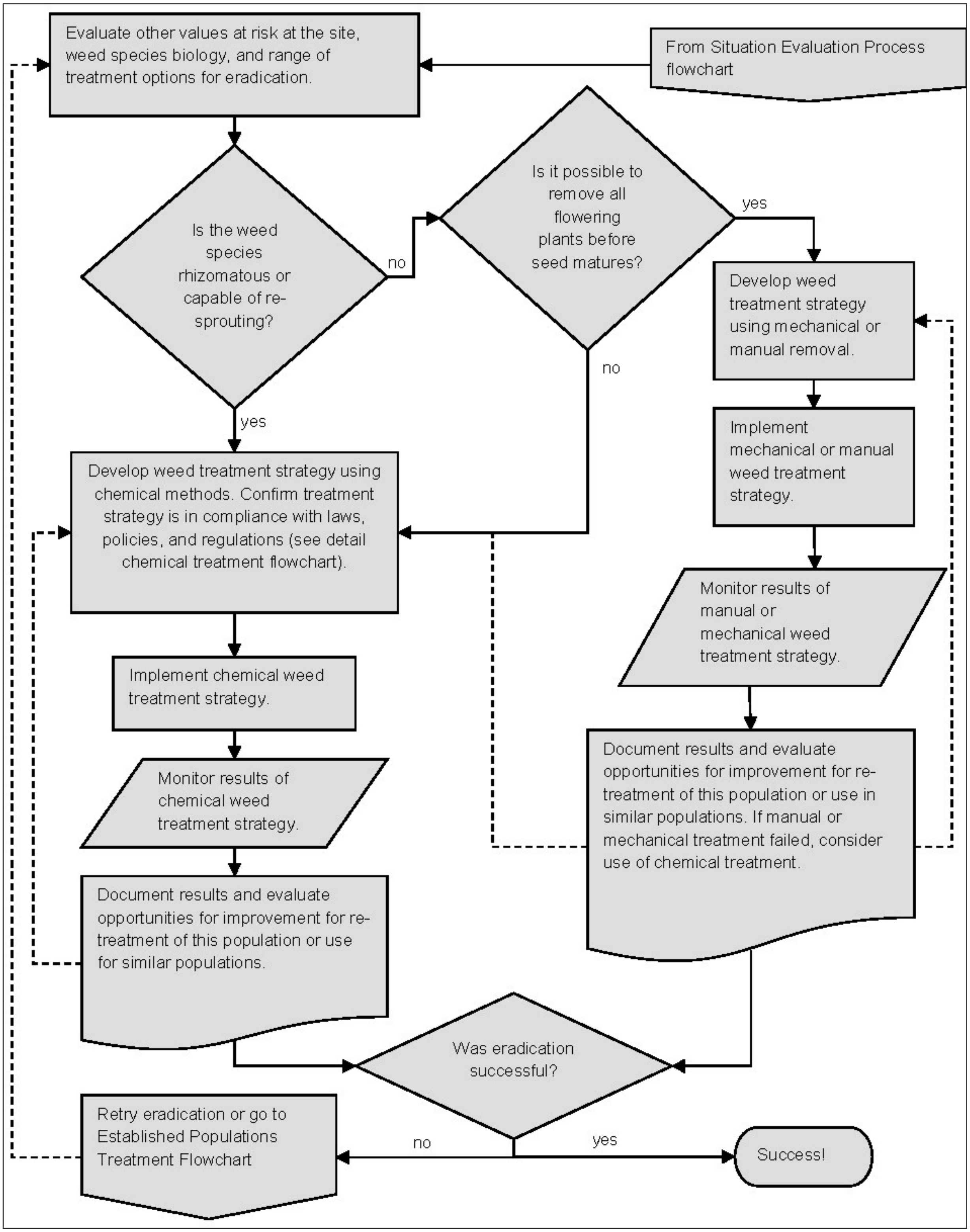

Figure C4. Flowchart for Incipient Population Treatment Process.

Figure C5 shows flowchart for Established Population Treatment Process. The following steps represent routes through flowchart.

1. Off-page connector: "From Situation Evaluation process (Figure C2.) flowchart or Incipient Population Treatment Process (Figure C4) flowchart"
2. Then, process: "Evaluate population including: spatial distribution within the populations and spatial relationships to other populations of same species"
3. Then, process: "Evaluate location including: vector to spread seed or propagules and accessibility for treatment"
4. Then, process: "Evaluate treatment options for containment including: manual/mechanical treatment, chemical treatment, biological control, prescribed fire, and combinations of treatment."
5. Then, process: 'Develop treatment strategy, including objectives for containment as first priority then on control of the population."
6. Then, decision: "Is the treatment strategy in compliance with laws, policies, and regulations (see detail chemical and biocontrol treatment flowcharts)?"
    - A. If "No", process: "Revise until strategy is in compliance."
        - i. Optional connector back to "Is the treatment strategy in compliance with laws, policies, and regulations (see detail chemical and biocontrol treatment flowcharts)?"
    - B. If "Yes", process: "Implement treatment strategy."
        - i. Then, data: "Monitor results of treatment strategy."
        - ii. Then, document: "Document results and evaluate opportunities for improvement for re-treatment of this population or use in similar populations.
        - iii. Then, decision: "Were containment and control objectives met?"
            - a. If "Yes", terminator: "Success!"
            - b. If "No" back to "Evaluate population including: spatial distribution within the populations and spatial relationships to other populations of same species."

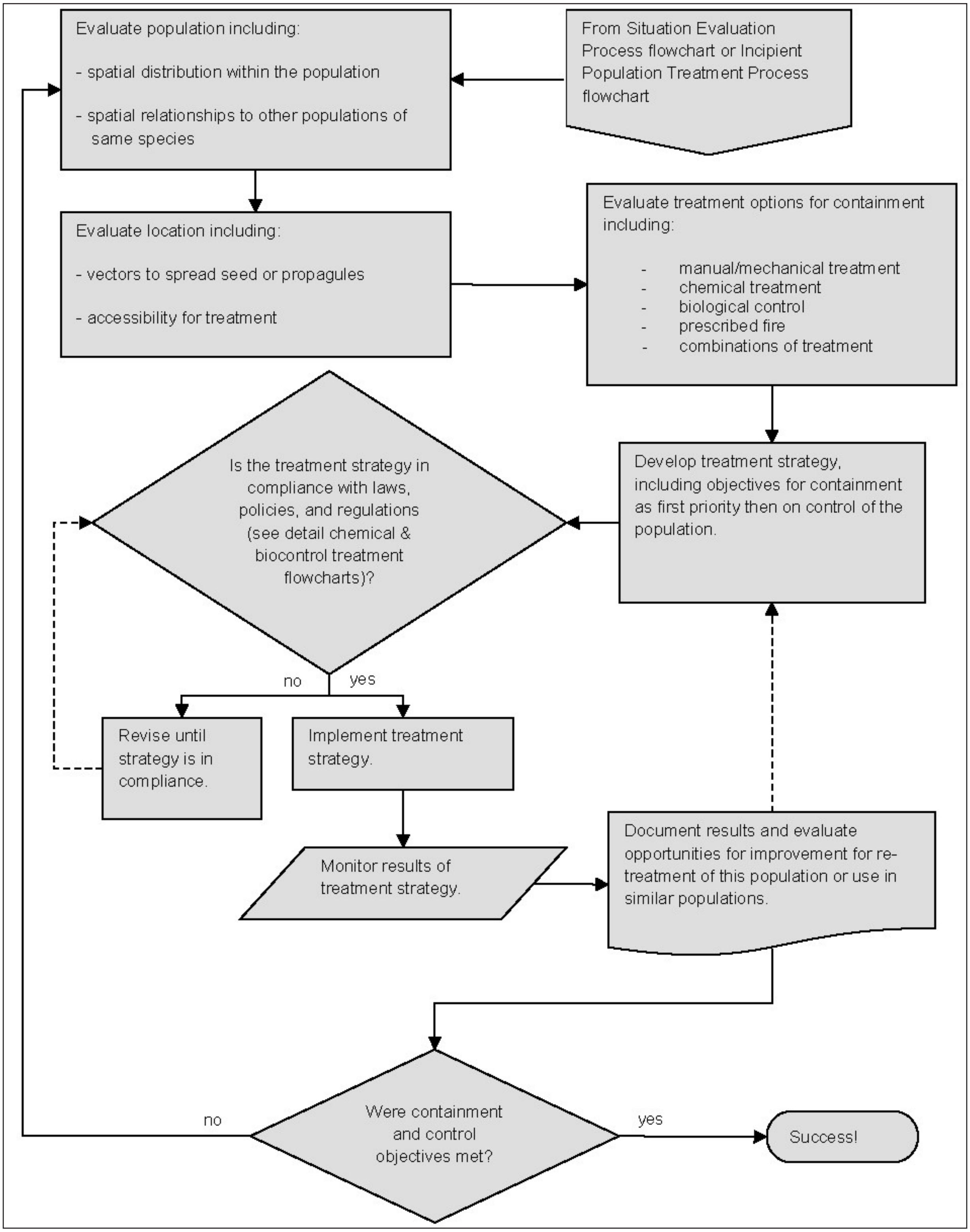

Figure C5. Flowchart for Established Population Treatment Process.

Figure C6 shows Detail Chemical Treatment flowchart to confirm compliance. The following steps represent routes through flowchart.

1. Off-page connector: "From Established Population Treatment Process (Figure C5) or Incipient Population Treatment Process (Figure C4)."
2. Then, process: "Determine Treatment Strategy and need for herbicide use to meet management objectives"
3. Then, process: "Select proposed herbicide and application method."
4. Then, decision: "Is the chemical registered for use by the US EPA?"
    A. If "No", terminator: "Do not use. Develop new treatment strategy."
    B. If "Yes", decision: "Is the product labeled for the target weed?"
        i. If "No", terminator: "Do not use. Develop new treatment strategy."
        ii. If "Yes", decision: "According to the label are there any special conditions that would prohibit its use at the proposed treatment site?"
            a. If "Yes", terminator: "Do not use. Develop new treatment strategy."
            b. If "No", process: "Submit pesticide use proposal and obtain approval from the NPS Regional IPM Coordinator (Or National IPM Coordinator for Restricted Use Herbicides).
                1. Then, process: "After approval, purchase only enough chemicals to be used within one year. Maintain inventory and pesticide use log."
                2. Then, off-page connector: "Return to Established Population Treatment Process (Figure C5) or Incipient Population Treatment Process (Figure C4)."

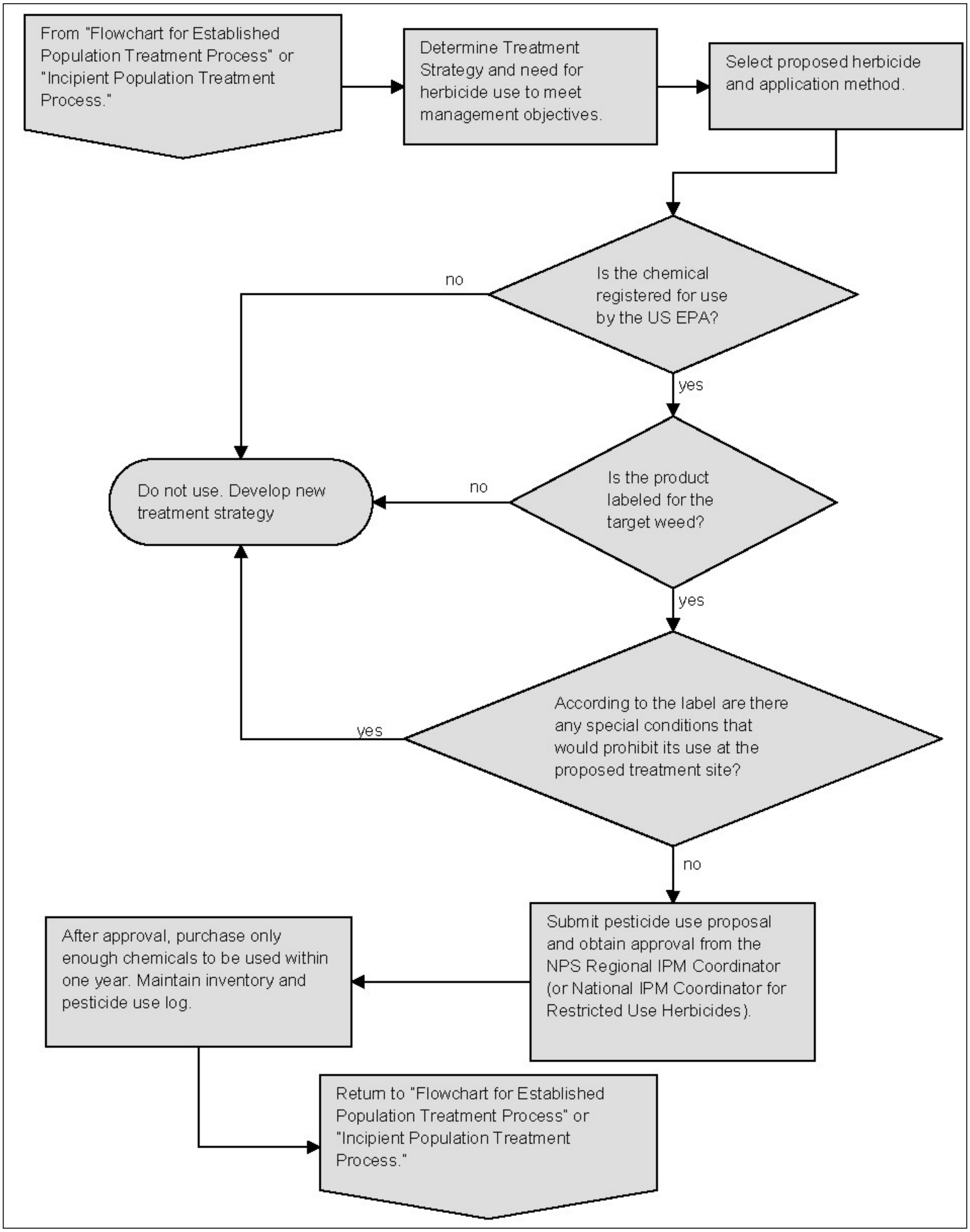

Figure C6. Detail Chemical Treatment Flowchart to confirm compliance.

Figure C7 shows Detail Biocontrol Treatment flowchart to confirm compliance. The following steps represent routes through flowchart.

1. Off-page connector: “From Flowchart for Established Population Treatment Process (Figure C5).”
2. Then, process: “Determine treatment strategy and need for biocontrol to meet management objectives.”
3. Then, process: “Select proposed biocontrol agent (s).”
4. Then, decision: “Is the biocontrol agent approved by USDA APHIS for release in the US?”
    - A. If “No”, terminator: “Do not use. Develop new treatment strategy.”
    - B. If “Yes”, decision: “If required, is the biocontrol agent approved by the State for release in your county?”
        - i. If “No”, terminator: “Do not use. Develop new treatment strategy.”
        - ii. If “Yes”, process: “Develop an implementation plan to include: a summary of species biology and effectiveness of control, establishment of population and/or control thresholds, acquisition of biocontrol agents, strategy for actual release of organisms, and a strategy for monitoring the success of the release.”
            - a. Then, process: “Submit plan and request to use biocontrol agent to Regional/National IPM Coordinator.”
            - b. Then, decision: “Will biocontrol agent be acquired from another state?”
                - 1. If “No”, off-page connector: “Return to flowchart for Established Population Treatment Process (Figure C5).”
                - 2. If “Yes”, process: “If required obtain permit to transport biocontrol agent across state lines.”
                    - A. Then, off-page connector: “Return to flowchart for Established Population Treatment Process (Figure C5).”

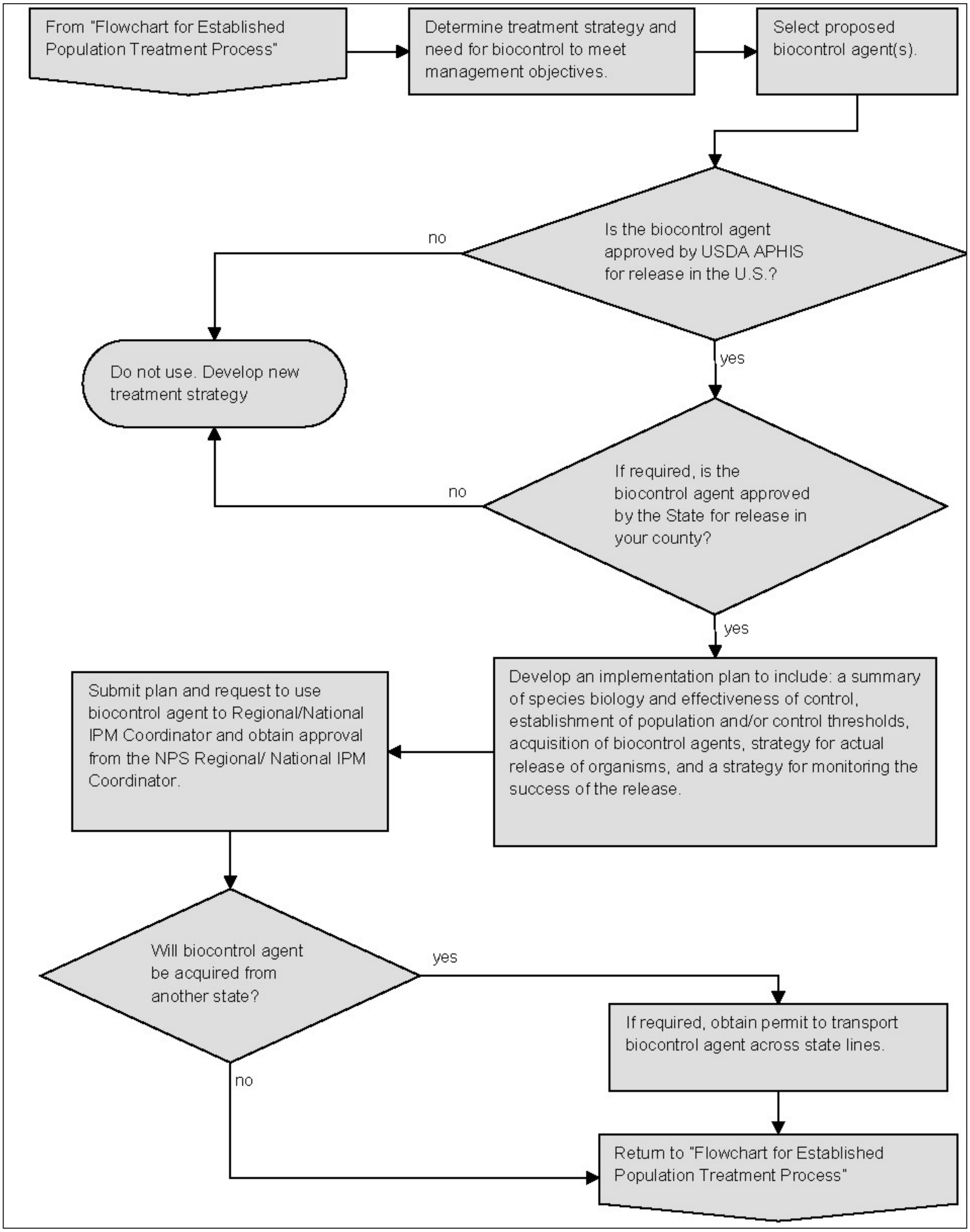

Figure C7. Detail Biocontrol Treatment Flowchart to confirm compliance.

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