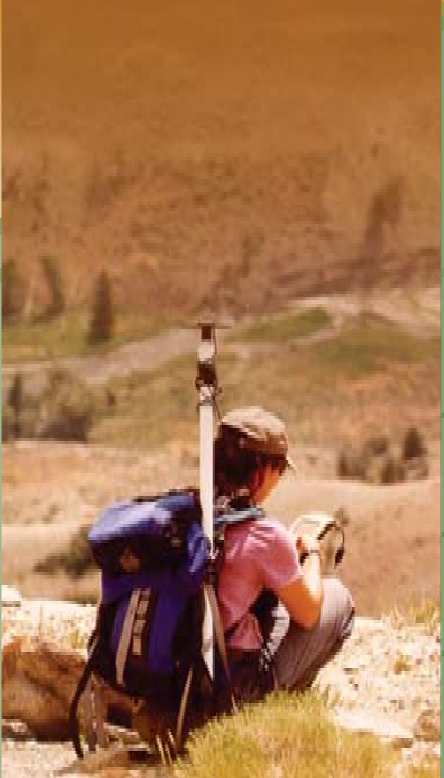

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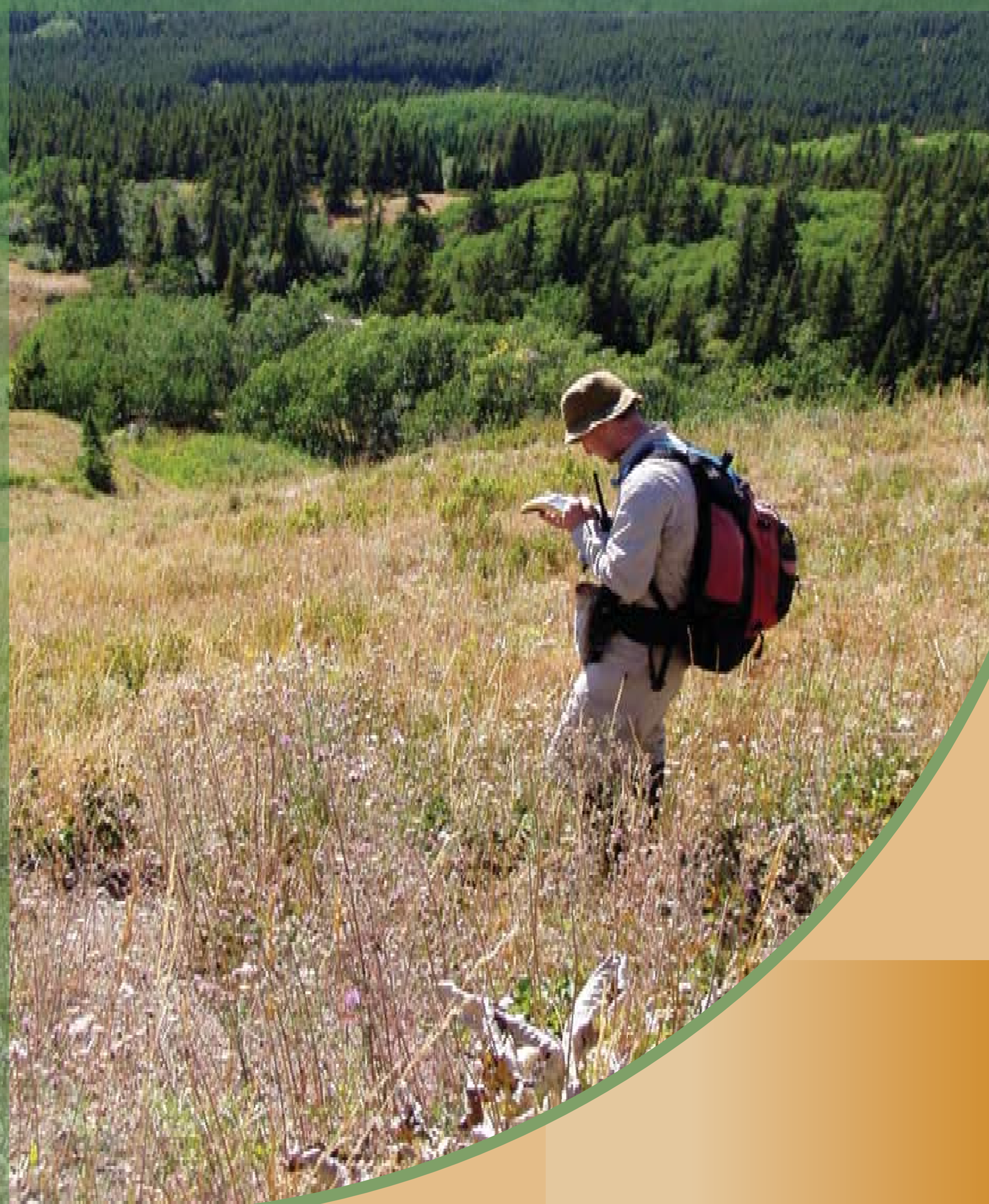

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MONTANA STATE UNIVERSITY | EXTENSION

CENTER FOR INVASIVE PLANT MANAGEMENT

Inventory and SURVEY METHODS for Nonindigenous PLANT SPECIES

First Edition

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Cover photo upper left: Yellowstone National Park. Courtesy of Ben Levy.

Cover photo lower right: Western Montana. Courtesy of Shana Wood.

MONTANA STATE UNIVERSITY | EXTENSION

CENTER FOR INVASIVE PLANT MANAGEMENT

The intent of this book is to describe inventory and survey methods currently used for the first step of nonindigenous plant species (NIS) management; namely, to determine which species are present in the area of interest, and where they are. A complementary aim is to outline the decision-making process that goes into selecting an inventory or survey method. We offer a science-based approach that accepts the real constraints of managers while demonstrating that inventory and survey methods must be based on land use goals and NIS management objectives.

Our goal is to provide straightforward explanations of a variety of inventory/survey methods, the data they provide, the objective(s) they fulfill, and how they are used to map an area, so that land managers can choose the most appropriate method for their needs. Nonindigenous plant species inventories and surveys often seem to be designed and conducted without rigorous consideration of land use goals and NIS management objectives. This can mean that the data collected do not meet the goals and objectives that were intended but not stated, or answer the implied questions that prompted the mapping effort, or that data are stored but not revisited or used, and even that more data fields are collected than needed—all of which are a waste of resources.

For each inventory/survey method, we give an overview and enough detail for readers to determine whether the method is appropriate for their needs. In some cases, working examples of the method are given. While we do not specifically recommend management or monitoring strategies, the reader will gain insights into these topics as well.

We hope this publication will make it easier for land managers to decide how to approach an inventory or survey, which method to use, and how to make the most of the NIS information obtained.

Our indebted thanks go to Connie Bollinger for her excellent and tireless editorial, content, and copyediting assistance. We also thank the Center for Invasive Plant Management for funding this project, and the Department of Land Resources and Environmental Sciences at Montana State University for additional support.

Introduction

Lisa J. Rew, Steven R. Radosevich, and Monica L. Pokorny

Most land managers in the West are responsible for large tracts of land and are mandated to control nonindigenous plant species (NIS) to some extent, but the necessary budgets and personnel are often limited. To develop an NIS management plan managers need to know which NIS are present in the area, where these species are—and equally important, where they are not—and possibly their approximate patch size and abundance. However, collecting such data is often expensive and difficult because of the size and topography of the areas in which NIS occur. Therefore, the method used to map the NIS must be accurate, efficient, and cost-effective, but also appropriate and relevant to the goals and objectives of the management area. In this book eight inventory and survey methods currently used in the Intermountain West are outlined. Two introductory chapters on terminology, sampling design, and data management, and a final chapter introducing NIS risk management add further dimension to the theme of selecting the right inventory/survey method for the management goals and objectives.

Chapter 1 sets the stage for the rest of the book. Commonly used mapping terminology is defined, and the process of setting clear land use goals and NIS management objectives to guide the selection of the inventory and survey methods is discussed. The general NIS inventory/survey categories which encompass all of the methods included here are outlined, along with sampling techniques common to all the methods described. Thus, Chapter 1 provides an excellent background and introduction to the rest of the book.

Chapter 2 discusses why and how inventory/survey and monitoring data should be collected, and ways to manage and utilize this information. Most inventory/survey methods provide data on which NIS are present, their abundance, and their spatial distribution. Inventory/survey data, properly collected and analyzed, can help land managers prioritize NIS management activities and explore strategies for prevention, early detection and rapid response, and other management options.

Inventory/survey methods are described in Chapters 3 through 9. Chapters 3, 4, and 5 explain methods for covering large areas of the landscape. Chapter 3 outlines the Utah State University method for mapping NIS infestations used primarily to support early detection and rapid response efforts by managers of public lands. A case study demonstrates how the Utah method is used to search as many acres as possible within the allotted time and budget, yet maintain an acceptably high level of detection confidence. Chapter 4 describes digital aerial sketch-mapping (DASM), a method that allows for rapid inventory/survey of NIS infestations over landscapes that are not only large but often remote. As a relatively costly method, DASM is generally used to survey high-priority areas where target NIS are more likely to be found. Chapter 5 describes Nevada's three-tiered approach that uses both inventory and survey methods. By using all three tiers, managers can inventory disturbed areas, where target NIS are most likely to be found; obtain a representative sample of the NIS populations in potentially infested areas by conducting a stratified random survey; and finally, randomly check at least 5% of previously sampled areas at a finer scale to test the accuracy of the inventory/survey data.

Forms of stratified sampling are enlarged upon in Chapters 6 and 7. Chapter 6 describes a stratified random sampling method that samples on and away from a stratification feature such as roads and trails. Utilizing ecological knowledge and preliminary data on NIS distribution, stratified random sampling provides representative samples of the actual distribution of NIS, and allows for probability of occurrence maps to be created that show the likelihood of the target species occurring over the entire area. The adaptive sampling method (Chapter 7) is best used on rare but problematic species. Sampling is stratified on areas or linear features most likely to harbor the target species; for example, roads, trails, campgrounds, and waterways. Traversing these linear features improves the efficiency of sampling, but once the target species is observed a concentric sampling pattern is used to locate other plants and patches of the same species. To check the validity of the stratification features some sampling is performed perpendicular to them.

Chapter 8 describes the use of remote sensing in NIS mapping, a sophisticated method that uses algorithms to process remotely sensed data to detect NIS across extensive landscapes, generally at fine resolutions ($\leq$ 10 m). Remotely sensed data can help prioritize areas to be investigated further and focus ground-based surveys to verify locations of new NIS populations. Despite the costs of specific software, trained personnel, and computer storage space, remotely sensed imagery can increase the detection rate of many NIS and thus improve detection programs.

Chapter 9, the final methods chapter, outlines and provides examples of coarse-scale mapping developed to acquire spatial information about NIS distribution at a quarter-section, quarter-quadrangle, county, or state scale. The spatial data provide coarse-scale (low-resolution) information on abundance, distribution, and spread of NIS over time for very large areas. This information can be incorporated into a geographic information system (GIS) and compared and analyzed with other spatial data (e.g., land use type, aspect, slope) to help in planning and execution of NIS management.

While NIS inventory/survey methods are central to this book, other aspects of making management decisions are also covered. The simple presence of an NIS is often considered to be enough to take management action, an approach that is intuitively appealing, particularly if the NIS is known to be highly competitive or associated with declines in native species. Proactive management requires identification and eradication of small patches of potentially invasive plant species before they become widespread. In addition, land managers require better predictive capabilities to determine which new NIS could cause problems, and where in the landscape these target NIS are likely to invade and have the most detrimental impact. Consequently, the final chapter deals with assessing the potential risk of new NIS.

Chapter 10 outlines the concept of NIS risk assessment and the benefits of using inventory/survey information to predict where NIS populations are likely to occur and to prioritize management actions. The chapter provides an example of how to construct an NIS risk assessment model based on the susceptibility of native plant communities to NIS invasion, the disturbance history of sites, and their proximity to current NIS populations. With good information on plant species biology and site characteristics, as well as GIS data of consistent quality in an area, watershed, or region, NIS risk assessment can be a valuable tool for land managers.

We have included different types of inventory/survey methods in this book because NIS are present on the landscape in many different stages of invasion. Some NIS are new to an area and hence their patches will be small and hard to find, while at the other end of the spectrum are species that have expanded to occupy a large area. There is little doubt that managers benefit from the ability to find and document NIS populations at all stages of the invasion process, so the methods described in this book address these different scenarios. The data collected allow for prioritization of areas and populations of NIS to target for eradication, containment, prevention, restoration, or no management. Management prioritization is often undertaken with prior knowledge of the area and its NIS, but this process can be streamlined and substantiated by selecting a number of populations to monitor more precisely for change after applying various treatments or no treatment. The more successful treatments and environments with more invasive populations will be highlighted through monitoring, and these data along with inventory/survey data can be incorporated into future management plans using the adaptive management approach.

Thus, land managers need a variety of methods and tools to inventory/survey, monitor, and consequently manage the NIS in their area. This book provides a comprehensive selection of inventory/survey methods that can be used to map NIS. We hope our readers find it useful.

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Glacier National Park. Photo courtesy of Shana Wood.

Nevada landscape. Photo courtesy of Bob Wilson.

Monica L. Pokorny, Steven A. Dewey, and Steven R. Radosevich

Introduction

Management programs for nonindigenous species (NIS) exist to help achieve the overall land use goals for an area. Without clearly defined land use goals and an NIS management program aimed at achieving those goals, the reason for an NIS management plan can be unclear and unquantifiable. Defining land use goals and NIS management objectives helps managers determine what kind of NIS data to collect and which inventory, survey, or monitoring methods to use. The differences between inventory, survey, and monitoring data are often misunderstood. Consequently, it may not be clear to managers how to collect these different types of data, and how to use them in a successful NIS management plan. In this chapter we define inventory, survey, monitoring, and other terms commonly used in NIS management. We then describe how NIS management objectives are used to determine the appropriate inventory, survey, and monitoring methods for a management area.

Definitions

We regard nonindigenous plant species as those that have been introduced to a region intentionally or accidentally by humans (see Richardson et al. 2000 for a complete discussion). The terms *exotic, nonnative, invasive, alien,* and *weed* are often used interchangeably. We have attempted to consistently use the term **nonindigenous species** throughout this book. We caution against *invasive* as a general term for NIS until monitoring determines that a particular plant population has been increasing or having an impact (Davis and Thompson 2000), thus making it actually invasive.

Considerable confusion also exists about the use of the terms *survey, inventory, monitoring,* and *mapping* as they relate to NIS. Nonindigenous plant inventories and surveys are observations made at a single point in time to determine the occurrence (location) of one or more NIS within a delineated management area (NAWMA 2003). The basic goal of an inventory or a survey is typically to list the species or a subset of species (such as noxious weeds) present in a management area. It may also include recording the location of populations of each species. We consider an **inventory** to be a cataloguing of the entire management area, whereas a **survey** is a sampling of a representative portion of a management area (Moore and Chapman 1986; Pugnaire and Valladares 1999). In this book, when we refer to techniques that may be applied to either an inventory or survey, we use the term **inventory/survey**. The results of NIS inventories/surveys are normally presented in descriptive reports; in databases, spreadsheets, or tables; and in the form of maps, which can be hard copies, geographic information system (GIS) layers, or both. The term *mapping* is often used to encompass a range of data-gathering and data-recording techniques. In other words, **mapping** may be used as a general description of the entire range of inventory/survey, data-recording, and data-depiction activities.

Population is another term that causes confusion when discussing inventory/survey or monitoring. We define a **population** or **patch** as a group of plants of the same species delineated by arbitrary boundaries for the purpose of study (Crawley 1997, p. 364). A group of individuals of the same species that are close enough to interbreed (a group of patches) is considered to be a **metapopulation** (Crawley 1997, p. 365). An **infestation** is a large number and/or area of NIS plants and patches, and is therefore essentially a metapopulation.

Monitoring is "the collection and analysis of repeated observations or measurements to evaluate changes in condition and progress toward meeting a management objective" (Elzinga et al. 2001, p. 2). Generally, monitoring is conducted at regular time intervals at representative site-specific locations, and can be designed to detect relatively small changes in the target population (Barbour et al. 1999; Winward 2000). Monitoring methods range from taking photographs at designated photo points to collecting detailed data in fixed plots or along permanent transects (Moore and Chapman 1986; Coulloudon et al. 1999).

In this publication, we use *monitoring* in the specific sense as defined above by Elzinga et al. (2001). However, those authors also point out that the term *monitoring* is sometimes used in a general sense to describe a broad variety of data-gathering activities, including inventories and surveys. We avoid this usage because it creates confusion between two very important but different aspects of an NIS management program: (1) conducting landscape-scale NIS inventories or surveys upon which to build and implement an overall NIS management strategy, and (2) collection of precise site-specific monitoring data over time to evaluate the effectiveness of NIS management practices, and/or to determine the spread or ecological impacts of NIS.

The major differences between NIS inventories, surveys, and monitoring include objectives, scales, details, precision, and reproducibility of results. Nonindigenous species inventories and surveys provide a single point-in-time assessment of the occurrence of NIS, they often provide data on the location and overall abundance of an NIS population, and they supply basic information upon which to develop NIS management plans. Inventories/surveys are generally conducted on and interpreted for a relatively large area with considerably less detail and precision than that required

Certain inventory/survey methods are ideal for large western landscapes. Photo courtesy of Shana Wood.

for monitoring. Due to differences in surveyors, inventory/survey designs, sampling methods, sampling scales, and other field procedures, comparisons among data from repeated inventories/surveys may be of limited value if they are intended to depict changes in NIS populations over time. The data collected from such inventories/surveys might be used to demonstrate changes in overall NIS distribution and/or total number of infested acres, but are generally not precise enough to indicate changes in the size or density of individual NIS patches, which is exactly where monitoring is important. Instead, the data derived from such projects should be used to identify populations or areas where site-specific monitoring might be conducted. Monitoring involves repeated measurements over time of individual plants or patches (e.g., density, height, canopy cover, etc.), usually made at the same location, using methods that allow statistically meaningful comparisons among time periods. Monitoring data can be used to determine whether populations are invasive or management practices are effective, and can thus improve management in the future.

Setting Goals and Objectives: The Essential First Step to Selecting an Inventory/Survey Method

Setting clear land use goals and realistic NIS management objectives is the most important step in any NIS management project. Predetermined goals and objectives will guide the selection of the inventory/survey and monitoring methods used in data collection. Knowing the identity, location, and relative abundance of NIS within a management area is essential to developing an effective NIS management plan. For example, if the land use goal is to graze 1,000 head of cattle, then the land management


Close examination may be needed to identify plants correctly. Photo courtesy of Lisa Rew.

goal must be to maintain an adequate amount of forage. An NIS management objective for such an area might include reducing the amount of NIS to less than 10%. Constraints on meeting NIS management objectives must also be considered; for example, having a large area to manage but very little staff. Constraints need to be revisited as inventory/survey objectives are defined and methods are selected because they influence the management, inventory/survey, and monitoring plans.

To identify NIS management objectives—for example, to minimize NIS density, area, and spread, or to eradicate the NIS completely—the following questions should be answered:

- What is the area of interest? What size is it? How much of it must be managed?
- What are the land use goals for that area (e.g., grazing, wildlife habitat, logging, recreation, native community conservation)?
- What are the desired plant community conditions? For example, is at least 90% cover/abundance of native vegetation desired?
- Are NIS present? How might they affect achieving the land use goals and the desired plant community?

After the NIS management objectives are identified, constraints to consider include:

- Cost and type (skill level) of labor required for data collection and data interpretation
- Time available for data collection (e.g., length of field season)
- Size, land type, and topography of management area
- Access and travel restrictions
- Availability of equipment
- Level of precision and accuracy needed in identifying and mapping NIS
- Regulatory considerations affecting management (e.g., threatened and endangered species, regulation of tools, regulation of habitats)
- Other constraints such as aesthetic values, public opinion, need to maintain wildlife habitat

When questions pertaining to the NIS management objectives are answered and constraints considered, it is then possible to establish the inventory/survey objectives, determine the inventory/survey methods, and decide what data to collect. These are the critical steps for selecting the most appropriate and efficient inventory/survey method. Questions to address before selecting an inventory/survey method include:

- What is the purpose of the inventory/survey? How will it help to meet land use goals and NIS management objectives?
- How will the data be used to achieve the land use goals and NIS management objectives?
- How much information does the manager need about the NIS patches? For example, their size, density, and cover; or simply whether a particular NIS is present or absent?
- At what scale (extent and resolution) does the inventory/survey need to be conducted within the management area? If it is the entire area, then it will be an inventory; otherwise, it will be a survey. Decide what resolution, or minimum mapping unit, is appropriate (e.g., 10 m^2, 20 m^2, 50 m^2, a single section).

To determine whether NIS management objectives are being attained, monitoring must take place. It is therefore important at the onset of a project to consider how the following monitoring objectives will influence the inventory/survey method. Monitoring may be needed to determine:

- If the population parameters are changing (e.g., area, density, cover.)
- If the population parameters are changing according to the location where the NIS is found (in certain habitats, disturbed areas, etc.)
- If new populations are establishing, and if so, what the spread vectors are (e.g., roads, paths, or streams)
- What impact the NIS may be having on the surrounding vegetation or ecosystem (changes in plant species composition or abundance may be the most observable response)

- Whether the management practice is decreasing population/patch size and density
- Whether the management practice is affecting the surrounding vegetation either positively or negatively

Figure 1 summarizes the cycle of setting goals and objectives, selecting inventory/survey and monitoring methods, and adjusting for constraints.

Inventory and Survey Categories

To help guide land managers in the development of inventory/survey objectives and selection of appropriate methods, it is useful to consider the four basic inventory and survey categories described by Kuchler and Zonneveld (1988): exploratory, reconnaissance, extensive, and intensive. We have adapted their categories to focus specifically on NIS inventories/surveys.

Exploratory

The exploratory category includes the most elementary steps of inventory/survey, which are used when little or nothing is known about the location and types of NIS in relatively large areas up to many square miles in size. In this situation, existing knowledge about the NIS population is based mostly on casual observations made during other field activities. The purpose of an exploratory inventory/survey is to search as many acres as possible in the least amount of time and at the lowest possible cost, while still providing the kinds of basic information needed to guide the initial development and implementation of a sound NIS management strategy. The primary aim in this situation would be to create a basic NIS map indicating the species present, their general distribution over a broad landscape, and perhaps their relative abundance (i.e., which species are abundant throughout the area, and which are in early stages of invasion). This aim might be achieved by conducting sample surveys in portions or all of the area, rather than a full landscape-wide inventory. In an exploratory inventory/survey, little if any data are collected beyond the species, location, and size of infestations, and the map scale is usually coarse (1:24,000 to 1:100,000).

Reconnaissance

Reconnaissance inventory/survey is used when the general abundance and/or distribution of common NIS are already known, and maps or data indicating such basic information may exist. The main objective of a reconnaissance inventory/survey is to locate and record as many small patches of early-stage invaders as possible to support the early detection and rapid response elements of an existing NIS management program. Another objective of reconnaissance inventory/survey might be to more accurately define the perimeter

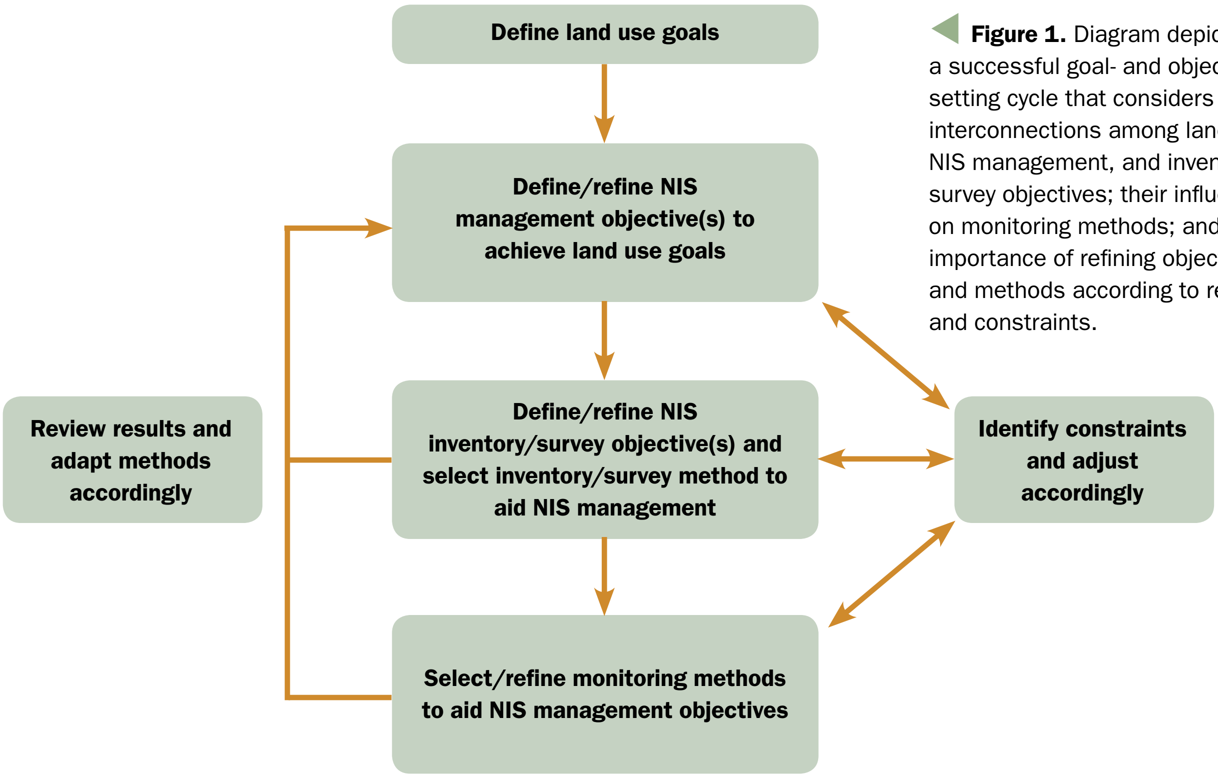


Figure 1. Diagram depicting a successful goal- and objective-setting cycle that considers the interconnections among land use, NIS management, and inventory/survey objectives; their influence on monitoring methods; and the importance of refining objectives and methods according to results and constraints.

of large NIS infestations and to locate all isolated patches discovered beyond the main infestation. Reconnaissance inventories/surveys should be conducted periodically in order to detect new patches before any become too large to eradicate. Reconnaissance inventories/surveys can be limited to specific areas considered most susceptible to new NIS introductions and/or establishment (roads, trails, campgrounds, etc.), or they may be performed over the entire area. Typically, little effort is devoted to locating and delineating large infestations of species already known to be abundant. This allows for faster coverage of targeted areas and ensures that a maximum number of acres can be searched for new patches or new species within the allotted time and budget. Reconnaissance inventories/surveys may involve searches over several hundred to many thousands of acres. Little if any additional data are collected beyond species, location, and size of patches. It may be reasonable to combine exploratory and reconnaissance inventory/survey into a single field operation. Map scale is typically 1:24,000 or finer.

Extensive

In general, extensive inventory/survey should not be conducted until after an exploratory and/or reconnaissance project has been completed. Extensive inventory/survey may involve relatively large tracts of land, much like the exploratory or reconnaissance categories. However, the objective of extensive inventory/survey is to collect data that are considerably more detailed, more accurately delineated, and/or at a finer resolution than those collected by exploratory inventories/surveys, in order to build upon and refine data gathered previously. One of the biggest differences between extensive inventory/survey and the previous two categories is that in an extensive inventory/survey data on indigenous species are also collected to study possible correlations or associations between NIS, native vegetation, and/or certain environmental factors. Extensive inventory/survey is generally more expensive than exploratory or reconnaissance types. Requirements for greater detection resolution and/or the collection of the additional data generally result in fewer acres being inventoried or surveyed per day. An extensive inventory/survey is almost always conducted at a finer scale than the exploratory or reconnaissance types, at a map scale of 1:24,000 or finer.

Intensive

The objective of intensive inventories/surveys is to obtain as much information as possible about NIS, other plant species, and environmental factors at a level of accuracy and detail sufficient to allow meaningful scientific interpretations of ecological relationships. According to Kuchler's definition, an intensive inventory/survey usually implies a relatively small area, perhaps a few hundred acres or less, but may require the same amount of time and expense as a much larger area inventoried/surveyed extensively (Kuchler and Zonneveld 1988). Inventories/surveys are considered intensive if locating individual NIS and characterizing the plant communities in which they are found are the major objectives of the project effort. Observers attempt to reduce the degree of generalization to a minimum by recording every detail of the NIS community structure, including other plant species. Intensive inventories/surveys may include collection of data on phenology, floristic composition, dynamic features, land use, elevation, relief, slope, exposure, soil, water, or geologic character. The level of detail involved in fine-scale inventories/surveys may make some of the collected data useful as a baseline for future monitoring projects. For example, with improved statistical analysis and modeling it is now possible to sample intensively over a relatively small area and predict the occurrence of the target NIS over a much larger management area which was not sampled. Intensive maps are often at scales of 1:5,000 to 1:1,000.

Sampling NIS in the Landscape

Nonindigenous plant inventories and surveys are used to locate plant populations and then record and/or delineate their location. Some fundamental techniques for sampling NIS and their advantages and disadvantages are discussed below.

Sampling Design

Once managers have identified their NIS management and inventory objectives—what NIS they want to search for, where, and why—they need to determine the inventory/survey sampling design for the landscape of interest. Nonindigenous plant location data are generally collected using point, transect, and swath (or band) sampling units in the landscape. Point sampling units are usually circular, transect and swath sampling units are linear and data are collected continuously, and unit size is predefined in all cases. In transect sampling, NIS can be inventoried/surveyed directly below a transect line or for a designated distance on either side of the transect line. Transects are often sampled in straight lines, and if reproducibility is desired, they may have a marked beginning and end. Swaths sample the management area in bands of land. The width of the swath is a predetermined distance on both sides of the surveyor (e.g., 25 to 100 m), and the length of the swath varies. Swaths are often not straight and the route is not always meant to be reproducible. Transects and swaths can also be established as designated routes of travel in which data (i.e., NIS presence) are collected as points along the route, potentially at randomly determined locations.

There are three considerations for locating sampling units in a landscape: (1) randomly locating the sampling units to ensure the data are not biased (i.e., not influenced by the position of the sampling unit), (2) positioning sampling units to achieve good interspersion across the entire area of interest, and (3) defining sampling units that are independent of each other (Elzinga et al. 2001).

The sampling units (points, transects, swaths) described here are located in the landscape according to either subjective (biased), random (unbiased), systematic, or stratified sampling designs. A random design can also be incorporated into the systematic or stratified sampling designs if a subset of the sample units/area is desired. The design selected is based on the manager's objectives, constraints, and knowledge of the area to be sampled (Herrick et al. 2005). Subjective sampling is biased because it does not sample from all areas in the landscape; for example, only specific areas such as roadsides may be selected for sampling. Random location of sampling units, on the other hand, is an unbiased process of selection in which any area has an equal probability of being chosen. Systematic sampling uses a defined order or plan to locate sample units in the landscape, but the initial point may be randomly selected. In a stratified sampling design, the sample area is divided into one or more subgroups (strata) before sampling units are located. For example, the sample area may be stratified on elevation ranges, roads, or habitat types.

Crew members may cover several miles in a long day of field work. Photo courtesy of Shana Wood.

We recommend using a random sampling design (described below) over a subjective design (i.e., a personal decision of where to locate the sample; **Figure 2a**). While subjective sampling can be inexpensive and sensitive to local land use, it is biased, difficult to extrapolate, and dependent on individual knowledge that may or may not be correct or complete (Herrick et al. 2005). For example, if managers sampled only where they knew NIS existed, they would overlook where, how, and in which environments NIS are spreading, all of which are important for effective management.

Simple random sampling involves randomly selecting areas of the landscape to sample (**Figure 2b**) by using maps, aerial photographs, GIS software, or other means. For example, a sample point, transect, or swath location, or a transect/swath starting location, could be randomly located at the intersection of a latitude/longitude location. Because the sample units are randomly located in a landscape, if a sufficient number of samples are taken, there is a good chance of sampling all environmental variables or habitat types in that landscape at the proportion in which they occur. In general, simple random sampling is easy to apply and statistically valid (Herrick et al. 2005). If the landscape of interest is large and point sample units are used, simple random sampling may involve high travel and labor costs to implement (Rew et al. 2006). Also, with the random point design, or any point design, there is a relatively high chance that field personnel will encounter NIS patches on the way to the next survey point, but these NIS should not be recorded under this sampling strategy. To decrease travel time and improve sampling efficiency, survey personnel could use randomly located transects that allow the collection of continuous data (Rew et al. 2006).

Systematic sampling is an easy way to establish sampling units in a landscape, and it has good interspersion between sampling units (Elzinga et al. 2001). Systematic random sampling locations follow a system or grid in the landscape generated from a random starting point, from which a number of data location points are randomly selected (**Figure 2c**). This is an unbiased method. Randomly subsampling from the full grid should provide equally accurate results as sampling the full grid, but will be quicker. An important benefit of systematic random sampling is that it is easily repeatable because it is based on a sampling unit (or point) at a specific location. However, depending on the distance between sample points, the field crew could possibly walk past NIS patches or miss sampling a habitat or environmental variable. Systematic random sampling generally involves a great deal of travel time and labor, which can be somewhat reduced if transects are used rather than points. However, even systematic transect sampling could miss some environmental habitat types, depending on scale of the landscape of interest and the number of sampling units.

The stratified sampling design requires that samples be stratified on a particular feature or variable known to be associated with NIS occurrence. Sampling can be stratified on an environmental variable such as elevation, or anthropogenic variables such as roads or trails. The feature that defines the stratum should not change significantly over time. For example, the sample area may be divided into elevations greater than 5,000 ft (montane forest) and elevations below 5,000 ft (grassland). Elevation may have been selected for defining strata because the elevation break may consistently coincide with different habitats (grassland vs. montane forest). Sampling within the different habitats

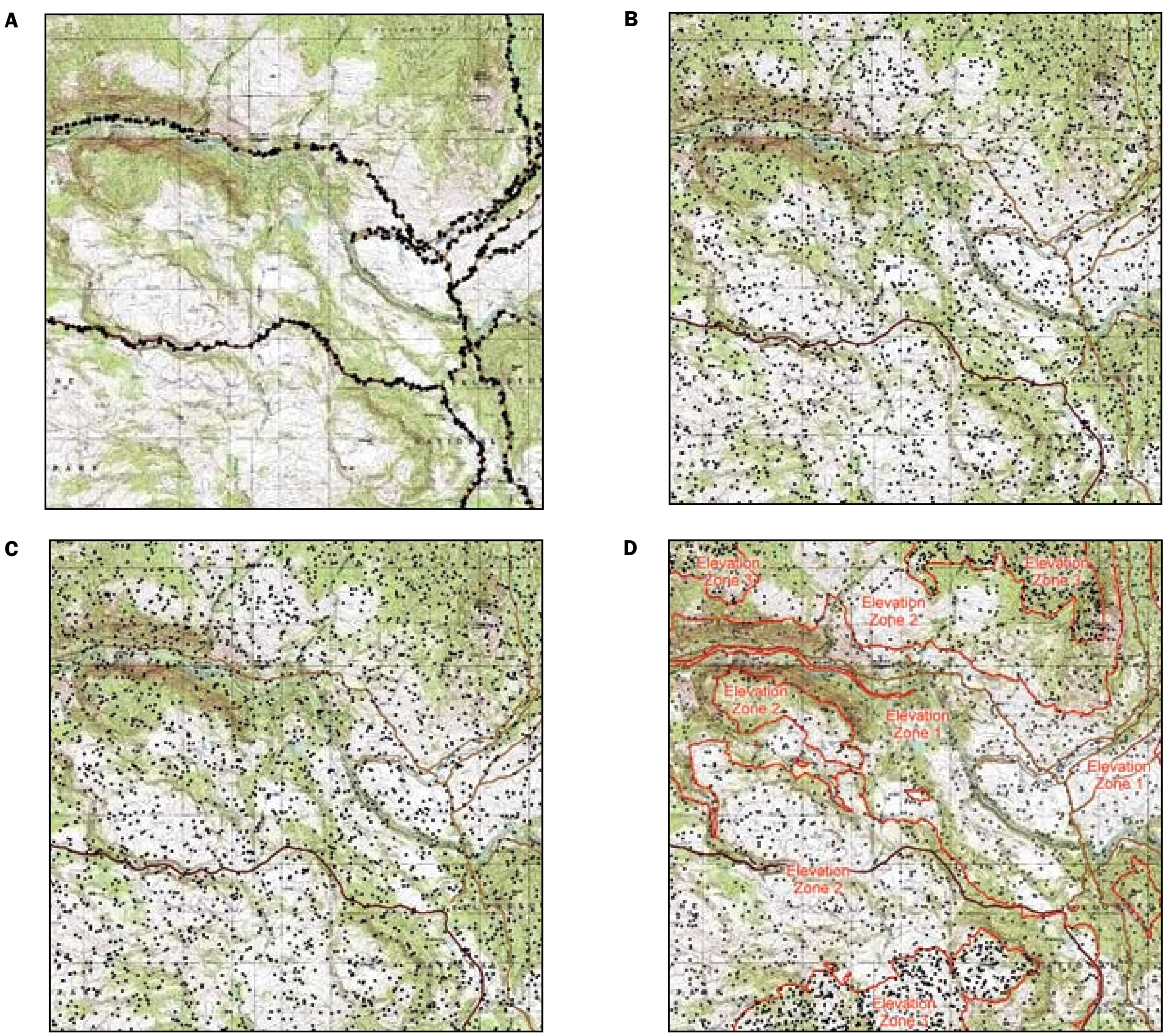


Figure 2. Four survey sampling designs for the landscape of interest. (a) Subjectively located sample points along roads and trails. (b) Randomly located sample points within the landscape. (c) Systematic random location of sample points where potential sample locations occur every 300 m² and a random subset of these sample locations are chosen for the survey. (d) Stratified random sample points where strata are defined by elevation and samples are randomly located within each stratum. Figure 2 courtesy of F. L. Dougher, Montana State University.

will give additional information on how NIS occurrence is related to the habitat types. Once the strata are defined, random samples or systematic samples can be taken within the strata (**Figure 2d**).

Roads, another example of a stratification variable, are often considered vectors of NIS dispersal, so we would assume that we would find more NIS close to roads. If we sample only along a road (biased sampling), we do not get a good understanding of NIS distribution in the landscape as a whole. Using the stratified random approach, sampling could begin on a road and move away from it, thus providing information on NIS occurrence close to the road and at distances farther away. Actual start locations of transects on the road would be random (see Chapter 6).

One of the advantages of stratified sampling is that it uses prior knowledge of where NIS occur or what influences NIS presence. This knowledge can help focus the sampling on specific areas and may then reduce the expense and/or labor required for the inventory/survey while still providing a representative sample of the population distribution. However, results may be compromised by incorrect or incomplete prior knowledge. If the random sampling design (point or transect) is incorporated in the design, samples are unbiased, and all environmental variables in the study area should be observed.

Delineating Population or Metapopulation Shape and Size

Once a population is found in a landscape, the location needs to be documented, preferably on a map. Whether NIS populations are hand drawn on U.S. Geological Survey (USGS) topographic maps or aerial photos, or digitally located with a geographic positioning system (GPS) unit to record the latitude and longitude (or Universal Transverse Mercator [UTM]), the size and shape of the patch needs to be correctly represented so it can be accurately applied to management and monitoring activities. Points, lines, or areas/polygons are generally used to capture the approximate size and shape of the metapopulation/infestation, population/patch, or plant, depending on the resolution required by the inventory/survey.

Point Feature

The point feature is used to designate the location of NIS infestations, NIS patches, or isolated plants. Points can be recorded and plotted on maps in various sizes to represent the size of the infestation. For example, when a GPS data dictionary is used, a point can be marked as 0.1 acre, 0.1 to 0.5 acre, or 0.5 to 1 acre, and so on. When a GIS program is used, points can then be scaled to the actual size of the NIS infestation on a map. Another way to represent various infestation sizes is to use a different symbol on the map for each infestation size. For example, ✕ is used for infestations less than 0.1 acre, △ for infestations of 0.1 to 1 acre, and ● for infestations of 1 to 5 acres (Bruno 1999).

Line Feature

The line feature is used to designate and visually depict the location of continuous linear NIS infestations such as those along a road, trail, or stream bank. When a GPS unit is used, the width of the line and direction of the NIS from the line (left or right of the line, or centered on it) can be designated to represent the actual area infested.

Area or Polygon Feature

The area or polygon feature is used to designate the location of an infestation usually more than 5 acres in size. To map an area, field surveyors generally walk the outer boundary of the infestation to digitally record the area in a GPS unit, or they can hand draw the area on a map which may or may not be digitized in a GIS program.

Gross Area Feature

The gross area feature is used when an infestation is too extensive to map on the ground. Generally, the NIS infestation is drawn on a USGS topographic map or aerial photograph in the field and can later be digitized in a GIS program. A gross area can be delineated around a specific infestation or can be delineated using a designated unit (township/range section).

Conclusion

The North American Weed Management Association (NAWMA) has developed a set of essentially formatting standards for NIS data (NAWMA 2003). While the NAWMA standards are a useful guide, they do not explain how to collect the data, in terms of which inventory/survey methods and metrics to use (Stohlgren et al. 2002). The following chapter highlights why standards such those developed by NAWMA are useful; data can be used by successive managers and can be shared between groups and agencies, adding greater data utility.

As emphasized repeatedly throughout this chapter the method used to collect NIS data should be selected in response to the land use goals and NIS management objectives. We hope the information provided in this introductory chapter will make embarking upon an NIS inventory/survey in your management area less daunting. We have explained mapping terminology and the importance of goals and objectives to assist you in selecting an appropriate inventory/survey method from among those detailed in Chapters 3 through 9.

References

Barbour, M. G., J. H. Burk, W. D. Pitts, F. S. Gilliam, and M. W. Schwartz. 1999. Pages 268-302 *in* Terrestrial Plant Ecology, 3rd ed. New York: Addison Wesley Longman.

Bruno, D. 1999. Guidelines for Terrestrial Noxious Weed Mapping and Inventory in Idaho. Boise, ID: Idaho Department of Agriculture. http://www.idahoag.us/Categories/PlantsInsects/NoxiousWeeds/Documents/mapping/handbook_ver1.pdf.

Coulloudon, B., K. Eshelman, J. Gianola, N. Habich, L. Hughes, C. Johnson, M. Pellant, P. Podborny, A. Rasmussen, B. Robles, P. Shaver, J. Spehar, and J. Willoughby. 1999. Pages 31-130 *in* Sampling Vegetation Attributes. Denver, CO: USDI-BLM Interagency Technical Reference 1734-4.

Crawley, M. J., ed. 1997. Plant Ecology, 2nd ed. Malden, MA: Blackwell Publishing, Inc.

Davis, M. and K. Thompson, 2000. Eight ways to be a colonizer; two ways to be an invader: a proposed nomenclature scheme for invasion ecology. Bull. Ecol. Soc. Am. 81:226-230.

Elzinga, C. L., D. W. Salzer, and J. W. Willoughby. 1998. Pages 1-10 *in* Measuring and Monitoring Plant Populations. Denver, CO: USDI-BLM Technical Reference 1730-1.

Elzinga, C L., D. W. Salzer, J. W Willoughby, and J. P. Gibbs. 2001. Monitoring Plant and Animal Populations. Malden, MA: Blackwell Science, Inc. 360 p.

Herrick, J. E., J. W. Van Zee, K. M. Havstad, L. M. Burkett, and W. G. Whitford. 2005. Monitoring Manual for Grassland, Shrubland and Savanna Ecosystems, Vol. 2: Design, Supplementary Methods and Interpretation. Las Cruces, NM: USDA-ARS Jornada Experimental Range.

Kuchler, A. W. and I. S. Zonneveld, eds. 1988. Pages 193-202 in Vegetation Mapping, Handbook of Vegetation Science, Vol. 10. Boston, MA: Kluwer Academic Publishers.

Moore, P. D. and S. B. Chapman. 1986. Pages 395-405 *in* Methods in Plant Ecology, 2nd ed. Boston, MA: Blackwell Scientific Publications.

[NAWMA] North American Weed Management Association. 2003. North American Invasive Plant Mapping Standards. http://www.nawma.org/.

Pugnaire, F. I. and F. Valladares, eds. 1999. Pages 847-858 in Handbook of Functional Plant Ecology. New York: Marcel Dekker, Inc.

Rew L. J., B. D. Maxwell, R. J. Aspinall, and F. L. Dougher. 2006. Searching for a needle in a haystack: evaluating survey methods for sessile species. Biol. Invasions 8(3):523-539.

Richardson. D. M, P. Pysek, M. Rejmánek, M. G. Barbour, F. D. Panetta, and C. J. West. 2000. Naturalization and invasion of alien plants: concepts and definitions. Divers. Distrib. 6:93-107.

Stohlgren, T. J., T. D. Barnett, and S. S. Simonson. 2002. Beyond North American Weed Management Association Standards. http://science.nature.nps.gov/im/monitor/meetings/FtCollins_02/StohlgrenBeyond-NAWMA.pdf.

Winward, A. 2000. Monitoring the vegetation resources in riparian areas. Pages 10-32 *in* USDA Forest Service General Technical Report RMRS-GTR-47. Ogden, UT: USDA Forest Service, Rocky Mountain Research Station.

Recording the location of an NIS is an important part of inventory/survey. Photo courtesy of Shana Wood.

Mandy Tu

Introduction

Invasive nonindigenous plant species are one of the biggest threats to the successful management of our natural resources. Not only do nonindigenous species (NIS) negatively impact our native species, communities, and ecosystems, but keeping track of NIS data can be challenging as well. In many instances NIS invasions can be reversed, halted, or slowed, and in certain situations, even badly infested areas can be restored to healthy systems dominated by native species (Chornesky and Randall 2003). In order to document such successes and failures, inventory/survey data are initially required to assess the current condition, followed by monitoring data to document changes over time. Good record keeping of the location, extent, and abundance of NIS, and the impacts of those NIS, management actions, and restoration efforts is essential for efficient NIS management. In addition, tracking the success or failure of such efforts can be used adaptively to improve the effectiveness of future management approaches.

Why Manage Nonindigenous Plant Species Data?

Natural resource managers need to know where the NIS of interest are in their management area. This can be achieved with one of the inventory/survey methods described in this book. However, once NIS inventory or survey data are collected, they must be managed if they are to fulfill any purpose. The most effective way to manage inventory/survey data is in digital format on a computer. A digital copy can be more easily kept current and shared with others than paper copies. Digital data management enables managers to immediately find all past NIS individuals/patches that have been mapped and treated and ensures that data will not be lost as a result of personnel changes.

Inventory/survey data must address the land management goals. Generally these data will include knowledge of the distribution and the degree of infestation (cover, density, etc.) of NIS populations (inventory/survey data) or their spread (monitoring data). Evaluation of such data allow managers to allocate time and other resources in the most strategic and effective way, and this is more easily done with digital rather than paper versions of the data. Additionally, if data are not recorded and organized in an easily decipherable format, site knowledge may be lost. With all NIS inventory/survey and monitoring data in one easily accessible and translatable format, managers can get a "snapshot" picture of the current NIS situation and potential dispersal pathways/vectors and determine changes in populations. Equipped with these data, managers can:

- Strategically spend resources to get the most work done at the lowest cost
- Develop strategies focused on prevention and early detection/rapid response, rather than control and containment only
- Share data at multiple scales with other partners
- Predict potential NIS problems and likely sites of invasion
- Generate awareness of NIS issues with the public
- Attract funding

The three examples provided below demonstrate that when inventory/survey data are collected and maintained in a digital format, it can be easily accessed and immediately used in a variety of applications to help meet NIS management objectives.

Snapshot of the Distribution and Abundance of NIS

A one-time survey or inventory for NIS can produce a map of the distribution and abundance of NIS populations in the sampled areas. Some inventory/survey methods also allow predictive maps to be made (see Chapter 6) showing where target NIS might be found over an entire area of interest, and where future inventories/surveys should be conducted.

Figure 1 shows an example "snapshot" from the San Pablo Bay National Wildlife Refuge in California, in which the distribution and abundance of only one NIS, perennial pepperweed (*Lepidium latifolium*), has been mapped (shown in red). A few things are immediately apparent. There are several small and large infestations, the infestations appear to start right at the edge of the impoundments/levees, and some of the large infestations have several smaller outliers. From this map, in which only the distribution of perennial pepperweed is shown, and the value of certain parcels of property or the presence of rare and endangered species is not designated, a management strategy for perennial pepperweed can still be developed. The small outlier populations will be controlled first, while the larger populations are kept in check to prevent spread, and the potential pathways and vectors of perennial pepperweed invasion are deciphered. For example, does the invasion appear to spread along the impoundment roads, which could be related to the movement of equipment, or does the species appear to be spread by water, which would restrict it to waterways or flood-prone areas? Identifying possible vectors and/or pathways of dispersal is key to preventing new invasions. It is equally important to identify uninfested areas, since it is much easier to implement an early detection/rapid response program than to control well-established NIS.

Figure 1. Example of a "snapshot" map of perennial pepperweed (*Lepidium latifolium*) distribution (shown in red). The map shows *Lepidium latifolium* patches adjacent to the mouth of the Petaluma River. Mapping was conducted from August to October, 2004. Base imagery, LandSat 7. Map courtesy of G. Downard, U.S. Fish & Wildlife Service.

Monitoring NIS Population Changes and Treatment Efforts over Time

After an inventory/survey of the management area has been performed, the next stage is monitoring. Monitoring should be performed on some of the NIS populations recorded as part of the inventory/survey to determine if the populations are changing in extent and abundance over time, if management practices are having the intended effect, and if NIS are impacting land management goals. This information helps determine whether a species needs to be managed, what management priorities should be set, and whether and in which environments the management treatments are effective (Elzinga et al. 2001; Maxwell and Rew 2005). Not all NIS have major ecological impacts, and time and other resources are often limited, so completing a good inventory/survey and follow-up monitoring are necessary to assess which species and infestations can be controlled with minimal effort and/or are most serious and require treatment.

Using NIS Data to Set Strategic Priorities for Prevention, Early Detection/Rapid Response, and Management

To focus management efforts on existing NIS problems, priorities must be based on the goals and objectives for the management area as a whole (see Chapter 1). The overall aim in setting NIS priorities is to direct resources in a way that will minimize the long-term damage caused by specific populations of NIS in the most cost-effective manner. Prioritizing all NIS management activities within the context of an overall NIS management plan is essential to maximizing resources, since funds are rarely available to manage all NIS and management may not be necessary for some species or situations.

By far the most effective and efficient approach to NIS management is to avoid the problem in the first place by preventing NIS from establishing in or near management areas (Hobbs and Humphries 1995; Rejmánek and Pitcairn 2002). Frequent monitoring can detect new occurrences of problem NIS, allowing for rapid response, treatment, and, ideally, eradication.

The best approach to NIS management prioritization comes from a model produced by the Department of Conservation in New Zealand (Owen 1998), which recommends balancing two approaches simultaneously: the species-based and the site-based approaches. The species-based approach assigns high priority to NIS that are especially damaging, that spread quickly, or that are recently established and can be readily eliminated or contained. It also takes into account the current and potential impacts of the NIS on native species, communities, ecosystem processes, and conservation targets, and also considers the likelihood of the species spreading, the difficulty of NIS control, the current extent of the NIS on or near the site, and the value of the habitats/areas that the NIS infests or may infest.

In contrast, the site-based approach assigns high priority to specific sites with highly valued native species and communities. Focusing on large blocks of uninvaded area, the site-based approach attempts to consolidate and expand the boundaries of the uninvaded area, reverse invasion trends, and expand the uninvaded area outward, while concentrating on desired species, communities, and ecosystems. In the case of nonindigenous riparian species and other NIS that commonly disperse over long distances, this method may control upstream to downstream movement, address large “source” populations first, and/or monitor roads, trails, and watercourses for new NIS. Using both of these approaches in concert is the best method that we have observed to prioritize management strategies.

What Data Should Be Collected?

The data to collect as part of an inventory/survey depends on what information is needed or wanted, at what scale and resolution, and on the goals and specific objectives of the project site (see Chapter 1). At the project scale (typically thought of as less than the size of a county, although this can vary), point and polygon data are useful not only to determine the exact location(s) of NIS, but also to provide some measure of their abundance. At the state, regional, and national scales, collecting the presence or absence data for target NIS for a particular measure of area is usually sufficient.

At the project scale, the data that must be collected depend on the inventory/survey and monitoring objectives, but using the minimum mapping standards developed by the North American Weed Management Association is advisable (NAWMA 2003). Using the NAWMA standards allows the manager to keep track of needed data, while also ensuring that the data will be compatible with that collected by partner agencies and organizations. Specifics about the NAMWA standards are available online at www.nawma.org. **Table 1** lists the types of data required to meet the NAWMA standards.

Table 1. Data required to meet minimum mapping standards as defined by NAWMA.

Inventory and Monitoring Standards	Survey Standards
Collection date	Area surveyed
Examiner	Type of survey
Plant name (scientific name and common name)	Date of survey
Infested area	Quad name
Gross area	Quad number
Canopy cover	
Ownership	
Source of the data	
Country	
State or province	
County or municipality	
Hydrologic unit code	
Location (latitude and longitude, UTM)	
Quad number	
Quad name	

How to Keep Track of Data in Digital Format

NIS-related data may be kept in spreadsheets and workbooks such as Excel (Microsoft Corp.), or in some type of computer database or geodatabase application program, such as Access (Microsoft Corp.) or ArcGIS (ESRI Inc.). Most agencies have required data standards and databases, but nonagency personnel can choose from several available databases suitable for keeping track of NIS-related data, depending on the scale at which the work is done, as well as on personal record-keeping preferences. At the project scale, certain tools that help natural resource managers keep track of their NIS data can also aid with management decisions and actions, such as control, management, and restoration. At both the project scale and coarser state scale, the data can be used to assist in prevention and early detection/rapid response activities.

Project-Scale NIS Databases and Data Management Tools

Most of the project-scale data management tools currently available are accessible only to federal agency staff. For instance, the USDA Forest Service NRIS-Terra system (Natural Resource Information System Terrestrial Database) keeps track of all land-related and management data, and the U.S. Fish and Wildlife Service is developing an all-encompassing geodatabase application called RLGIS (Refuge Lands GIS). The National Park Service has an NIS-specific database application called APCAM (Alien Plant Control and Management Database) that is used by all of their NPS Exotic Plant Management Teams. APCAM keeps track of all mapped NIS locations, other associated NIS survey data, and all management treatments applied.

A project-scale database that is available to all other resource managers is the Weed Information Management System (WIMS) developed by The Nature Conservancy (TNC). Recognizing the threat imposed by NIS to its mission, TNC decided in 1999 to create a data management tool that allows natural resource managers to keep track of their own NIS data, assist with NIS mapping efforts, and easily share data with partners.

WIMS is an integrated system of hardware and software that simplifies the collection and management of NIS data. The central piece of WIMS is the relational Microsoft Access database that keeps track of all NIS occurrences, assessments (coarse-scale monitoring), and management treatments for all NIS within a defined area. Data can be easily exchanged between multiple users, exported in NAWMA format, and written to shapefiles for mapping in most geographic information system (GIS) program. WIMS can be used in combination with handheld personal digital assistants with attached global positioning system (GPS) units (or with Trimble GeoXT or XM units) to facilitate the collection of mapping data in the field.

WIMS is available free by download at http://tncweeds.ucdavis.edu/wims.html, along with extensive documentation showing how to use the system, including a User's Manual outlining how to store and maintain data.

State and Regional-Scale NIS Databases

With regard to coarse-scale data, as of 2006 there are several databases, some of them Web-accessible, that can keep track of NIS inventory and survey data, mostly at the state and regional (multistate) scales. **Table 2** lists a few examples of these state and regional NIS databases. At the state scale, many states keep track of NIS or state-listed noxious weeds through their state agriculture departments, heritage programs, the NatureServe online database (http://www.natureserve.org), or a designated state herbarium. Chapter 9 gives detailed information on the Montana and Colorado NIS survey and mapping databases.

Data that are readily accessible to land managers in such state databases may be at a resolution from detailed to coarse, but even NIS maps that are produced at a coarse scale can assist in setting state- or region-wide prevention, early detection/rapid response, and management priorities. What makes some of these regional databases extremely useful, beyond making and displaying maps of NIS locations, is that they also include associated data for each NIS record, allow users to input new NIS data, provide maps at various scales, include NIS ranking information, and provide NIS alerts and recommendations for early detection activities. More examples of state and regional NIS databases can be found in the Plant Databases section of Invasivespeciesinfo.gov, at http://www.invasivespeciesinfo.gov/databases/plantdb.shtml.

Conclusions

The management of NIS inventory/survey data can be easy to complex, depending on project objectives, data needed, and the manager's predisposition for managing data. Depending on the degree of detail needed, there are already some data management tools and frameworks available for use by natural resource professionals. For managing NIS data beyond keeping track of data on paper or in simple spreadsheets, one of the existing data management tools should be considered, since the construction and maintenance of data management systems from scratch is a demanding and expensive long-term commitment. Using a preexisting data management tool has the added advantage of making it easy to share data between and among existing systems and their databases.

Ultimately, complete and current NIS data are essential to inform prevention, management, and policy decisions. Managers with access to up-to-date inventory/survey and monitoring data that track the species of concern, their locations, rate of spread, and native communities affected will find themselves in a better position to make the NIS management decisions necessary to achieve their land management goals.

Table 2. Examples of model NIS databases.

USGS National Institute of Invasive Species Science (USGS-NIISS): National scale NIS database	http://www.niiss.org
Alaska Exotic Plant Information Clearinghouse (AKEPIC)	http://akweeds.uaa.alaska.edu/
Invasive Plant Atlas of New England (IPANE)	http://invasives.eeb.uconn.edu/ipane/
Invaders Database System	http://invader.dbs.umt.edu/
Southwest Exotic Plant Information Clearinghouse (SWEPIC): A regional compilation of several databases	http://www.usgs.nau.edu/SWEPIC/

References

Chornesky, E. A. and J. M. Randall. 2003. The threat of invasive alien species to biological diversity: Setting a future course. Ann. Missouri Bot. Gard. 90: 67-76.

Elzinga, C., D. Salzer, J. Willoughby, and J Gibbs. 2001. Measuring and Monitoring Plant and Animal Populations. Malden, MA: Blackwell Science, Inc. 360 pp.

Hobbs, R. J. and S. E. Humphries. 1995. An integrated approach to the ecology and management of plant invasions. Conserv. Biol. 9(4): 761-770.

Maxwell, B. and L. J. Rew. 2005. Agroecology/Weed Ecology Web site, http://weedeco.msu.montana.edu/.

[NAWMA] North American Weed Management Association. 2003. North American Invasive Plant Mapping Standards. http://www.nawma.org/.

Owen, S. J. 1998. Department of Conservation Strategic Plan for Managing Invasive Weeds. Wellington, NZ: New Zealand Department of Conservation. http://www.doc.govt.nz/Conservation/003~Weeds/003~DOCs-Strategic-Plan-for-Managing-Invasive-Weeds.pdf.

Rejmánek, M. and M. J. Pitcairn. 2002. When is eradication of exotic pest plants a realistic goal? Pages 249-253 *in* C. R. Veitch and M. N. Clout, eds. Turning the Tide: The Eradication of Invasive Species. Proceedings of the International Conference on Eradication of Island Invasives. Cambridge, UK: IUCN Publications Services Unit.

Landscape-Scale Wildland Inventories/Surveys: Utah State University Methods

Steven A. Dewey and Kimberly A. Andersen

Introduction

Inventories and surveys of nonindigenous plant species (NIS) in wildlands are conducted by Utah State University (USU) primarily for generating distribution maps that will then be used in support of improved management, strategic planning, and control efforts. *Mapping* is used here in its broadest sense to cover a range of observational and data-recording activities, conducted both singly and over time, and over a broad range of landscape scales. It therefore encompasses inventory and survey, as defined in Chapter 1. Inventories/surveys are essential elements of the early detection and rapid response strategy being promoted today in most wildland NIS management plans. A rotating schedule could be developed to search a portion of the land each year, so that within a specified number of years the majority of the management unit could be inspected. Inventories or surveys of high-likelihood areas might need to be performed annually, whereas systematic inventories/surveys of the most remote sites or habitats deemed least suitable for NIS establishment or spread might be performed only once every five to ten years. The goal is to schedule inventories/surveys often enough to detect all new populations before they exceed a size considered feasible for eradication. Early detection of NIS through regular inventories/surveys is just as essential to successful NIS management as the early detection of wildfires is to effective fire management.

The first step in any NIS mapping project is to establish a clear set of objectives (see Chapter 1). The critical questions that must be answered before any field work begins include "what is the primary purpose of the project?" and "how will the data be used?" Factors to consider in setting objectives include the size of the area to be mapped and overall cost. The types of data that could be collected during field inventories/surveys are nearly limitless, as are the number of possible methods. Costs can range from a few cents to many dollars per acre. It is our observation that without first establishing clear objectives, the tendency of many project planners is to collect far more information than will be needed, thus reducing the number of acres that can be mapped and lowering overall project efficiency.

USU Objectives and Methods

USU field crews have conducted numerous plant inventories/surveys, ranging from exploratory to extensive in nature, on tens of thousands of acres of western wildlands in support of NIS management programs for the Bureau of Land Management, Forest Service, National Park Service, and Utah Division of Wildlife Resources. The primary objective of these projects has been to find and map infestations of newly established NIS plants and populations to support early detection and rapid response efforts by land managers. Infestations of other targeted species have usually been mapped too, but generally not at an equally high level of detail or resolution. The overarching goal has been to search as many acres as possible within time and budget constraints, while still maintaining an acceptably high level of detection confidence.

Terminology

Some of the terms used in this chapter have been created by the authors to describe methods and standards developed by USU for conducting NIS inventories/surveys on wildlands (Dewey and Andersen 2005a,b,c). Terms unique to this chapter are defined as follows:

Search Target (ST): Refers to plant species that are the object of a field search. ST descriptions must always include species, growth stage, and Minimum Detection Target Size (MDTS).

Minimum Detection Target Size (MDTS): The smallest population size (single plant or patch) of the least visible targeted species that observers are confident of detecting and identifying, at a stated level of probability, under actual field conditions using their stated protocols. In most of our projects the MDTS was set at 0.01 acre.

Effective Detection Swath Width (EDSW): The maximum width of a linear search pattern (a band transect) in which a walking observer is confident of visually detecting at least 90% of all targeted species' populations of the stated minimum target size. EDSW must be adjusted according to factors influencing target visibility, such as species, stage of growth, topography, and associated vegetative cover, in order to maintain the 90% minimum detection standard. Data dictionary choices for effective detection swath widths in most projects were 25, 50, 100, 150, 200, 250, and 300 yards. (See inset box on next page for metric equivalents.)

Patch Separation Resolution (PSR): The minimum distance used to distinguish between different populations (single or multiple plants) of target species. Populations separated by the PSR distance or more must be recorded as separate patches. Plants separated by less than the stated PSR are

The USU method primarily uses English units (feet, yards, and acres). Metric conversions are summarized here.

Units of Length

Yards	Meters
25	22.9
50	45.7
100	91.4
150	137.2
200	182.9
250	228.6
300	274.3

Units of Area

Acres	Hectares	Meters^2
0.001	–	4.0
0.01	–	40.5
0.1	–	404.7
0.25	0.1	1011.7
0.5	0.2	2023.4
1.0	0.4	4046.9
2.5	1.0	10117.1
5	2.0	20234.3

usually mapped as a single population. The PSR for a typical project was 50 yards.

Detection Confidence (DC): The percentage of the total number of infestations that crew members estimate they were able to find in a searched area, based on the likelihood of seeing patches of the established minimum detection target size of the least visible target species in that terrain. Detection confidence is essentially meaningless without also stating the growth stage of the target species and the MDTS associated with that DC. The minimum required DC set for most of our projects was 90%, based on an MDTS of 0.01 acre for plants of the least visible target species in a mature or flowering stage of growth.

Between-Feature Positions (BFP): A series of location points recorded automatically by global positioning system (GPS) units that indicate daily search routes traveled by each crew member. The distance interval for collecting BFPs was generally set to correspond to the average effective detection swath width (EDSW) for each area inventoried/surveyed. The BFP can be used to demonstrate that an area was searched but no target species were located; i.e., to create presence/absence data, which are useful for both future searches and statistical analysis of data.

Case Study

Perhaps the simplest way to illustrate some of the methods and standards used by USU is to provide an example of a recent NIS mapping project. It will also place readers in a better position to decide whether or not the USU method might fit their own mapping needs. The following is taken from a report summarizing an NIS inventory conducted by USU in portions of twelve national parks in southern Utah (Dewey et al. 2003). This project would probably fall into the extensive mapping category (see Chapter 1).

Utah State University conducted a two-year project to inventory and map selected NIS targeted for control by the Northern Colorado Plateau Network of the National Park Service in selected areas of the network. The project included portions of Arches National Park, Black Canyon of the Gunnison National Park, Bryce Canyon National Park, Canyonlands National Park, Capitol Reef National Park, Cedar Breaks National Monument, Colorado National Monument, Dinosaur National Monument, Hovenweep National Monument, Mesa Verde National Park, Natural Bridges National Monument, and Zion National Park.

The principal objective of this project was to document the distribution and abundance of the targeted species on a total of 95,738 acres within the designated parks. It was anticipated that these data would provide baseline information useful in the development and implementation of effective vegetation control strategies.

Areas to be inventoried were determined on the basis of what was considered to be the most likely NIS habitat, with priority given to areas of present or anticipated park development and high visitor use. Areas of likely NIS seed introduction as well as sites already known to contain NIS seed sources, or vector areas, were also given priority (**Figure 1**).

Forty-seven NIS were included in the GPS data dictionary, representing all species targeted for inventory by the twelve parks included in this project, plus some additional species of regional or national concern.

Categories of data collected in this project are listed in **Table 1.** GPS-entered data included the location and size of each infestation, percent canopy cover, phenology of the target species, woody growth stage (if a woody species), presence of site disturbance, hydrology, dominant native species present, date, time, and any other pertinent notes about the site. Data entered in the office during postprocessing included ecological status, park code, record numbers, detection confidence for inventory area polygons, scientific

Figure 1. Priority areas selected for NIS inventory in Arches National Park (Dewey et al. 2005d).

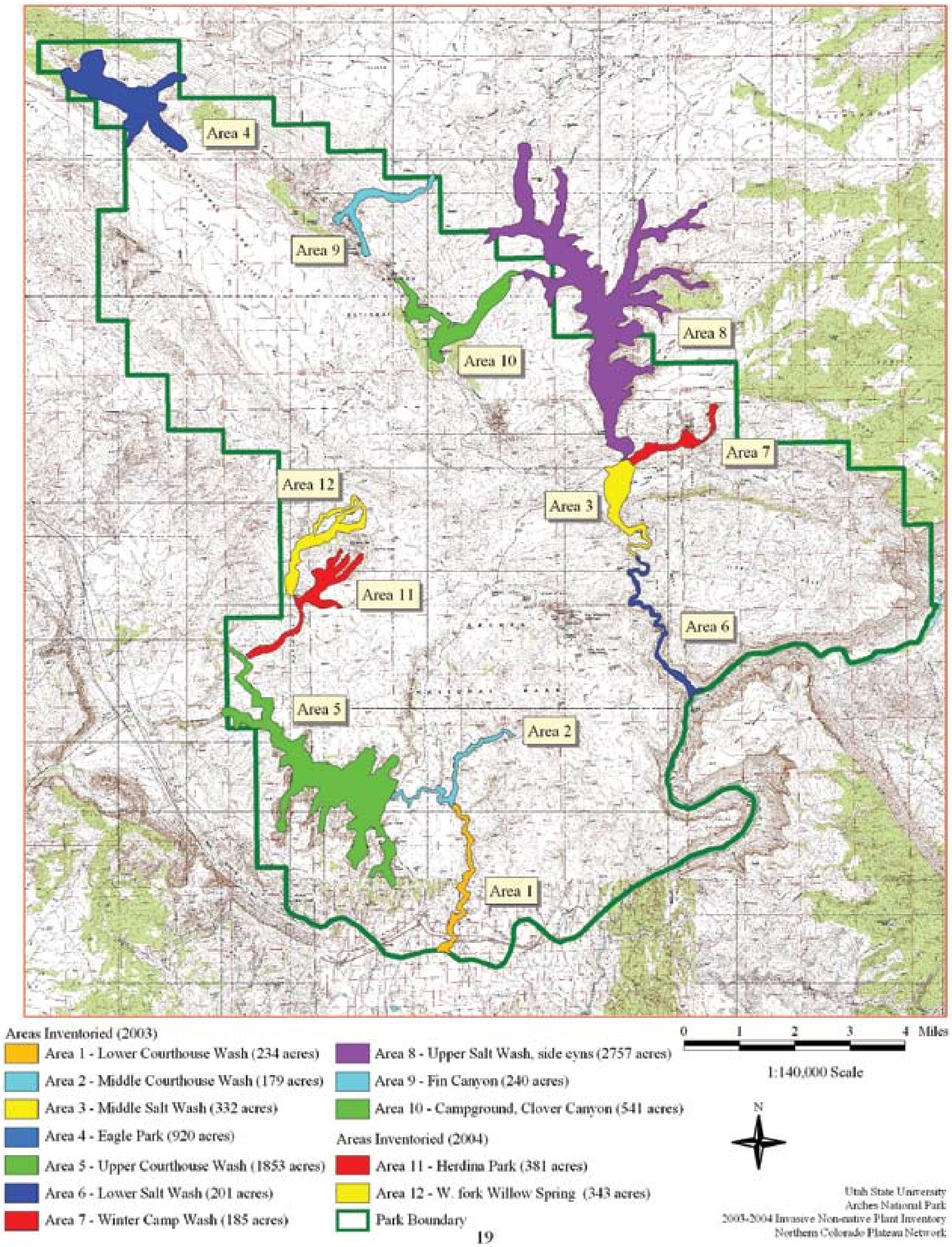


Table 1. Description of data fields used in USU inventory of NIS in national parks.

Data Field	Description	Options/Values	Priority	Entry
Species Name	Latin name of species	Pick-list to be provided by park staff	Required	GPS
Species Code	ITIS		Required	Office
Additional Names	Common name of species		Optional	Office
Date	Date species observed		Required	GPS
Observer	Name of person observing population	First initial of person's last name used in data file name	Required	GPS
Location ID	Unique identifier for species population (Record #)		Required	GPS
Park Code	Four-letter abbreviation of park		Required	Office
Country	Name of country (e.g., USA)		Required	Office
State	Two-letter state abbreviation		Required	Office
County	County name		Required	Office
UTMN	UTM northing coordinate for population		Required	GPS
UTME	UTM easting coordinate for population		Required	GPS
Elevation	Elevation in meters (or feet)	Meters (or feet)	Required	GPS
Size of Infested Area	Size of population (if a point feature). Based on average diameter of NIS infestation.	1 to few plants 0.1 acre 0.25 acre 1.0 acre 2.5 acres 5.0 acres	Required only for points	GPS
Gross Area		Gross estimate of land area occupied by an NIS species	Required in specific situations	GPS
Cover of Infested Area	Estimated percent of area infested with NIS	Trace (less than 1%) Low (1 to 5%) Moderate (6 to 25%) High (26 to 50%) Majority (51 to 100%)	Required	GPS
Distribution	Characterization of density	To be determined by the project manager	Optional	GPS
Phenology	Life stage of majority of population. Use most progressive life stage if population appears evenly split.	Vegetative Bud Flower Immature Fruit Mature Fruit Seed-dispersing Dormant	Required	GPS
Woody Growth	Predominant growth stage of species. Use for woody NIS species only (elm, tamarisk, Russian olive, etc.) If stages are mixed, use most advanced stage (valuable for planning control efforts).	Seedling Sapling Mature Old-growth	Optional	GPS
Life Form	Life form of species	Tree Shrub Graminoid Forb	Required	Office

Table 1. Description of data fields used in USU inventory of NIS in national parks, continued.

Data Field	Description	Options/Values	Priority	Entry
Ecological Status	Qualitative description of the level of infestation that identifies ability of site to recover to natural state once the NIS have been removed	No NIS. The management emphasis is preventing NIS encroachment. New and/or small infestations. These infestations have good potential for eradication because they are small and there is a good understory of desirable plants. Large-scale infestation with 30% or greater understory of residual grasses and good potential productivity. Management of these sites in a way that selects for the recovery of the residual native grasses and shrubs has good potential for control but not eradication of the NIS. May be more that one noxious NIS, but the underlying biologic integrity of the unit is good. Large-scale infestations with few or no (less than 30% cover) desirable grasses in the understory. Infestation often dense and/or multiple NIS. Control will require intense treatment and probably revegetation. Control may be possible, but not eradication. In some areas, the infestation may have changed the character of the land so much that attempts for rehabilitation are cost prohibitive.	Required	Required
Dominant Species	Species Latin name for dominant species at site (up to four species can be recorded)	Two to three dominant species need to be provided at each point (list of possible dominant species provided by park). If single or few plants, use dominant species in 0.1 acre area.	Required	GPS
Buffer	Buffer needed to encompass population if GPS'ed as a line or polygon feature	Enter number in feet	Required for lines, optional for polygons	GPS
Hydrology	General hydrologic setting of site. If further specificity is needed in park, add items as subcategories to existing terms (e.g., *wetland*; subcategory, *seep*).	Upland (above and away from floodplains) Riparian (along rivers or stream channels) • Perennial: stream flows continuously in time. • Intermittent: stream flows only at certain times of the year (typically on seasonal basis) when it receives water from springs or from melting snow. • Ephemeral: stream flows only in direct response to precipitation. Ephemeral streams generally lack obligate riparian vegetation. Wetland (saturated soil for majority of growing season) Playa lakebed (poorly drained depressions)	Required	GPS
Disturbance	Evaluate disturbance at population site	No disturbance apparent Light to moderate disturbance Site heavily disturbed	Required	GPS

Table 1. Description of data fields used in USU inventory of NIS in national parks, continued.

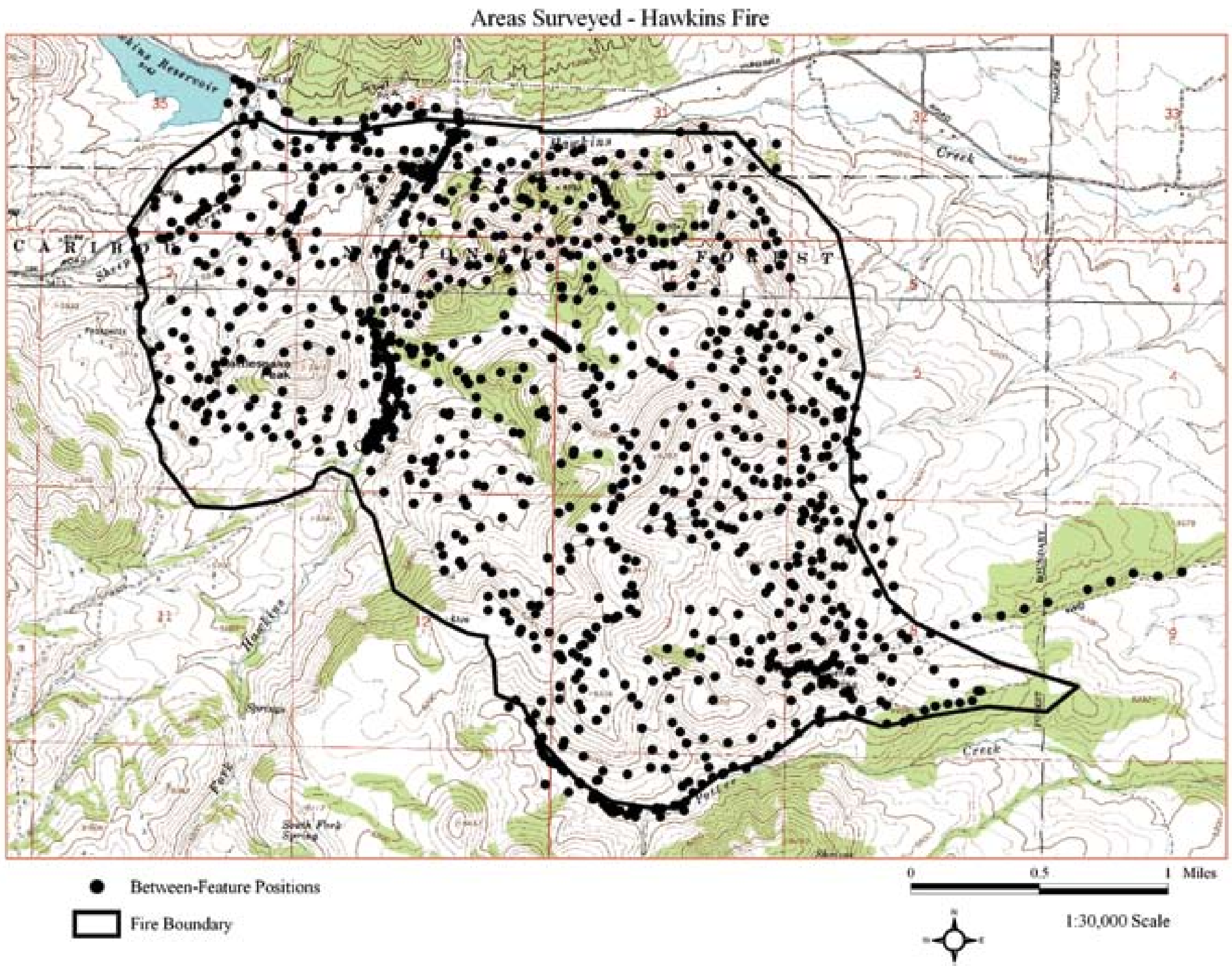
Data Field	Description	Options/Values	Priority	Entry
Notes	Additional comments	Can include compass bearing for photos, description of plant community other than NIS, etc.	Optional	GPS and field notes
Area ID	Unique identifier for inventory area		Required	GPS
Disturbance Comments	Comments on type and extent of disturbance noted in inventory area. If area is undisturbed, note as such.	Agriculture/Livestock grazing Construction/Development Fire Fire suppression Flooding Wind Geothermal Animal disturbance (e.g., gopher mound, buffalo wallow) Irrigation/Ditches Mining and quarries Oil and gas exploration/Production Habitat improvement project Recreation/Visitor use Right-of-way construction/Maintenance Utility construction/Maintenance Trail/Outfitter/Off-road vehicle use	Required	Field notes

name, Integrated Taxonomic Information System (ITIS) code, life form of species, county, state, and country. Additional data elements such as datum, UTM (Universal Transverse Mercator) zone, and source of data that pertain to the spatial data set as a whole were provided as metadata files.

A six-person crew conducted the inventories in most parks. When arriving at a site, crews would discuss the best method for searching the area to achieve the required level of detection confidence for the established minimum detection target size. Consideration of terrain, vegetation cover, expected visibility of target species, and crew size were all factored into setting effective detection swath widths and other mapping techniques and standards used for each site. In areas that were open and in which visibility was generally good, systematic coverage of the entire area was achieved using the EDSW method. When inventorying areas wider than a single swath width, multiple parallel passes by a lone crew member (or multiple crew members walking parallel transects or contours) were made as contiguous or slightly overlapping strips to avoid coverage gaps. On flat or gently sloping terrain, surveyors usually searched on parallel swaths determined by compass bearings or GPS UTM eastings/northings. This method is particularly useful in timbered flat terrain where it is not possible to pick out landmarks on a distant horizon or to see the path of previous swath passes. In hilly country we usually find contouring swaths to be preferable. Contouring is defined as walking as perpendicular to the slope as possible, thus maintaining a relatively constant elevation. Having completed a full pass across a slope, the surveyor moves upslope or downslope a distance equal to the swath spacing or EDSW for that terrain, and repeats the process in the opposite direction. This creates a series of parallel contiguous search swaths that completely cover the landscape. The contouring method results in representative sampling of all microhabitats associated with the terrain—ridges, draws, and side slopes over the full range of aspects, elevations, and plant communities. Compared to normal grid or straight-line transect search methods, contouring also minimizes the greater physical exertion required of surveyors on hilly terrain. Daily inventory routes of each crew member were recorded and mapped using the BFP tracking function of the GPS units (**Figure 2**). The BFP tracking distance setting was adjusted as needed to correspond to the EDSW distance.

Field searches were conducted at the scale required to

Figure 2. Daily inventory routes of each crew member were recorded and mapped within the project area (black line) using the between feature points (BFP, black points) tracking function of the GeoExplorer GPS units. Here BFP were taken every 500 ft (152 m) to show that a surveyor had been in an area even if no NIS locations were recorded.



maintain confidence that at least 90% of all infestations of target species 0.01 acre or larger within the entire inventory area were detected. Search swath widths were adjusted as needed according to variations in terrain, walking speed, associated vegetation, and target species. In heavy cover and/or for difficult-to-see species, swath widths were as narrow as 25 yards. In very open terrain and/or for highly visible species such as salt cedar (*Tamarix ramosissima*), some effective EDSWs were 100 yards or greater. Inventorying steep terrain using the EDSW method was not always possible, so in that case crew members used binoculars to visually scan the open but inaccessible hillsides for suspected target species. Binoculars were also used to search flats and wash bottoms for target species in any openings surrounded by impenetrable woody vegetation.

Each inventoried area was assigned a detection confidence value based on the crew's estimated ability to see 0.01-acre and larger infestations of the least visible target species, taking into account terrain, vegetation cover, and the size and growth stage of the targeted plant species. Detection confidence was broken into three categories: low (1 to 50%), medium (51 to 89%), and high (90 to 100%).

Locations of all target species were documented using GPS units with 2 to 5 m accuracy (**Figure 3**). Crews also recorded the location and documented the identity of any other nontarget species they encountered if that NIS had a known history of invasiveness in other regions in the West. The crew recorded the occurrence of target species on a hard copy map (U.S. Geological Survey 7.5-minute topographical maps) in any situation where GPS satellite reception was not possible (such as in narrow side canyons) or in cases of GPS equipment malfunction.

Figure 3. Locations of all target species within the area inventoried were documented with GPS units. This example is from Lost Spring Canyon, Arches National Park (Dewey et al. 2005d).

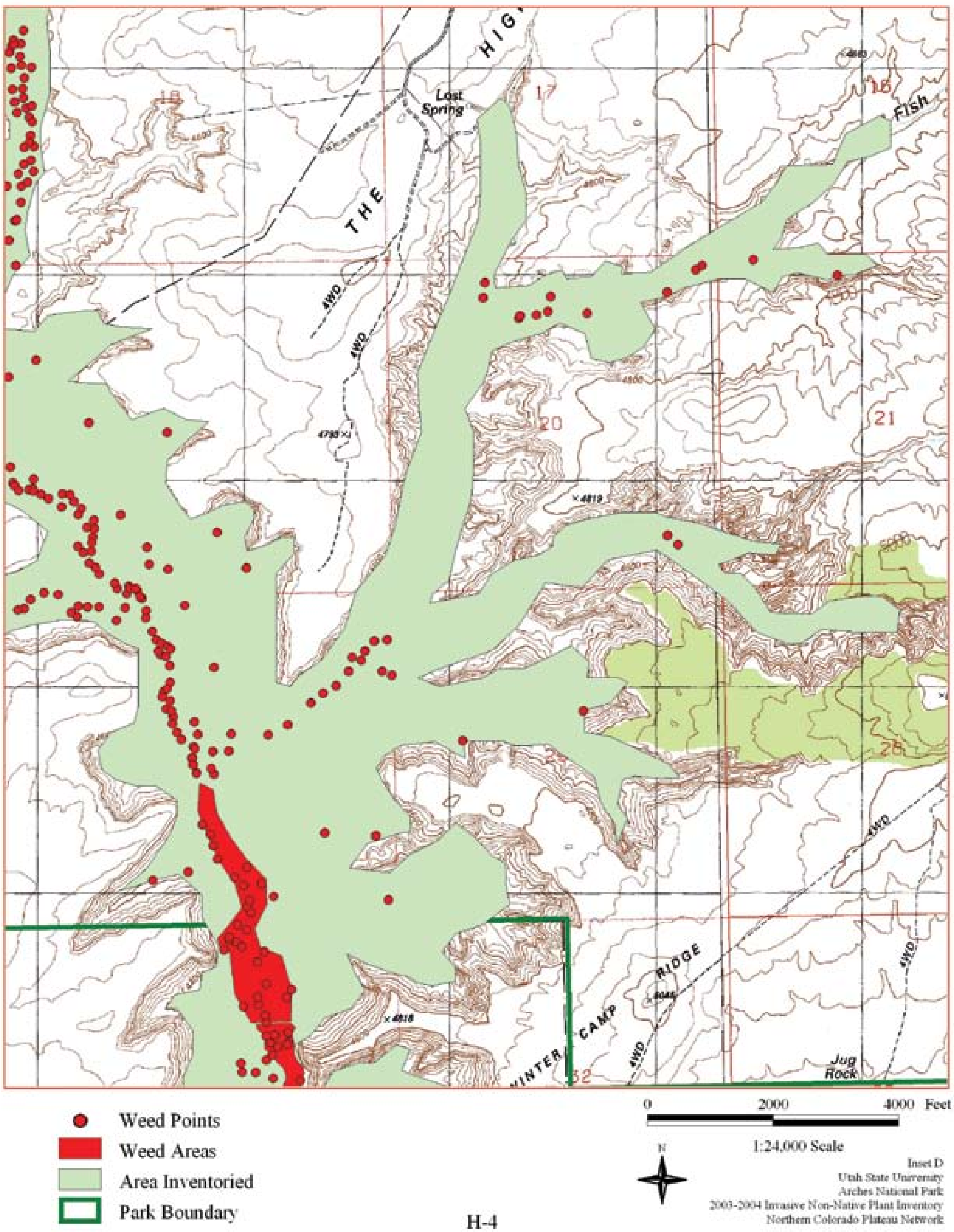
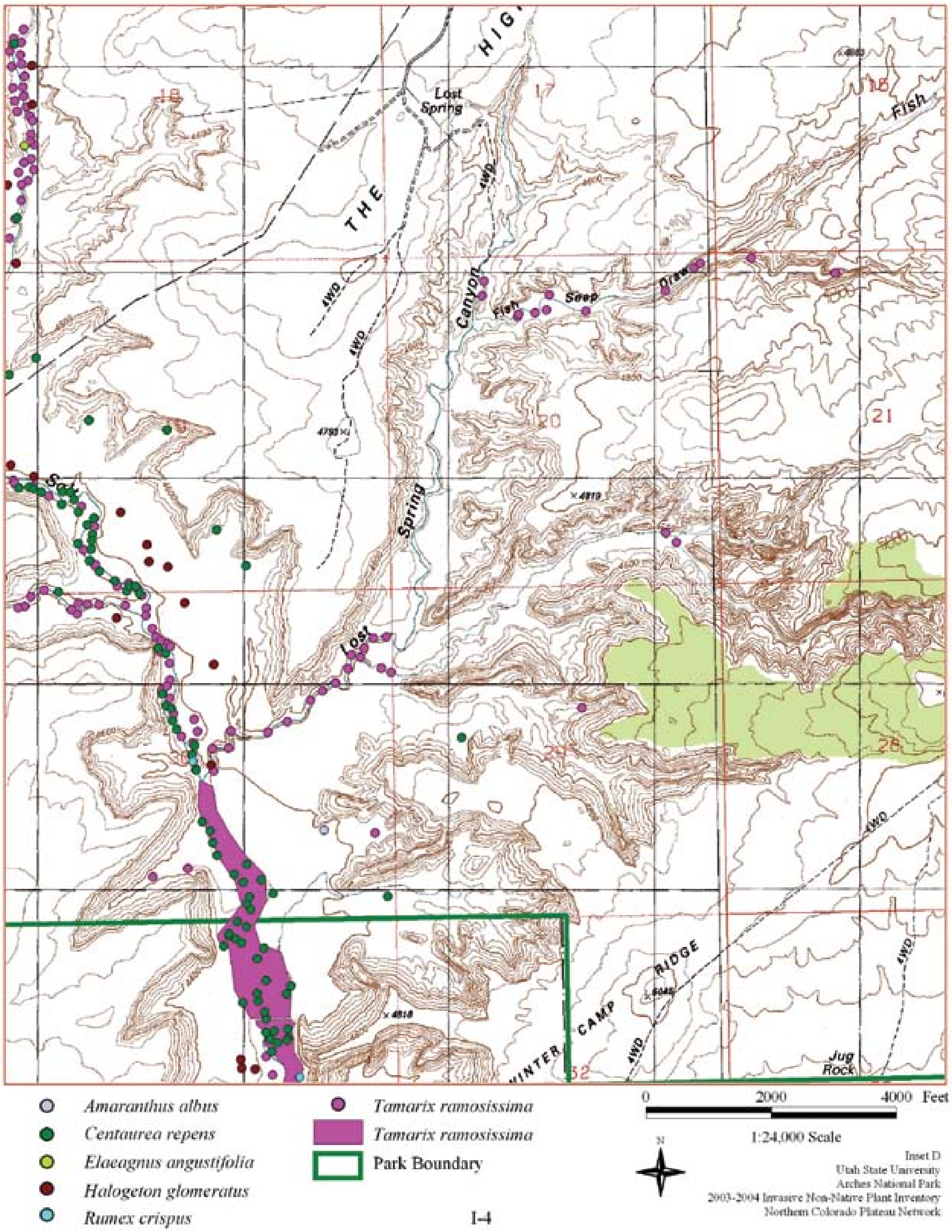


Figure 4. An example of an inventory product depicting individual NIS locations by species in Lost Spring Canyon of Arches National Park (Dewey et al. 2005d).



Nonindigenous plant species infestations up to 1 acre were typically recorded as point features. Crew members were given the option to record infestations between 1 and 5 acres as points, polygons (actual areas or gross areas), or line features, depending on which feature they felt would best represent the situation. However, in this project essentially all populations within the 1- to 5-acre size range were recorded as point features. The few patches in this size range that were recorded as polygon or line features were later converted in the office to point features in order to facilitate viewing on geographic information system (GIS)-generated maps.

Crews mapped larger infestations (more than 5 acres) of target species either as actual field polygons (by walking the patch perimeter with the GPS), or by collecting GPS "generic points" in the field at key locations along the boundary of the infestation and then using those points later to digitize the infestation polygon on the computer in the office (**Figure 4**). Generic points were deleted after such polygons were drawn, and were not included in the final report. This type of mapping was used exclusively for large infestations of salt cedar found in some inventory areas.

The size of each population recorded as a point feature was estimated visually (using a laser rangefinder) and placed in the size category most closely matching its actual area: (1) one to few plants, 0.001 acre, (2) 0.01 acre, (3) 0.1 acre, (4) 0.25 acre, (5) 0.5 acre, (6) 1.0 acre, (7) 2.5 acres, or (8) 5.0 acres. Canopy cover of each population was estimated visually and placed in one of five categories: (1) trace = less than 1%, (2) low = 1 to 5% , (3) moderate = 6 to 25%, (4) high = 26 to 50%, or (5) majority = 51 to 100%. As a general rule, individuals or clusters of NIS plants of the same species separated by less than 50 yards (PSR) were considered a single infestation/patch and were mapped as a single feature (point, line, or polygon). Plants or groups of plants separated by more than 50 yards were mapped as separate infestations/patches (refer to definition of PSR).

Equipment Needed

To collect field data, USU mapping crews used Trimble GPS units (GeoExplorer III, Geo XM, or Geo XT; Trimble Navigation Ltd.), chosen because of their capacity to have a programmed data dictionary to ensure all relevant data are collected in the field. All location data were differentially corrected with postprocessing software. Other GPS units may be suitable, but noncorrected data reduce the accuracy of the work and make returning to specific locations more difficult, especially in variable terrain. GPS data files were downloaded each night and reviewed on a laptop computer using Trimble's Pathfinder Office GIS software program. Other GIS software programs, such as ArcView or ArcMap (ESRI Inc.), are available to process data collected by other GPS units. Other basic field equipment included a laser rangefinder, compass, clinometer, binoculars, two-way radio, field maps, and field pack.

Although GPS units were used in all USU projects, they would not be required to apply the fundamental techniques and standards described by this inventory method. Even projects limited to recording NIS distribution data by hand on paper field maps could incorporate most of these methods.

Advantages and Disadvantages of the USU Inventory Method

This method is designed for landscape-scale NIS mapping projects in which hundreds or thousands of acres must be searched by ground crews in a relatively short time, but it can also be effectively used in small landscapes (up to 100 acres). The objective in most USU inventory projects is to locate and map the distribution and relative abundance of infestations of targeted species with a high level of detection confidence. Searches are conducted in such a way that crew members can be confident of finding 90 to 100% of all occurrences of a minimum specified infestation size in the area inventoried. Typically the minimum specified infestation size is 0.01 acre.

For inventories/surveys to be meaningful, *what* is being inventoried/surveyed must be clearly defined. In other words, it has to be stated and documented exactly what is being searched for. In our case, we are searching for infestations/patches of specified NIS of a minimum declared patch size and larger. We consider our approach to be a type of *qualified* inventory/census rather than a survey/poll because the goal is to account for *all* NIS patches of the specified size categories within the defined land area. With our technique, we do not claim to be doing an inventory/census of every individual plant or of patches less than the MDTS. We also do not inventory *within* patches; that is, we do not know or care how many individual plants make up a patch. We only need to know patch size and the relative abundance (canopy cover estimate) of NIS plants making up each patch in order to meet our objectives. We plan and adjust our sampling design so we are confident of finding essentially all target species patches of the minimum stated size (and larger) within the inventory area. Obviously, a search resolution that is barely fine enough to inventory all 0.01-acre patches on a 1,000-acre block of land would not be fine enough to inventory all individual plants. We do find and map a number of individual target NIS plants and patches smaller than the MDTS, but not enough to be considered an inventory of these smaller infestation sizes.

Nonindigenous plant species occurrences are mapped as points, which means that the USU method can be considerably faster than methods that primarily use polygons or lines, thus helping to reduce inventory/survey costs (Andersen et al. 2003; Ballard et al. 2003). In the case study mentioned above, crews were able to inventory an average of 10 to 15 acres per person per hour over gently undulating terrain.

Methods and data standards used by USU are compatible with North American Weed Management Association Plant Mapping Standards (NAWMA 2003). Data obtained using the USU method can be used for a variety of purposes, including strategic planning, tracking changes in overall NIS distribution and abundance over time, and calculating acreage-based control costs. This method is not intended to provide data for site-specific monitoring purposes or detailed statistical analysis (Dewey and Andersen 2004), although the data collected can be used to relocate populations for future monitoring. For methodologies designed specifically for vegetation monitoring the reader is referred to publications by Elzinga et al. (1998) and Winward (2000).

References

Andersen, K., S. Dewey, and M. Ballard. 2003. Field techniques for improving accuracy and efficiency of GPS wildland weed surveys. Page 87 *in* Proceedings, Western Society of Weed Science, Vol. 56. Papers presented at the Annual Meeting, March 11-13, 2003, Kauai, Hawaii. Newark, CA: Western Society of Weed Science.

Ballard, M., S. Dewey, and K. Andersen. 2003. Using GPS point features to describe spot, line, and area infestations in wildland weed surveys. Page 86 *in* Proceedings, Western Society of Weed Science, Vol. 56. Papers presented at the Annual Meeting, March 11-13, 2003, Kauai, Hawaii. Newark, CA: Western Society of Weed Science.

Dewey, S., K. Andersen, M. Ballard, J. Simonsen, R. Richards, and E. Lamalfa. 2003. Invasive non-native plant inventory conducted in portions of Arches, Canyonlands, Hovenweep, Natural Bridges, Black Canyon, and Zion National Parks. Annual Progress Report (8 volumes). Denver, CO: Intermountain Regional Office of the National Park Service.

Dewey, S. A. and K. A. Andersen. 2004. Distinct roles of surveys, inventories, and monitoring in adaptive weed management. Weed Technol. 18:1449-1452.

Dewey, S. A. and K. A. Andersen. 2005a. Determining effective search swath widths for wildland weed surveys. Page 27 *in* Proceedings, Western Society of Weed Science, Vol. 58. Papers presented at the Annual Meeting, March 8-10, 2005, Vancouver, BC. Newark, CA: Western Society of Weed Science.

Dewey, S. A. and K. A. Andersen. 2005b. Quality assurance measures for noxious weed surveys on wildlands (abstract 121). Page 37 *in* WSSA Abstracts, Vol. 45. 2005 Meeting of the Weed Science Society of America, February 7-10, 2005, Honolulu, Hawaii. Lawrence, KS: Weed Science Society of America.

Dewey, S. A. and K. A. Andersen. 2005c. An inventory of noxious weed plants in Zion National Park (2003-2004) – Final Report. Prepared for the National Park Service, Northern Colorado Plateau Network by Utah State University; Plants, Soils, and Biometeorology Department; Weed Science Research Project Report No. SD0521A, 33 p. plus appendices. http://www1.nature.nps.gov/im/units/ncpn/Reports.cfm.

Dewey, S. A. and K. A. Andersen. 2005d. An Inventory of Invasive Non-native Plants in Arches National Park (2003-2004) – Final Report. Prepared for the National Park Service, Northern Colorado Plateau Network by Utah State University; Plants, Soils, and Biometeorology; Weed Science Research Project Report No. SD0510A, 30 pp. plus appendices. http://www1.nature.nps.gov/im/units/ncpn/Reports.cfm.

Elzinga, C. L., D. W. Salzer, and J. W. Willoughby. 1998. Pages 1-10 *in* Measuring and monitoring plant populations. USDI-BLM Technical Reference 1730-1 BLM/RS/ST-98/005+1730.

Kuchler, A. W. and I. S. Zonneveld (eds.). 1988. Pages 193-202 *in* Vegetation Mapping, Handbook of Vegetation Science, Vol. 10. Boston, MA: Kluwer Academic Publishers.

[NAWMA] North America Weed Management Association. 2003. North American Invasive Plant Mapping Standards. http://www.nawma.org.

Winward, A. 2000. Monitoring the vegetation resources in riparian areas. Pages 10-32 *in* USDA Forest Service General Technical Report RMRS-GTR-47. Ogden, UT: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 49 p.

Digital Aerial Sketch-Mapping for Early Detection and Mapping

Jason W. Karl and Mark Porter

Introduction

An ideal technique for conducting cost-effective and timely nonindigenous species (NIS) inventories/surveys in large, rugged landscapes would allow detection of multiple species at a time, would not be overly sensitive to environmental conditions, and could be readily performed by most experienced weed managers without extensive training. Digital aerial sketch-mapping (DASM) was pioneered by the USDA Forest Service to detect infestations of forest insects and pathogens (Morris 2001). Using DASM, a trained observer in an aircraft draws locations of infected stands on a touch-sensitive, digital, moving-map computer display (McConnell et al. 2000), downloads the information immediately upon landing, and gives it to land managers for treatment of infected areas. Here we propose a standard protocol for conducting DASM for nonindigenous plant species, review technical requirements for conducting DASM, and discuss practical considerations affecting the efficacy of DASM as an inventory/survey technique.

Survey Protocol

Protocols for digital aerial sketch-mapping of nonindigenous plant species (NIS) were derived from those used in mapping forest pathogens (Pywell et al. 2001; B.C. Ministry of Forests 2000) and surveying big game populations (Unsworth et al. 1999), with modifications specific to plants. Since survey protocols aid researchers in controlling for factors that could confound results, deviating from the protocols can seriously affect the quality of data collected. Once an inventory/survey protocol has been set, such factors as the number of observers, type of aircraft used, flight pattern, and survey subunits should not be changed during successive flights (Unsworth et al. 1999).

Simply put, DASM is a method for rapidly identifying and recording NIS infestations over large areas. Hence, DASM can be employed within the context of either a full inventory or a (biased or unbiased) survey. Due to flight costs, however, DASM is most commonly used in a biased survey approach where areas with a high likelihood of target NIS are prioritized for searching, and lower priority areas are either not searched or are searched with less effort.

Selecting Targets and Timing the Inventory/Survey

Flights should be designed around one or a few NIS to aid delineation of survey areas and timing. It is important to understand the life history and habitat associations of target NIS so that the detection reliability can be judged and the appropriate time of year for conducting surveys can be identified.

Aerial mapping should be timed to coincide with the phenological stage of the target species that is most visible to the human observer. Many plants have certain phenological stages that are more distinct than others (see Lass and Callihan 1997), while other species may be difficult to detect regardless of their growth stage. Likewise, the minimum patch size (i.e., survey resolution) that can be reliably identified by observers may also vary by species, although it can be assumed that smaller patches and individual plants will be more difficult to detect than larger patches. Almost any plant species or any size patch is detectable if the observer can get close enough to it. However, the closer to the ground and slower the flight required to identify target species (i.e., to obtain finer resolution), the less cost efficient DASM surveys become because less area per unit time is covered.

One advantage of DASM over other techniques for covering large areas is that the observer is able to detect occurrences of nontarget NIS over the course of the survey. It is important, however, to recognize that detections of nontarget NIS during DASM may not be reliable indicators of their actual distribution within the study area for several reasons. First, detection rates of NIS patches may decrease with patch size (i.e., it is harder to see small patches than to see large ones). Second, flights designed around maximum visibility of one target NIS may not be optimal for nontarget species. In a trial DASM flight for hoary cress (*Cardaria draba*) conducted in Hells Canyon, Idaho, on May 17, 2004, we also detected 26 patches of Dalmatian toadflax (*Linaria dalmatica*). A subsequent flight over the same area targeting Dalmatian toadflax in full bloom on June 14, 2004, found a 350% increase of Dalmatian toadflax (91 patches) detected. Despite the potential limitations of mapping nontarget NIS, such incidental observations can be quite useful and should be recorded when observed.

Subunits

A DASM inventory/survey area may be divided into subunits, making it easier to track progress during the flight, quantify effective area sampled, and estimate confidence intervals of detection rates and population sizes. Properly defined subunits help focus the sampling and increase its efficiency. Subunits can be any size, but Unsworth et al.

(1999) suggest that subunits that take about one hour to sample are efficient and allow adequate breaks for observers. Subunits should be defined by features easily recognized from the air (such as ridge tops, streams or rivers, and roads), but not by impermanent features such as fence lines or vegetation boundaries. Subunit boundaries should be loaded as a background layer on the DASM computer. To sample subunits completely before moving on, the pilot should be informed of subunit boundaries. Progress in sampling subunits can also be tracked with the tracklog feature of the global positioning system/geographic information system (GPS/GIS).

Subunits may be considered as statistical stratifications of the survey area, particularly if they are based on features thought to be significant to the distribution of the target NIS. Otherwise, they should be considered subdivisions of the survey area only for efficiency and tracking purposes. If NIS population changes are to be monitored using methods of estimating populations from aerial mapping (see Pollock and Kendall 1987), subsequent surveys must be flown with the same subunits and pixel resolution as the original survey (Unsworth et al. 1999).

Aircraft and Flight Patterns

Digital aerial sketch-mapping can be flown from either an airplane or a helicopter. Airplanes are less expensive per hour than helicopters and may be adequate for sampling large infestations of easily visible NIS or in flat or gentle terrain. However, the minimum speed of 70 to 80 miles per hour for most small fixed-wing airplanes may be too fast for NIS surveys. At that speed, unless the map display is zoomed out, the GPS cursor indicating current position will frequently move off the screen, forcing the map display to redraw. Additionally, limitations on how close to the ground a fixed-wing airplane can safely fly may induce error in the location of infestations sketched on the map display.

Helicopters are much more expensive to use than airplanes, but may be more suitable for DASM. Sampling speed is variable with a helicopter, although wind and site (e.g., topography) conditions may require that a minimum speed be maintained for safe operation. Helicopters also offer much greater flexibility in the altitude above ground level at which sampling can be conducted.

Since both inventories and surveys assume subunits are canvassed completely, flight patterns must allow all parts of the subunits to be seen. Unsworth et al. (1999) recommend that subunits with minimal topographic relief be flown in strip transects and those with rugged topography be flown along elevation contours. They further recommend that contours or transects be 300 ft (91.4 m) or less apart in dense vegetation or in gentle terrain, and up to 500 ft (152.4 m) apart in rugged, open areas (**Figure 1**). Observers should make sure not to overlook the edges of subunits. In sampling river banks, wide riparian areas, or other linear habitats, we have found it useful to view one side at a time.

Altitude above ground level (AGL) and flight speed both affect the observer's effective sight distance. Altitudes of 100 to 150 feet (30.5 to 45.7 m) AGL are recommended for big game surveys (Unsworth et al. 1999); our 2004 trial surveys were flown at altitudes of 30 to 100 feet (9.1 to 30.5 m) AGL. Helicopter speeds of 40 to 50 miles per hour (64.4 to 80.5 kilometers per hour) are recommended for big game surveys (Unsworth et al. 1999), but in NIS inventory/survey, slower speeds may be required for hard-to-detect species or small patches.

Observers

Ideally, two observers should view and record target NIS in the same areas at the same time, with one observer designated as primary. Double observers provide backup if one system fails, and can take advantage of methods used to estimate population sizes (Pollock and Kendall 1987) and the proportion of plants or patches missed by the primary observer. If one DASM system and one traditional GPS/voice recorder system are being used, the primary observer should record on the DASM system and the second on the GPS/voice-recorded system.

Observers must be proficient in the chosen mobile GIS software; otherwise, data may be inaccurate, incomplete, or even lost. They should practice collecting data on the ground and/or be trained by experienced observers before conducting DASM surveys alone. Observers should also be familiar enough with the configuration of the DASM system and the data used to troubleshoot basic problems while in flight.

DASM Methods

Digital aerial sketch-mapping methods are straightforward. The aircraft enters a subunit, the pilot flies according to a predetermined flight pattern, and the observers look for and record NIS from both sides of the aircraft. Most aerial survey methods assume that all or most infestations near the observer are recorded, and that the probability of detection decreases with distance from the observer (Pollock and Kendall 1987). However, since it is possible to miss seeing areas close to and directly below the aircraft, special attention is required so that infestations in such areas are not missed. When an infestation is seen, the observer identifies its ground location on the DASM map display and, using the stylus, draws the infestation on the map and fills in the attribute data before resuming the survey. If the survey results are to be used for estimating population sizes or proportions of infestations missed, observers must sample independently

A

B

C

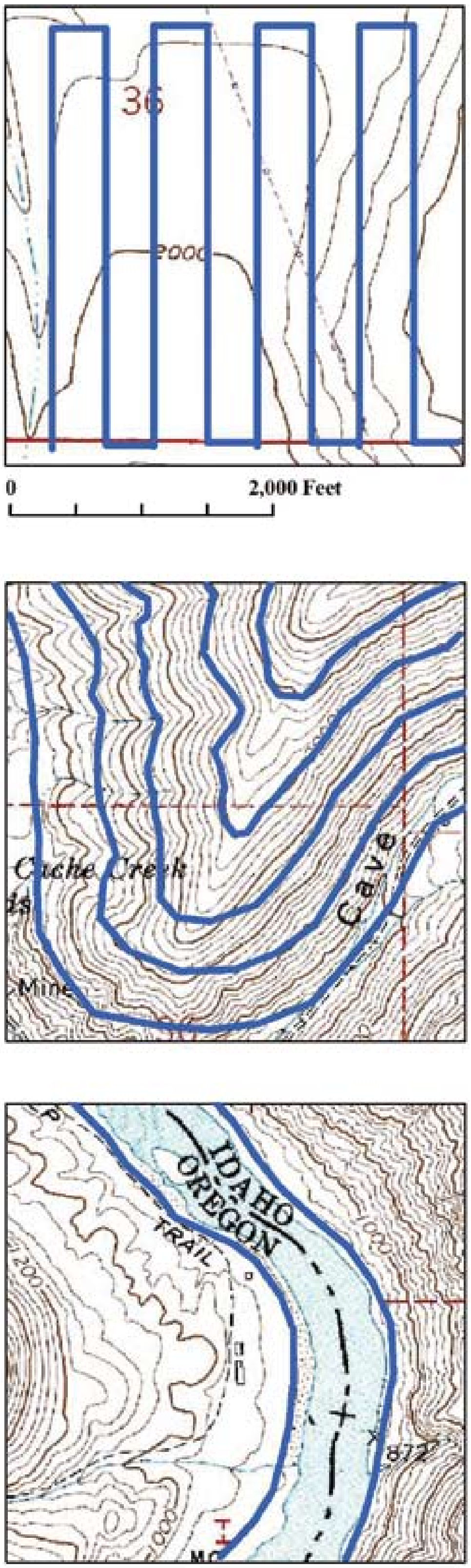


Figure 1. Examples of recommended DASM flight patterns. (a) Strip transects work best for flat or gentle terrain. (b) Elevation contours are used for covering rugged areas. (c) Linear transects work best for corridors like rivers or roads where one side is mapped at a time.

of each other and later agree upon which infestations they both recorded (Unsworth et al. 1999).

Data Collection and Processing

The goal of a DASM inventory/survey is to record, as quickly as possible, enough information to relocate and treat the NIS patches, and then resume sampling. Data recording is faster with custom data entry forms utilizing drop-down menus, check boxes, and similar features. Essential data to record include species name, approximate percent cover, infestation size (if mapping target locations as points), and distribution (e.g., isolated patch, multiple patches, uniform coverage). A unique identification number assigned to each mapped NIS location should be shown on the map display to reference each observation. The degree of confidence in the identification of the target species and the spatial location of the mapped target feature should be recorded to help relocate infestations for treatment. Many of the attributes (e.g., survey date, observer names, county and state of survey) advocated for use by published standards (NAWMA 2003) do not change during a survey and could be entered later. Some software packages, such as Arc Pad (ESRI Inc.), allow default values to be assigned to attributes for automatic entry; these attributes could also be added and populated in a GIS after the survey.

Testing and Calibration

Before beginning DASM inventories/surveys, observers should fly over a location with known infestations of the target species to practice identifying both the target and similar nontarget species to avoid error. Observer estimates of infestation size and density should be calibrated, and preferably ground-truthed, and the DASM system should be tested to ensure proper functioning. For this step, it may be helpful to have some known locations of target species loaded as a background layer in the DASM computer. If possible, the calibration and testing area should be similar in topography and vegetation to the target area, and close to it, to minimize potential differences in phenology or expression of the target NIS.

Accuracy Assessment

While a good understanding of the characteristics of target NIS, DASM protocols, DASM limitations, and minimum accuracy levels may help determine the feasibility of DASM *a priori*, a postsampling assessment of the accuracy of the DASM results should be conducted following an inventory/survey. Accuracy assessments should consider rates of omission (infestations missed) and commission (areas mistakenly identified as infestations). While some indication of accuracy can be obtained from existing inventory/survey data, a complete understanding of sampling accuracy requires knowledge of where the target NIS does not occur as well as where it does occur. Thus, a rigorous accuracy assessment would necessitate thorough ground-truthing of a selected subset of the inventory/survey area. Fielding and Bell (1997; see also Fielding 2002) review methods of estimating the accuracy of classifications and survey results, and the merits of different metrics. Positional accuracy of feature placement (i.e., how close mapped locations were to their true ground location) with DASM should also be evaluated and reported to recipients of the DASM data.

Postsurvey Data Processing

Depending on the software used, postflight data processing may be required; e.g., to convert data to a common GIS format. Accidental data entry errors should be corrected and all features checked for the necessary attribute information. A backup copy of the data should be made immediately, and all postprocessing should be done with the copy, not the original. Survey design, subunit definitions, methods, postprocessing steps, and accuracy should be documented and should accompany the data. Flight GPS tracklogs may be truncated to include only those areas within the sample boundaries and should also accompany the data.

Technical Requirements: Selecting Hardware Suitable to Perform Digital Aerial Sketch-Mapping

Computer

The essential hardware for DASM is a mobile computer with touch-sensitive screen for displaying and entering data, and a GPS unit for panning the computer's moving-map display and navigation during flight. (The specific hardware, software, and data systems mentioned are examples, not endorsements of any particular system.) Many "rugged tablet PCs" (personal computers) suitable for DASM applications are available (**Figure 2 a,b; Table 1**). The most important considerations in selecting a DASM computer are the visibility of the screen in direct sunlight and whether the

Figure 2. Examples of computers used for DASM surveys. (a) The NavAero T-pad 800 touch-sensitive, external computer display (lower left) attached to the laptop computer on top of the helicopter's instrument console (upper right) is a low-cost alternative to purchasing a rugged tablet PC if a suitable laptop is available.

Figure 2. (b) Using field rugged tablet PCs such as the Xplore Technologies C2 is a compact and reliable method for DASM applications.

display responds to simple touch or to a specialized stylus. Tablet PC screens have a backlight that makes the display visible. Generally, the stronger the backlight, the more readable the display will be outside. However, in full sunlight, even the best outdoor computer display may still seem dim and lacking in contrast. Most handheld mobile computers; e.g., personal digital assistants (PDAs), and many tablet PCs have touch-sensitive displays that respond to pressure from anything—the stylus, your finger, or a stick. In DASM applications, vibrations from the aircraft may cause inadvertent taps on the computer display, so an active-stylus display that responds only to taps from a specific stylus is recommended.

The DASM computer must have sufficient resources for running the mapping software and displaying the data quickly. Most DASM applications use either digital topographic maps or aerial photography as background layers for navigation and orientation. These can be large files, and upgrading random access memory and graphics cards can boost screen refresh speeds. Handheld PDAs are inadequate for DASM applications because they lack the processor speed and memory needed to quickly refresh moving-map displays as the aircraft moves.

The DASM computer and GPS unit can be powered either by the aircraft's power system or by batteries. Using the onboard power supply must be discussed with the pilot beforehand. Some tablet PCs can achieve stronger display backlighting from external power than from internal battery power. If batteries are used, make sure they are fully charged and that spares are carried.

GPS Unit

The mapping software on the DASM computer uses the GPS data to identify the location of the aircraft on the map display and pan the map as the edge is approached. The GPS unit is usually not directly used for mapping or recording survey data. Rather, observers manually sketch NIS locations on the DASM computer map display, orienting themselves on the map by the aircraft location cursor and background data layers. Slight inaccuracies in the GPS coordinates are not crucial. While it is advisable to use the best GPS unit available, DASM can be done successfully with most commercially available GPS units, and although differentially corrected data are not essential, they do improve accuracy.

Most commercial GPS units (e.g., Garmin, Magellan, Trimble) can be connected to the DASM computer via a data cable. Wireless GPS units using the Bluetooth standard are also supported by DASM applications. Because no cables are required, wireless GPS units can be positioned more easily for a good GPS signal, and they may be safer for flying because there is no GPS cable to interfere with cockpit controls.

Software

DASM requires mobile GIS software that integrates mapping technologies with traditional GPS functions. Three popular DASM software packages are ArcPad (ESRI Inc.), GeoLink (M. J. Baker Corp.), and Terrain Navigator Pro (MapTech). Each package offers essential DASM features (e.g., display of background data layers, GPS integration, moving-map displays where the map is panned automatically, and data recording) but differ in their degree of customization and the data formats they can use (**Table 2**).

Some advanced mobile GIS software packages (e.g., ArcPad) allow the program interface to be customized to simplify menus or add and remove buttons. Custom data entry forms using drop-down menus, check boxes, and buttons allow data to be recorded rapidly without the use of a keyboard. As an alternative to custom data entry forms, the NIS locations can be recorded on the DASM system and the attributes dictated into a voice recorder, although dictation can lead to error and transcribing the tapes is tedious. A GIS professional can help with software setup, customization, and use before the survey takes place.

Since DASM data will be useful only if they can be shared, analyzed, and manipulated outside of the DASM system, the needs of users should be considered during the project setup. For example, ArcPad records data in shapefile format, a commonly used, easily shared GIS format. GeoLink data can be converted to shapefile format with an ArcView extension. Terrain Navigator Pro data must be exported to an ASCII text format and imported into shapefiles.

Background data layers such as topographic maps, aerial photography, or survey boundaries help in locating NIS infestations quickly on the moving-map display. It is important to be able to incorporate vector (i.e., point, line, or polygon) background layers to represent features that may not be easily discernible in an image, such as roads, streams, ownership boundaries, or survey subunits. Most DASM flights also use images such as 1:24,000 or 1:100,000 U.S. Geological Survey topographic maps or 1:24,000 orthophotographs for background data. Images used for DASM should have good contrast so they can be seen on the PC in full sunlight (**Figure 3**).

Most mobile GIS packages generate a GPS tracklog that records and displays the route traveled during the flight (**Figure 4**). On the map the tracklog is displayed as a distinct line or series of dots representing the flight path, which is useful in managing flight patterns through inventory/survey areas to ensure adequate coverage.

Table 1. Manufacturers of hardware and software that can be used for DASM.

Mobile GIS Software	Rugged Tablet PCs	GPS Units
ESRI ArcPad 6.0.3 1-800-447-9778 http://www.esri.com/software/arcgis/arcpad/	Itronix 1-800-441-1309 http://www.itronix.com	Garmin 1-800-800-1020 http://www.garmin.com
MapTech Terrain Navigator Pro 6.0 1-888-839-5551 http://www.maptech.com/land/terrainnavigatorpro/	Panasonic 1-888-270-5615 http://www.panasonic.com	Magellan 1-800-707-9971 http://www.magellangps.com
Michael Baker Corporation GeoLink 6.1 1-800-MIBAKER http://www.mbakercorp.com/services/gis/prod-ucts/geolink.html	Walkabout 1-888-925-5226 http://www.walkabout-comp.com	Transplant GPS (U.S. distributor for EMTAC) 1-507-529-0041 http://www.transplantgps.com http://www.emtac.com
	Xplore Technologies 1-888-449-7567 http://www.xploretech.com	Trimble 1-800-874-6253 http://www.trimble.com

Table 2. Comparison of features helpful for DASM for three common mobile GIS software packages.

Features	Products		
	ESRI ArcPad 6.0.3	MapTech Terrain Navigator Pro 6.0	Michael Baker Corp. GeoLink with Raster and Sketch module
Image background layers	Any image in several formats	USGS topographic maps or orthophotographs	Any image in several formats
Seamless background images	No	Yes	Yes
Vector background layers	Yes	Limited–points and lines only	Yes
GPS tracklog	Yes–tracklog exportable	Yes	Yes
Data entry	Points, lines, polygons	Points, lines	Points, lines, polygons
Output to common GIS format	Yes–shapefile	Requires conversion of data	Requires conversion of data
Custom data entry forms	Yes	No	Yes
Customizable interface (e.g., buttons, menus)	Yes	No	Yes
Large buttons	No	Yes	Yes
Cost	Medium	Low	High

Other DASM Considerations

Reliability and Redundancy

Two important considerations for DASM are reliability and redundancy. Aircraft time is expensive, and in-flight failure of hardware or software can result in costly delays, data loss, or even cancellation of a mapping flight. All equipment, software, and data should be thoroughly tested, and observers sufficiently trained before survey flights to minimize the potential for problems during flight. Whenever possible, it is also advisable to have backup systems in place in the event of problems (e.g., a backup GPS unit that can be used with the DASM system, or a handheld GPS unit and voice recorder in case the DASM system fails). At least one observer should be familiar enough with the system to do basic troubleshooting during the flight.

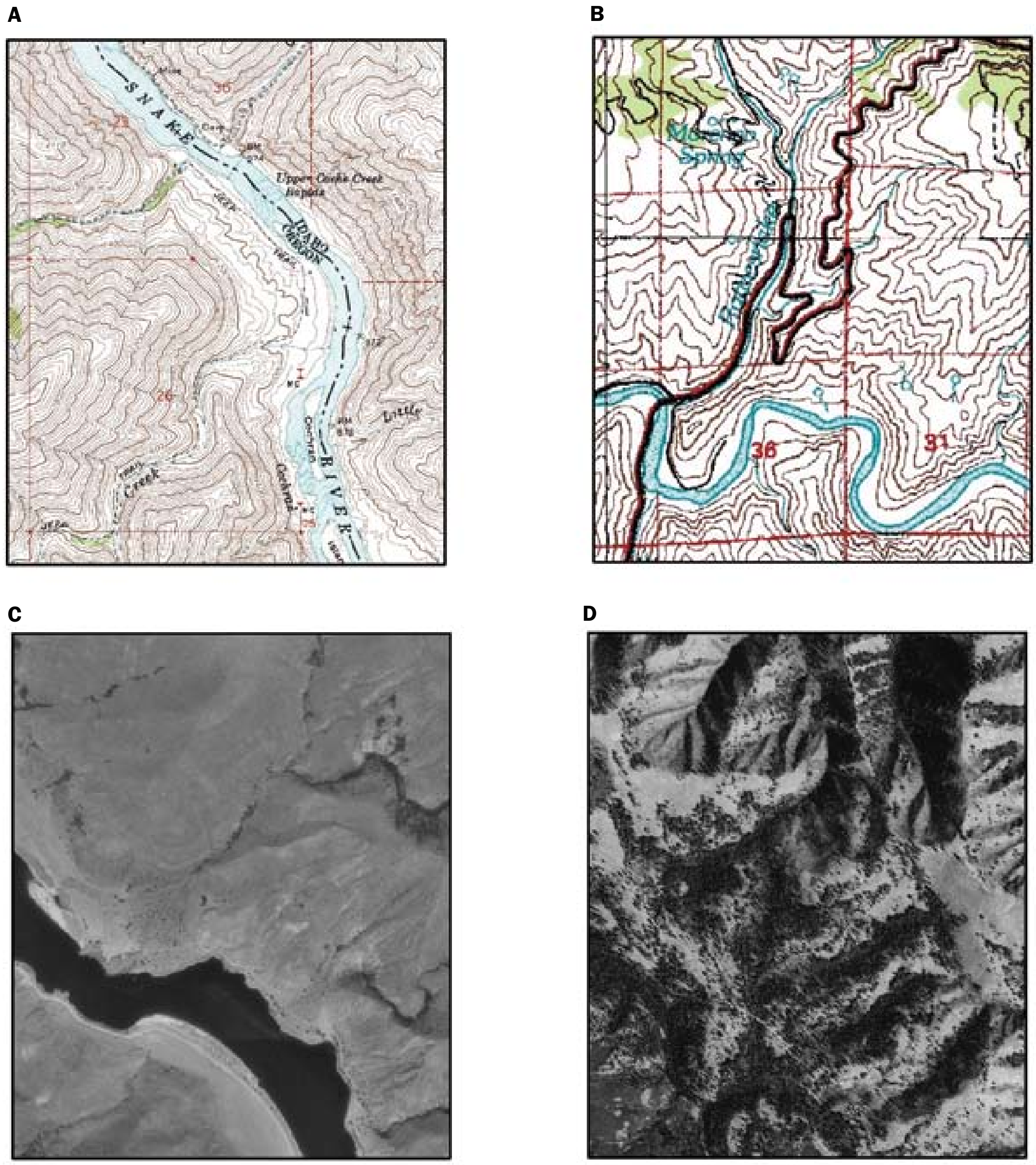


Figure 3. Examples of low- and high-contrast background imagery that could be used in DASM surveys for nonindigenous plant species. Topographic maps with light contour lines and little color (a) may be difficult to see on a DASM map display in outdoor conditions, whereas images with dark features (b) will be easier to see and locate features on. Likewise, aerial photographs with little shading or distinctive land features (c) may be difficult to locate ground features on. Imagery with high-contrast shading and distinctive landscape features (d) may be useful as DASM background layers.

▲ **Figure 4.** GPS tracklogs are visible records of the DASM survey flight lines and are very useful for ensuring adequate survey coverage.

Safety

When conducting DASM, the utmost priority is returning to the ground safely: "No data set is worth a human life!" (Unsworth et al. 1999). Pay attention, be aware of your surroundings, and do not put yourself at risk. The pilot's job is to fly the aircraft, not to look at the ground. The observer's job is to collect data and to communicate with the pilot about potential flight hazards such as power lines. Extreme caution must be observed to ensure that the DASM system and cables routed throughout the cockpit do not interfere with the aircraft controls, and that each part of the DASM system is properly secured so it cannot move around during flight.

DASM observers should obtain instruction on basic aviation safety, as well as safety procedures for aerial inventories/surveys. Observers should communicate with the pilot, be familiar with basic emergency procedures, and have all necessary emergency equipment and provisions in place before leaving the ground. Above all, observers should be comfortable with the aircraft and the pilot.

Survey Cost and Efficiency

Factors that can affect the total cost and efficiency (cost per acre) of DASM inventories/surveys include fuel costs, type of aircraft, number of refueling stops, and ferrying (the time taken flying to and from the target area). We estimated a cost of $0.11/acre to $0.29/acre for 2004 DASM trial surveys where ferry time to the survey areas was less than 30 minutes. For two surveys where ferry time was approximately 1.5 hours, the cost increased to approximately $0.71/acre.

Advantages and Disadvantages of DASM for NIS Inventory/Survey

The greatest advantage of DASM is that inventories/surveys can be conducted on large, difficult-to-access landscapes efficiently, and data on NIS infestations can be recorded and distributed to treatment crews very quickly. Digital aerial sketch-mapping also offers an advantage over other remote sensing techniques for detecting and mapping NIS infestations in that observers can look for multiple NIS targets at once and the potential exists to detect nontarget species.

Digital aerial sketch-mapping as an inventory/survey technique is not without its disadvantages. Certain NIS infestations may be difficult to detect from the air, and small patches or individual plants which are critical to NIS management (Moody and Mack 1998) may not be detected as reliably as larger patches. In the absence of ground verification of results, the classification and spatial accuracy of DASM data can be difficult to quantify. Conducting DASM flights also requires an understanding of computer, GIS, and GPS technologies and an initial investment in the DASM hardware and software, although this equipment is not as costly as in many other remote sensing techniques. Additionally, flight time can be expensive and potentially hazardous.

The protocol for DASM presented here is a general recommendation for conducting aerial NIS inventories/surveys, but should be adjusted to fit local conditions. Also, DASM may not be cost effective (or may not even work at all) in some situations, and advantages and disadvantages should be weighed against other inventory/survey methods. Thorough planning and thought concerning factors affecting DASM will help to ensure that the data collected are accurate, timely, and worthwhile for meeting NIS management objectives.

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References

B.C. Ministry of Forests, Forest Practices Branch. 2000. Forest Health Aerial Overview Survey Standards for British Columbia. TR810.F67 2000. The Province of British Columbia, Resources Inventory Committee. 3-30-0005. 46p. http://ilmbwww.gov.bc.ca/risc/pubs/teveg/foresthealth/assets/aerial.pdf.

Fielding, A. H. 2002. What are the appropriate characteristics of an accuracy measure? Pages 271-280 *in* J. M. Scott, P. J. Heglund, and M. L. Morrison, eds. Predicting Species Occurrences: Issues of Accuracy and Scale. Washington, D.C.: Island Press.

Fielding, A. H. and J. F. Bell. 1997. A review of methods for the assessment of prediction errors in conservation presence/absence models. Environ. Conserv. 24:49.

Lass L. W. and R. H. Callihan. 1997. Effects of phenological stage on detectability of yellow hawkweed (*Hieracium pratense*) and oxeye daisy (*Chrysanthemum leucanthemum*) with remote multispectral digital imagery. Weed Technol. 11:248-256.

McConnell, T. J., E. W. Johnson, and B. Burns. 2000. A Guide to Conducting Aerial Sketchmapping Surveys. FHTET 00-01. Fort Collins, CO: USDA Forest Service, Forest Health Technology Enterprise Team. 88 p.

Moody, M. E. and R. N. Mack. 1998. Controlling the spread of plant invasions: the importance of nascent foci. J. Appl. Ecol. 25:1009-1021.

Morris, A. J. 2001. Aerial Sketchmapping and GIS within the U.S. Forest Service. ESRI Inc., Redlands, CA. http://gis.esri.com/library/userconf/proc01/professional/papers/pap403/p403.htm.

[NAWMA] North American Weed Management Association. 2003. North American Invasive Plant Mapping Standards. http://www.nawma.org/.

Pollock, K. H. and W. L. Kendall. 1987. Visibility bias in aerial surveys: a review of estimation procedures. J. Wildl. Manag. 51:502-510.

Pywell, R., L. Lewis, J. D. Mullen, and C. Schrader-Patton, C. 2001. Digital Aerial Sketch Mapping User Guide, v.1.0. Salt Lake City, UT: USDA Forest Service, Remote Sensing Applications Center, http://www.fs.fed.us/eng/rsac/dasm2004/.

Unsworth, J. W., F. A. Leban, E. O. Garton, D. J. Leptich, and P. Zager. 1999. Aerial Survey: User's Manual. Idaho Department of Fish and Game, Boise, ID.

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Introduction

Nevada is a region primarily of large landscapes with few towns or people. Detecting nonindigenous plant species (NIS) in these vast landscapes is problematic. Although there are places where NIS may predictably be found (e.g., roadways, waterways, disturbed areas), it is important that NIS be detected in more nonpredictable areas (e.g., forests, grasslands) as well. The tiered sampling method provides an approach to locating and recording infestations that has proven effective and efficient. The method employs three tiers to enable land managers to locate NIS in both predictable and nonpredictable situations with a reasonable degree of accuracy and reliability.

Objectives

The primary goal of the tiered sampling method is to detect and map the location, density, and spatial extent of specific established populations of nonindigenous plant species within the area of interest. The tiered sampling method is being used to map most of the state of Nevada's noxious weed species, and this is the example presented throughout this chapter.

The term *survey* is defined here as an investigation of an area using a sampling method to obtain an estimate of the NIS populations. Not every square yard is observed in the survey sampling process. Information gathered through the sampling is extrapolated to unsurveyed areas. Elsewhere in this chapter, the term *inventory* is used to reflect an intensive viewing of an area in order to gain an accurate understanding of the NIS population over the entire area. The method described in Tier I is considered in this chapter to be an inventory, while Tier II and III methods are considered to be surveys. Thus, the inventory/survey terms are used in accordance with the definitions in Chapter 1.

Managers need to know which NIS are problems, and where they are, before they plan strategies of control or containment, and to avoid actions which would make the NIS problem more severe. The U.S. Bureau of Land Management Ely Field Office Resource Management Plan/Environmental Impact Statement for the Ely District (available from the Ely Field Office, 775-289-1880) provides an example of the need for knowledge about noxious weed populations before management activities are implemented. However, it is obviously impossible to devote adequate resources to inventory all noxious weed populations, let alone all NIS populations, over very large landscapes. In Nevada noxious weeds are the target of the sampling protocol. The sampling protocol uses a tiered approach to prioritize inventory/survey locations and to ensure with some degree of accuracy that most of the target species populations will be located. Based on the premise that disturbed areas are the most likely places for the target populations to occur or become established, Tier I inventories are directed toward disturbed or wet areas (e.g., along transportation systems, and around waterways or water bodies). The second tier surveys occur in areas with limited disturbance that are presumably less probable sites for NIS invasion. Thus, Tier II surveys are performed to locate target species infestations that might have been inadvertently introduced by other means (e.g., livestock, wildlife, humans) into remote and/or undisturbed areas. The third tier is a random check to validate the reliability of the inventory and survey completed in the first and second tiers. Essentially, Tier I is an inventory because all disturbed areas are sampled, while Tiers II and III are surveys because they are subsamples of the whole area. Regardless of the tier level, when a target area is defined the whole area is sampled.

This multitiered approach is designed to ensure a high level of accuracy, reliability, and repeatability across the landscape. In Nevada this approach provides greater than 90% confidence that all noxious weed infestations have been found. The data should be added to a central geographic information system (GIS). Once target NIS populations have been located, control or management efforts can begin. Information on these efforts should also be added to the GIS, and some of the populations monitored. Such field collection of data and record keeping allow for evaluation of the control and management effectiveness.

Using the tiered approach means that the inventory/survey can be tailored to meet a variety of different land use and inventory/survey objectives, and can be adjusted according to constraints such as funding, area, and/or desired accuracy, as described in Chapter 1. For example, managers may be interested in finding as many NIS patches as possible so they can be eradicated from an area, or they may need a general assessment of NIS present in a large area. The following section on planning includes a series of questions a surveyor using the tiered method will need to address at the start of the inventory/survey so that the sampling protocol can be adjusted accordingly. If the method is modified; i.e., if one or more tiers are removed from the protocol, then the confidence level will decline significantly. Management of NIS populations is separate from the inventory/survey methodology.

Method

Planning

The inventory/survey protocol presented was developed in east-central Nevada in the Tri-County Program and has been simplified to the current protocol for use across the state by any management group, thereby ensuring some consistency and confidence in the collected NIS data. The following issues must be considered when using this method.

1. Depending on the resources allocated for the inventory/survey, decide upon the amount of time available and the acceptable level of confidence (the probability that all of the NIS populations within a given area will be found). Determine the inputs necessary to achieve a level of confidence indicating that most of the NIS will be found. Inputs can be various types of resources such as funding, labor, and equipment, or they can be less tangible inputs such as knowledge about the area. No one is ever able to find every single NIS, even though that might be the initial goal. It is inevitable that individual NIS and some NIS patches will be missed, due to such factors as the size and growth stage of the plant, as well as the concentration level of the observer. The more closely the protocol is followed and the more intense the inventory/survey, the smaller the size of NIS patches that will be found and the greater the chance of finding all patches in the designated area.
2. Identify all NIS of concern that will be targeted for detection.
3. Understand the dispersal mechanisms of each NIS.
4. Select areas to sample that are easily definable by landscape criteria, such as a watershed or valley. This allows the inventory/survey crew to define and record more easily where NIS were or were not inventoried/surveyed for.
5. Select a global positioning system (GPS) and database library (data dictionary) that is compatible with the GIS being used. In our example the GPS library has to be compatible with the centralized GIS of the state of Nevada.
6. Ensure that fields are available in the GPS database library for the surveyor to note the size and location of NIS patches, NIS name and density, and any other data needed for planning future management and monitoring activities (**Table 1**). We use library attributes referenced in the *Guidelines for Terrestrial Noxious Weed Mapping and Inventory in Idaho* (Bruno 1999).

Tier I

The goal of the Tier I method is to inventory specified areas and locate all populations of target species. We assume NIS are most likely to become established near disturbed or wet areas, transportation systems, and around waterways or water bodies, so we prioritize these areas for our Tier I inventory. When infestations are found, the location (Universal Transverse Mercator [UTM] coordinates or latitude/longitude) is stored in a GPS as a point, line, or area feature (polygon). The steps in the Tier I method are outlined below.

Table 1. Information included in the Idaho data dictionary and used in Nevada.

GPS Library Attributes	Format
GPS data	Yes or no
Survey date	Enter date
Surveyor	Enter name
Weed code	From the WSSA weed ID codes
Common name	Commonly used weed name
Genus	Genus of weed located
Species	Species of weed located
Size in square feet	Estimated size of weed infestation if small in size
Acres (optional)	Estimated number of acres of weed
Cover class	Estimate of amount of ground covered by the weed
Wetness	Distance to standing water
Distance to road less than 150 feet	Is the site within 150 feet of the road: yes or no
Access	How the area can be accessed (foot, vehicle, ATV, etc.)
Suggested control measures	Add notes
Comments	Add notes

1. Inventory all roads, trails, byways, railways, utility corridors, and/or other transportation systems. Make sure that the chosen method of travel allows the surveyor to find any NIS populations along the chosen route. If sight distances are adequate, then traveling in or on slow-moving vehicles will suffice (**Figure 1**). If not, the route needs to be traveled on foot or by some other means, such as all-terrain vehicle (ATV) or bicycle, that will allow a more complete view of the area (**Figure 2**). Inventory results should reflect the route traveled and the approximate sight distance at which NIS populations can be determined.
2. Inventory all known seeps, springs, streams, dry streambeds, riparian systems, irrigation canals, stock ponds, wetlands, and/or reservoirs, etc., that are likely to contain target NIS. The locations of these are downloaded from the GIS to the GPS to ensure that all locations are visited and inventoried. As above, take care that the method of travel enables the surveyor to find any NIS populations along the route, so that the results reflect the route traveled and approximate sight distances.
3. As important as documenting where NIS infestations occur is documenting where they *do not* occur. While inventorying disturbed areas, record all paths, routes, or areas inventoried with the GPS unit and database library in order to document places inventoried where no NIS infestations were found (**Figure 3**). The Nevada protocol calls for turning on the GPS and database library when inventory begins, with all the routes traveled recorded. Any NIS populations are noted in the GPS database library with all associated database fields. Areas without NIS are not noted specifically, but because we are recording our route at 100-ft (30.5-m) intervals throughout the inventory, we have presence and absence data for each NIS. We can then calculate the frequency of each NIS in the area inventoried.
4. Additional disturbed areas may be specifically selected for inventory depending on other management objectives and considerations such as the probable presence of rare or endangered species and/or the prevention of NIS spread into rare habitat.
5. Data collection and storage is an essential step in each tier of the three-tiered process (**Figure 4**). In Nevada, the Tier I data are collected by the user (e.g., county agents, government agencies) and sent to a centralized database.

Figure 1. Conducting inventory/survey from a slow-moving vehicle.

Figure 2. Using an all-terrain vehicle as an alternative means of inventory/survey.

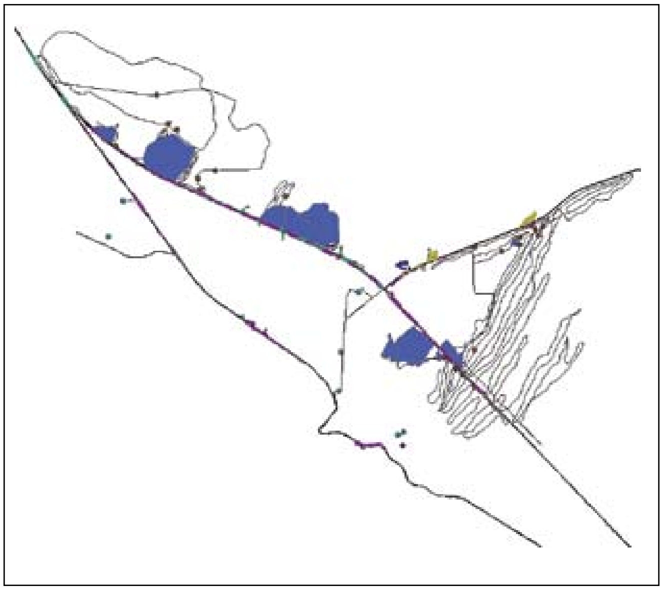


Figure 3. Diagram of how the landscape is covered and weeds are marked. The black line represents the traveled route. The colored lines and polygons represent different NIS patches and/or NIS treatments.

Figure 4. Supervisor Brandon Vaught (Tri-County Weed Program, Ely, NV) inputting NIS data into a Trimble GPS unit.

Training

Training crews to rapidly and accurately identify NIS patches is always a challenge. Ensuring that the results of the inventory are accurate by cross-checking data is essential for the credibility of the inventory data collected.

There are many training methods available, but one we have used successfully is to preidentify NIS patches before crews are sent into an area. If the target species are not found in the training area, then the plastic weeds available from the Center for Invasive Plant Management (www.weed-center.org) are planted in places where NIS are likely to be found, and where the crews should be looking (**Figure 5**). NIS patches, including the plastic weeds, are recorded by the trainer in a GPS unit.

Figure 5. Plastic Dalmatian toadflax (*Linaria dalmatica*) model used for training field crews.

Crews are then sent through the area with instructions to inventory all NIS, including plastic weeds, according to the protocol described in this chapter. Results in their data library are compared to the known NIS locations. It immediately becomes apparent to both the trainer and the crew when known NIS patches are not located. We continue to send crews back to the same area until they locate all of the known patches, including the plastic weeds. Finding the plastic weeds drives home the point that crew members were not looking in obvious places. It is especially humbling if the plastic weeds are labeled with a note telling anyone who finds them to return them to the trainer.

When discrepancies occur, the trainer has an opportunity to teach the crews about the survey protocol and how to better locate NIS patches. This process can be repeated as often as necessary, until the crews obtain 100% accuracy in identifying all NIS locations within the target area. We have had to send a crew to the same area as many as three times. We also "plant" plastic weeds throughout the season to check for continued accuracy. These training exercises are conducted in addition to the procedures designed to cross-check for the accuracy of the survey protocol, and continually reinforce the accuracy of the field crews.

Tier II

The Tier II method is a stratified random survey of areas that are not associated with disturbances, but may potentially be infested with NIS. For example, areas not necessarily considered impacted by disturbances constitute huge geographic regions of Nevada; therefore, it is not feasible to inventory such areas, and representative areas can only be spot checked or surveyed. Because sites for Tier II data collection are selected using a stratified random process, they are representative of the whole area; thus, if few NIS patches are found it will not be necessary to sample more of the area. Furthermore, collecting data in this way means that predictive maps can be made of the whole area (see Chapter 6).

1. Random areas to survey are selected from 1:24,000 U.S. Geological Survey quadrangle maps where disturbances have not previously been found.
2. The selected area should be stratified either by elevation or plant community, but not both. For example, random points should be selected either all within the same elevation range on the map, or within a specific type of plant community, such as a Wyoming sagebrush plant community or a salt desert shrub plant community. This stratified random sampling method helps determine where NIS populations not associated with disturbances are most likely to occur, and therefore where further survey efforts should be concentrated. Such infestations might be occurring from random seed dispersed from wildlife or from other unpredicted events.
3. A representative number of sites to field check within the stratified area should be randomly selected.
4. The stratified areas are then checked intensively for NIS infestations, according to the inventory protocol outlined under Tier I. As above, take care that the method of travel enables the surveyor to find any NIS populations along the route, so that survey results reflect the route traveled and approximate sight distances.
5. These data are collected with the same GPS equipment and database library as used in the Tier I method, and the information is handled in the same way.

Tier III

The Tier III method was established to randomly check at least 5% of all areas (both disturbed and undisturbed) previously sampled, and using the data stored in a database, to establish the accuracy of Tier I and Tier II efforts. To increase the confidence that most NIS populations were found, the number of random checks can be increased and accuracy assessed in more Tier I inventories or Tier II surveys. To accomplish Tier III, previously sampled areas are randomly selected. Different observers then follow the same routes (transects, etc.) as followed by the initial crew, and record any NIS populations found. If the initial crew missed a population, then that crew receives additional training to lessen the chance of future errors (see sidebar). We have not tried to quantify the error rate or the decrease in error rate from this additional training.

Safety

An important consideration when conducting operations in very remote areas such as rural Nevada is the safety and efficiency of personnel. Crews must be adequately trained and supervised, and be provided with necessary equipment. Be sure that all members of the team can quickly and accurately identify all growth stages of the NIS of interest, and that they have a comprehensive knowledge of inventory/survey procedures, GPS operation, and database management. Adequate training takes about a week and a half, but that time is quickly recouped in the speed and accuracy of the inventory/survey. (See training sidebar.)

For safety, we prefer to work in crews of four, with crew members who are familiar with the area and are capable of handling themselves in adverse situations in remote areas. In vehicles, travel in pairs is preferred; on foot, crew members should keep within reasonable distance of each other. Vehicles should stay within reasonable distance, and within radio contact, of each other. One vehicle should be within radio contact of the base station as well.

Advantages and Disadvantages of the Tiered Sampling Method

The Nevada methodology outlined here is applicable when used to cover large acreages which have limited amounts of disturbances with a relatively high degree of reliability and confidence that most of the NIS populations will be located. It would not work well in a more urban environment with significant percentages of total land area disturbed by development and construction, because its efficiency comes from the limited amount of disturbance relative to the total area. If the majority of the land has some form of anthropogenic disturbance a different inventory/survey method might be more applicable.

Managers within Nevada want to decrease the application of Tiers II and III, but to do so significantly reduces the checks of the sampling methodology, thereby reducing the confidence that most NIS populations have been or will be located. Currently, when all three tiers are used together, this method locates more than 90% of noxious weeds in the areas searched in Nevada. However, this is a point-in-time inventory/survey and is not designed to locate populations that occur after the inventory/survey is taken. It may also miss NIS infestations when the phenology of the plant makes it hard to identify at the time when the inventory/survey is conducted (e.g., at the rosette versus flowering stage). Nonetheless, we have found this method to be well suited to mapping NIS populations in the vast Nevada landscape, and would expect it to be applicable to other areas in the West.

References

Bruno, D. 1999. Guidelines for Terrestrial Noxious Weed Mapping and Inventory in Idaho. Boise, ID: Idaho Department of Agriculture. http://www.idahoag.us/Categories/PlantsInsects/NoxiousWeeds/Documents/mapping/handbook_ver1.pdf.

Mack, R. 2000. Assessing the extent, status, and dynamism of plant invasions: Current and emerging approaches. Pages 141-168 *in* H. A. Mooney and R. A. Hobbs, eds. Invasive Species in a Changing World. Washington, D.C.: Island Press.

Montana Noxious Weed Survey and Mapping System Handbook. 1999. http://www.montana.edu/places/mtweeds/index.html.

(NAWMA) North American Weed Management Association. 2003. North American Invasive Plant Mapping Standards. http://www.nawma.org/.

Steel, R., G. D. Steel, and J. H. Torrie. 1980. Principles and Procedures of Statistics, A Biometrical Approach, 2nd edition. New York: McGraw-Hill Book Company.

Lisa J. Rew and Bruce D. Maxwell

Overview

Under most land management scenarios it is not possible to observe all of the plant species or even plant communities in a managed area. In most cases we do not know which nonindigenous species (NIS) are present within a managed area, their frequency or their distribution pattern, how much their distribution is changing, or the impact they are having on the ecosystem or on land management goals. Only when equipped with all of this information can land managers most effectively control or manage NIS. Even if the location of all NIS populations within a management area were known, most land managers have insufficient funds to treat all the populations. Therefore, some way of prioritizing which populations to manage should be used, and this should be based on objective assessments of the populations. Here we discuss how to achieve such prioritization.

Once the NIS management objectives have been defined for an area (see Chapter 1), the next step is to conduct an inventory/survey of the species present. In this chapter we concentrate on a survey method to sample large areas. There are two basic approaches to survey design, biased or unbiased. We will concentrate on a stratified random sampling approach, a form of unbiased sampling, which takes into account prior knowledge and information about NIS.

Biased Sampling

The first goal of some survey methods is to search for NIS with the usual intention to manage them once they are found, and previous intuition about NIS distributions is used to select the areas to survey; i.e., the sampling pattern is biased. In some cases, the intuitive approach is also used to monitor the results of management. Thus, once an NIS population is found the position is recorded (geo-referenced) on a map or with a global positioning system (GPS), and at the same time the size of the patch is estimated or measured, often in categories such as less than 0.1 acre, 0.1 to 0.5 acres, 0.5 to 1.0 acres (less than 0.04 ha, 0.04 to 0.2 ha, 0.2 to 0.4 ha), and so on.

The intuitive approach to NIS survey offers several advantages. It capitalizes on the integrated knowledge of the person conducting the survey, so that certain areas are targeted for sampling and control. It may be the best approach if the total management area is small (up to 100 acres, or 40 ha). In such situations this method may be the most time- and cost-efficient way to manage small infestations. Of course no treatment is 100% successful so the populations will need to be monitored. The intuitive approach also provides a rapid method for estimating patch size, but it has low accuracy because it relies on visual estimates, which are often grouped into broad categories. Additionally, if the patches are monitored over time, using estimates or categories, it will be difficult to detect change in patch size unless the patch is growing very fast (i.e., more than 15 to 33 ft [5 to 10 m] in radius per year), or management actions are extremely effective (i.e., patch size is declining rapidly each year). We have no experience of patches growing or declining this fast, which suggests more accurate measurements need to be made.

There are substantial disadvantages to the intuitive approach. The intuitive method uses an observer's prior knowledge or perception of where NIS may be located to determine the sampling pattern. Consequently, it potentially fails to base the sampling pattern on disturbances (e.g., wildfire, road corridors) or environments (e.g., forested versus grassland) that may influence the distribution and spread of NIS. This means that areas which may have ideal conditions to harbor the NIS may not be sampled. To check the quality of intuitive knowledge a number of untargeted areas (i.e., areas where no NIS are believed to occur) should be sampled. If NIS are located in the untargeted areas, it will be necessary to adjust the intuitive knowledge and expand the sampling area, or, if the area is small, aim to sample the area entirely (i.e., inventory) over a number of years. Using the intuitive approach little shared knowledge is gained about the factors that may help predict the distribution of a given NIS in the surrounding landscape which has not been surveyed. Consequently, results can be highly variable because they depend on how well the people conducting the survey use their intuitive knowledge to select where to sample, and how accurately they estimate NIS patch size.

Unbiased Sampling: The Stratified Random Method

An unbiased approach to an NIS survey means that the data collected are representative of the whole management area and not just the sampled area, thus overcoming the disadvantages of the intuitive method. Since the data represent the whole management area they can be used to predict where else species may occur in the unsampled management area. We recommend stratified random sampling because it uses prior knowledge, preliminary data, and first principles of the NIS and the environment to design the survey.

Stratified random sampling utilizes a survey to discover factors that may help explain the NIS distribution, predict NIS distribution in areas not surveyed, and locate NIS patches and metapopulations (a set of patches of the same species that are close enough to permit interbreeding) under a wide range of environments. Such an approach increases the accuracy of future monitoring and impact studies that lead to prioritization for management.

Prior knowledge may include a list of the NIS identified in the management area and region, previously observed patches in the area, and scientific literature on the biology and distribution of the target species. Prior knowledge tells us that most NIS are introduced via human activity, so source areas of NIS can be assumed to be associated with areas of such activity. Thus, roads, power lines, and other areas of human-mediated disturbances will serve as source areas in most habitats. NIS occurrence can generally be expected to decline with increased distance from these sources into areas of little or no human activity. Therefore, we could use these areas to stratify our sampling.

First principles relate to the ecological processes that interact to determine where any particular NIS is located. For example, a first principle of plant dispersal is that there will be more propagules (seeds or vegetative units) near the source, and the propagules will decline along a gradient with increased distance from the source. Other first principles relate to species-specific habitat requirements. Annual colonizing species usually require recently disturbed soils with a lack of competitors. Because many colonizing NIS require higher light intensities than native species and thus cannot tolerate extensive shade from a forest canopy, they will invade only meadows and grasslands, or areas where the forest canopy has been removed. Other species may be moisture limited and thus are more likely to be found in riparian plant communities. Again, we would expect NIS abundance to decline with distance from roads and trails if they are the source, but we may also expect certain habitats or environments to influence NIS abundance.

Objectives

In large landscapes (more than 50,000 acres or 20,200 ha), where inventorying the entire area will not be possible because of time and funding constraints, a survey method such as stratified random sampling can help prioritize areas by environments that are apt to influence the growth of the NIS. We use a stratified random survey method because it is useful for prioritizing sample locations, and the resulting data can be used to predict where NIS infestations may be located and which habitats may be more susceptible to NIS invasion. By using first principles, stratified random sampling increases the probability of finding locations for any given NIS in the areas perceived to contain NIS, while still collecting data away from those “known” key areas. However, knowing where a species is not located is as important as knowing where it is located. Only with information on both presence and absence can we predict where a species is likely to be found and improve our management strategies.

Using our knowledge and first principles we have chosen roads and trails as our feature to stratify on and sample away from when conducting NIS surveys in parts of the Greater Yellowstone Ecosystem. Other factors such as habitats or fire history could also be used, provided sampling was performed in the area known to contain the species, and also in a location away from that area. There are different forms of stratified random sampling; Hirzel and Guisan (2002) and Maggini et al. (2002) provide good overviews.

The method is called stratified random because the sampling selects a factor or feature to stratify on—roads and trails in this example—but the actual locations of the samples along or within these areas are randomly selected. We are also using transects because they are more time and cost efficient than sampling points randomly or on a grid (Rew et al. 2006).

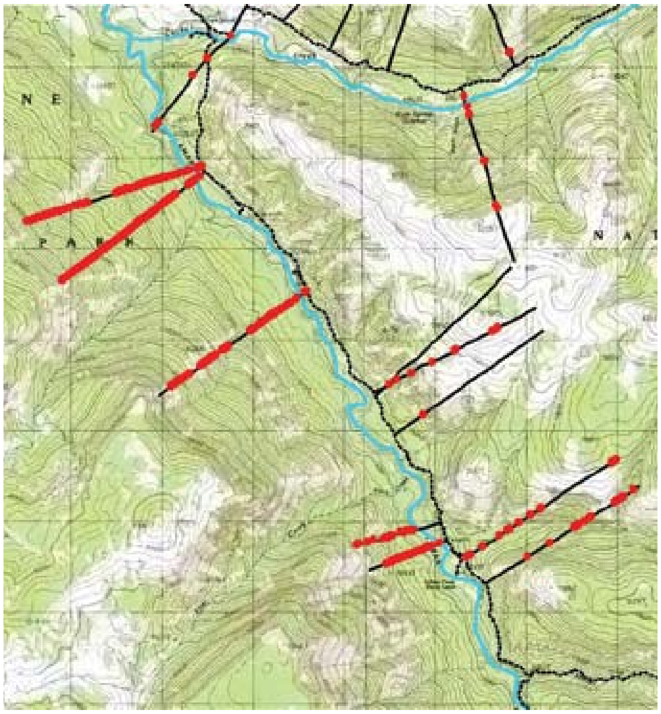
Methods: Steps to Conducting a Stratified Random Nonindigenous Plant Survey

Presample to Identify the Stratification Feature and General Sampling Procedure

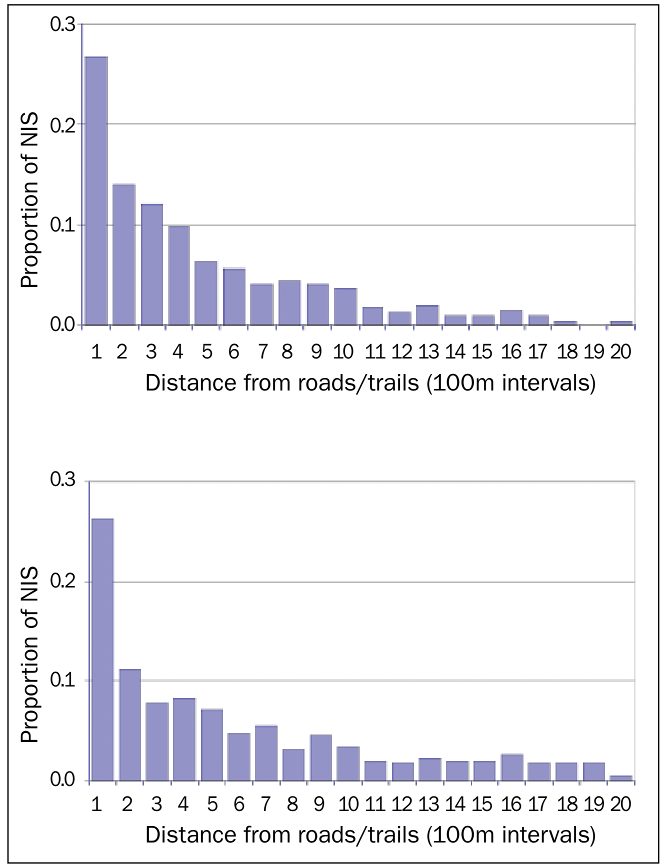
The presample is typically based on two assumptions: (1) nonindigenous plant species occurrence will decrease with distance from human activity, and (2) plants of a particular NIS will be more frequent in some plant communities than others (e.g., grass-, forb-, and shrub-dominated communities, rather than forested communities). The presample is established to verify these two assumptions. Therefore, an essential part of the presample is that data are plotted and analyzed. This is true of any data collection. There is no point collecting data on a regular basis unless they are analyzed to ensure the data collected are answering the intended questions—if not, then some adjustments need to be made to the sampling protocol. Checking data partway through a season is a step that many people avoid, with the unfortunate result that filing cabinets and computer hard drives are full of unusable data.

Even if changes are made to the sampling protocol after the presample data analysis, the data can usually be incorporated into the main sample data. So, it is not as if the presampling stage is a waste of time and energy.

To conduct the presample, establish randomly located transects on and perpendicular to the chosen stratification factor—in our example, roads and trails (**Figure 1**). As a transect is traversed, data on NIS presence, length and width of patch, and major vegetation changes and disturbances are recorded using a GPS. We use a 10-m-wide transect because we predetermined this distance as the maximum distance



▲ **Figure 1.** Location of random stratified transects (solid black lines) starting on roads or trails and generally finishing 2 km from any road or trail. Red circles represent the location of a target NIS observed along transects. Area shown is a 10-km by 10-km area in the Northern Range of Yellowstone National Park.



▲ **Figure 2.** Distribution of a representative NIS, Dalmatian toadflax (*Linaria dalmatica*), relative to roads/trails along continuously sampled 2-km-long transects in the Northern Range of Yellowstone National Park. Distribution after (a) one year of sampling, (b) three years or sampling.

at which a surveyor could accurately identify an NIS in our landscape. Different transect widths may be possible in different management areas, but the width should not vary within a management area.

Data from our presample (42 transects) suggested there was a clear relationship between distance from roads and trails and the number of NIS sightings for most of our target species (**Figure 2**). We therefore concluded that the source of NIS (roads and trails) and dispersal from that source was useful information and could be used to stratify (or guide) future sampling during the survey.

In addition, we found that most of the NIS observed were in a few vegetation habitat types (primarily the shrub-, forb- and grass-dominated types rather than the forest habitat types; **Figure 3**). Thus, vegetation type was another identified factor which could be used to further stratify our sampling to increase the chance of finding a high proportion of NIS patches. However, in our example, as will be true of many studies, we were searching for many NIS (63 species), which would make it difficult to correctly stratify on a second factor, due to the slightly different environmental and habitat requirements of each species. (Also, it is rare that vegetation maps are available for stratification.) Therefore, we continued to stratify only on one factor—roads and trails—but ensured that we sampled all the different habitats present in our management area.

If our presample data had shown a decline with distance from roads and trails for most species but no response for a few others, it would still be appropriate to sample as described above because by sampling away from roads and trails and ensuring we sampled all habitats, we would be able to determine the requirements of those nonresponding species too. If none of the species had shown a response to our stratification feature but had a response to a different

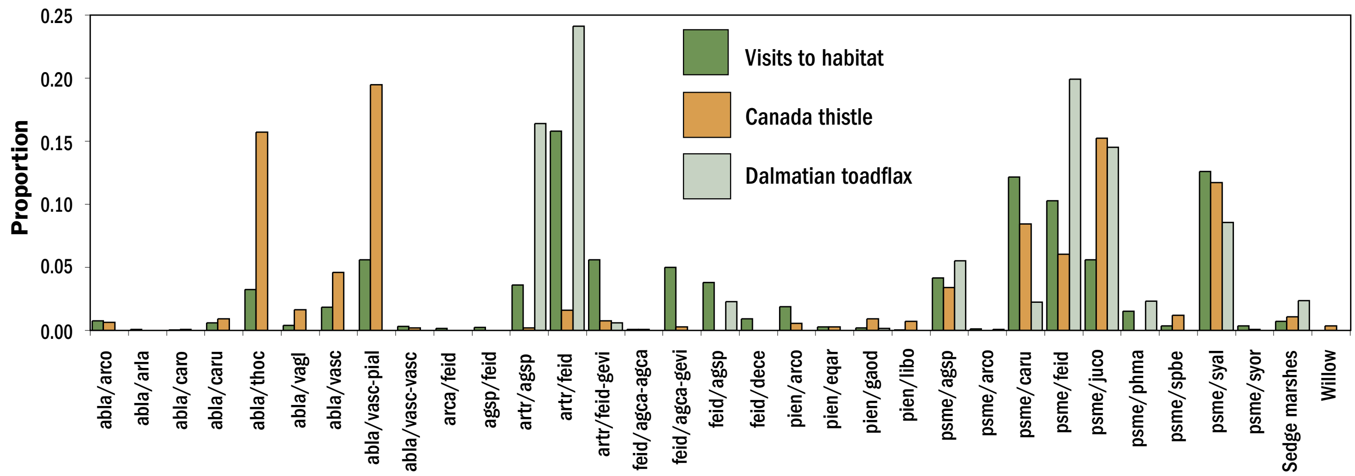


Figure 3. Proportion of different habitats sampled (in dark green) and target species presence (Canada thistle, *Cirsium arvense*, in orange; and Dalmatian toadflax, *Linaria dalmatica*, in light green) in those different habitats, presample data only from the Northern Range of Yellowstone National Park. The aim of the graph is to demonstrate that target species have higher occurrence in some habitats than others. Habitat abbreviations are the first two letters of genus and species, except for sedge marshes and willow.

feature (e.g., habitat type, cattle grazing, or wildfire areas), future sampling could be stratified on that factor. Taking the wildfire example, transects would start within the wildfire area but continue outside of it into unburned areas.

Specific Methodology for Stratified Random Sampling

The position of each transect and the bearing (azimuth) traveled need to be randomly selected prior to arrival in the field using a geographic information system (GIS) with a roads and trails layer, or a layer indicating any other human disturbance that preliminary data has shown to be correlated with NIS presence. Within the GIS it is easy to set up a buffer around the roads and trails, which basically highlights all the areas within a set distance from the roads and trails. The buffer distance should be the transect length to be used in the field and should not change within the same management area. In surveys in the Northern Range of Yellowstone National Park we have used transect lengths of 2 km since that is generally as far as one can get from a road or trail; in the Gallatin and Kootenai National Forests we have used 1-km transects because in those forests it is rarely possible to get more than 1 km from a road or trail. There is no advantage to making some transects longer than others because this will mean that the final dataset will have unequal numbers of samples at different distances, and therefore make the results difficult to analyze and interpret. Obviously some transects will end up being less than the desired distance due to terrain features, but stopping short should be avoided where possible.

Once the buffer layer is generated in the GIS the start and end locations of transects can be randomly generated, but within a set of confines; for example:

- Starting on a road and finishing 2,000 m (2 km) from all roads but at all times ensuring the transect runs more than 2,000 m from any known trail
- Starting on a trail and finishing 2,000 m from all trails but at all times ensuring the transect runs more than 2,000 m from any known road
- Starting on a road or trail and finishing 2,000 m from all roads and trails

The transect locations, indicated by start and finish points, are then loaded into a GPS unit so the crew can locate and navigate between points. A conventional compass or the GPS compass can be used to navigate along a set azimuth from the start to the finish position of each transect. In addition, the GPS can be easily programmed to record all the data fields to be collected in the field. In our experience, the use of a well-designed data dictionary reduces data collection and input errors. Preferably, the fieldwork will be completed by teams of two to ensure that the whole transect width (10 m) is seen, as well as for purposes of safety.

We recorded NIS patch length and width (in meters), percentage cover and density per patch, aspect, dominant vegetation, disturbance (e.g., wildfire, additional trails, logging), and elevation (an automatic field in the GPS), as well as other fields recommended by the North American Weed Mapping Association (NAWMA 2003) (see Chapter 2, Table 1). Many of the NAWMA fields can be entered later in the office.

Data are then downloaded from the GPS unit to a main computer and imported into a GIS. By collecting NIS presence and patch length, and changes in habitat and dominant native species in the field, but no absence data, time spent on any one transect is minimized. Because the start, end, and trajectory of each transect is known, we can use the data to generate continuous NIS location data (presence and absence) using extensions created in ArcView (version 3.2; ESRI, Inc.) and macros in Excel (Microsoft Corp.).

Predicting NIS Occurrence Using Stratified Random Sampling Data

While it is good to have a map of where a particular species is along each transect sampled (**Figure 1**), these data can be used to provide much more information (**Figure 4**), as well as predictions for the whole management area (**Figure 5**). The initial approach, and the simplest, is to create graphs from the field and GIS data to visualize how target NIS populations are correlated with specific variables measured in the field (**Figure 4**). If it is not possible to develop predictive models, the type of graphs depicted in Figure 4 could be used to direct and prioritize further survey activities because they demonstrate the environments in which target species are more likely or less likely to be observed.

However, we can also use the field and GIS data to generate probability of occurrence maps for individual NIS (**Figure 5**). Such maps are for the entire management area and not just the area sampled. This is important for large management areas where it will be impossible to ever sample the area entirely but where NIS management needs to address the entire area.

Using the data we collected in the field and processed in the office we have presence/absence data for each target NIS along every transect. We use 10-m by 10-m data cells because that fits with the GIS data layers, but other cell sizes can be used. For each 10-m cell of NIS occurrence we also have information on factors such as distance to nearest road and trail, aspect, elevation, and slope, which we obtain from the GIS data layers. These data can then be analyzed using a logistic regression model to predict the occurrence of target NIS for the entire area. The model takes the form:

$$P(y=1|x_j)=\frac{\exp(\beta_0+\beta_1 x_1+\ldots\beta_i x_j)}{1+\exp(\beta_0+\beta_1 x_1+\ldots\beta_i x_j)}$$

where y = target NIS, and xj = the variables that the target species could be correlated with, including slope, elevation, distance from road, distance from trail, and vegetation habitat type. The best model—that is, the one which best predicts the distribution of the target NIS—can be determined using a formula called the Akaike Information Criterion. The results or coefficients from the model can then be used to generate a probability of occurrence map of the target species (see Rew et al. 2005 for more detail). The only limitation is that the factors put in the model must be ones for which there is a GIS layer of the whole area. For example, if there is no GIS layer which depicts habitat for the management area as a whole, the habitat information would be used descriptively as discussed above (e.g., **Figure 4**), but

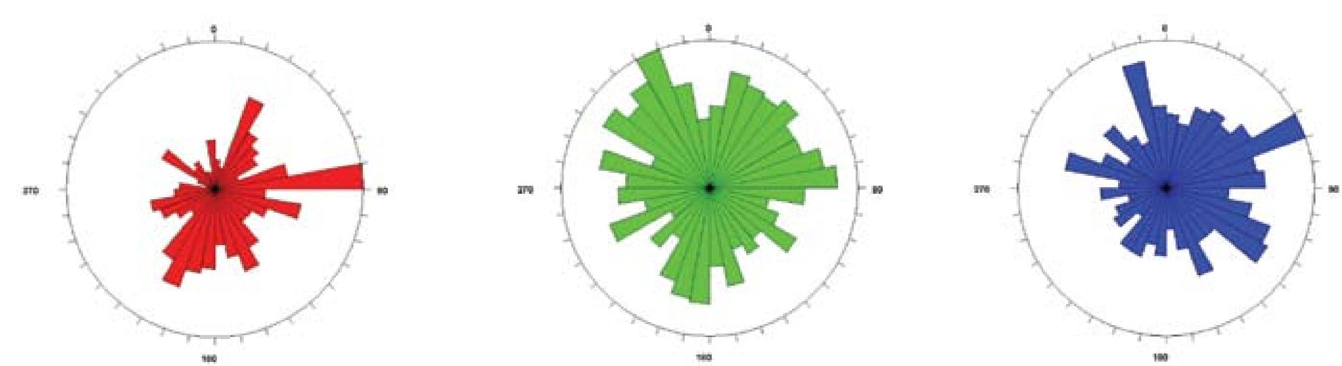
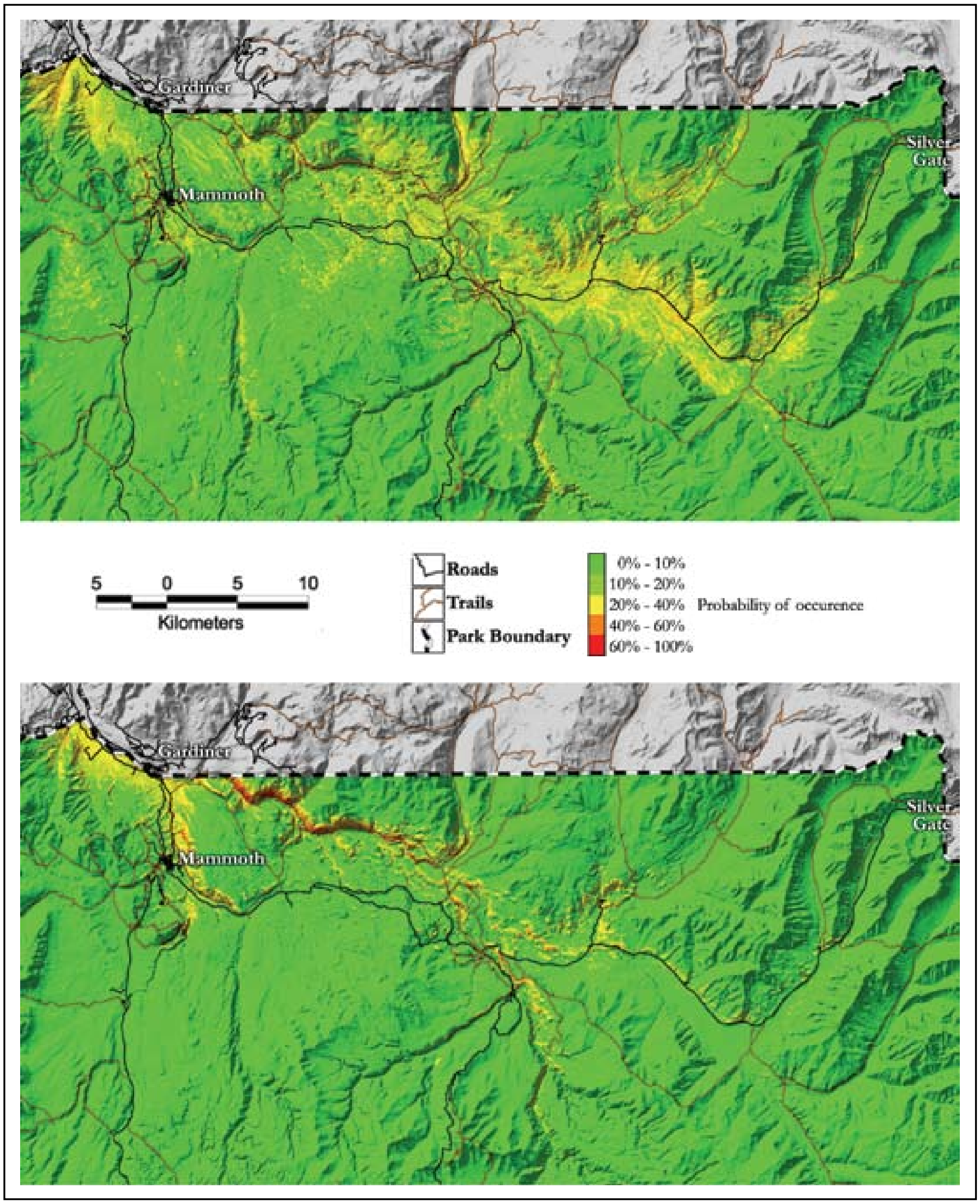


Figure 4. Proportional rose diagrams demonstrate that different target species have higher occurrence on some aspects than others. Similar graphs could be produced to demonstrate different slope, elevation, soil type, etc., preferences. Data are from three years of sampling in the Northern Range of Yellowstone National Park. Red, Dalmatian toadflax (*Linaria dalmatica*); green, timothy (*Phleum pratense*); blue, Canada thistle (*Cirsium arvense*).



Predicted probablility of *Linaria dalmatica* occurrence

Figure 5. Probability of occurrence maps for two target species in the Northern Range of Yellowstone National Park, Dalmatian toadflax (*Linaria dalmatica*) and cheatgrass (*Bromus tectorum*).

Predicted probablility of *Bromus tectorum* occurrence

could not be used in the model. Examples of the probability of occurrence maps for the northern range of Yellowstone National Park are provided in Figure 5.

The probability of occurrence maps represent the suitability of the environmental conditions for the target NIS. Thus, propagules of a target NIS may not have reached a particular area, but if they do these maps demonstrate whether the area is "more ideal" to "less ideal" for colonization. Therefore, the maps can be used to prioritize areas for future sampling, both for finding new populations and also to select populations to monitor for change and impact, consequently providing information for improved management decisions.

Equipment Needed

Any GPS unit with postprocessing capability to improve data accuracy (e.g., differential correction) is acceptable. We have used Pro XR receivers or GeoExplorer3 units (Trimble Navigation Ltd.). Preferably, the unit should be able to store a data dictionary that would contain all the data fields which need to be collected in the field. The data dictionary streamlines data processing in the office because the dictionary is designed so that it does not allow fields to be skipped or incorrectly formatted data to be entered. In addition, a handheld compass can be used to navigate transect bearings, which is particularly useful in steep and variable country where the GPS reception is likely to be intermittent.

It is possible to train field crews relatively quickly even if they have little prior knowledge of plant identification and GPS. Our field crews have generally been undergraduate students with little to some prior plant identification skills and/or knowledge of GPS and GIS. Training the crew to accurately identify the target NIS and dominant native vegetation takes longer than teaching them to master the GPS, including the data dictionary—mastering this generally takes only a few hours.

Analyzing the field data to create diagrams such as those in Figure 2, 3, and 4 can be performed in Excel with basic Excel knowledge. The predictive models require a statistical and GIS package; we use S-Plus (Mathsoft Inc.) and ArcView. Statistical and GIS training is required, but the authors can provide some guidance if requested.

Advantages and Disadvantages of the Stratified Random Sampling Method

We developed a simulation model in a GIS to evaluate seven different survey methods for consistency and reliability of (1) intersecting patches of NIS in a large landscape (24,710 acres or 10,000 ha), (2) producing samples which reflected the spatial distribution of the populations in the landscape, and (3) considering cost and time efficiency. This evaluation helped to quantify the advantages and disadvantages of the stratified random sampling method compared to other methods in a large wildland area. For detailed methods and results see Rew et al. (2006).

In short, the stratified random sampling method provides one of the most reliable samples of the true spatial field distribution. Grid and random point sampling provided results that were similar to each other and to the results from the stratified random sampling method; however, stratified random sampling was more time efficient than the grid and random point sampling because less ground had to be covered to sample the same area. Therefore, if the objective is to find out which NIS are present and where they occur in the management area, stratified random sampling is the preferred method. It can be used on most landscapes, or areas of any size where a survey rather than an inventory is required. This method provides information on the environments in which species are more likely or less likely to be found. Even without the probability maps, this information can help prioritize further surveys and monitoring efforts.

With regard to producing maps, more data are likely to improve the accuracy of the maps, but at the very least the maps provide visualization of the entire management area and also help with prioritization and targeting of particular areas and species for monitoring and management.

The method could also be used for rare plants or taxa other than plants, except that different stratification factors would be necessary.

Although the stratified random sampling method can seem complicated, it is basically building on current knowledge, but collecting data in such a way that we can learn more about the current and likely future distribution of target NIS.

Collecting data in areas where NIS are less likely to be found is often seen as a disadvantage and a waste of resources, but absence as well as presence data are important if we, land managers, want to understand more about NIS distribution over the whole management area.

To produce the probability models, technical knowledge of statistics and GIS are required, but the more basic analyses can be performed by anyone with knowledge of Excel or other spreadsheet programs. We are developing a step-by-step guide to initial data analysis and the modeling procedures. The data dictionary we used in the field, the Excel macros, and ArcView GIS extensions which our office has written are available to anyone. Contact either author of this chapter for more information (see List of Contributors).

References

Hirzel, A. and A. Guisan. 2002. Which is the optimal sampling strategy for habitat suitability modelling? Ecol. Modelling 157:331-341.

Maggini, R., A. Guisan, and D. Cherix. 2002. A stratified approach for modelling the distribution of a threatened ant species in the Swiss National Park. Biodivers. Conserv. 11:2117-2141.

[NAWMA] North American Weed Management Association. 2003. North American Invasive Plant Mapping Standards. http://www.nawma.org/.

Rew L. J., B. D. Maxwell, and R. Aspinall. 2005. Predicting the occurrence of nonindigenous species using environmental and remotely sensed data. Weed Sci. 53:236-241.

Rew L. J., B. D. Maxwell, R. J. Aspinall, and F. L. Dougher. 2006. Searching for a needle in a haystack: evaluating survey methods for sessile species. Biol. Invasions 8(3):523-539.

Timothy S. Prather

Background

Increased global trade has great potential for bringing new plant species to our doorstep (Mack and Lonsdale 2001), some of which may disperse and establish, usually along transportation routes (MacDonald et al. 1989). Because an increase in nonindigenous plant species (NIS) in an area is related to the density of roads in that area (Kalin et al. 2000), conducting an NIS inventory/survey biased towards roads makes sense. Rivers and streams are also important to plant movement (Nilsson et al. 2002; Parendes and Jones (2000). However, wind-dispersed plant species and species dispersed by birds will have less association with roads, trails, and rivers. The seeds of wind-dispersed species such as Russian thistle (*Salsola iberica*) may move as little as 60 m and as much as 4 km, depending on wind speed and duration (Stallings et al. 1995). Topography and thermal updrafts were considered more important than wind speed in a study involving mouse-ear hawkweed (*Hieracium pilosella*) dispersal. As topographic relief increased, thermal updrafts increased in strength, resulting in long-distance dispersal of at least 250 m (Tackenberg 2003). Dispersal by birds is not as likely to be related to road and trail systems, but rather to perches such as fencerows. For example, dispersal of seeds by hornbills in tropical West Africa measured 1.1 to 2.0 km on average, with maximal distances of up to 6.9 km (Tackenberg 2003).

A strategy for NIS survey that focuses on transportation routes should increase the efficiency of the survey, especially as the size of the area managed increases. Furthermore, when rivers and streams are in proximity to roads or trails, areas downstream from infestations should be examined. Because a survey biased toward transportation routes may not accurately assess species dispersed by wind or birds, transects perpendicular to the transportation route should be included.

Objective

Areas of disturbance and human activity (roads, trails, etc.) provide both the conditions and the opportunity for NIS establishment. The adaptive sampling method prioritizes areas to survey by focusing on roads, trails, campgrounds, and waterways. Biasing the survey to areas more likely to contain NIS improves efficiency, much like using a stratified sampling technique increases sampling efficiency. The primary objective of adaptive survey is to efficiently sample areas for NIS, particularly areas with little or no prior inventory/survey data. An additional objective is to record all the areas sampled, rather than just locations of NIS. Knowledge of areas where NIS do not reside is of considerable importance for management and these data are useful to better understand the potential distribution of an NIS.

Method

The adaptive sampling method presented in this chapter uses areas of human activity as a starting point. For example, the starting point may be a trail, campground, or beaching area for rafts. The area is then traversed, and lack of NIS are recorded until a target NIS is located. Once a target NIS is located, the crew spaces themselves at twice the detection distance (**Figure 1**) of the targeted species. The crew then moves away from the known location into the surrounding area, either in concentric circles in gentle terrain, or by walking the elevational contour from the known location. As the target NIS are found, the survey crew continues away from the new individual/patch, in circles or on contours, until no target NIS are found for a predefined distance.

NIS are mapped as point features and the radius of the population is recorded. If infestations are large (radius greater than 40 m) and irregularly shaped, the perimeter of the infestation is walked and recorded directly as a polygon. NIS populations are recorded as separate points or polygons if 20 to 40 m separate the individual plants or patches. The separation distance between patches is defined before the survey begins and depends on the visibility of the targeted species. Identifying every plant is not important; rather, it is important to identify the outer boundary of the infestation. The outer boundary is considered to be located when no target NIS have been found for 400 m (species not wind dispersed) or 800 m (wind-dispersed species). A survey distance of 800 m has been adopted for wind-dispersed species such as hawkweeds (*Hieracium* spp.) because survey crews have found that wind-dispersed species could be found up to 650 m from the last known plant. The radius data for each population is used later within the geographic information system (GIS) software to extend points to circular polygons to represent the size of each infestation.

Perpendicular Transects

Once an outer boundary of an adaptive survey is determined (i.e., no target NIS have been recorded for 400 to 800 m depending on dispersal type), the survey crew returns to the trail (or other area of interest) and continues to survey. If NIS are not found for the next 4 km, a transect is taken

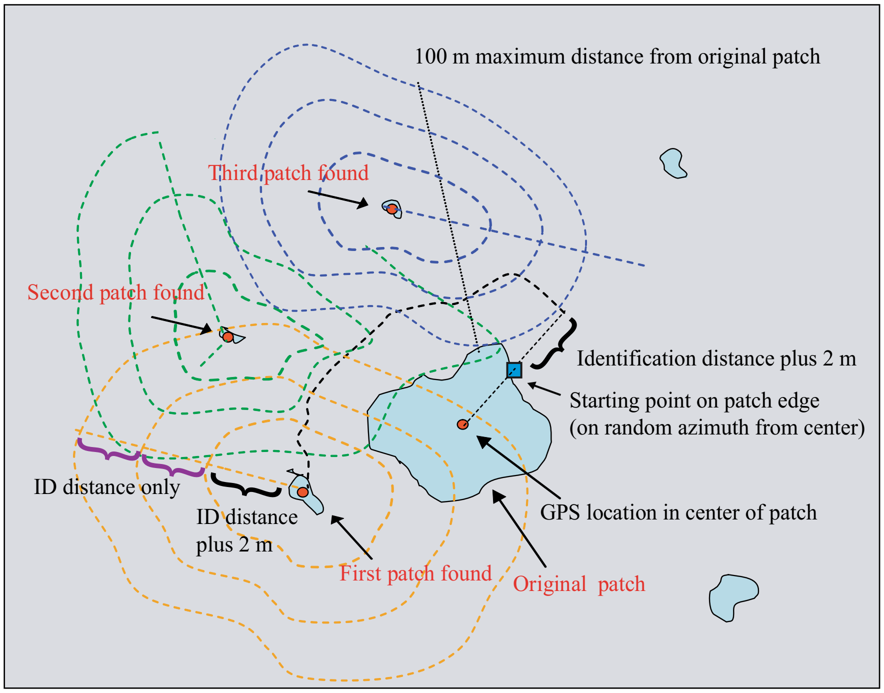


Figure 1. Hypothetical map showing NIS patches (solid light blue areas), their boundaries (solid lines), and the adaptive sampling walking paths (dashed lines) used for finding new patches of the same species. In this example a detection distance of 2 m was used with a maximum distance (outer boundary) from the original patch of 100 m.

perpendicular to the trail for 400 m (**Figure 2**) to check that the chosen stratification variable (in this case trails) was valid. If target NIS are not found along the perpendicular transects, then the crew returns to the trail or area of interest and the survey continues.

Detection Distance

The distance between crew members when they are sampling an area is calibrated in the field with known locations of NIS to ensure that the sampled area is covered adequately. The crew members walk away from a targeted NIS population until they no longer feel confident about visual identification of the plant. The longest identification distance they feel confident with is labeled the detection distance. The detection distance is often no less than 10 m. Twice the detection distance is used to establish the distance between crew members. In addition to defining the detection distance, the crew member is creating a mental image (a search image) of the target NIS in that environment. Multiple NIS can be targeted with this method, but it is best suited to mapping of six or fewer species. Experience shows that survey crew members can retain at least 10 to 12 search images for an extended period.

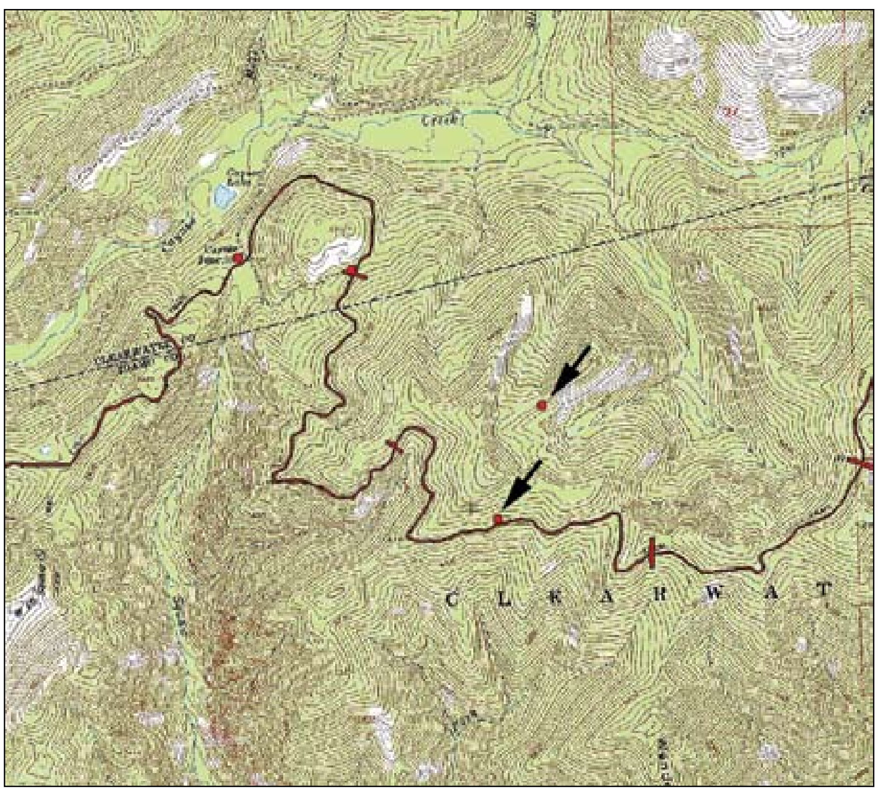


Figure 2. A section of the Lewis and Clark Trail surveyed in 2003 using the adaptive sampling method. The area along the trail and the four transects are presented in brown, and NIS locations are presented as red circles. The NIS infestation away from the trail (upper arrow) was found using the adaptive concentric circle approach as a result of originally locating the NIS patch on the trail's edge (lower arrow). The maximum distance (i.e., outer boundary) to be walked from the original patch was 800 m; the patch away from the trail (upper arrow) was within 800 m.

Data Collection

Data are collected using handheld computers with a global positioning system (GPS) unit attached. The handheld computers run ArcPad (ESRI Inc.) software, a GIS program. ArcPad menu screens are written specifically for the survey project and downloaded from a computer to the handheld computers. Several agencies and organizations now have their own screens for data entry, including the National Park Service, the USDA Forest Service, and The Nature Conservancy (see Chapter 2).

The user may record the NIS location (latitude/longitude, Universal Transverse Mercator [UTM], etc.) as either a polygon or point feature (see "Method," above). Location data can be recorded (logged) while standing at the center of the patch. Location data for remote points can also be logged by recording the crew member's current GPS location and then offsetting the location of the remote point by recording the distance, compass bearing, and inclination to the point.

In addition to the NIS patch location, several data parameters are recorded, including the date, crew member, and NIS detected. The plant codes listed in the USDA PLANTS database (http://plants.usda.gov/) are used to identify each NIS. The radius of the patch is also recorded, along with an estimate of how the target NIS are distributed within the infestation; i.e., whether coverage is uniform or scattered. Additional data can be taken but should be kept to only two or three additional fields to prevent loss of survey efficiency.

While these other data are being entered by the crew, the GPS is set with the tracklog on so that the whole area sampled by each crew is known. This log allows crews to delineate areas free of NIS as well as NIS-infested areas. This absence information is as important as the presence information. Tracklogs can be set to record according to time elapsed or distance traveled; distance traveled is preferred.

All these data are saved within ArcPad as shapefiles on a data card that is later removed from the handheld computer and loaded onto a desktop computer running ArcView (ESRI Inc.). Depending on the GPS used, data are either corrected using Wide Area Augmentation System (WAAS) technology or differentially corrected to improve accuracy. While more expensive GPS units do increase accuracy, often resources are limited and must be allocated to either equipment or personnel. When resources are limited, it is better to allocate resources to personnel rather than to expensive equipment. While accuracy may be reduced with less expensive equipment, surveying larger areas allows managers to make better decisions about allocation of resources dedicated to control. Errors of several meters should not jeopardize data collection from an operational perspective. Relocating NIS with errors of up to 15 m should not place the species outside the detection distance.

Equipment Required

A handheld computer with a color screen visible in daylight and running Microsoft's PDA operating system is required. The Compaq IPAQ has worked well, as have the new Hewlett-Packard models with 640 by 480 pixel screens. We use a Nexia sleeve with the unit to provide two compact flash (CF) slots and an additional rechargeable battery. A number of CF slot GPS units are now available. Since models change rapidly, no specific models are listed here. A GPS unit that also allows attachment of an external antenna should be considered for use in steeper and forested terrain. A CF data card with a minimum capacity of 512 kilobytes should be purchased to hold data. Clear adhesive screen covers are needed to protect the handheld computer screen. Cases that enclose the PDA and GPS but still allow data collection can be purchased for additional protection.

Data layers are downloaded onto the CF data card. Digital orthophoto quads are used as a background data layer on the handheld units to help crew members visually locate themselves. Ownership boundaries are useful to include; roads and streams are visible on the orthophoto quads. On the desktop computer, ArcGIS ArcView (ESRI Inc.) is used to store data in shapefiles. The ArcPad application builder software is needed to build customized screens for data collection on the handheld computers.

Advantages and Disadvantages

An important advantage of this survey technique is its efficiency in mapping large areas, particularly when target NIS are of limited distribution. By design, areas to survey are limited to roads, trails, camping areas, livestock movement corridors, and waterway systems, thus simplifying survey planning. Targeting areas of human activity biases the survey to NIS that are primarily dispersed through human activity. However, the perpendicular transect, used if no NIS are found for 4 km, reduces the bias of the sampling technique. Utilizing such transects allows the survey crew to determine whether some NIS are found only in transects, which would suggest that stratification on a human disturbance features only is inappropriate. If the NIS found in the transect is a species of concern, then the survey technique can be adjusted.

The hardware and software required by this method are relatively inexpensive and easily used. Inexpensive handheld computers running ArcPad software allow flexibility in data recorded through use of ArcPad custom screens. The data are saved as shapefiles so transfer to a desktop is easy. When budgets are tight, the handheld computer linked to a GPS unit is considerably less expensive than GPS with inbuilt computers and higher positional accuracy.

Furthermore, limiting data collection to a few data fields reduces the time required to map an infestation.

In using the adaptive sampling method, two sources of error must be considered: positional error and detection error (the NIS is not found within area sampled when it is actually present). If budgets are limited, accepting greater positional error allows more money for labor, which reduces detection error. If the GPS satellite signal is lost, the units have sufficient detail in the background to do fairly accurate sketch-mapping directly on the handheld computer.

A final advantage of the adaptive sampling method is that using the tracklog of the GPS allows the entire area surveyed to be recorded, so that NIS-free areas can be determined, allowing us to infer additional information on the biology of the NIS of interest (e.g., habitat or aspect most susceptible to invasion and equally, those areas least likely to be invaded).

While the advantages of the adaptive sampling method outweigh the disadvantages, there are a few drawbacks to consider. Given the bias of the adaptive survey method towards trails and waterways, NIS that are not associated with travel routes or waterways, such as white bryony (*Bryonia alba*), would not be mapped well by this method. Although the efficiency of the survey methods allows large areas to be mapped, if an NIS is well distributed or if infestations are dense, then the method becomes too labor intensive. In addition, when several NIS co-occur on the landscape, mapping them simultaneously can make delineation of the outer boundary of each NIS confusing.

Other disadvantages are related to the equipment demands of the adaptive method. While the handheld units are easily mastered, at least one person on the crew should have GIS or computing skills to troubleshoot the inevitable problems with handheld computers, and the same individual is needed to assemble all the data on a desktop computer. In addition, the cheaper GPS hardware has greater positional error (inaccurate recording of location) than more expensive GPS units. However, the greatest disadvantage of cheaper equipment becomes apparent with steep terrain and/or a tree canopy cover where the GPS signal may be lost by the cheaper system, but still received by more sophisticated GPS units.

Regardless of these problems, adaptive survey is an efficient approach to sampling large areas for both the presence and absence of NIS, giving managers valuable data to inform their management decisions and allocate their limited resources for control.

References

Kalin, M. T., C. Marticorena, O. Matthei, and L. Cavieres. 2000. Plant invasions in Chile: present patterns and future predictions. Page 385 *in* H. A. Mooney and R. J. Hobbs, eds. Invasive Species in a Changing World. Washington D.C.: Island Press.

MacDonald, I. A. W., L. I. Loope, M. B. Usher, and O. Hamann. 1989. Wildlife conservation and the invasion of nature reserves by introduced species: a global perspective. Pages 215-255 *in* J. A. Drake, H. A. Mooney, F. di Castri, R. H. Groves, F. J. Kruger, M. Rejmánek, and M. Williamson, eds. Biological Invasions: A Global Perspective. Chichester, UK: John Wiley and Sons, Inc.

Mack, R. N. and W. M. Lonsdale. 2001. Humans as global plant dispersers: getting more than we bargained for. Bioscience 51:95-102.

Nilsson, C., E. Andersson, D. M. Merritt, and M. E. Johansson. 2002. Differences in riparian flora between riverbanks and river lakeshores explained by dispersal traits. Ecology 83:2878-2887.

Parendes, L. A. and J. A. Jones. 2000. Role of light availability and dispersal in exotic plant invasion along roads and streams in the H. J. Andrews Experimental Forest, Oregon. Conserv. Biol. 14:64-75.

Stallings, G. P., D. C. Thill, C. A. Mallory-Smith, and L. W. Lass. 1995. Plant movement and seed dispersal of Russian thistle (*Salsola iberica*). Weed Sci. 43:63-69.

Tackenberg, O. 2003. Modeling long-distance dispersal of plant diaspores by wind. Ecol. Monogr. 73:173-189.

Timothy S. Prather and Lawrence W. Lass

Background

Ground-based inventories and surveys can be very successful at finding nonindigenous species (NIS) across a landscape. Unfortunately, ground-based inventories/surveys can also be expensive, and variable terrain can limit their utility. Incorporating remotely sensed data into an NIS detection program can allow detection of NIS that are established within regional landscapes of interest. Ideally, remotely sensed data are used in tandem with ground-based inventories/surveys. In Bonneville County, Idaho, when a yearly ground-based survey program was augmented with remotely sensed data, county weed personnel were able to locate 50% more NIS patches.

Historically, detecting NIS using remotely sensed data involved aerial photography (Arnold et al. 1985), which was used to detect a range of species including salt cedar (*Tamarix ramosissima*), leafy spurge (*Euphorbia esula*), and Brazilian pepper (*Schinus terebinthifolius*) (Anderson et al. 1996; Bellmund and Kitchens 1997; Everitt et al. 1996). More recently, satellite and airborne multispectral sensors have been used for NIS detection (Lass et al. 2005). Multispectral sensors can record visible, infrared, and thermal reflectance into separate bands (usually less than 10 bands) that are saved in digital format. Data from multispectral sensors are typically referenced to ground coordinates so these data can be used within a geographic information system (GIS). The spatial resolution from multispectral sensors ranges from 30 m to less than 1 m, depending on the sensor used.

Sensor technology continues to change with the addition of hyperspectral sensors that record visible, infrared, and sometimes thermal bands into 30 to 255 bands (Lass et al. 2005). Increasing the number of bands increases the spectral resolution to allow distinction among intensity of colors; for example, shades of green can be measured instead of a single green band. The ability to more finely divide light reflected from the earth's surface allows greater distinction among colors of plants and, potentially, among chemical compounds within plants. The spatial resolution of hyperspectral sensors ranges from 20 m to less than 1 m. Finer spatial resolution allows detection of smaller patches of an individual plant species; however, the species must still occupy at least 30% of the ground surface in most cases before commissional error (presence on the image but not on the ground) rates begin to increase.

Objective

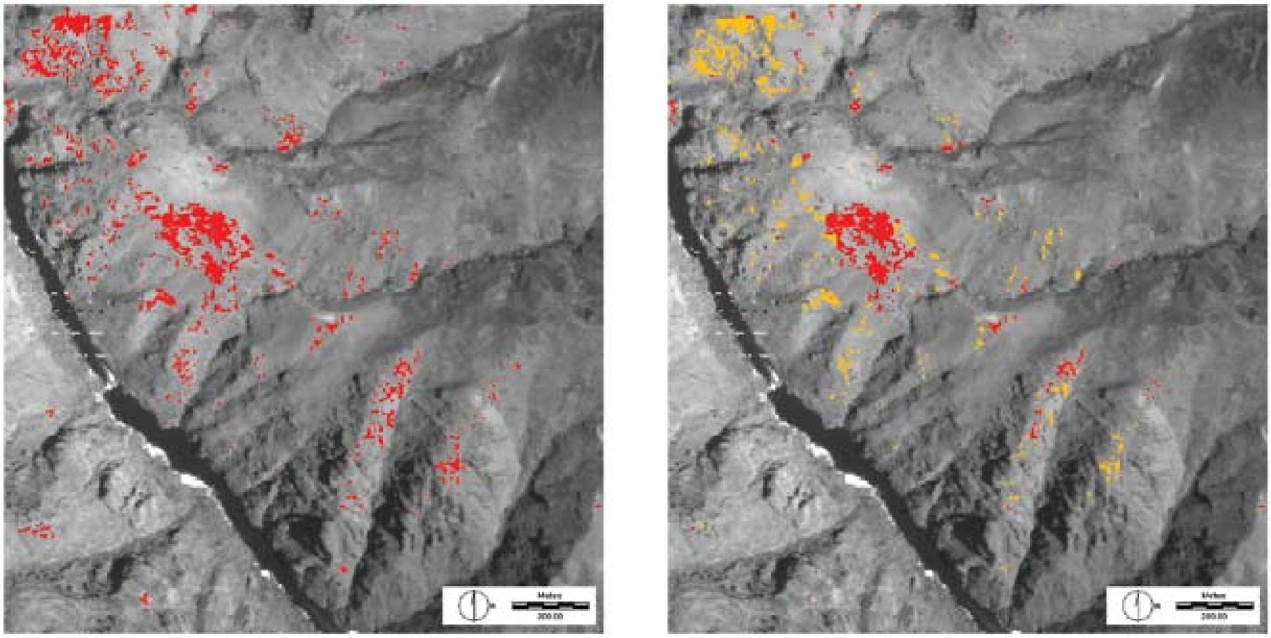
Remotely sensed data are used to detect plants and plant communities across extensive landscapes where ground-based survey resources are insufficient to cover all lands under management. In addition to plant detection, the data from multispectral and hyperspectral sensors can be used for other purposes, such as determining the percentage of exposed soil, water temperature in rivers or streams, vegetation health with respect to insect or disease damage, leaf area index, or the severity of a previous fire. Multiple uses for remotely sensed data should be explored prior to data acquisition, in order to identify an acquisition (time) window that meets as many objectives as possible. This chapter is intended for use by land managers as they consider whether remote sensing will help them meet their NIS management objectives and consequently plan to acquire suitable remotely sensed data.

Method

Classification of Data

Classification methods can be broadly divided between supervised and unsupervised classifications of the image data. A supervised classification uses spectral reflectance values of important features to classify pixels on the image. An unsupervised classification clusters data with similar values into groups of pixels, and those groups are then ground-truthed to determine what they represent. Supervised classifications, which are more likely to properly identify individual plant species, are further divided into hard and soft classification methods (Campbell 2002). Hard classification methods use known spectral values of features like NIS and compare those known values to the spectral values found within a pixel of the remotely sensed data. Soft classification methods require spectral reflectance values for all dominant features represented on the image. Both hard and soft methods are useful for classification of individual species.

Supervised classification is usually the first step toward detecting the presence of an NIS on the image. Classification assessment using errors of omission and commission will estimate the accuracy of the classification and indicate whether further procedures are necessary. An error of omission occurs when the classified image does not indicate the presence of an NIS even though it is present on the ground (its presence is known due to ground-truthing data). An error of commission occurs when the classified image indicates the presence of an NIS when it is not present on



1a 1b

Figure 1. Hyperspectral image of the Salmon River west of Grangeville, Idaho. Yellow starthistle (*Centaurea solstitialis*) was classified as red in (a). Some of the pixels classified as yellow starthistle in (a) contain annual grasses, particularly west of the river. Yellow starthistle in (b) was classified using a Bayesian method that used a yellow starthistle probability of occurrence model. Notice the lack of pixels classified as containing yellow starthistle west of the river. In addition, the gold color in (b) indicates pixels that have a moderate probability of containing yellow starthistle. The Bayesian method reduces commissional error.

the ground. With respect to NIS detection, errors of omission are considered more serious than errors of commission because NIS populations remain undetected with the former. Reducing the errors of omission tends to increase the errors of commission when supervised classification methods are used. Errors of commission increase the cost of ground-truth survey because time is spent visiting areas where the NIS is actually absent. Errors of commission also increase the area to ground-truth, but not substantially so, because the total area classified as containing infestations is generally a small percentage of the entire area imaged.

A Bayesian classification method (soft supervised classification) can be used to reduce errors of omission without increasing errors of commission when additional information such as the patchiness of a given NIS, areas less likely to be infested, or soil exposure necessary for establishment is available. The Bayesian classification uses the additional information to reduce the chance that some pixels will be incorrectly classified as containing the species of interest (**Figure 1**) (Lass and Prather 2004; Shafii et al. 2004). More information on classification methods can be found in Lass et al. (2005).

Timing

Differences in both color and texture of features on the ground need to be shown in images. Ideally, images should show maximum color and texture differences between the target NIS and other vegetation in order to provide the best differentiation between the features. Data used to identify a particular plant species should be acquired when that species is at a stage of growth that increases its chance of detection from surrounding plants. For example, leafy spurge (*Euphorbia esula*) is detectable from surrounding vegetation during its flowering period.

Typically, images for NIS evaluation are acquired from late spring to early fall, because factors that vary according to the time of year and the terrain, such as the angle of the sun, vary less at that time. Summer provides a longer daily window for image acquisition because image quality is best when the sun is near its high point in the sky. However, the months of July and August can present a challenge, since those months are ideal for detection of many NIS, yet data may be difficult to collect during fire season due to hazy conditions. Imagery should be acquired under minimal cloud cover, so times of year with high precipitation should also be avoided if possible. In areas where afternoon thunderstorms are common, data should be acquired earlier in the day.

Training Sites for Developing Reflectance Values

Successful detection of plant species with hard classification methods requires knowledge of the reflectance curves of the target species. There are two commonly used methods for obtaining reflectance curves. Measurements can be made of target NIS using handheld spectrophotometer instruments that quantify reflectance in discrete wavelength bands. Developing reflectance curves with a handheld instrument requires a spectrally calibrated sensor and atmospherically corrected remotely sensed images that have been corrected using light and dark panels placed on the ground for data acquisition. If the handheld sensor and the airborne sensor are not calibrated properly, the reflectance curve will not match the reflectance curve of the target NIS on the image. However, if both instruments are properly calibrated, the reflectance curve from the handheld spectrophotometer can then be used to classify pixels as potentially containing the target NIS.

Alternatively, data collected within the images may also be used to develop the reflectance curves. This is achieved by selecting training sites at locations where there is a known NIS patch of high cover density and area. The size of the training area should be 40 to 80 pixels, and it would be ideal to have several such locations in the data acquisition area. The reflectance curves are calculated either by averaging all pixels within the site, or by using a set of algorithms; i.e., artificial signature development algorithms using *a posteriori* least square orthogonal subspace (PLOS) projections (Chang 1999; Chang and Ren 2000; Chang et al. 1998; Ren and Chang 1998). Determining a spectral reflectance curve of both target NIS and nontarget species is critical for accurate classification.

Validation Sites for Assessing Classification Accuracy

Validation sites are locations that contain the vegetation being classified, but are separate from training sites. The size of the validation site is dependent on the image registration error based on ground coordinates. Image registration error occurs when the image does not exactly match features on the ground. Positional error is the horizontal variability in the GPS location data. Validation sites should be at least 3 by 3 pixels plus twice the sum of the expected image registration error plus the positional error. So if positional error is equal to the length of 1 pixel with registration error equal to 1 pixel, the validation site should be at least 7 by 7 pixels. Validation sites should include dense populations of target NIS and areas without the NIS; in other respects these sites should be environmentally similar to those used as training sites. Pixels within the validation sites are examined to determine if they are properly classified to calculate omissional and commissional error. A second set of validation sites should be established using smaller areas containing the target NIS at varying foliar plant cover amounts. The second set of validation sites allows determination of the percent cover occupied by the NIS that is detectable.

Equipment

Software

Classification of remotely sensed data requires considerable storage space (100 to 300 gigabytes) on a workstation-quality computer. Software for image classification is available from many companies; commonly used software includes Imagine, ENVI, IDRISI, and HyperCube (**Table 1**). Considerable technical training is required for processing imagery.

A handheld spectrophotometer is useful for collecting data during the acquisition process, and aids in correcting the data for atmospheric-related errors. Instruments measuring

Table 1. Sources of software for image classification.

Product	Organization	Address	Website
IMAGINE	Leica Geosystems Geospatial Imaging, LLC	Worldwide Headquarters 5051 Peachtree Corners Circle Norcross, GA 30092-2500	http://gis.leica-geosystems.com
ENVI	RSI	Corporate Headquarters 4990 Pearl East Circle Boulder, CO 80301	http://www.rsinc.com/index.asp
IDRISI	Clark Labs	950 Main Street Worcester, MA 01610-1477	http://www.clarklabs.org/Home.asp
HyperCube	U.S. Army Topographic Engineering Center	Alexandria, VA	http://www.tec.army.mil/Hypercube/

Table 2. Sources of high spatial resolution and high spectral resolution images.

Organization	Address	Website
AquilaVision, Inc.	121 East Broadway, Suite 105 Missoula, MT 59802	http://www.aquilavision.com/
HyVista Corporation	PO Box 437 Baulkham Hills NSW 1755 Australia;	http://www.hyvista.com/
ITRES Research Limited	#110, 3553-31st Street N.W. Calgary, Alberta, Canada T2L 2K7;	http://www.itres.com

reflectance in the visible and near-infrared range (400 to 1,000 nm) will work for most plant detection and atmospheric correction. A handheld unit measuring 400 to 1,000 nm costs about $10,000, and a semiportable unit measuring 400 to 2,500 nm costs about $65,000.

Positioning Equipment

A GPS should be used to identify locations where spectral data are collected by handheld units and to map the perimeter of the training and validation sites. If high-spatial-resolution (less than 3 m) remotely sensed data are acquired, then the GPS used should allow Wide Area Augmentation System (WAAS), so that differential correction can be employed to remove the effects of the atmospheric positional error.

Data Selection

The statement "It is the stingy man who spends the most" applies here. Data can be acquired at little or no up-front cost, but savings may be offset by frustration and failure to accurately detect target NIS populations because the spectral and spatial resolutions were not appropriate. There is an interesting rule of thumb suggesting that at least 9 pixels should cover the smallest desired target feature for best detection. If the desired detection level is a 1-m NIS patch, then there should be 9 pixels covering the patch. Such a fine spatial resolution problem illustrates the current limitations to use of remotely sensed data. The need for defining the appropriate resolution also applies to spectral resolution. If the target species is yellowish green and the background plants are green, then finer spectral resolution will be required for detection than if the background species were the orange or red of senescing vegetation.

Archived data for satellite-borne sensors launched by NASA can be acquired for $250 per scene (7.7 km to 37 km wide and 42 km long), or a scene (i.e., an individual image) can be requested for approximately $1,500 (Lass et al. 2005). Spatial resolution for these sensors, the Advanced Land Imager and Hyperion sensors, is limited to 30-m by 30-m pixel size. Detection of small patches requires finer spatial resolution than is available from most satellite-borne sensors. One satellite option for high spatial resolution is Quickbird, a multispectral sensor with 1- to 3-m pixel size (cost is $20,000 per 20-km by 40-km scene). High spatial resolution and high spectral resolution images from airborne hyperspectral sensors are available, at a cost of $17,000 to $35,000 per 20-km by 40-km scene, from a number of commercial companies; e.g., AquilaVision, HyVista, and ITRES (**Table 2**).

Advantages and Disadvantages of Remote Sensing for NIS Detection

Using remotely sensed data in an NIS detection program helps to prioritize where ground-based survey crews should search, but it does not replace the ground-based survey. The NIS detected on remotely sensed images focus ground-based surveys to confirm locations of new populations. In addition, the images classified for NIS patch locations are useful within a GIS to help plan NIS management activities.

Remotely sensed data can be used to gain a better understanding of conditions that may indicate increased susceptibility to NIS invasion. For example, purple loosestrife (*Lythrum salicaria*) requires moist sites to survive, so identifying areas with a high greenness index (i.e., lush growth) could indicate areas that should be monitored for possible future invasion. Rush skeletonweed (*Chondrilla juncea*) requires more open areas to establish, so low plant cover may indicate areas susceptible to its invasion. Other GIS-based techniques allow for the development of probability of infestation maps (Shafii et al. 2003) that can be further refined by using remotely sensed data (Prather et al. 1994; Rew et al. 2005).

Acquiring remotely sensed data that is classified for NIS can be expensive, as much as $20,000 or more, depending on the size and resolution of the area imaged. Airborne sensors are becoming less expensive for companies to purchase, and with lower capital outlay costs the cost of imagery may drop somewhat, but the images will still require classification by someone with training and experience in remote sensing.

Techniques for using remotely sensed data for detection of NIS continue to evolve. New techniques for classification, particularly ones that use a Bayesian approach, allow for proper classification of NIS populations when ground cover drops below 30%. The technology of the sensors also continues to evolve and will continue to provide additional spatial and spectral resolution that improve our ability to detect sparse patches of NIS. Remote sensing, coupled with ground survey, provides a potent combination for the future of NIS detection.

References

Anderson, G. L., J. H. Everitt, D. E. Escobar, N. R. Spencer, and R. J. Andrascik. 1996. Mapping leafy spurge (*Euphorbia esula*) infestations using aerial photography and geographic information systems. Geocarto Int. 11:81-89.

Arnold, G. W., P. G. Ozanne, K. A. Galbraith, and F. Dandridge. 1985. The capeweed content of pastures in south-west Western Australia. Aust. J. Exp. Agric. 25:117-123.

Bellmund, S. and W. Kitchens. 1997. Landscape Ecological Indices. Chapter 7 *in* Ecological and Precursor Success Criteria for South Florida Ecosystem Restoration. A Science Sub-Group Report to the Working Group of the South Florida Ecosystem Restoration Task Force. www.fiu.edu/~glades/taskforce/precursor/chapter7.html.

Campbell, J. B. 2002. Introduction to Remote Sensing. 3rd ed. New York: The Guilford Press. 622 p.

Chang, C. I. 1999. Least squares error theory for linear mixing problems with mixed pixel classification for hyperspectral imagery. Recent Res. Dev. Opt. Eng. 2:214-268.

Chang, C. I. and H. Ren. 2000. An experiment-based quantitative and comparative analysis of target detection and image classification algorithms for hyperspectral imagery. IEEE Trans. Geosci. Remote Sens. 38:1044-1063.

Chang, C. I., X. Zhao, M. L. G. Althouse, and J. J. Pan. 1998. A *posteriori* least squares orthogonal subspace projection approach to mixed pixel classification in hyperspectral images. IEEE Trans. Geosci. Remote Sens. 36:898-912.

Everitt, J. H., D. E. Escobar, M. A. Alaniz, M. R. Davis, and J. V. Richerson. 1996. Using spatial information technologies to map Chinese tamarisk (*Tamarix chinensis*) infestations. Weed Sci. 44:194-201.Lass, L. W. and T. S. Prather. 2004. Detecting the locations of Brazilian pepper trees in the Everglades with a hyperspectral sensor. Weed Technol. 14:537-442.

Lass, L. W., T. S. Prather, N. F. Glenn, K. T. Weber, J. T. Mundt, and J. Pettingill. 2005. A review of remote sensing of invasive weeds and example of the early detection of spotted knapweed (*Centaurea maculosa*) and babysbreath (*Gypsophila paniculata*) with a hyperspectral sensor. Weed Sci. 53:242-251.

Ren, H. and C. I. Chang. 1998. A computer-aided detection and classification method of concealed targets in hyperspectral imagery. Pages 1016-1018 *in* International Symposium Geosciences and Remote Sensing. Seattle, WA, and Piscataway, NJ: International Geoscience and Remote Sensing Society.

Rew L. J., B. D. Maxwell, and R. Aspinall. 2005. Predicting the occurrence of nonindigenous species using environmental and remotely sensed data. Weed Sci. 53:236-241.

Shafii, B., W. J. Price, T. S. Prather, L. W. Lass, and D. C. Thill. 2004. Using landscape characteristics as prior information for Bayesian classification of yellow starthistle. Weed Sci. 52:948-953.

Coarse-Scale Mapping: The Section or Quadrangle-based Method

Shana D. Wood and Eric M. Lane

Introduction

Land managers often need general coarse-scale information about the distribution and abundance of nonindigenous species (NIS) in large management areas, such as a county, state, or region. The minimum mapping units for such coarse-scale mapping projects have included Public Land Survey System (PLSS) sections and quarter-sections, and U.S. Geological Survey (USGS) 7.5-minute topographic quarter-quadrangles (Colorado Department of Agriculture 2005). Presence, absence, or unknown occurrence of the target NIS is recorded for the entire mapping unit, but no other biophysical attributes are recorded. If NIS presence is indicated for a mapping unit, an estimate of the acreage infested can also be recorded, thus providing a narrower range of total acres infested.

Objectives

The main objectives of coarse-scale mapping are to obtain rough estimates of the spatial distribution and acreages infested by NIS for large areas at coarse resolutions. For example, in Colorado, quarter-quad mapping (i.e., presence or absence and estimated infested acreage within each quarter-quad) shows the rivers and streams along which salt cedar (*Tamarix* spp.) is known to occur throughout the entire state. Such maps can also provide an indication of spread into new areas over time.

Coarse-scale maps can be put together using data gathered from weed management professionals on the ground and are therefore relatively inexpensive to produce. They provide a "big picture" of the current status of target species invasion on the landscape. And, as they are relatively easy to update, they can be used to monitor, in the broadest sense, where these species are moving, or where they have been eradicated. These maps are invaluable when trying to determine how to best coordinate management actions across a large area or region.

Background

In 1995 a group of federal, state, county, industry, and private land managers and researchers from Montana developed a plan to implement a standardized methodology for mapping NIS and for storing this spatial information in a statewide database. The working group established and sought funding for the Montana Noxious Weed Survey and Mapping System (MTWMS). The MTWMS developed standards for accurately mapping NIS populations at the 1:24,000 scale (Cooksey and Sheley 1998). A main objective of the MTWMS was to quantify rates of spread of designated noxious weeds by comparing noxious weed inventories over time. Many land managers utilized the MTWMS standards for mapping, and by 1999, county, state, and federal agencies had submitted spatial data from over 20 counties to the MTWMS. However, the MTWMS methodology is labor intensive and requires ground mapping unique NIS patches as points, lines, or polygons, either by hand sketching onto maps or aerial photos, or by global positioning system (GPS) mapping. If large areas are being mapped, extensive time in the field is required to perform the ground inventory/survey. Additional time is required to edit, process, and export the data to a geographical information system (GIS), where the data are stored and managed. The training, support, and technology required to implement and manage the highly detailed 1:24,000 mapping system precluded the rapid acquisition and updating of spatial data. As a result, monitoring short-term invasion rates was not a realistic outcome of the detailed mapping system. Furthermore, the time and effort required to implement such intensive mapping methods often prevented managers from implementing the MTWMS. As a result, while the need for highly detailed and accurate data to meet certain NIS management objectives was recognized, managers began to explore methods for obtaining NIS maps that were more rapid and less expensive, and that provided a more general picture of occurrence.

In 1997, the Montana Department of Agriculture (MDA) requested that the MTWMS undertake a coarse-scale (statewide) generalized inventory based on documenting the presence or absence of an NIS in square-mile sections of the Public Land Survey System (PLSS). This was called the Section Based Weed Mapping Project. The goal was to map the presence, absence, or unknown occurrence of five of Montana's noxious weeds for the entire state. Montana State University completed the first phase of the Section Based Weed Mapping Project in 1999. The MDA, the Montana Natural Resource Information System (NRIS), and county personnel currently manage the project, and have recently created a Web-based interactive map and data application for Section Based Weed Mapping. The Internet mapping interface increases the cost-effectiveness of the project by allowing weed managers to interactively complete and update section-based data for all Montana noxious weed species. Statewide noxious weed maps are updated regularly in the program, can be readily accessed online by selected county weed personnel, and will eventually allow users to produce maps to track spread into new sections over time.

Methodology

Coarse-scale maps are most efficiently generated using a GIS, which involves graphical depiction of the data stored in a database. In the simplest form, coarse-scale or generalized

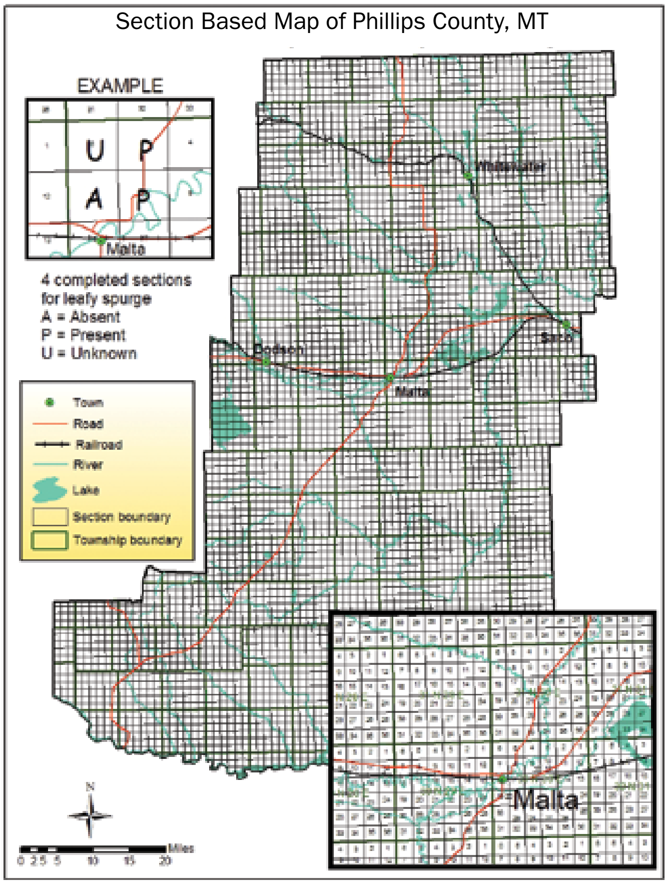


Figure 1. Example of a blank section-based map of Phillips County, MT. Data would be filled in for leafy spurge by the weed coordinator for Phillips County (after Powell County Quarter-Section Based Mapping Project, Jason Smith, Weed Coordinator).

mapping links the spatial unit (for example, square-mile sections) to a table that identifies whether an NIS is present, absent, or unknown in that entire unit. Spatial layers that form the framework of coarse-scale mapping are available for download from digital GIS data clearinghouses on the Internet. For example, the Section Based Weed Mapping Project implemented by the MDA uses several spatial layers available from the online digital library of the NRIS (http://nris.state.mt.us/), including PLSS sections and townships, county boundaries, highways, railroads, towns, and rivers.

Powell County Weed District includes weed management area boundaries on their quarter-section maps. These additional layers provide a spatial reference for each section's location.

County Level Examples

The NIS attributes are populated in the database table associated with the PLSS section. The NIS attribute can simply denote whether the species is present, absent, or status unknown in the given section, or the attribute can be assigned a category based on estimated number of acres infested in the unit. For example, Powell County uses the following categories: absent (no NIS), low (less than 8 acres), moderate (8 to 40 acres), and high (more than 40 acres) for each quarter section (160 acres). These attribute values provide a more accurate estimate of the acres infested.

Coarse-scale mapping takes advantage of the knowledge of landowners and land managers familiar with local landscapes. The utilization of local knowledge and direct experience is called knowledge-based mapping. Hard copy maps detailing each mapping unit (i.e., quarter-sections, sections, or quarter-quadrangles) are created and distributed to county weed coordinators if mapping at the statewide level, or to private landowners and state and federal land managers if mapping at the county level.

Examples of how coarse-scale maps are created are provided for Phillips and Powell counties in Montana. In both cases landowners participate to some extent with the data input into the map. In Phillips County, the weed coordinator receives a map that depicts each section within the county (landscape features such as roads and streams make identifying infested areas easier as well), and then records, for example, the status of leafy spurge (*Euphorbia esula*) in the sections where the information is known (**Figure 1**). The coordinator then consults with local land managers to fill in the knowledge gaps. If nothing is known about a particular section, the leafy spurge status is left as unknown, or changed to present or absent if knowledge is available. Completed maps for all noxious weed species are returned to the statewide mapping coordinator so a GIS specialist can compile data and generate final maps. An alternative approach is used by the Powell County weed coordinator who sends a quarter-section map for NIS of interest to each landowner participating in a cooperative weed management area in the county. Landowners fill in the target NIS information for their property and return the map to the weed coordinator. The county then compiles the information and can update the county-wide NIS maps. The compiled county data can easily be submitted to the statewide database.

State Level Examples

In Montana, the MDA and NRIS have designed a mapping application that enables county weed coordinators and other NIS managers to enter NIS location information interactively through the Internet. Weed managers with restricted access

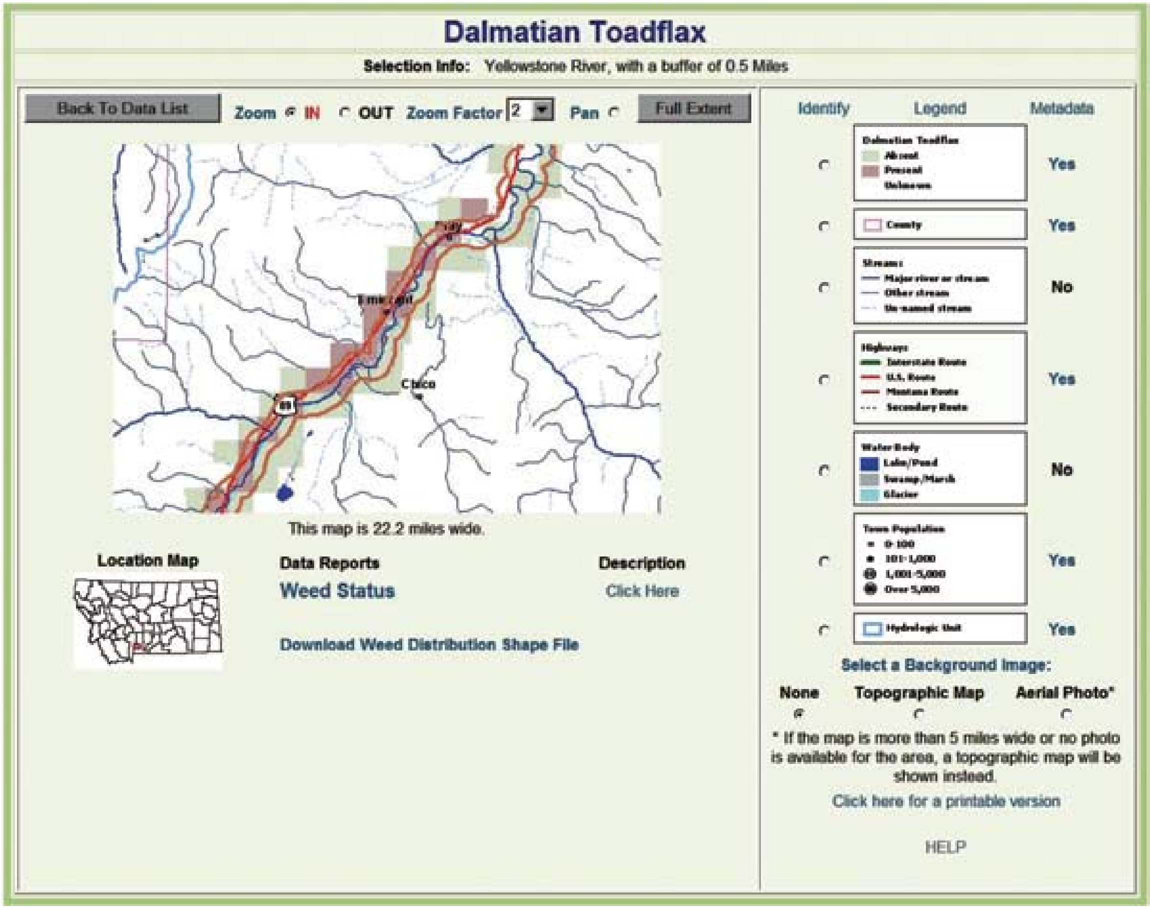


Figure 2. Interactive map of Dalmatian toadflax (*Linaria dalmatica*) along the Yellowstone River in Park County, MT, created by querying the NRIS Digital Atlas of Montana. The website for this interactive database is http://maps2.nris.state.mt.us/mapper/index.html. Users choose a search option (i.e., county), click on the "Land Information" tab, then choose which NIS to display from the "Section-based Weed Distribution" category.

to the application can update the database as they acquire new spatial information on the presence or absence of NIS per section. NRIS serves section-based maps on the Internet through their Digital Atlas of Montana (http://map2.nris.state.mt.us/mapper/index.html). Any interested user can query the atlas and build maps depicting NIS infestations using several search options, including counties, Indian reservations, national forests, towns, rivers, and highways (**Figure 2**). These section-based NIS maps can be made at any scale and laid over other map layers (e.g., topography, land ownership), printed from the Web interface, and imported into ArcView (ESRI Inc.) if desired.

In 2002, the Colorado Department of Agriculture, Colorado State University, the USDA Forest Service, and the Bureau of Land Management developed a statewide mapping program utilizing the quarter-quadrangle grid. A quarter-quadrangle is one quarter of a standard 1:24,000 USGS 7.5-minute topographic quadrangle. Twenty species of noxious weeds were mapped across Colorado by this methodology to determine statewide distribution and abundance. In addition, two species, leafy spurge and yellow starthistle (*Centaurea solstitialis*), were mapped across the western region through the Western Weed Coordinating Committee, utilizing the same methodology. In 2004 the Colorado Department of Agriculture remapped several species and mapped one new species, absinth wormwood (*Artemisia absinthium*), using the quarter-quad methodology.

The success of quarter-quadrangle mapping relies on the knowledge of county weed managers and other weed management professionals from state and federal land management agencies. Acreage data are solicited periodically for identified species of concern, typically state noxious weeds targeted for coordinated statewide management. A formal request is sent out to county weed supervisors requesting

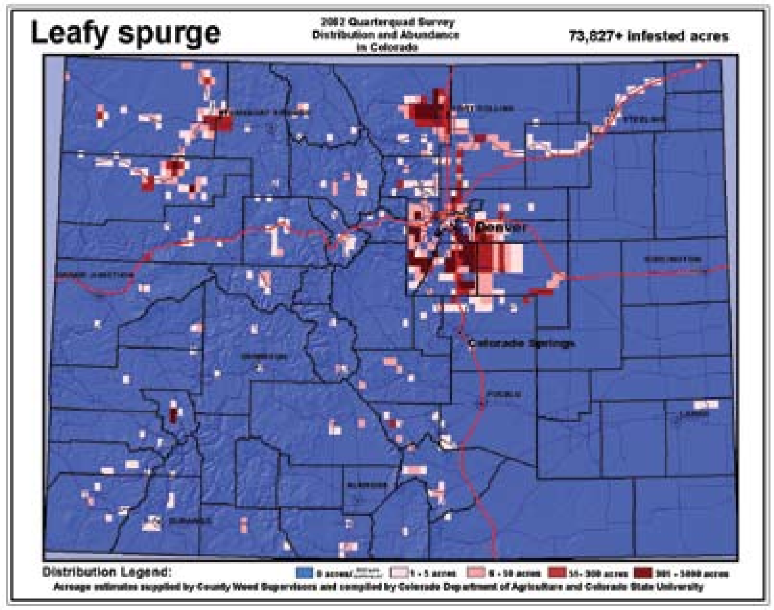


Figure 3. Example of a quarter-quadrangle survey map of leafy spurge (*Euphorbia esula*) distribution and abundance in Colorado.

basic information on the presence or absence of specific NIS within their county. If they reply that any of the target NIS are present in their county, then a hard copy of a map is created for the county. The hard copy is then mailed to the county weed supervisor along with instructions and a spreadsheet. The county weed supervisor is responsible for supplying and/or coordinating the collection of information regarding the targeted NIS for all lands within their county (private, city, state, and federal). The county weed supervisor fills out the spreadsheet by inputting the number of acres present (according to North American Weed Management Association standards [NAWMA 2003], and using their definition of "infested acreage") within a particular 9,000-acre quarter-quadrangle for each species. This information is then sent to Colorado Department of Agriculture to be input into the GIS database. A few counties simply send in their GIS data layers to be merged with the Colorado Department of Agriculture's GIS data layers. Maps depicting the statewide distribution and abundance are then created for each target species on a statewide level based on the information sent in by county weed supervisors. On the online maps, each block of color represents that the 9,000-acre area is infested (**Figure 3**). The number of infested acres within each quarter-quadrangle for each NIS is represented by different colors: lighter colors for lower acreages, to darker colors for greater acreages. The black patches are infestations that have been successfully eradicated since the initial mapping. The few counties that do not report are shown with a crosshatch pattern over the county.

All completed species maps can be found on the Colorado Department of Agriculture, Noxious Weed Program, QuarterQuad Survey Web page, at http://www.ag.state.co.us/CSD/Weeds/mapping/QuarterQuadSurvey.html. The

Table 1. Equipment required for implementing a quarter-section-based mapping program such as the one administered by Powell County, Montana.

Equipment	Example	Purpose
Computer		Store data
GIS software	ESRI ArcGIS 9 or ESRI ArcView 3x	Capture, store, manage spatial data
Spreadsheet or database software	Microsoft Excel or Access	Enter, store, manage tabular data
Digital spatial layers	Administrative layers (counties, towns, transportation routes) Environmental layers (rivers, lakes)	Create maps for capturing and displaying NIS data. Many states have digital data clearinghouses online that have spatial layers available for download.
Color printer		Print 8½ by 11-inch maps for distribution to local land owners/managers
Plotter		Print poster-sized maps for display and management
Personnel	County weed supervisor	Administer and manage mapping project, generate maps, contact land owners/managers, manage spatial data (computer management and GIS skills required)
Office/computer equipment	Paper, pens, printer/plotter ink cartridges, envelopes/stamps, etc.	Print maps, mail maps to cooperators, back up digital data

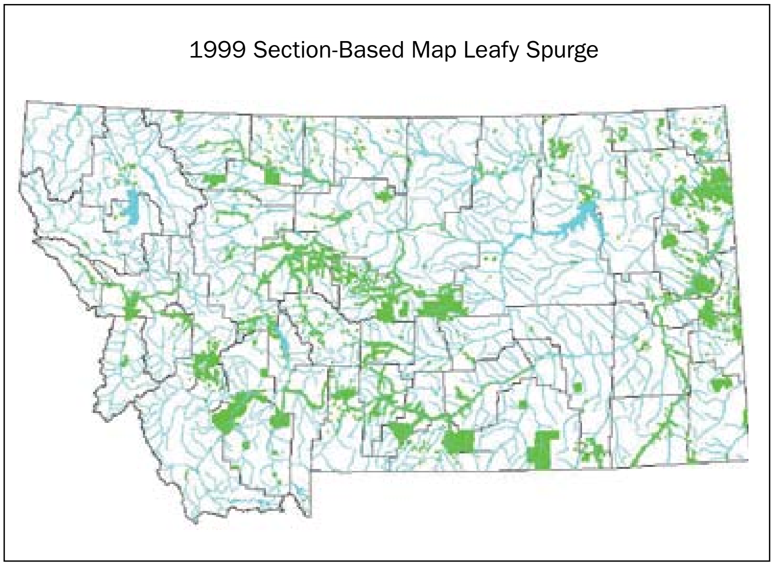


Figure 4. Montana Department of Agriculture section-based map of leafy spurge (*Euphorbia esula*).

2002, 2004, and 2005 GIS datasets can also be downloaded from that Web page. (The QuarterQuad Survey page is best viewed in Internet Explorer.)

Equipment Needed

If there is no existing state- or agency-led initiative to perform and store coarse-scale mapping data, establishing a program from scratch requires a relatively simple combination of personnel and equipment. The basic equipment required to implement a coarse-scale mapping program includes computer hardware and software, digital spatial layers for creating maps, a color printer or plotter, trained personnel, and miscellaneous office equipment. **Table 1** details a more specific list of essential equipment. If an objective is to make the data available on the Internet, additional software is required as well as a secure network connection, computer server, Internet map server software, and trained information technology and systems analysis support.

Advantages and Disadvantages of Coarse-Scale Mapping

Coarse-scale mapping is a time- and cost-effective method for obtaining an approximate picture of NIS distribution and abundance over large and jurisdictionally complex areas such as counties, national forests, and states. Further, coarse-scale maps span multiple management boundaries and landscapes, allowing landowners and managers to develop shared management objectives and coordinate nonindigenous plant management efforts over large areas. For example, section-based maps for five NIS were included in the Montana Weed Management Plan (Weed Summit Steering Committee and Weed Management Task Force 2001), and **Figure 4** illustrates distribution of leafy spurge in Montana.

Mapping at coarse scales such as mile-square (640-acre) or quarter-quadrangle (9,000-acre) grid cells is based on landowners' and managers' knowledge of the land. Consequently, it is much less detailed than ground-based and other mapping methods, and even at the coarse scale collected, it is potentially inaccurate because it is very dependent on the identification and memory skills of the people involved. However, the advantage is that maps can be made of the probable occurrence of NIS over large areas of land, and depending on the approach taken, the relative location (presence within the grid or minimum mapping unit) and estimates of infested acreage can be compiled quite quickly and inexpensively. For example, it takes only two weeks for Powell County to update their maps. The coarse-scale maps can also be used to monitor, in the broadest sense, spread or loss (eradication) of target NIS over the area of interest. However, coarse-scale mapping does not provide exact acreages (size) or correlation with environmental variables. Therefore, coarse-scale maps are not appropriate for site-specific management or as a tool for analyzing invasion biology and processes.

Acknowledgements

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References

Colorado Department of Agriculture. 2005. 2002 and 2004 QuarterQuad Survey. http://www.ag.state.co.us/DPI/NIS/mapping/QuarterquadSurvey.html.

Cooksey, D. and R. L. Sheley. 1998 (revised 2001). Mapping Montana's Noxious Weeds. Bozeman, MT: Montana State University Extension EB 148. 20 p.

[NAWMA] North American Weed Management Association. 2003. North American Invasive Plant Mapping Standards. http://www.nawma.org/.

Weed Summit Steering Committee and Weed Management Task Force. 2001. The Montana Weed Management Plan. Helena, MT: Montana Department of Agriculture. 96 pp. http://www.mtweed.org/News/the_weed_plan.pdf.

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Introduction

Anticipating species that will become invasive and knowing where to look for them is a critical aspect of nonindigenous plant management. Managers and policy makers alike want to know the likelihood that new nonindigenous species (NIS) will become prevalent over large areas, as well as which habitats and ecosystems are at risk of invasion. Although NIS inventory/survey and monitoring activities are critical to developing effective NIS management programs, they are limited in their ability to predict the likelihood of future invasions by different species. Thus, ecologists generally have been able to provide only after-the-fact explanations for NIS invasions. Risk assessments, like those currently employed by state and federal land management agencies to assess wildfire risks, are an emerging tool to assess the risk of NIS establishment and spread. Here we introduce the concept of nonindigenous plant species risk assessment and provide an example of an ongoing project in northeast Oregon. Additionally, potential benefits to land managers and current challenges to the development of usable, effective, on-the-ground NIS risk assessments are discussed.

What Is an NIS Risk Assessment?

The primary objective of an NIS risk assessment is to serve as a proactive tool for land managers and policy makers that (1) evaluates the likelihood of NIS establishment and spread, (2) identifies which species pose the greatest threat in a particular area or landscape, and (3) highlights areas at greatest risk to certain NIS. The information can then be used to prioritize management actions, including NIS inventory/survey, monitoring, prevention, control, and restoration activities.

Risk assessments generally include information on (1) ecological and environmental characteristics of an area, such as vegetation, land use, disturbance history, slope, elevation, and soil; (2) biological information on particular NIS, such as their habitat requirements and spread rates; and (3) locations of NIS taken from patch observations. This information can be combined using a geographic information system (GIS) so that areas can then be classified or ranked on their "invasability" or degree of risk to NIS invasions.

How Is an NIS Risk Assessment Planned and Conducted?

In 2002, we began developing a prototype NIS risk assessment model. The study objectives were to assess the feasibility of creating effective risk models using existing data from the USDA Forest Service, and to identify challenges limiting their development and use. The Starkey Experimental Forest and Range (SEFR), located in the Blue Mountains of northeastern Oregon, was chosen as the initial study area because of its manageable size (77.6 km^2, or 19,180 acres), diverse landscape of forest and grassland communities, and the availability of a GIS database for the area. Elevations in SEFR range from 1,122 to 1,500 m (3,681 to 4,921 ft), and dominant plant communities include mixed conifer and ponderosa pine (*Pinus ponderosa*) forests, as well as grasslands dominated by bluebunch wheatgrass (*Pseudoroegneria spicata*). Here we outline the process of conducting an NIS risk assessment by focusing on one NIS, sulfur cinquefoil (*Potentilla recta*).

In 2003, after sulfur cinquefoil was initially found in SEFR during an NIS inventory, we wanted to assess the risk of its further spread within SEFR. Sulfur cinquefoil can invade and dominate a variety of vegetation types (see Rice 1999; Zouhar 2003; and Endress and Parks 2004 for summaries of sulfur cinquefoil ecology and management). Roadsides, abandoned agricultural fields, clear-cuts, and other disturbed sites are particularly susceptible to invasion by this plant species. Additionally, low-disturbance sites, including native bunchgrass communities, ponderosa pine stands, and open-canopied mixed-conifer forests, are also susceptible. Sulfur cinquefoil can pose a serious threat in many areas of the Blue Mountains ecoregion due to its prolific seed production. When plant communities become infested with sulfur cinquefoil it is believed that native plant diversity decreases and natural ecosystem processes are altered (Rice 1999).

To determine areas at risk to sulfur cinquefoil invasion and to produce a risk map for SEFR, we considered three factors: (1) the susceptibility of existing plant communities to invasion, (2) disturbance history, and (3) the proximity to current infestations.

Susceptibility

Susceptibility is the vulnerability of plant communities in SEFR to the establishment of sulfur cinquefoil. To determine susceptibility we collected sulfur cinquefoil occurrence information from state, federal, and private organizations within the Blue Mountains ecoregion (including Wallowa, Union, Umatilla, and Baker counties) and combined this information with existing vegetation information in GIS. The combined data verified which plant communities within the

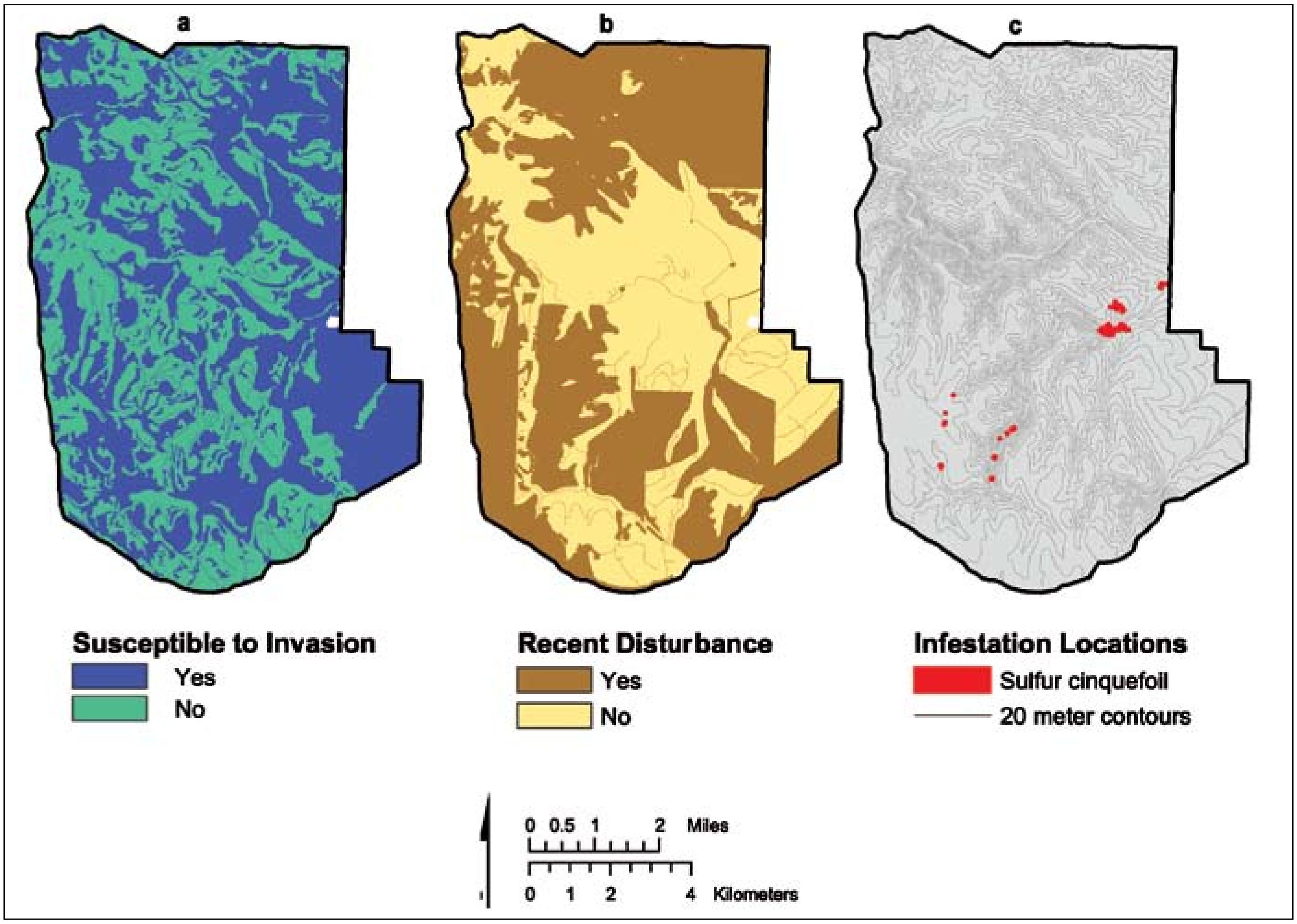

Figure 1. The three components of the NIS risk assessment for Starkey Experimental Forest and Range, including (a) susceptibility of areas to invasion by sulfur cinquefoil (*Potentilla recta*), based on previous infestations in the Blue Mountains ecoregion, (b) areas of disturbance (fire, timber harvest, roads) that increase site susceptibility to invasion, and (c) location of sulfur cinquefoil infestations as identified by an inventory in 2003.

region have been invaded by sulfur cinquefoil. Plant communities in SEFR were then assigned to one of the following susceptibility levels: (1) susceptible: the plant community is susceptible to sulfur cinquefoil invasion, (2) nonsusceptible: the plant community is not susceptible to sulfur cinquefoil invasion, and (3) unknown: the susceptibility of the plant community to sulfur cinquefoil is unknown. The resulting susceptibility map for SEFR is shown in **Figure 1a.**

Disturbance History

Previous studies indicated that soil or vegetation disturbances increase the vulnerability of areas to sulfur cinquefoil invasion (Rice 1999; Zouhar 2003). Therefore, we constructed a disturbance layer using available information on timber harvest, fuels reduction activity, prescribed fires and wildfires, and roads for areas within SEFR. Areas were assigned to the following categories: (1) disturbed: vegetation or soil disturbance in the past 15 years, and (2) undisturbed: no major disturbance in the recent past. The resulting disturbance layer for SEFR is shown in **Figure 1b**.

Proximity to Current Infestations

Observations from SEFR in 2003 revealed the locations of several sulfur cinquefoil infestations (**Figure 1c**). Because sulfur cinquefoil reproduces only by non-airborne seeds, we assumed that areas near current infestations are more likely to be invaded than areas farther away. We then created three qualitative categories based on their proximity to current

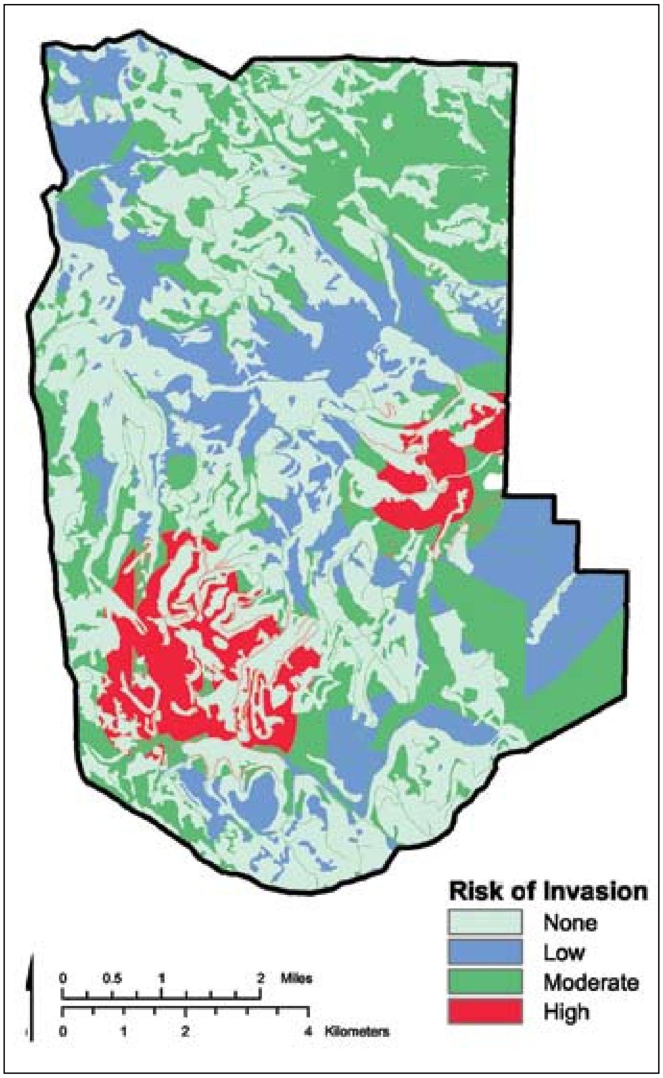

Figure 2. Risk map for sulfur cinquefoil (*Potentilla recta*) invasion in Starkey Experimental Forest and Range. Risk levels were assigned on the basis of site susceptibility, disturbance history, and proximity to current infestations.

infestations: (1) high exposure: areas within 500 m (1,640 ft) of current infestation, (2) moderate exposure: areas from 500 to 1,000 m (1,640 to 3,281 ft) from infestation, and (3) low exposure: areas farther than 1,000 m (3,281 ft) from a current infestation.

Developing a Risk Map

A risk matrix was then constructed based on the susceptibility, disturbance, and proximity classifications, and areas were assigned to four levels of risk: none, low, moderate, and high (**Table 1**). A risk map for potential sulfur cinquefoil spread in SEFR was then developed (**Figure 2**). The risk map indicated that 41%, or 5,526 ha (13,654 acres), of SEFR is susceptible to invasion by sulfur cinquefoil; of this, 5% of SEFR is at high risk, 21% is at moderate risk, and 15% is at low risk of invasion. The risk assessment also provides additional information about at-risk areas (**Table 2**). For example, 61% of bluebunch wheatgrass grasslands are at moderate or high risk of invasion, while over 95% of Idaho fescue (*Festuca idahoensis*) grasslands, which make up less than 3.2 ha (8 acres) within SEFR, are at moderate or high risk of invasion. This type of information can be valuable for land managers, particularly when assessing threats to rare or sensitive habitats or plant communities, or when managers are estimating costs of control or prevention efforts and prioritizing management activities of an area.

Additional Approaches to Risk Assessment

NIS risk assessments can be performed in a variety of ways. For example, although our approach identified areas susceptible to invasion by using regional reports of occurrence of sulfur cinquefoil in specific plant communities, a different variable could have been used to assign levels of susceptibility, such as percent tree canopy cover. In another area of the Blue Mountains, data indicates that sulfur cinquefoil rarely infests areas with more than 50% canopy cover (Endress, unpublished data). Thus, we could have used this variable to classify susceptible areas. Clearly, a wide range of variables (e.g., canopy cover, soil, slope, disturbance) or combinations of variables could be used to assign levels of site susceptibility if the variable(s) predictably influence the likelihood of invasion, and the data are available for inclusion into a GIS database. In the case of sulfur cinquefoil, existing plant community information was used because it was the most current data available, and because existing vegetation often incorporates a suite of environmental variables such as soil type, elevation, and precipitation. We used disturbance in our model because sulfur cinquefoil invasions are associated with areas of vegetation and/or soil disturbance (Rice 1999; Zouhar 2003).

Additional components can also be included when assessing NIS risk. For example, an NIS risk assessment for northern Idaho and western Montana included a "threat" component, which ranked plant communities according to the degree of change to their structure, composition, or function as a result of an invasion (Mantas 2003). This component could be a useful addition to our model because both mixed conifer forests and bluebunch wheatgrass grasslands are susceptible to sulfur cinquefoil invasion; however, the detrimental effects of the invasion are likely to be greater in

Susceptibility	Disturbance	Proximity	Risk
Yes	Yes	Low	Moderate
Yes	Yes	Moderate	High
Yes	Yes	High	High
Yes	No	Low	Low
Yes	No	Moderate	Moderate
Yes	No	High	High
No	Any level	Any level	No Risk
Unknown	Any level	Any level	Unknown

Table 1. Risk assessment classification based on susceptibility, disturbance, and proximity to current infestations.

Table 2. Summary information on risks to selected plant communities within Starkey Experimental Forest and Range, including the number of hectares/acres and percent area of the plant communities exposed to the different levels of risk.

	Bluebunch wheatgrass			Sandberg's bluegrass			Idaho fescue			Ponderosa pine			Ponderosa pine-Douglas fir		
Risk level	% area	ha	acres	% area	ha	acres	% area	ha	acres	% area	ha	acres	% area	ha	acres
Low	37	867	2143	22	64	158	5	< 1	0.4	28	136	335	45	463	1144
Moder-ate	47	1081	2670	46	133	329	95	3	7	60	288	712	40	413	1021
High	14	326	805	31	91	224	< 1	< 1	0.1	11	51	126	14	147	363

the grassland (where a transition from a perennial bunchgrasses to a forb-dominated system would ensue) than in the forest, where sulfur cinquefoil is unlikely to affect overstory composition, structure, or succession.

Multiple NIS in a Single Risk Assessment?

Adding other species to the risk assessment involves estimating susceptibility, disturbance, and proximity information for each species. Combining risk information for multiple species would result in a powerful database where land managers could examine which areas or habitats were at risk of impacts from multiple NIS. Such a multiple species model could also assist in deciding which areas or NIS populations should receive attention from land managers. Additionally, NIS risk assessments can expand beyond our current description (to determine specific areas at greatest risk of establishment and spread of one or more NIS) to include information to help direct management actions. For example, NIS risk assessments could be expanded to be capable of (1) identifying and delineating areas for protection by defining areas of highest risk but low frequency of invasion, (2) delineating areas for restoration (high risk and high frequency), and (3) assessing the effects of various control efforts on the spread of NIS.

Advantages and Disadvantages of NIS Risk Assessments

When NIS risk assessments are coupled with monitoring activities they can be a powerful tool for land managers to use in prioritizing NIS management activities. Assessments can help identify which NIS require the most attention and what areas are most at risk to new invasions. The greatest advantage of NIS risk assessment is that it provides a proactive approach for management of NIS. The use of risk assessments allows:

- Proactive and preventative management, not just reactive response to NIS invasions
- Assessment of NIS management priorities and costs
- Production of maps that assist in the efficiency and effectiveness of land management over time
- Assessment of large landscapes for NIS at a fraction of the costs of complete inventory or systematic survey and monitoring procedures

However, despite their promise, NIS risk assessments are only in the developmental stage, and usable, verified risk assessments are in their infancy. Several conceptual and practical challenges, as listed below, must be addressed before NIS risk assessments become a reliable tool for land managers and policy makers:

- Assessments need to be general enough to predict risk for many NIS, but adaptable enough to change criteria for different species.
- Resolution of the information must be considered: scales too coarse for application and too fine for use in detecting invasions within the landscape are of limited use to land managers.
- Biological information that is needed to parameterize risk assessments is lacking for many NIS. For example, information on NIS habitat suitability, long- and short-distance dispersal mechanisms, relationships with disturbance agents, and ecological and socioeconomic impacts of invasion are needed.
- GIS coverage on existing vegetation (i.e., not "potential" vegetation) is often absent or not recent, which can have considerable impact on the quality of results.
- Risk assessments are most effective when based on information from recent, in-depth NIS inventories or surveys. Such activities can be time consuming and expensive and are lacking for many managed landscapes. However, previous chapters in this book suggest effective inventory/survey methods.

Many of these challenges can be overcome by additional work and research. Without doubt, NIS risk assessments hold great promise for enabling land managers to proactively address NIS problems and increase the effectiveness of prevention, control, eradication, and restoration efforts in an efficient, cost-effective manner.

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References

Endress, B. A. and C. G. Parks. 2004. Element Stewardship Abstract (ESA) for *Potentilla recta* L. Sulfur cinquefoil. Wildland Invasive Species Team, The Nature Conservancy. http://tncweeds.ucdavis.edu/esadocs/poterect.html.

Mantas, M. 2003. Evaluating Risk to Native Plant Communities from Selected Exotic Plant Species (draft report). National Fire Plan Cohesive Strategy Team, Northern Region. http://www.fs.fed.us/r1/cohesive_strategy/data/weeds.htm.

Rice, P. M. 1999. Sulfur cinquefoil. Pages 382-387 ***in*** R. L. Sheley and J. K. Petroff, eds. Biology and Management of Noxious Rangeland Weeds. Corvallis, OR: Oregon State University Press.

Zouhar, K. 2003. *Potentilla recta.* In Fire Effects Information System. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory. http://www.fs.fed.us/database/feis/plants/forb/potrec/index.html.

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