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PRIORITIZING NON-NATIVE INVASIVE PLANT MANAGEMENT ON ARMY INSTALLATIONS

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Facilities Engineering
Environmental

PRIORITIZING NON-NATIVE INVASIVE PLANT MANAGEMENT ON ARMY INSTALLATIONS

1. Purpose.

a. This Public Works Technical Bulletin (PWTB) provides an overview of non-native invasive plant species (NIS) management prioritization on Army installations, including general recommendations and specific examples of approaches useful for technical experts. Rather than provide an exhaustive treatment of every potentially relevant aspect of prioritization, the intent is to present sufficient information to stimulate greater consideration of the necessity and benefits of prioritizing NIS management efforts. The information provided will help installation personnel anticipate and avoid common pitfalls and errors associated with NIS management, particularly when confronted with multiple and potentially conflicting land use needs. The information provided should also help installation personnel hire or supervise an expert to conduct appropriate prioritization analyses.

b. All PWTBs are available electronically (in Adobe® Acrobat® portable document format [PDF]) through the World Wide Web (WWW) at the National Institute of Building Sciences' Whole Building Design Guide web page, which is accessible through URL:

http://www.wbdg.org/ccb/browse_cat.php?o=31&c=215

2. Applicability. This PWTB applies to all U.S. Army training and testing facilities but particularly to training and testing installations.

3. References.

a. Federal Noxious Weed Act of 1974 (FNWA) as amended [7 U.S.C. 2809].

b. Endangered Species Act (ESA) [Public Law (PL) 93-205 as amended, 16 U.S.C. 1531-1544].

c. Pollution Prevention Act of 1990 [PL 101-508].

d. Executive Order (EO) 13112, "Invasive Species," [64 CFR 6183], 8 February 1999.

e. Army Memorandum, Army Policy Guidance for Management and Control of Invasive Species, Department of the Army, Assistant Chief of Staff for Installation Management (DA-ACSIM), 26 June 2001.

f. Army Regulation (AR) 200-1, "Environmental Protection and Enhancement," 28 August 2007.

4. Discussion.

a. In 2001 DA-ACSIM issued policy guidance (reference 3e above) for the management and control of invasive species. This guidance summarizes Army requirements for compliance with EO 13112, which outlines Federal agency duties to prevent the introduction of invasive species, provide for their control, and minimize the impact that invasive species may cause. The DA-ACSIM policy guidance requires installations to:

i. budget funds to effectively plan and execute invasive species management on installations;

ii. manage invasive species within the context of the goals and objectives of their Integrated Natural Resources Management Plan (INRMP);

iii. monitor invasive species populations to determine when control measures are necessary and to evaluate the effectiveness of prevention, control, and restoration measures;

iv. give priority to invasive species management actions that restore native species habitat in ecosystems that have been invaded, support the installations primary military mission and/or contribute to the protection of federally listed threatened and endangered species and critical habitat; and

v. ensure that invasive species do not detract from the usefulness of military training and testing lands.
Although the requirements of this guidance are clear, implementing management efforts to accomplish these multiple and potentially competing requirements is not without challenges.

b. In general, comprehensive strategies for NIS management depend upon a multi-pronged approach that includes prevention, early detection, control, monitoring, assessment, and education. NIS control is arguably the most challenging of these because it typically requires the greatest monetary investment, suffers the greatest setback from poor choices, and demands the greatest coordination among multiple stakeholders. This document addresses the highly important but under-emphasized process of prioritizing NIS control efforts. In this overview, NIS prioritization is driven by two sub-objectives: minimizing impacts to training and natural resources management, and ensuring certain management efficiencies are realized. This problem is not trivial and requires an objective, transparent resolution. To date neither guidance nor general discussion of NIS management prioritization has been widely available to Army or other public land managers.

c. NIS management prioritization can be aided by multi-criteria decision analysis (MCDA). MCDA is defined as an evaluation based on multiple criteria, wherein the criteria are quantifiable indicators of the degree to which decision objectives are realized (Malczewski 1999). MCDA is intended to provide a rational way to help decision-makers solve complex problems objectively. MCDA is ideal for NIS management prioritization because it can provide a framework in which to incorporate multiple diverse stakeholder interests with multiple datasets describing NIS impacts. Although MCDA forces certain assumptions and uncertainties are inherent, the process strives to provide the best answer available using limited data and an incomplete understanding of the problem. The process can also help identify datasets that might aid MCDA. The prioritization process also presents an ideal opportunity for Army installations to integrate NIS management planning with other natural resources management planning; a requirement of AR 200-1.

d. The cost relative to the benefit of applying a NIS management prioritization process similar to the one described in this document depends upon the complexity of the NIS management issues on a given installation as well as the availability of data to support the analysis. However, the cost of planning typically represents only one or two percent of the total NIS management cost, making the potential payoff significant.

e. Appendix A contains a detailed approach for prioritizing NIS management on Army installations, based on MCDA. This approach is illustrated with two case-study examples representative of the NIS management scenarios common to many Army installations.

f. Appendix B lists literature cited in Appendix A.

g. Peter Frank of Invasive Species Management, Inc. provided invaluable assistance in developing this document.

5. Points of Contact (POCs). Headquarters, U.S. Army Corps of Engineers (HQUSACE) is the proponent for this document. The POC at HQUSACE is Malcolm E. McLeod, CEMP-II, 202-761-0632, or e-mail: Malcolm.E.Mcleod@hq02.usace.army.mil.

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APPENDIX A: Introduction

Non-native invasive plant species (NIS) pose difficult challenges for environmental and natural resource management on military lands. NIS have the potential to negatively impact military operations, reduce military carrying capacity, compromise long-term sustainability of training lands, and degrade threatened and endangered species (TES) habitat (Westbrook and Ramos 2005). A critical first step that installations face when attempting to effectively mitigate NIS impacts is the development of a comprehensive integrated NIS management plan. Ideally, an integrated NIS management plan objectively combines input and data from multiple stakeholders, as well as invasive plant distribution data, to generate a basis from which control efforts can be prioritized, budgeted, implemented, and monitored.

Management prioritization is a critical component of integrated NIS management plan development because NIS impacts are spatially variable and management needs will typically exceed the funds available for controlling NIS infestations. Because land use and management are more diverse on Army installations than most other public properties, Army land managers often struggle to simultaneously manage TES habitat, sustainable training lands, wildlife populations, forestry programs, and agricultural out-leasing, while attempting to control NIS populations. Consequently, Army land managers need assistance in making complex management decisions that can ultimately have real consequences for both the short- and long-term success of NIS control efforts, whether highly localized or installation-wide. A formalized, objective, and transparent methodology for prioritizing management efforts is especially necessary when multiple stakeholder needs must be incorporated into NIS control strategies.

NIS management prioritization can be aided by a multi-criteria decision analysis (MCDA). MCDA is defined as an evaluation based on multiple criteria, wherein the criteria are quantifiable indicators of the degree to which the decision problem may be influenced (Malczewski 1999). MCDA is intended to provide a rational way to help decision-makers solve complex problems objectively. MCDA is ideal for NIS management prioritization because it can provide a framework in which to incorporate multiple diverse stakeholder interests with multiple datasets describing NIS impacts.

Each installation faces unique NIS management challenges due to varied training land uses, land management needs, protected species concerns, and habitat types. The type of MCDA most appropriate for prioritizing NIS management on a particular installation is influenced by the complexity of the training and land management requirements, as well as the availability of data to support analyses. For example, a relatively simple MCDA may suffice for small installations with few NIS impacts, patch-level NIS presence/absence data, and a limited number of stakeholders. Larger installations with multiple NIS impacts, detailed NIS distribution data, and many stakeholders representing diverse interests will likely need a more complex MCDA approach.

MCDA is an umbrella term that includes both multi-attribute decision analysis (MADA) and multi-objective decision analysis (MODA) (Malczewski 2007). MADA consists of selecting from a relatively limited set of discrete alternative solutions. In MODA there is a one-to-many relationship between objectives and criteria, with the most general objective at the top of the hierarchy and the most specific evaluation criteria used in the decision analysis at the lowest level. When prioritizing NIS management, there are often no discrete alternative actions as required in MADA. Instead, it is a choice of where and when to implement unspecified actions within a spatial boundary. This situation demands a MODA approach rather than a MADA approach. Many of the better-known decision analysis methods common to the literature were developed for MADA (e.g., weighted summation, Analytical Hierarchy Process, outranking methods). Their extension to MODA is not well-studied. Still, there are many different methods that can be applied to a MODA depending on the problem being addressed. Here we apply a variety of different MODA methods to two fictional installation case studies that are generally representative of many installations’ NIS management challenges (Table A-1).

Table A-1. Stakeholders, non-native invasive plant species data and impacts for two fictionalized military installations case studies.

Installation Case Study	Stakeholders	NIS Data	NIS Impacts
Camp Central Prairie	Few: military trainers, endangered species biologists	5 species with patch-scale presence/ absence data	Clearly definable risks limited to training and TES management
Fort Southeastern Forest	Many: military trainers, endangered species biologists, wildlife biologists, foresters, cultural resource managers	Detailed installation-wide abundance maps for 35 moderate and highly invasive NIS	Multiple direct and indirect impacts affecting near- and long-term management goals of several Natural Resource Programs

Case Studies

Camp Central Prairie is a relatively small Army installation in Nebraska used primarily for tank maneuver and target training. Camp Central Prairie's Integrated Natural Resources Management Team is represented by three people: (1) a Range and Training Land Program Manager who works closely with range officers and trainers, (2) an Integrated Training Area Manager responsible for maintaining sustainable training lands, and (3) an endangered species biologists who manages three state-listed rare plants, as well as the federally endangered Least Tern (*Sterna antillarum*) and threatened Piping Plover (*Charadrius melodus*). Five highly invasive NIS species have been identified and their distributions have been recorded by estimating the extent of the infestations on paper maps and collecting Global Positioning System (GPS) point locations.

Fort Southeastern Forest is a relatively large installation in South Carolina. Training uses and natural resource management activities are diverse. The installation's Integrated Natural Resources Management team is represented by six people: (1) a Range and Training Land Program manager who works closely with range officers and trainers, (2) an Integrated Training Area Manager responsible for maintaining sustainable training lands, (3) an endangered species biologist who manages three federally endangered rare plants, as well as the federally endangered Red-cockaded Woodpecker (*Picoides borealis*), (4) a forester, (5) a wildlife biologist, and (6) a cultural resource specialist. Thirty-five moderately and highly invasive NIS species have been identified and their distributions have been estimated within a

1-hectare grid, based on an exhaustive, installation-wide survey.

A series of stakeholder planning meetings is held at each installation to determine how the installations will manage their NIS. A MODA can fit into their planning process by formally determining where and when NIS management should occur. This is done by framing the MODA to determine NIS management priorities using the methods discussed in this PWTB. Participants in the planning meetings are referred to as stakeholders because they have a specific interest in NIS management on the installations. People who are not considered NIS management stakeholders should not play an active role in the meetings because they may bias the results.

Another important function of the stakeholder planning meetings is to communicate to the stakeholders the essential role they play in each step of the MODA. This active participation helps ensure a final decision that is suitable for all stakeholders. The meetings are moderated by someone who has experience with MODA and can implement the various steps throughout the meetings, which helps the stakeholders see the outcome of their decisions and make changes appropriately. Jankowski et al. (2001) emphasizes the importance of using interactive maps throughout the decision-making process to capture "geography-induced knowledge" from stakeholders that could not be obtained from an aspatial decision analysis process. This sort of input responsive planning will add credibility to the final decision because all stakeholders will be able to visualize the results. Throughout, this PWTB will refer back to the stakeholder planning meetings to illustrate certain points and describe how certain methods can be implemented.

Background

MCDA has assisted groups and individuals with complex decision problems in many different fields for many years. Some examples include the distribution of public goods and services, transportation management, urban and regional planning, water resource management, agriculture, hazardous waste management, environmental planning and management, tourism, and real estate development. MCDA has a history of application in environmental planning and natural resource management (e.g., Janssen and Rietveld 1990; Guikema and Milke 1999; Prato 1999; Kangas et al. 2001; Chertov et al. 2002; Heirs et al. 2003; Geneletti 2004; Huth et al. 2004), but to our knowledge a formal MCDA approach has not been applied to NIS management.

NIS management decisions commonly rely on internalized preferences of individuals (e.g., readily apparent infestations of commonly recognized species are often given primary focus for control), often without an installation-wide assessment of NIS distribution and abundance, or consideration of the many potential direct and indirect impacts NIS may pose for different land management objectives. This sort of informal, subjective decision-making often results in the inefficient use of limited management resources (Hobbs and Humphries 1995). When the costs of making a poor decision or poor use of resources are high, formal decision analysis methods are necessary (Jankowski et al. 2001).

In most cases, MODA of NIS management prioritization on military installations will need to focus on where NIS management actions should occur to minimize impacts to the goals of the installation and minimize NIS management inefficiencies. The MODA should combine relevant data as evaluation criteria and stakeholders' preferences as criteria weights to objectively identify a reasonable course of action. All MODA frameworks essentially consist of five elements or steps:

1. Identification of relevant evaluation criteria,
2. Criteria standardization,
3. Criteria preference weighting,
4. Criteria combination, and
5. Uncertainty analysis.

Brief explanations of these steps are provided below and expanded upon in the following sections using the installation case studies as examples.

1. To identify relevant evaluation criteria for NIS management, stakeholders must work together to define the MODA problem (i.e., where to implement management to minimize risk of NIS impacts to training land use and natural resource management goals, and to ensure management efficiencies are realized). Specific criteria can then be developed to describe all aspects of the MODA problem. Data are then collected as parameters to provide values for each criterion.

2. Criterion data must be standardized because they have likely been measured with different units. The standardization should make all of the values positively correlated with the desired outcome of the problem.

3. Not all criteria are as important or relevant to determining the overall outcome of the MODA. The various stakeholders will have different preferences or opinions about the importance of each criterion. Stakeholders' preferences are captured and applied by weighting the criterion data.

4. The standardized and weighted criteria are then combined to determine the overall outcome of the MODA. This process can be a simple addition of criteria, or it can involve more complex combination functions.

5. To build confidence in the MODA results, uncertainty should be analyzed. A sensitivity analysis will assess the general stability of the stakeholders' rankings, identify criteria that are especially responsive to weight changes, and help visualize the spatial dimension of weight sensitivity.

Figure A-1 provides a general visual representation of the five steps. Specific methods for each of the steps are then discussed as they apply toward prioritizing NIS management on Camp Central Prairie and Fort Southeastern Forest.

Evaluation Criteria

The first step of any MODA is to identify criteria that can be used throughout the MODA to evaluate the decision problem. The decision problem must be clearly defined and based on established goals of the individual or organization attempting to solve the problem (i.e., where to implement management to minimize risk of NIS impacts to training land use and natural resource management goals, and to ensure management efficiencies are realized). This ensures the MODA explicitly serves the needs of the individual or organization.

The criteria are then developed to evaluate the decision problem. It is critical to the success of the MODA that the evaluation criteria possess certain properties before they are applied (Table A-2; Malczewski 2000).

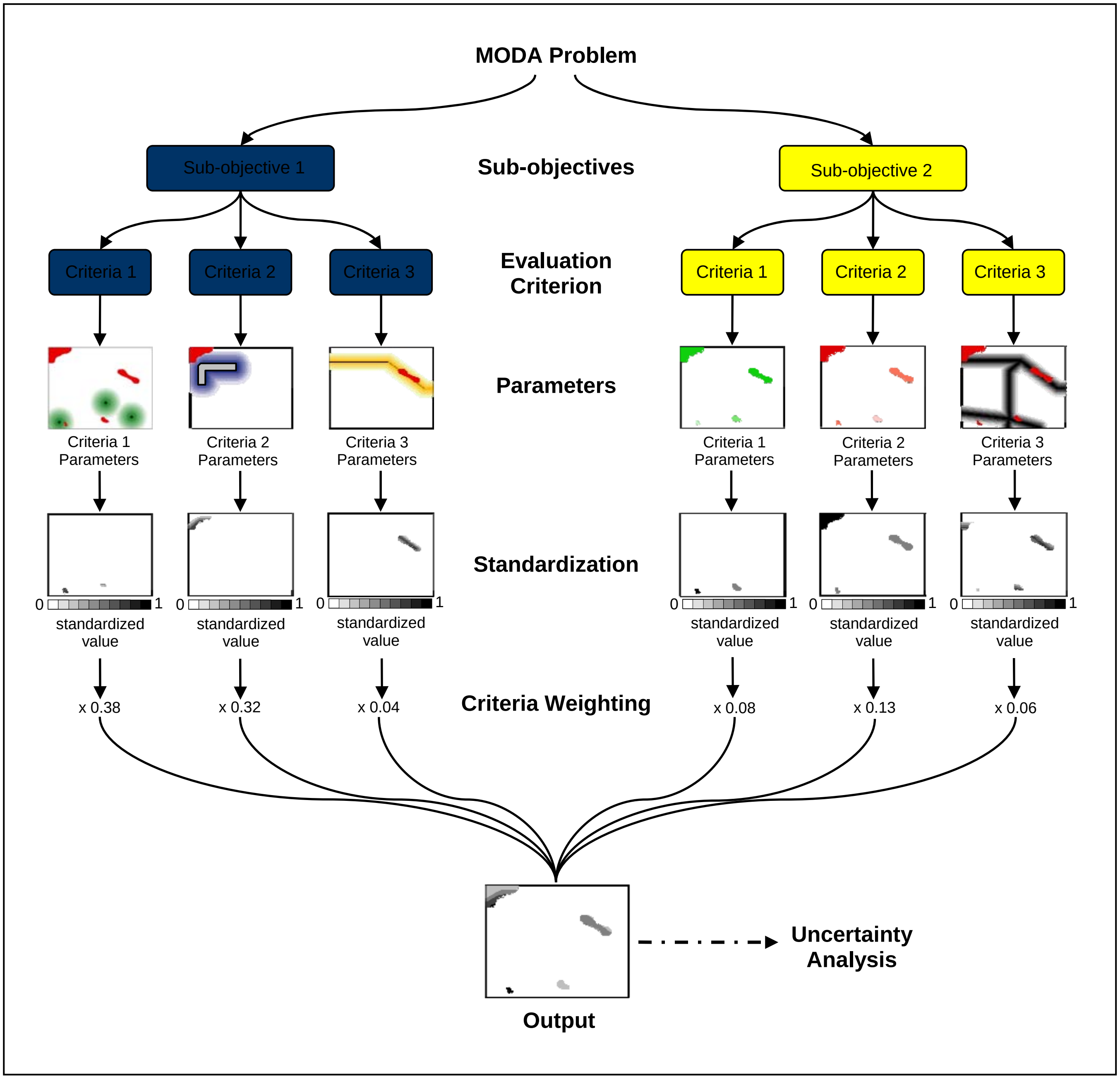


Figure A-1. Conceptual diagram of a general MODA process.

Table A-2. Properties evaluation criteria must meet to be used in MODA.

Property	Definition
comprehensive	criteria are representative of the degree to which MODA objectives are achieved
measurable	can be assigned a number, and preferences can be applied
complete	adequately covers all aspects of the decision problem
operational	able to be used in the analysis
decomposable	performance of criteria can be evaluated independently of all other criteria
non-redundant	criteria are not double counted
minimal	criteria measures are as few as possible

After identifying the appropriate evaluation criteria (e.g., management cost, opportunities for early detection/rapid response management, risk of impacts to training land use, infrastructure, management practices, TES and critical habitat, etc.), the next step is to select suitable metrics for the criteria. These metrics are referred to as parameters and are used to capture the salient elements of the criteria as they relate to the problem. Examples of parameters relevant to assessing risk of NIS impact include,

1. NIS abundance,
2. NIS proximity to TES habitat,
3. NIS proximity to training areas,
4. NIS proximity to suspected dispersal corridors,
5. Availability of effective control methods for different NIS,
6. Consequences of delay in initiating management action, and
7. NIS traits that affect cost and feasibility of management.

Because evaluation criteria and the process of prioritizing NIS management are inherently spatial, the values of the parameters are best presented as Geographic Information System (GIS) grid layers, which also facilitate mathematical manipulation associated with standardization, weighting, and combination. However, before proceeding to the next step (i.e., criteria standardization, page A-23), constraint maps should be multiplied by the criteria maps to ensure only logical or feasible locations are analyzed (Malczewski 2000). An example of an area that may not need to be specifically included into a MODA of NIS management prioritization is an installation's Impact Area, since management options will likely be constrained by access restrictions. A constraint map displays feasible geographical areas with a value of '1' in a geographic information system (GIS) grid layer, while infeasible locations have a value of '0'. The resulting GIS grid layers are used in the following sections that describe criteria standardization and weighting methods.

Case Studies

As required by AR 200-1, Camp Central Prairie and Fort Southeastern Forest conserve, restore, and manage their natural resources in support of the military mission. The planning and implementation of natural resources management is coordinated in the installations' Integrated Natural Resource Management Plans (INRMPs). The INRMP contains clearly defined goals guiding their natural resource management programs. Using these goals, information about training land use, and knowledge of NIS abundance, the MODA problem (i.e., prioritization of NIS management) can be defined in terms of two sub-objectives: minimizing (1) NIS impacts and (2) management inefficiency. These sub-objectives help to clarify the decision problem and aid identification of suitable evaluation criteria. Tables A-3 and A-4 list the INRMP goals, NIS impacts, and management efficiencies for the two case study installations. Figures A-2 and A-3 illustrate conceptual diagrams for the MODA problem of identifying priority NIS management sites at Camp Central Prairie and Fort Southeastern Forest. Figures A-4 and A-5 show GIS data layers for the various parameters that serve as metrics for the evaluation criteria in each case study. Figure A-6 shows constraint maps for each installation.

Table A-3. INRMP goals, anticipated NIS impacts, and opportunities to increase the long-term efficiency of NIS management at Camp Central Prairie.

Camp Central Prairie

INRMP Goals

- Maintain at least 30 continuous miles of trails for tracked vehicle maneuver training.
- Maintain target visibility from established firing points.
- Maintain viable populations of state listed plant species.
- Maintain stable populations of federally listed bird species.

NIS Impacts

- Dense Russian olive (*Elaeagnus angustifolia*) stands have made parts of tank trails unusable and have obscured visibility of targets.
- Infestations of spotted knapweed (*Centaurea maculosa*), musk thistle (*Carduus nutans*), and Canada thistle (*Cirsium arvense*) have been found within protected plant populations, threatening their viability.
- Saltcedar (*Tamarix ramosissima*) is encroaching on endangered Least Tern (*Sterna antillarum*) and threatened Piping Plover (*Charadrius melodus*) nesting sites. If left unmanaged, these sites will likely be abandoned and the installation could be issued a jeopardy opinion.

NIS Management Efficiencies

- Early detection and rapid response (ED/RR) control of small isolated infestations (i.e., invasion foci) can greatly increase the overall efficiency and cost effectiveness of NIS management.
- Once NIS become well-established, containment and eradication are increasingly difficult and cost prohibitive. Sites having high % cover of NIS often require significant restoration efforts, which have often forgotten costs. After ED/RR controls have been implemented, the greatest overall NIS management progress is gained by maximizing the area treated with the available dollars.
- Targeted control of NIS along tank trails, where soil disturbance aids NIS establishment, will greatly reduce the likelihood that propagules (i.e., seeds and meristematic tissues) are carried on tank tracks and rapidly spread across the installation.

Table A-4. INRMP goals, anticipated NIS impacts, and opportunities to increase the long-term efficiency of NIS management at Fort Southeastern Forest.

Fort Southeastern Forest

INRMP Goals

- Maintain open longleaf pine ecosystem for diverse training needs.
- Maintain viable populations of endangered plant species.
- Increase the installation’s federally listed Red-cockaded Woodpecker (*Picoides borealis*) population.
- Maintain the structural integrity and character of historic buildings.
- Maintain the infrastructure necessary for operating modernized training ranges.

NIS Impacts

- Dense Chinese lespedeza (*Lespedeza cuneata*) stands are altering the behavior of prescribed fires and threaten to reduce the effectiveness of this management tool for maintaining desired training conditions.
- Isolated infestations of cogongrass (*Imperata cylindrica*) a federally designated noxious weed) are quarantined and limit access to training areas. This quarantine is also impacting out-of-state visitor training.
- Spotted knapweed (*Centaurea maculosa*), Japanese stiltgrass (*Microstegium vimineum*), and giant reed (*Arundo donax*) have been found within endangered plant populations, threatening their viability.
- Kudzu (*Pueraria lobata*) and wisteria (*Wisteria spp*) are degrading the condition of several historic buildings and the installation’s electrical infrastructure.
- Historical plantings of shrubby bushclover (*Lespedeza bicolor*) are escaping from wildlife food plots and invading Red-cockaded Woodpecker foraging habitats.

NIS Management Efficiencies

- Early detection and rapid response (ED/RR) control of small isolated infestations (i.e., invasion foci) can greatly increase the overall efficiency and cost effectiveness of NIS management.
- Once NIS become well-established, containment and eradication are increasingly difficult and cost prohibitive. Sites having high % cover of NIS often require significant restoration efforts, which have often forgotten costs. After ED/RR controls have been implemented, the greatest overall NIS management progress is gained by maximizing the area treated with the available dollars.
- Targeted control of NIS along roads and trails can greatly reduce the likelihood that propagules (i.e., seeds and meristematic tissues) are rapidly spread across the installation on the tires or tracks of military and maintenance vehicles.
- Eliminating shrubby bushclover with wildlife food plots will reduce the dominant source of propagules for this NIS.

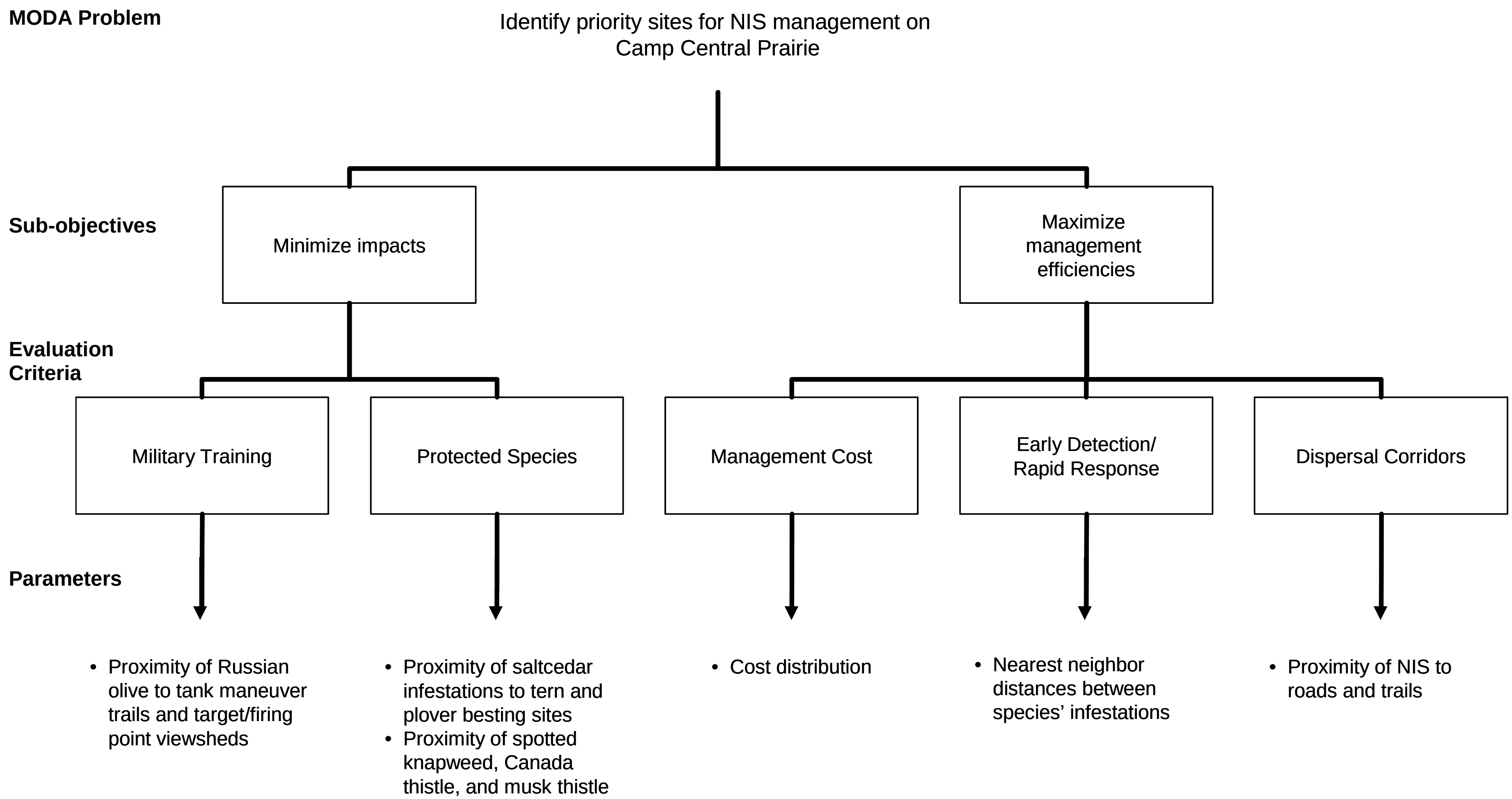


Figure A-2. Conceptual diagram of the MODA problem of identifying priority sites for NIS management on Camp Central Prairie.

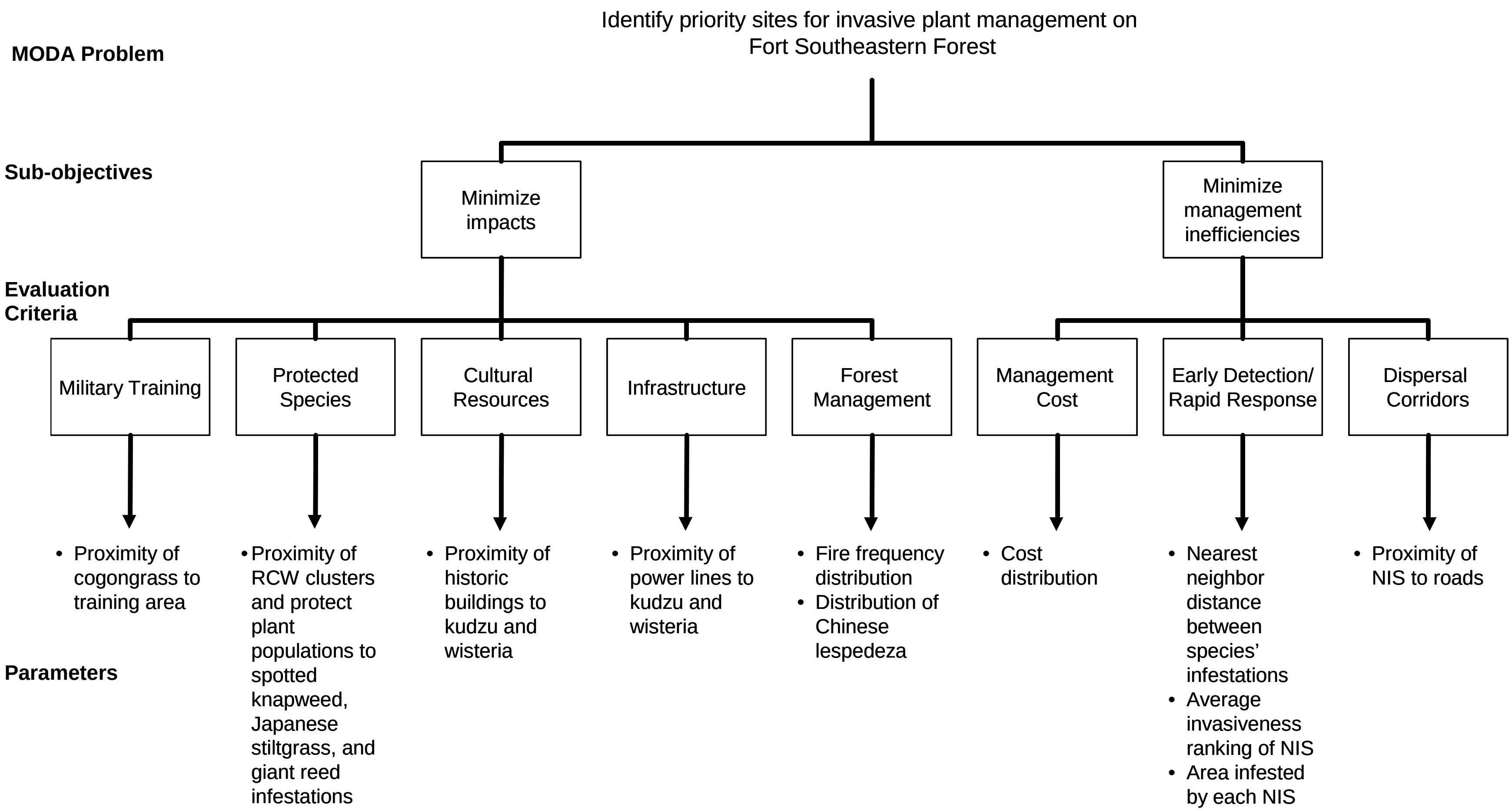
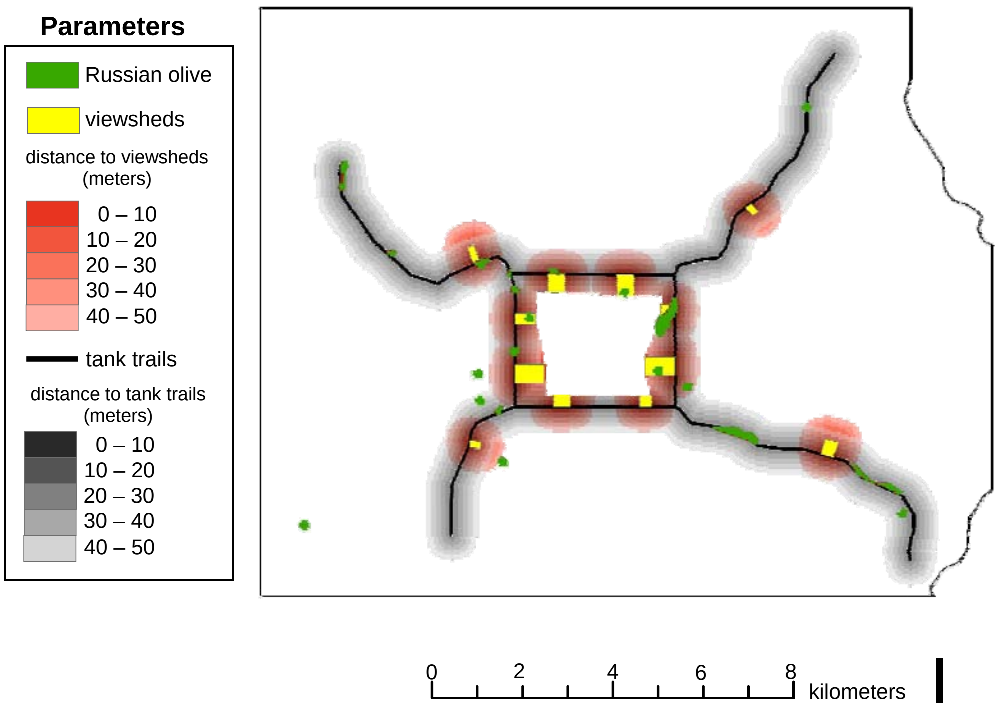
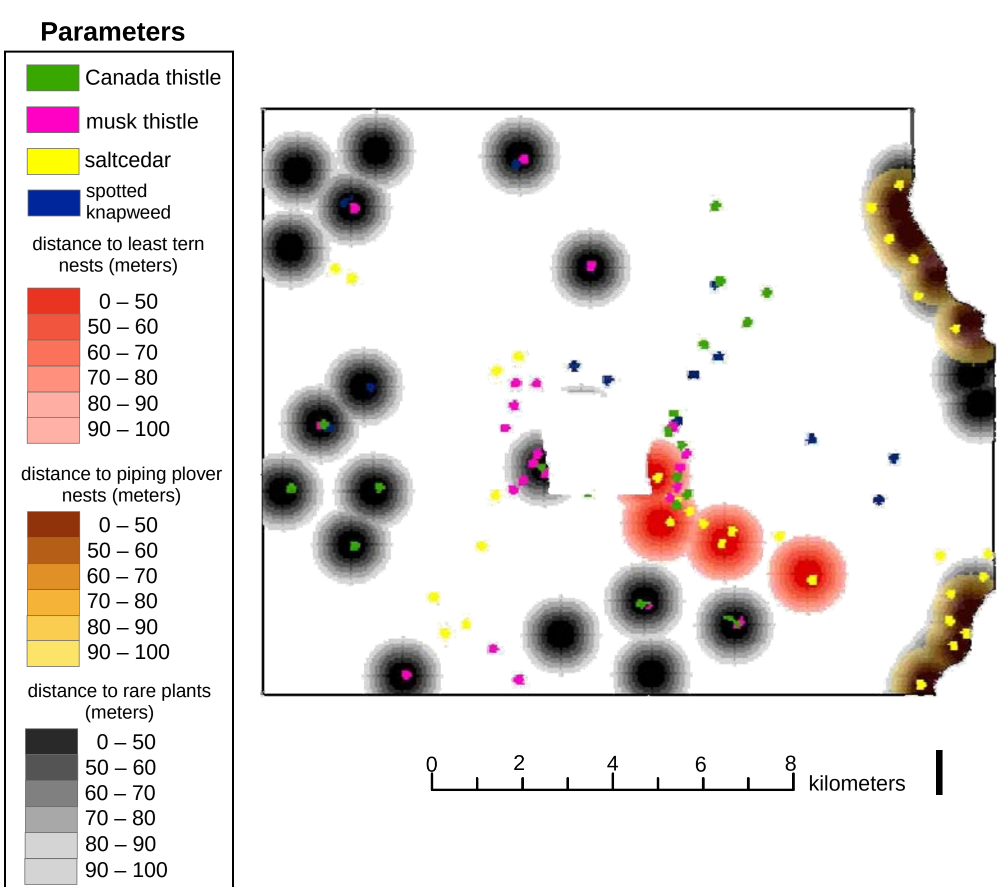


Figure A-3. Conceptual diagram of the MODA problem of identifying priority sites for NIS management on Fort Southeastern Forest.

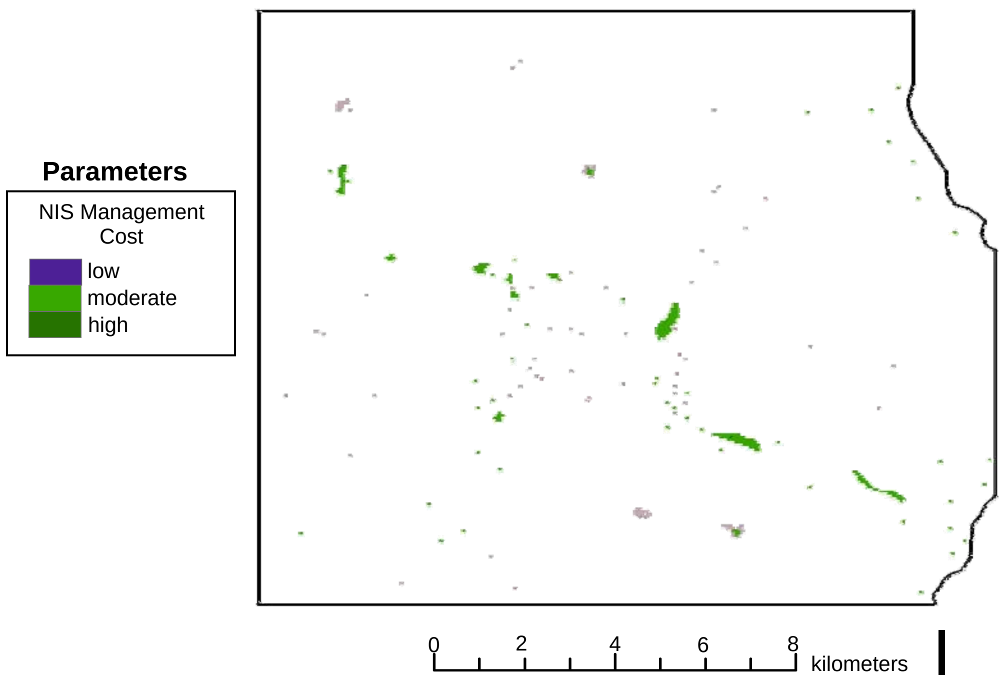
a). Criteria: Military Training



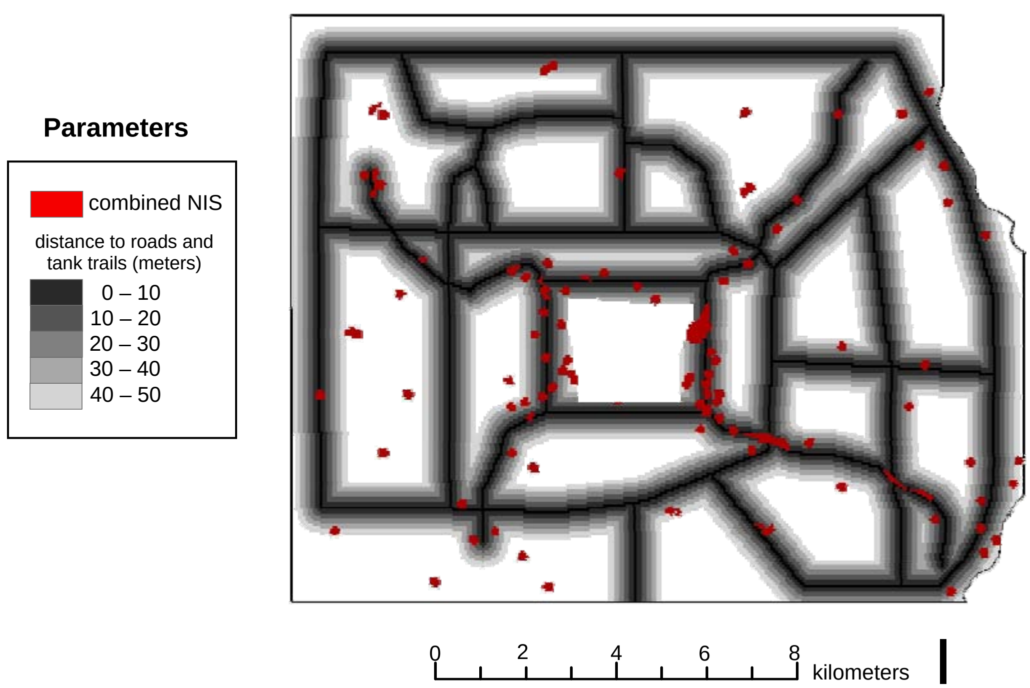
b). Criteria: Protected Species



c). **Criteria: Management Cost**



d). **Criteria: Dispersal Corridors**



e). **Criteria: Early Detection/Rapid Response**

Parameters

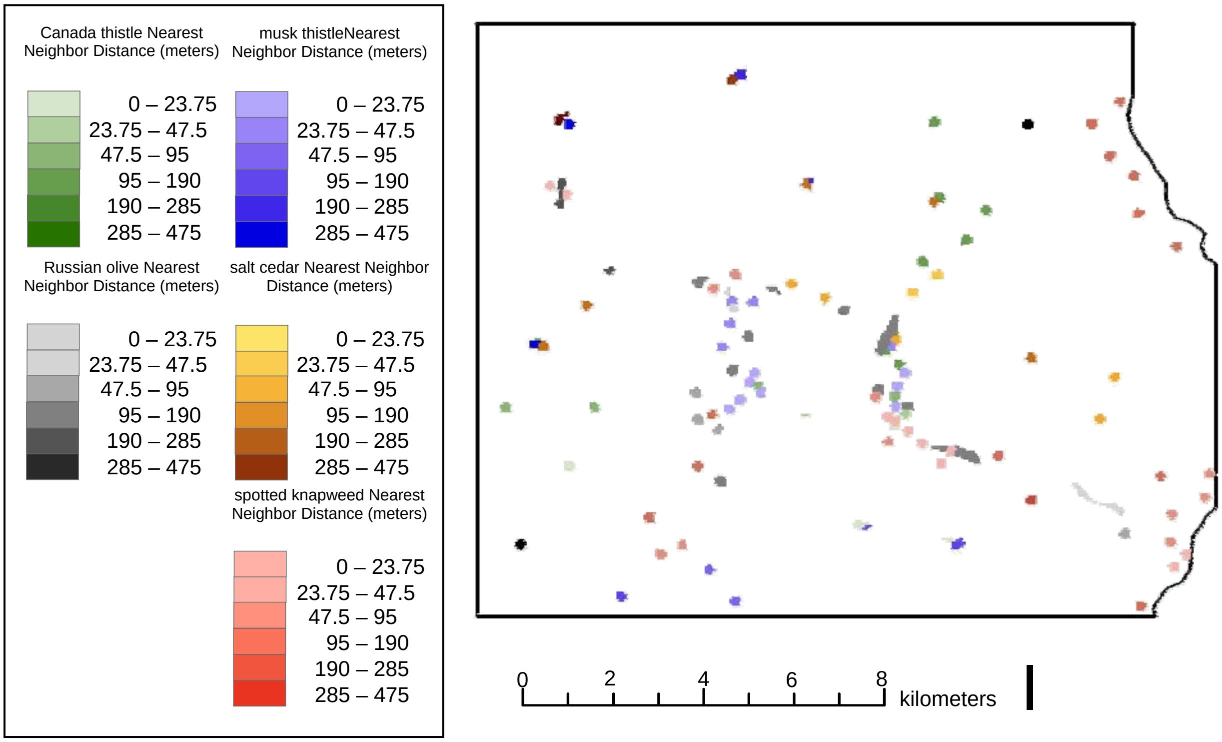
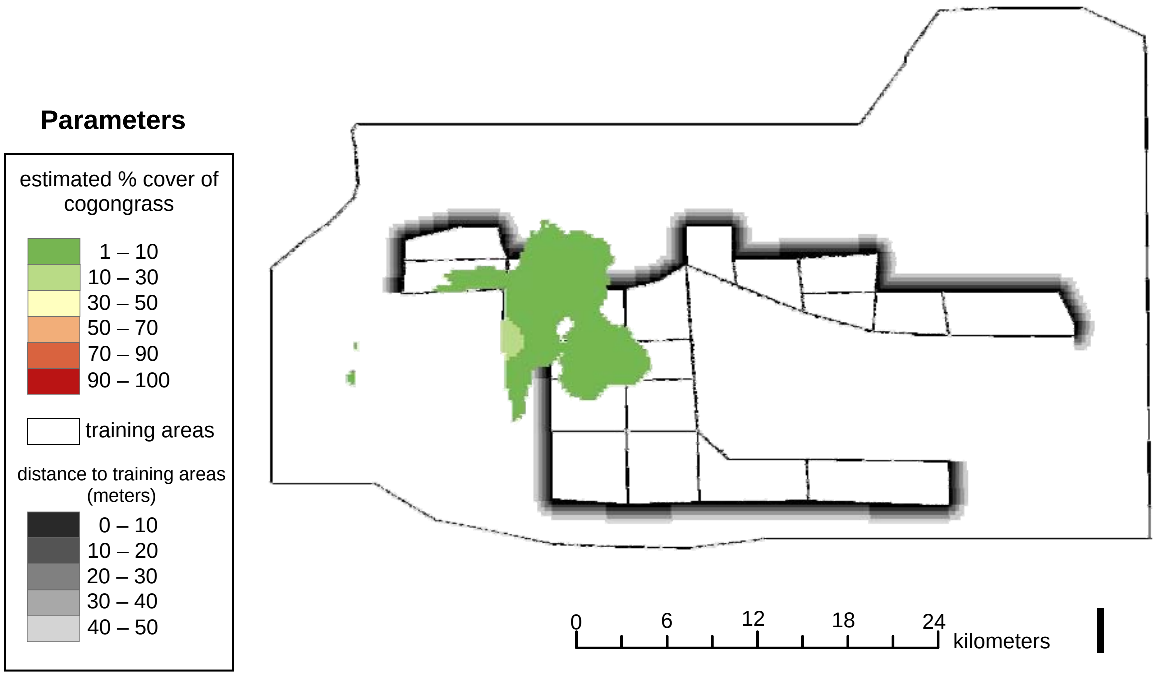
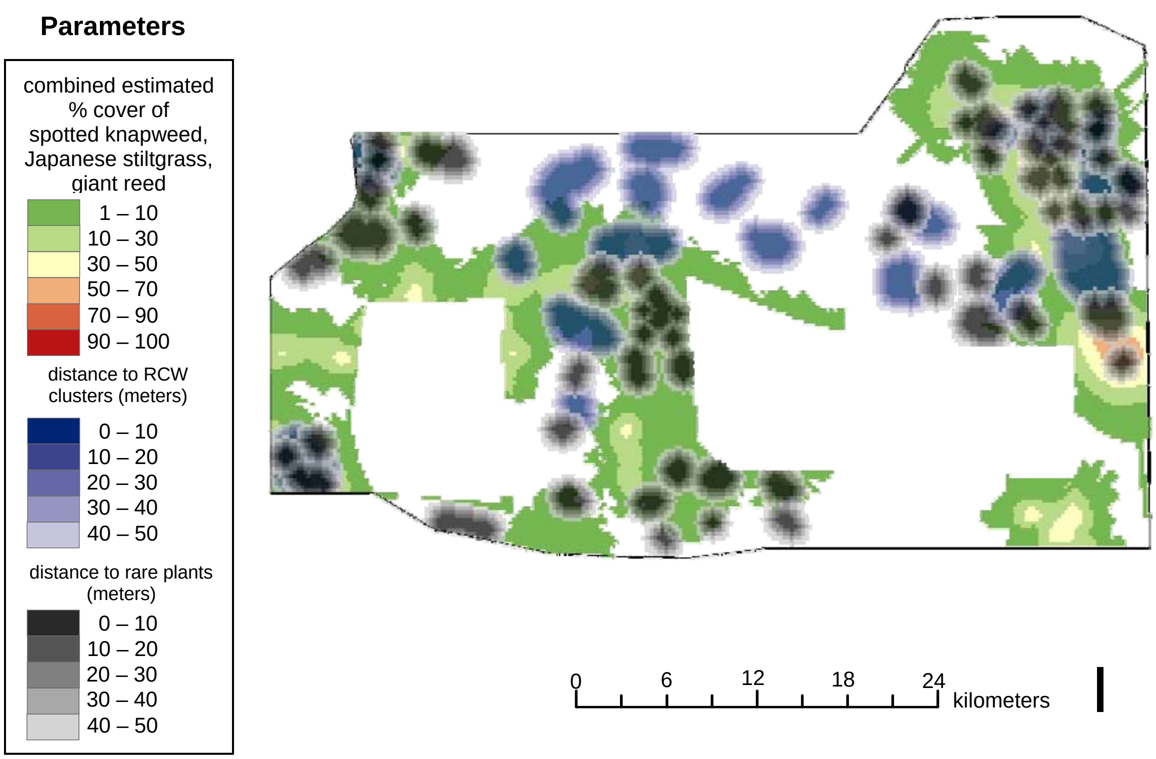


Figure A-4. GIS data layers of parameters used as evaluation criteria for the prioritization of NIS management at Camp Central Prairie:
a) military training, b) protected species, c) management cost, d) dispersal corridors, and e) early detection/rapid response.

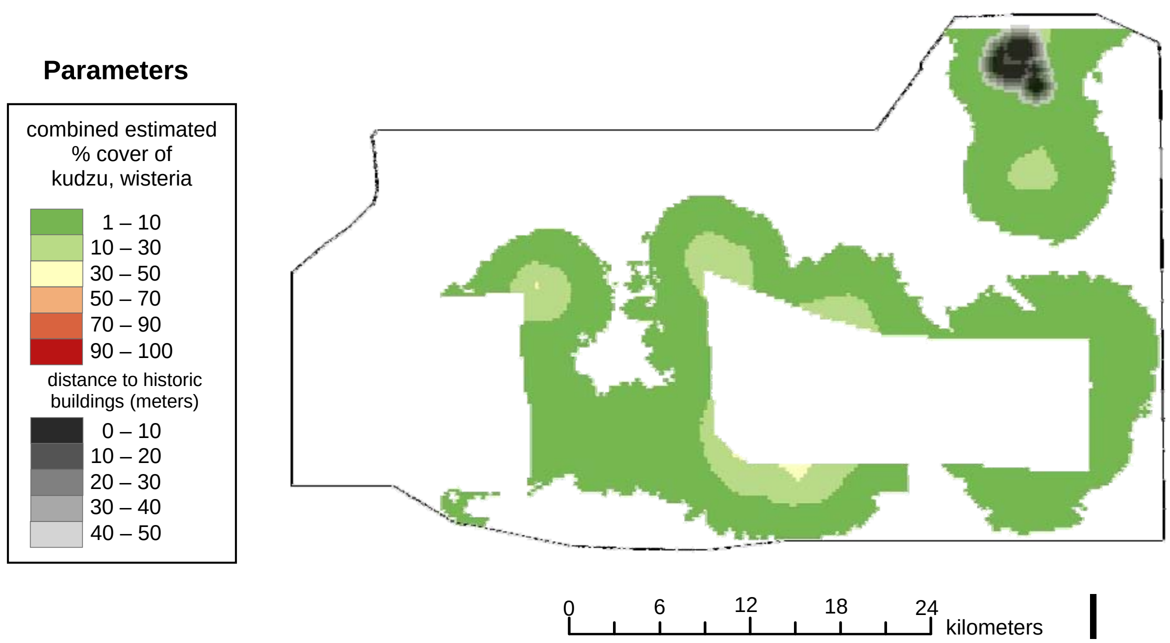
a). **Criteria: Military Training**



b). **Criteria: Protected Species**

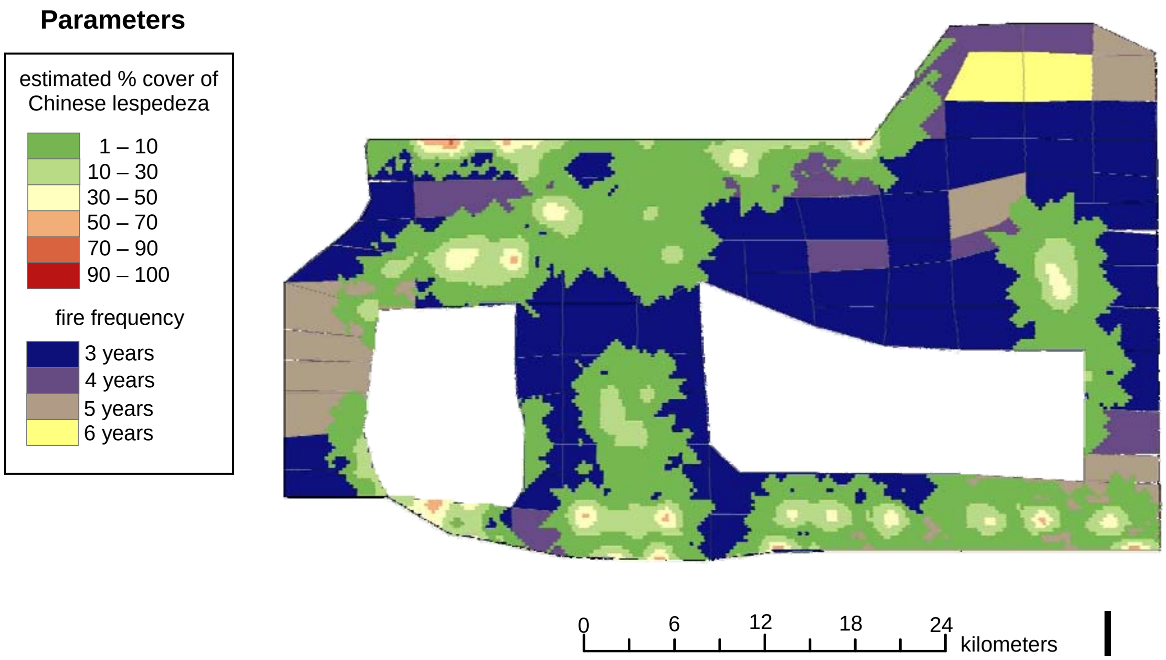


c). **Criteria: Cultural Resources**

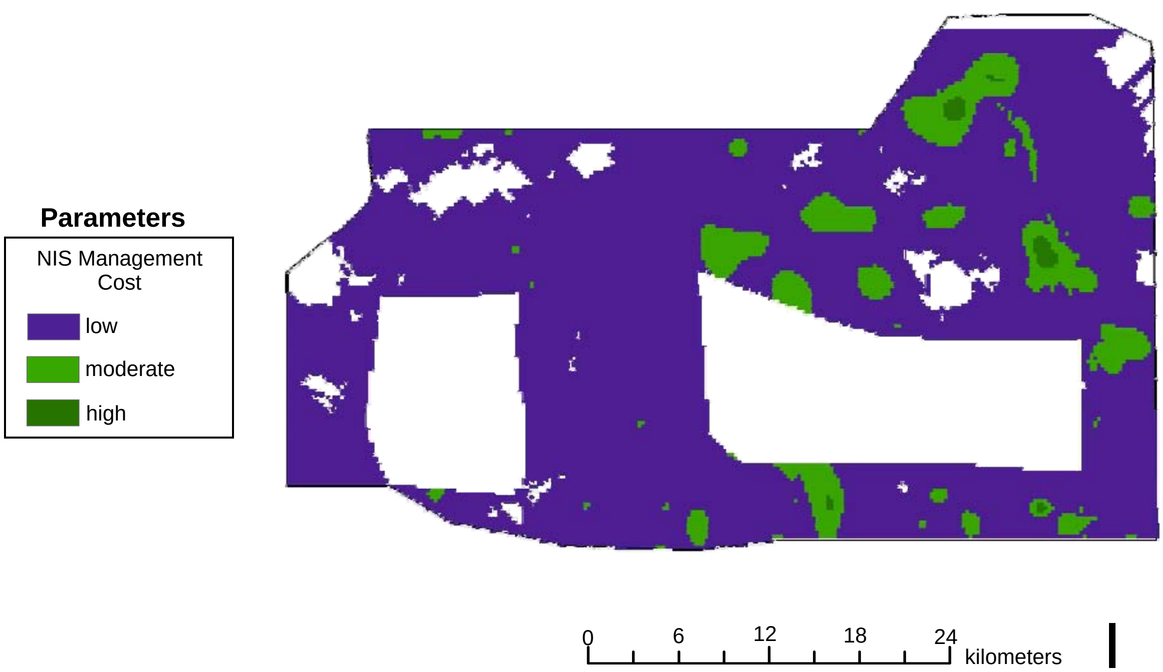


d). **Criteria: Infrastructure**

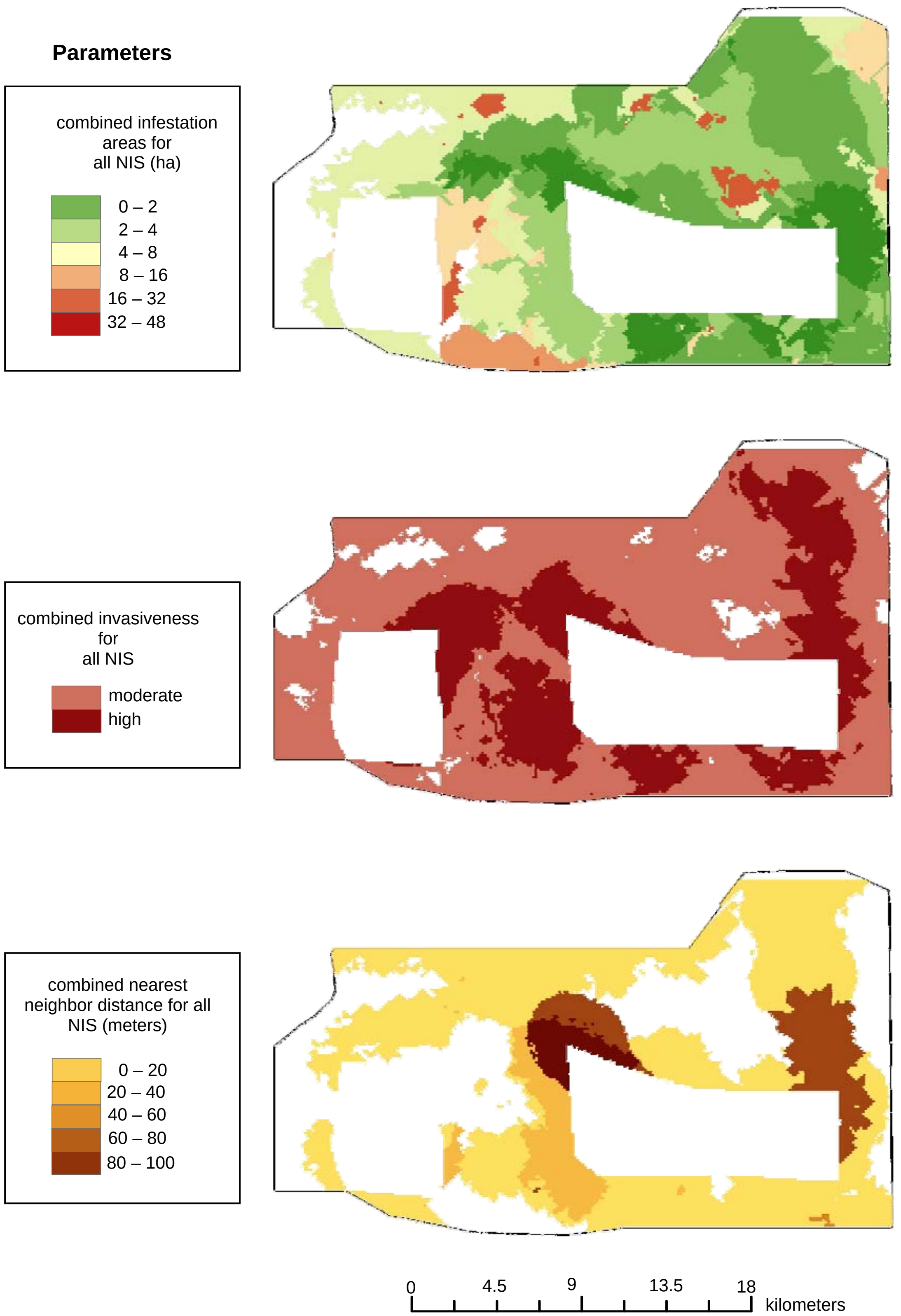
e). Criteria: Forest Management



f). Criteria: Management Cost



g). **Criteria: Early Detection/Rapid Response**



h). **Criteria: Dispersal Corridors**

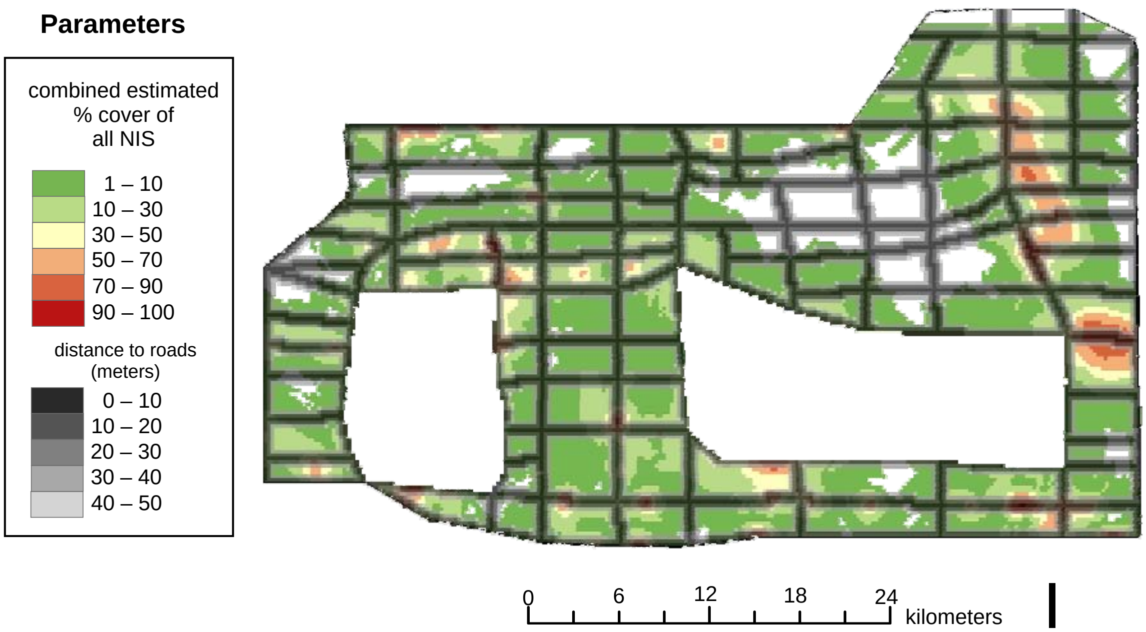
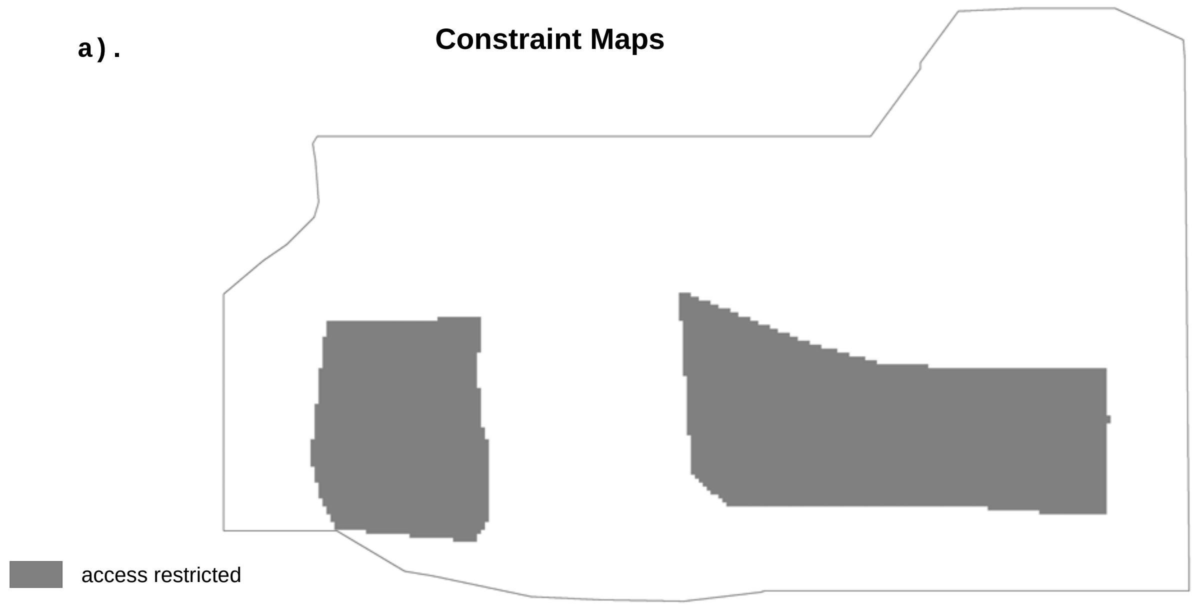


Figure A-5. GIS data layers of parameters used as evaluation criteria for the prioritization NIS management at Fort Southeastern Forest: a) military training, b) protected species, c) cultural resources, d) infrastructure, e) forest management, f) management cost, g) early detection/rapid response, and h) dispersal corridors.

a).



b).

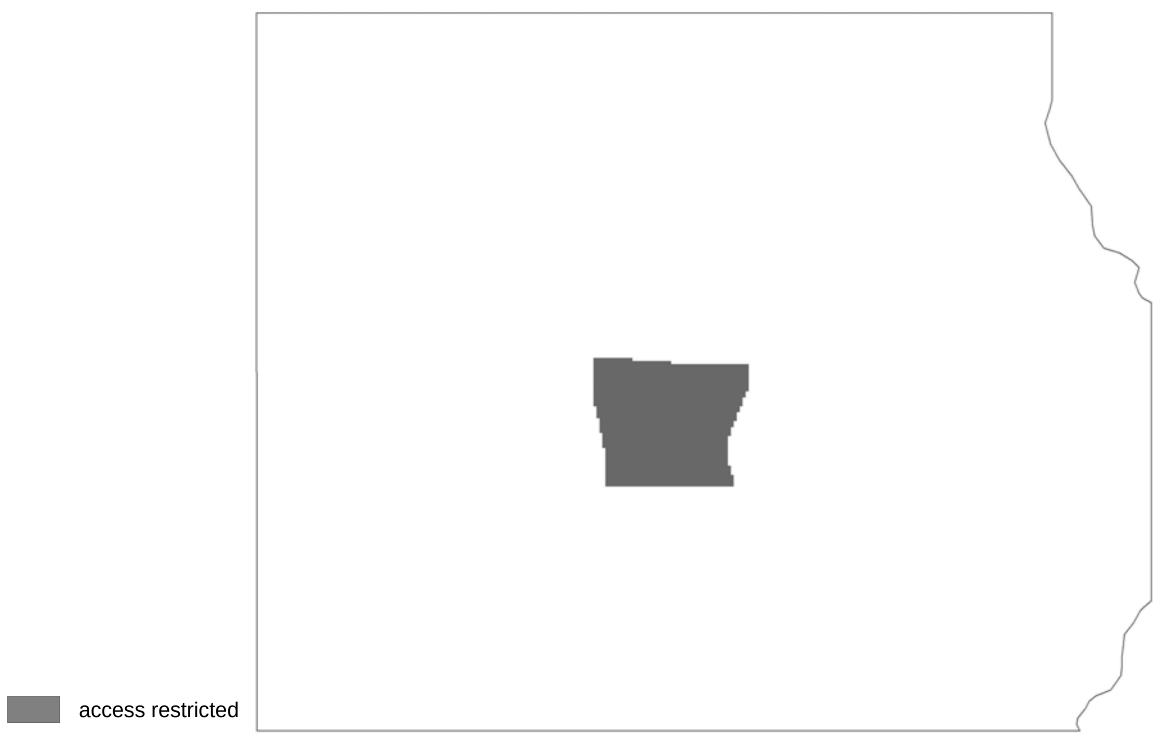


Figure A-6. Constraint maps for a) Fort Southeastern Forest, and b) Camp Central Prairie. Dark gray areas indicate where access restrictions prevent NIS Management Activities from occurring.

Criteria Standardization

Before using the parameters in any analysis it is important that they are standardized to a common scale. For example, distances to rare species locations measured in meters cannot be logically combined with NIS abundance data expressed as % cover, unless they are first standardized. During standardization, parameters lose their dimension and become positively correlated with the MODA problem (Eastman et al. 1995; Eastman 1999). In the cases discussed here, all data should be positively correlated with NIS management priority (0 = lowest priority, 1 = highest priority).

Standardization can be accomplished using various approaches depending on the type of data available and its relationship to the MODA problem.

The most frequently used GIS-based standardization method is the linear scale transformation, for which several transformation procedures exist (Malczewski 2000). The score range procedure is the most common:

$$x_i = (R_i - R_{min}) / (R_{max} - R_{min}) \qquad (1)$$

This procedure subtracts the minimum parameter value (R_{min}) from the parameter value (R_i), and then divides by the overall range of the parameter values (R_{max}-R_{min}) to derive transformed values x_i (Pereira and Duckstein 1993; Malczewski 2000). Values range from 0-1, with higher values associated with a higher relevance to the MODA problem. To illustrate this, NIS % cover is used as an example (Figure A-7). The combined cover of spotted knapweed (*Centaurea biebersteinii*), Japanese stiltgrass (*Microstegium vimineum*), and giant reed (*Arundo donax*) on Fort Southeastern Forest varies from 0-80 percent. These three NIS specifically impact protected species. After applying the linear scale transformation, the highest combined % cover (80) has a value of 1.

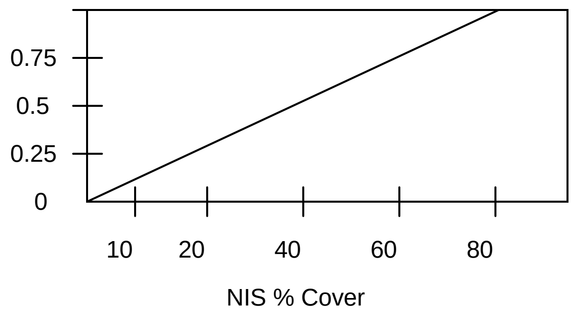


Figure A-7. Linear-scale transformation for the combined % cover of spotted knapweed, Japanese stiltgrass, and giant reed, which is a parameter for the “Protected Species” evaluation.

Linear transformations assume the data are measured on a linear scale. However, data are often measured on nonlinear scales and are best transformed by a value function based on the natural scale of each parameter (Pereira and Duckstein 1993; Malczewski 2000). For example, the likelihood of NIS dispersal along road corridors is nonlinear, displaying an inverse exponential decay as distances of NIS infestations increase from a road. The natural scale is the range of measured values for the parameter. A value function converts the natural scale of the parameter to a new scale (typically 0-1) through preference judgments. Here, the midvalue method is used to derive a value function (Pereira and Duckstein 1993; Malczewski 2000). This method involves the estimation of the midpoint value that creates an equal value difference between the minimum and the midpoint and the maximum and midpoint. Using the same example of NIS % cover, the natural scale is 0-80 percent. Since higher NIS % cover is expected to have greater impacts, 80 % cover is given a value of 1. The least impact is expected where there are no NIS, so 0 % cover is given a value of 0. An endangered species biologist is then asked to make further preference judgments as they relate to NIS impacts on the Red-cockaded Woodpecker and the rare plant species. Using the midpoint (40), the preference question becomes “Which change would represent the greatest NIS impact to protected species population viability?” Given the following choices:

1. from 0 to 40% cover,

2. from 40 to 80% cover, or

3. they are equal,

the endangered species biologist chose 2. This shifts the midpoint from 40 to 60, which is the midpoint between 40 and 80% in Option 2 (Figure A-8).

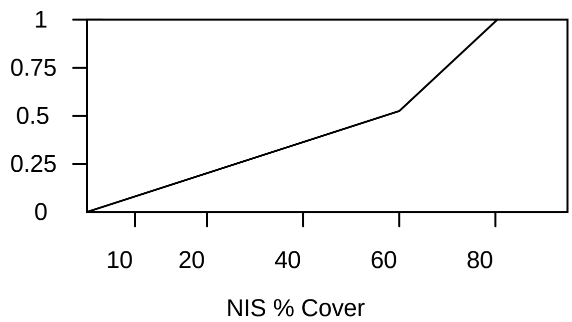


Figure A-8. Natural scale value function transformation for the combined % cover of spotted knapweed, Japanese stiltgrass, and giant reed, which is a parameter for the “Protected Species” evaluation criteria.

This procedure could continue by identifying quarter points between the midpoint and maximum and the midpoint and minimum. As long as the decision maker can confidently identify preferences between value ranges, the procedure should continue. The more points established, the greater accuracy the curve will have (Malczewski 2000). It is important, however, that someone with close knowledge of the parameter make these judgments.

Using the natural scale alone to determine the minimum and maximum scaling points may not be the best option (Eastman 1999). Referring to land management goals may also help assign minimum and maximum scaling points according to the parameter’s inherent meaning. For example, an established management goal for rare plants is to “maintain viable populations.” Based on field studies, it has been determined that NIS impact rare plant numbers and demographics when cover is greater than 10% on a typical site. Consequently, the most important values may be any combined cover estimates greater than 10 (value of 1), as they affect rare plant management goals. Figure A-9 shows the value function adjusted accordingly. Regardless of standardization method, the shape of the value functions should be chosen carefully because they can significantly influence the overall MODA results.

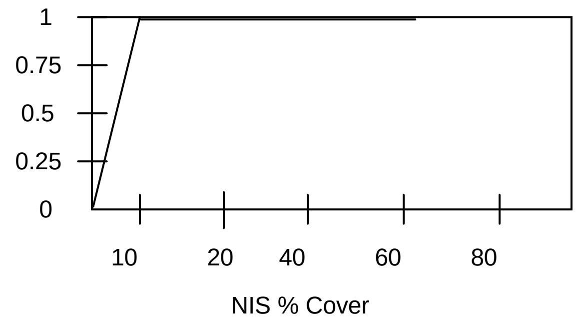


Figure A-9. Natural scale value function for the combined % cover of spotted knapweed, Japanese stiltgrass, and giant reed, adjusted to reflect the anticipated negative impacts at >10% cover.

When there are uncertainties associated with the parameter data, probabilistic or fuzzy set membership functions are the most robust standardization approaches (Malczewski 1999). For example, inherent uncertainty is associated with the location of infestation boundaries. It may not be possible to unequivocally identify the position of a natural boundary (Burrough 1996), so rather than adhere to a binary criterion of presence/absence along boundary locations, intermediate values (i.e., some real number between 0 and 1) can be applied during standardization using fuzzy sets (Wang and Hall 1996; Jiang and Eastman 2000). Therefore, the concept of fuzzy sets can provide not only a standardization tool but also a means of incorporating data uncertainty into the decision analysis. Other cases may involve uncertainty about how the values of a parameter are precisely related to a MODA problem. For example, precise data on NIS densities, numbers of distinct infestations, sizes of infestations and their spatial isolation may be available to evaluate early detection rapid/rapid response strategies on management efficiency, but the threshold values of these parameters that ultimately influence the success of ED/RR will probably not be known. Robinson (2003) provides a recent review of fuzzy sets and their use in GIS.

Criteria Weighting

Individual evaluation criteria will never be equally relevant to the outcome of a MODA. To express differences in the importance of criteria, stakeholders should weight them according to overall relevance to the MODA problem. In the case of NIS management prioritization on Army installations, criteria relevance is based on the two sub-objectives (Figures A-2 and A-3); minimization of NIS impacts, and minimization of NIS management inefficiencies. Without properly weighting the criteria, one could erroneously invest significant effort in controlling NIS at sites having little overall relevance to the training or natural resources conservation needs of the installation.

If available, empirical evidence or previously agreed upon goals, rather than stakeholder preferences, should be used to determine weights, particularly if they clearly describe relative importance between criteria (Williams and Araújo 2002). Weights chosen by stakeholders can be challenged as being arbitrary, whereas objectively collected data or established goals are more defensible for determining criteria weightings. In many cases, however, empirical evidence and explicit goals do not exist and stakeholder-defined preferences must be used.

The simplest weighting method involves distributing weights that add up to 1.0 among the criteria (Eastman 1999). This is an appropriate weighting method for MODAs with relatively few, easily comparable criteria.

For more complex MODAs, with too many criteria to easily compare at once, a more sophisticated weighting process should be applied. One such approach is to compare criteria two at a time, which helps to capture stakeholder preferences about the relative importance of a limited number of criteria (Eastman 1999). These preferences are then organized into a pair-wise comparison matrix that conveys the entire set of stakeholder preferences. Commonly a 9-point rating scale is used to compare preferences between criteria (Figure A-10, Table A-5) (Saaty 1977; Barron 1992). Each stakeholder compares each pair of criteria, essentially filling in the appropriate values of the matrix. A 9-point scale is used because psychologists conclude that nine objects are the most an individual can consistently rank. If two criteria are deemed to be of equal importance, a value of 1 is assigned to the comparison, whereas a 9 indicates the absolute importance of the first criteria over the second, and 1/9 indicates absolute importance of the second over the first.

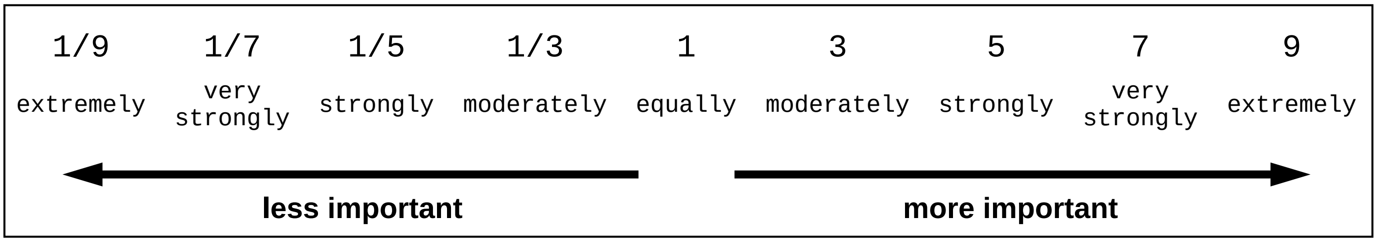


Figure A-10. Nine-point comparison scale used to rank the importance of criteria (row criteria relative to corresponding column criteria).

Table A-5. Pair-wise comparison matrix using the 9-point comparison scale.

	Military Training	Early Detection/ Rapid Response	Management Cost	Dispersal Corridors	Protected Species
Military Training	1				
Early Detection/ Rapid Response	1/5	1			
Management Cost	1/7	3	1		
Dispersal Corridors	1/5	3	3	1	
Protected Species	1	5	7	5	1

Another method involves stakeholders expressing their perceptions about the relative importance of criteria through the use of interval judgments, also known as fuzzy preferences (Wang and Parkan 2005). Interval judgments allow stakeholders to express and reason with their preferences when they are uncertain. A fuzzy preference approach is especially useful when determining NIS management priorities because NIS impacts and management inefficiencies are not always obvious, and management preferences often differ between stakeholders, making precise judgments nearly impossible.

A number of different methods can be used to express stakeholders’ fuzzy preferences. Arbel and Vargas (1993) suggest stakeholders determine numerical upper and lower bounds to their preferences (Table A-6). These lower (l) and upper (u) bounds can be taken as values from the previously mentioned 9-point comparison scale (Figure A-10).

Table A-6. Pair-wise comparison matrix using fuzzy preferences.

	Criteria1	**Criteria2**	**Criteria3**	**Criteria4**	**Criteria5**	**Criteria6**
Criteria1	1	$[l_{12}, u_{12}]$	.	.	.	$[l_{16}, u_{16}]$
Criteria2	$[l_{21}, u_{21}]$	1	.	.	.	$[l_{26}, u_{26}]$
Criteria3	.	.	1	.	.	.
Criteria4	.	.	.	1	.	.
Criteria5	.	.	.	.	1	.
Criteria6	$[l_{61}, u_{61}]$	$[l_{62}, u_{62}]$	.	.	.	1

To derive criteria weights from a fuzzy comparison matrix, one can use a preference simulation (Arbel and Vargas 1993). This method randomly samples values within the lower and upper bounds of each matrix cell. The resulting matrix can then be used to calculate weights as described below.

To derive weights for a comparison matrix, the principal eigenvector is calculated; values of the vector are the criteria weights. The principal or dominant eigenvector of a matrix is an eigenvector corresponding to the eigenvalue of largest magnitude (for real numbers, largest absolute value) of that matrix. Software to calculate the principal eigenvector within GIS are limited (e.g., the module WEIGHT in IDRISI GIS software) (Eastman et al 1995), but this step can also be performed outside a GIS environment using various online on commercial matrix calculators. If software is not available, a good approximation is to sum the comparison values for each column and average over all columns (Eastman 1999). Using preference values in Table A-5 as an example, the first column sums to 16.53. Dividing each value in the first column by 16.53 results in values of 0.06, 0.30, 0.18, 0.42, 0.01, and 0.02. This process is repeated for each column and the values are averaged across the columns (Table A-7). The results generally represent a good approximation of the weights calculated from the principal eigenvector of the matrix (Table A-8).

Table A-7. Weights derived from averaging comparison values across columns of the pair-wise comparison matrix. Consistency ratio = 0.02.

Criteria	**Weight**
Military Training	0.38
Early Detection/ Rapid Response	0.05
Management Cost	0.07
Dispersal Corridors	0.12
Protected Species	0.38

Table A-8. Weights derived from the principal eigenvector of the pair-wise comparison matrix. Consistency ratio = 0.03.

Criteria	Weight
Military Training	0.37
Early Detection/ Rapid Response	0.05
Management Cost	0.07
Dispersal Corridors	0.13
Protected Species	0.38

Once weights have been calculated, it is informative to analyze the variation in the importance rankings provided by stakeholders and also inconsistencies of individual stakeholders. This can be accomplished by calculating a *consistency ratio* that describes the probability the matrix rankings were randomly generated (Eastman 1999). As a general rule, matrices with a *consistency ratio* greater than 0.1 should be re-evaluated (Saaty 1977). Mendoza and Martins (2006) point out that regression can be used as an alternative to the calculation of the consistency ratio. This method derives quantitative estimates of the uncertainties based on the modeling of the variance components.

Although the discussion of weighting has thus far focused solely on evaluation criteria, sub-objectives (at the next hierarchical level of the MODA) can be similarly weighted if they are deemed to have different levels of importance for the MODA problem. For example, if compliance requirements related to minimizing impacts are determined to have greater importance than management efficiency in deciding NIS management prioritization, the two sub-objectives can be appropriately weighted to reflect the differences.

Criteria Combination

Having standardized and applied weights to the criteria (and/or sub-objectives) as described above, the criteria can be combined using a simple map algebra procedure. The standardized and weighted criteria maps are simply added together to create an overall prioritization map having highest values where the likelihood of NIS impacts on training and natural resource management objectives are greatest, and where NIS management could provide the greatest payoff by minimizing long-term cost and NIS dispersal from existing infestations (Figures A-11 and A-12).

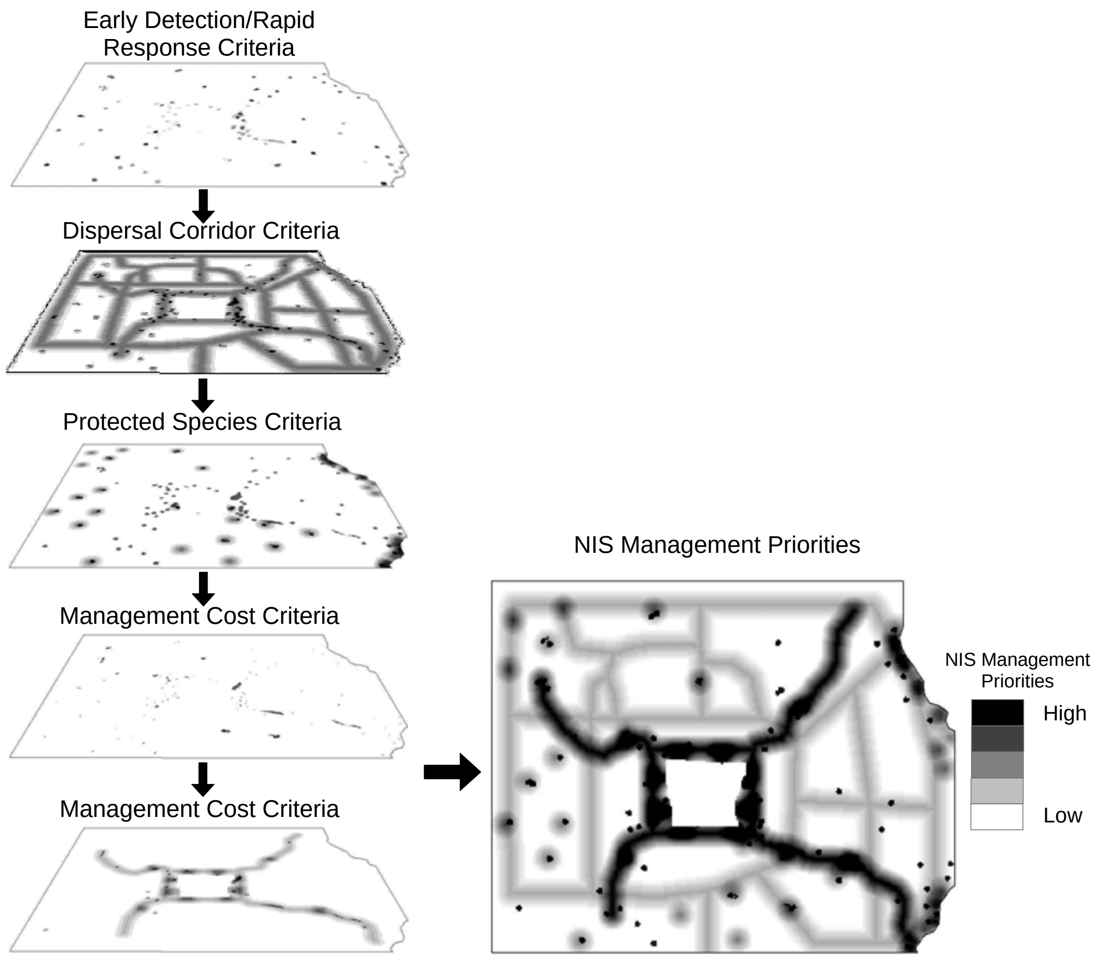


Figure A-11. Conceptual diagram of the combination of weighted criteria, creating a NIS Management Priority map for Camp Central Prairie.

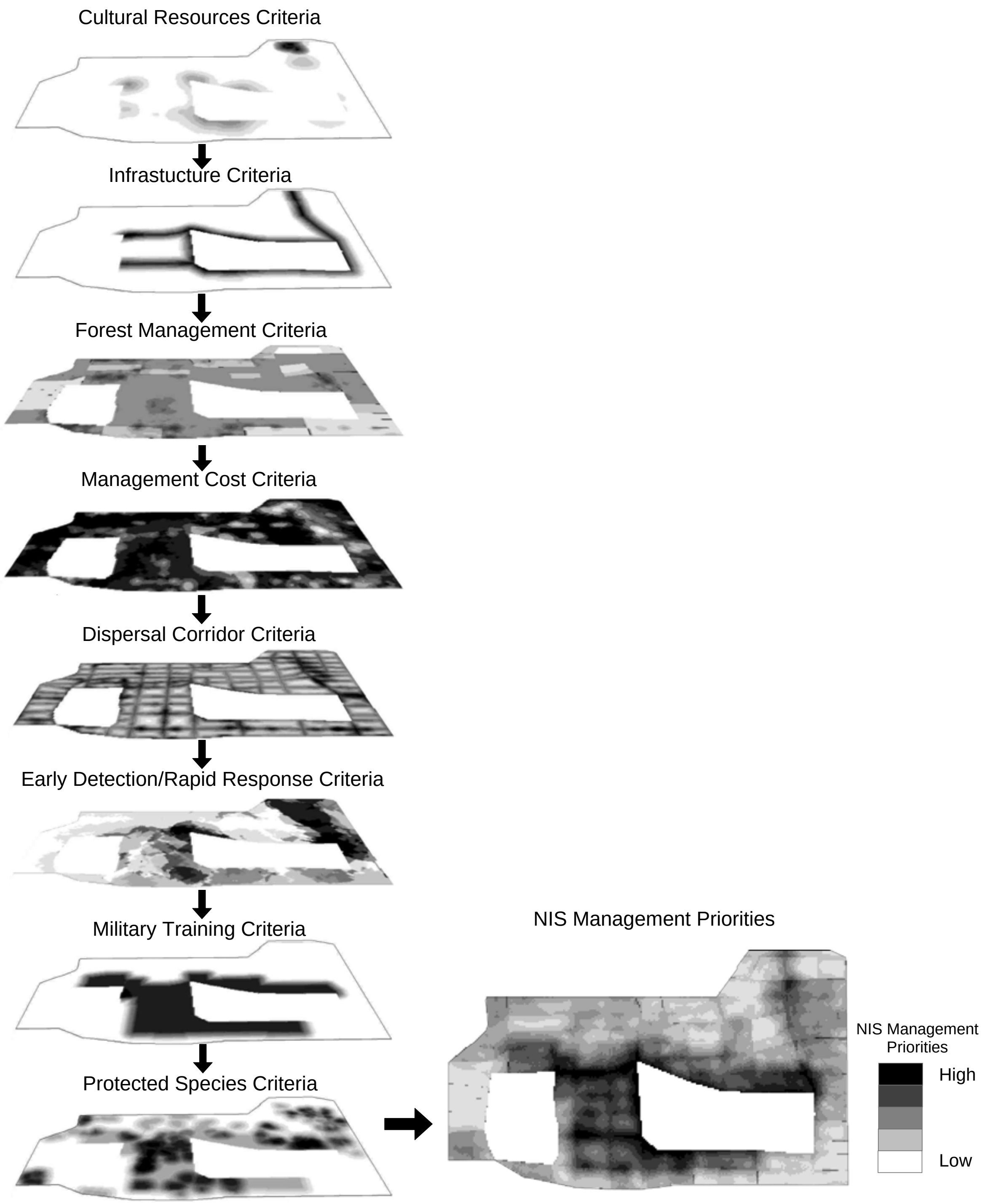


Figure A-12. Conceptual diagram of the combination of weighted criteria, creating a NIS Management Priority map for Fort Southeastern Forest.

The only potential complication of this step of a MODA is the issue of mismatched spatial scale. A mismatch between the scale of the decision problem and the scale of the parameters needs to be handled carefully as it can greatly influence results (Malczewski 2000). The scale of the decision problem should be determined by how the results of the analysis will be used, whereas the scale of the parameters is determined by how the parameter data are collected, which in many cases will have been for a purpose other than supporting a MODA of NIS management prioritization. Consequently, each criteria map should have the same spatial scale before they are combined. However, changing the spatial scale of parameter data is necessarily an aggregative process (i.e., high resolution fine grain data are converted to lower resolution or course grain data). This conversion effectively smoothes the data values and can affect the MODA results. Decision makers need to consider whether important aspects of data are lost by changing the spatial scale and whether the chosen scale is best suited to address the MODA problem.

Uncertainty

Uncertainty is an inherent part of any decision-making process. Here, uncertainty resulting from the derivation of criteria weights is specifically addressed. Uncertainty associated with determining preferences among criteria weights can be a result of an absence of information or limitations on a stakeholder’s understanding of the behavior of the criteria. This uncertainty should not be considered a flaw, but rather something that needs to be understood and accommodated as part of any decision analysis (Eastman 1999). Unfortunately, most published examples of decision analyses do not consider uncertainty (Malczewski 2006), despite the fact that most decision analyses have some uncertainty that needs to be accounted for. The section on criteria weighting (page A-26) showed how uncertainty can be accounted for in the criteria weights by using fuzzy preferences. This section discusses how additional effects of uncertainty can be measured and accounted for with a sensitivity analysis (SA).

SA allows one to measure the effect of certain evaluation criteria or the choice of weights on the MODA output. An SA is intended to improve the objectivity of the decision analysis, build confidence in the results, identify criteria that are especially sensitive to weight changes, and visualize spatial sensitivity of weights. The ad-hoc SA recommended here is performed by introducing a known amount of change to each criteria weight, then observing and measuring the subsequent changes that take place. Each criteria weight should be adjusted individually by adding and subtracting a constant value. It was chosen to adjust each criterion by the standard deviation of the weight scores (Camp Central Prairie = ±0.17; Fort Southeastern Forest = ±0.13).

The criteria maps are then recalculated and combined with the other criteria maps to depict the outcome of each weight adjustment. To visually observe the effects of weight sensitivity, maps generated during the SA should be compared to the original MODA outcome (Figure A-13) (Feick and Hall 2004).

An SA can identify the most critical criteria weights. Critical weights are those that have the greatest influence on the outcome of the MODA. To measure the impact of a change in criteria weights on the outcome, correlation coefficients can be calculated. Correlation coefficients provide measures of similarity and dissimilarity between two maps. Table A-9 shows the correlation coefficients calculated by comparing the maps in Figure A-11. The Kappa Index of Agreement is used to measure the similarity between the original outcome maps in Figures A-8 and A-9 with those created by adjusting the criteria weights individually (Eastman 1999). Values range from 0.0 indicating no correlation to 1.0 indicating perfect correlation. Low correlation coefficient values indicate a difference between two maps. In terms of the SA discussed here, a low correlation value indicates a critical weight because the introduced change caused a significant change in the MODA outcome.

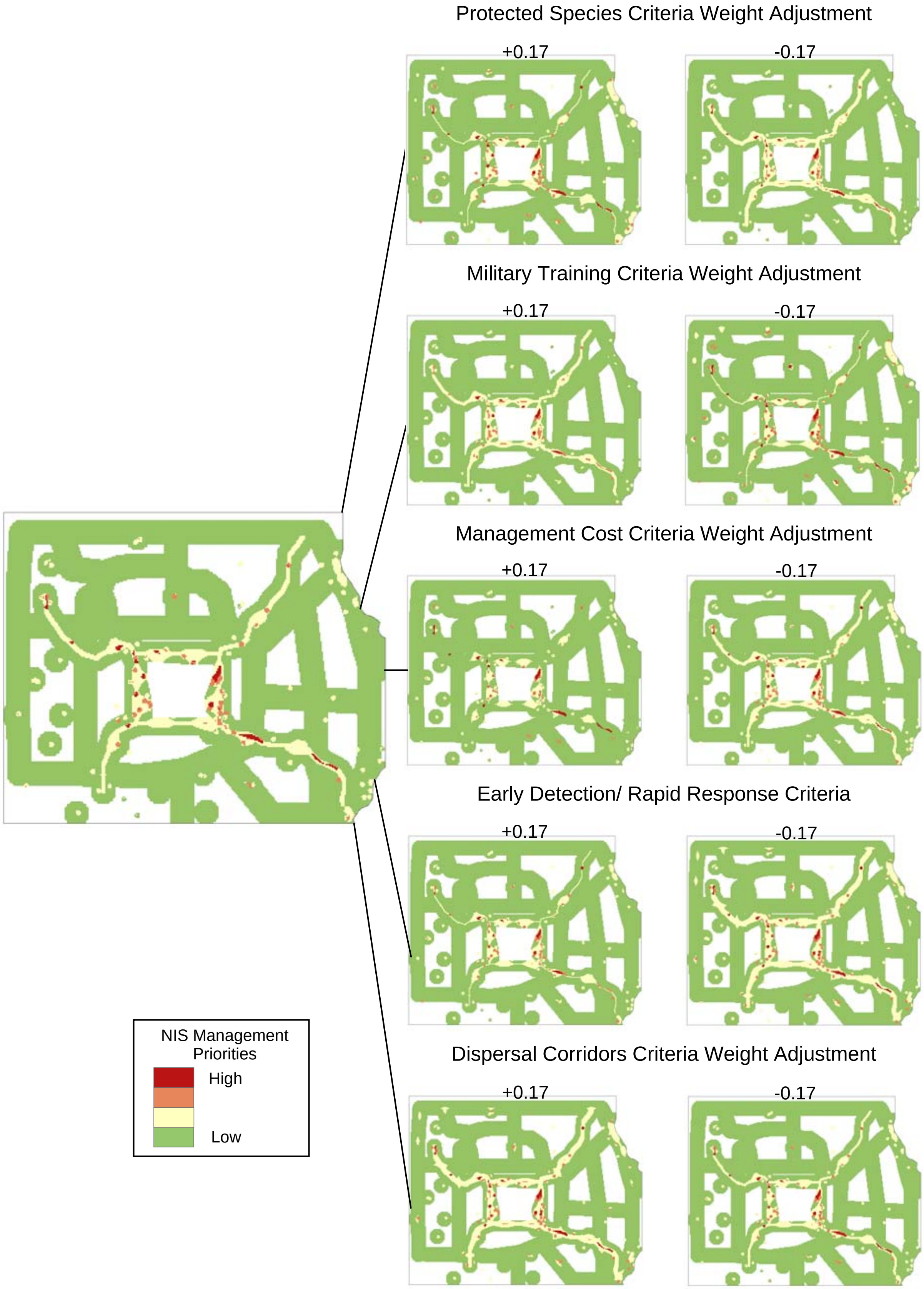


Figure A-13. Visualization of a sensitivity analysis for Camp Central Prairie in which criteria weights were adjusted by the standard deviation (±0.17) of the weights.

Table A-9. Kappa Index of Agreement values calculated to examine how changes in criteria weights affect the overall MODA outcome for Camp Central Prairie. The standard deviation (± 0.17) of the weight scores was used for all criteria.

Evaluation Criteria	Kappa Index of Agreement	
	+ stndev	- stndev
Military Training	0.69	0.69
Early Detection/ Rapid Response	0.71	0.88
Management Cost	0.71	0.87
Dispersal Corridors	0.32	0.34
Protected Species	0.71	0.72

The most critical weights can then be reevaluated by stakeholders to ensure they truly represent their perceptions about the relative importance of criteria. This sensitivity analysis is easy for non-experts to understand, and it gives stakeholders immediate feedback about the impacts of criteria weight uncertainty on the MODA outcome (Jankowski et al. 1997).

Conclusion

This document describes the utility of MCDA for identifying NIS management priorities on Army installations, where the complexities of simultaneously satisfying multiple land management objectives in support of military training usually cripple attempts at integrated management. It describes MCDA approaches that can substantially improve installation decision-making by forcing careful consideration of the best available knowledge about NIS impacts, NIS biology, compliance requirements, and management costs within a hierarchy of objectives. The approaches described are systematic, flexible, transparent, and reproducible.

The MCDA process features distinct logical steps that can foster greater understanding among all installation stakeholders about the necessity for integrated NIS management. Identifying relevant evaluation criteria and parameters that serve as accurate metrics is an important first step of MCDA. Typically many of these criteria have spatial dependencies that generate heterogeneous relevancies for NIS management prioritization across an installation. Criteria standardization allows criteria to be compared on a common scale and provides an opportunity to incorporate uncertainties into the analysis. Criteria weighting then allows installation stakeholders to provide input on the relative importance of different criteria within the hierarchy of objectives. Finally, the use of sensitivity analysis provides a means of assessing the influence weights have on the final results, which can also supply insights about the robustness of the results.

Unfortunately, modules to support MCDA have not been integrated into most GIS software (e.g., ESRI). Currently, IDRISI is the most widely available and powerful GIS software for implementing MCDA. Still, many MCDA steps can be accomplished with common GIS map algebra capabilities, as well as spreadsheet and mathematical software (e.g., MATLAB). Importing and exporting large files among various software programs can create numerous complications. Additional software capabilities are needed to aid the use of MCDA, specifically MODA, for NIS management prioritization on large multi-use public properties where complex NIS management issues invariably arise.

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