FOREST INVASIVE ADAPTIVE MANAGEMENT ON NATIONAL WILDLIFE REFUGE LANDS IN THE CENTRAL HARDWOOD REGION

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Abstract.—Approximately 2.4 million acres of National Wildlife Refuge System lands are impacted by invasive plants and are the primary challenge for habitat management in the Central Hardwood region. In 2011, biologists, managers, and contracted support staff from six national wildlife refuges in southern Indiana, Illinois, and Missouri developed an adaptive management project to control 42 forest-adapted invasive plant species on refuge lands. Structured decisionmaking was used to identify and refine the management problem, objectives, and alternative management actions, and to assess consequences and tradeoffs among selected management alternatives. Objective hierarchies and an influence diagram were developed to link our monitoring and objectives at two scales, the refuge scale and a management grid scale (1 ha). The project formalized a step-by-step process for prioritizing actions at the refuge scale and for applying management actions at the grid scale. Both inventory and monitoring has provided a feedback loop to inform future management. The grid scale model has allowed formal learning about the effectiveness of prior and ongoing management actions. We demonstrate the approach using data collected from Muscatatuck National Wildlife Refuge (30.9 km^2) during 2011-2013.

INTRODUCTION

Invasive plant species (IPS), which affect approximately 2.4 million acres of U.S. Fish and Wildlife Service (USFWS) National Wildlife Refuge System (NWRS) lands, are ecologically and economically costly (Leung et al. 2002). As mandated by the NWRS Improvement Act of 1997 and subsequent policy, the NWRS is to be managed so as to ensure maintenance of the biological integrity, diversity, and environmental health (BIDEH). The BIDEH policy states that where it is feasible and supports the refuge purposes, the NWRS will be managed for historic conditions that were present prior to substantial human-related changes to the landscape. Most refuges report that IPS interfere with their wildlife management objectives (U.S. Fish and Wildlife Service 2003), but control with cost-effective and publicly acceptable methods is a challenge. Refuge managers rank IPS the highest threat to the NWRS, scoring almost double that of any other threat. Costs to combat IPS, including staff and resources for control, are exponentially increasing each year. In fiscal year 2011, the NWRS spent $15.8 million directly on IPS management (U.S. Fish and Wildlife Service 2013). Further, many federally-listed threatened and endangered species are increasingly impacted by exotic species. Although considered top priority for most National Wildlife Refuge (NWR) managers, there is limited funding and staff to control established infestations or prevent new infestations.

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National Wildlife Refuge managers in the Central Hardwood region do not have a standardized IPS control and monitoring program. They need cost-effective tools to properly plan, prioritize, manage, monitor, and understand IPS infestations. Structured decisionmaking (SDM) and adaptive management (AM) are rarely used to design and implement management strategies for IPS (Blomquist et al. 2010, Bogich and Shea 2008). Based in decision theory and risk analysis, SDM is a carefully organized analysis of problems in order to reach decisions that are focused clearly on achieving fundamental objectives (Hammond et al. 1999). Adaptive management, as framed within the context of SDM, uses flexible decisionmaking that can be adjusted to reduce uncertainties as outcomes from management actions and other events become better understood (Williams et al. 2007). Often in the face of temporal, budgetary, and personnel constraints, managers plan their management strategies with little *a priori* information as to the nature of infestations and have little information as to the effectiveness of management actions. This dilemma is difficult to overcome, as many managers feel the need to use the limited resources to control IPS rather than using those resources to manage IPS (e.g., inventories). However, effective IPS management depends on reliable vegetation monitoring data, and area-wide IPS inventories should be conducted before prioritizing and adopting specific management strategies (Dewey and Andersen 2004).

U.S. Fish and Wildlife Service policies (including BIDEH) mandate managers to adopt integrated pest management (IPM) strategies when managing invasive plant species and inventory, monitoring, and mapping are critical components of a successful IPM program (U.S. Fish and Wildlife Service 2004). Inventories for an IPM strategy should be conducted with the objective of creating accurate species distribution maps that are used to set priorities and select treatments. The most powerful benefit is that monitoring effectiveness is predicted to lower management costs by up to 30 percent (Haight and Polasky 2010). For an inventory or monitoring strategy to be effective, certain critical data must be acquired, including identifying which IPS are present, their location, and their relative abundance (Christensen et al. 2011, Rew and Pokorny 2006). IPS monitoring often focuses on presence only data, however, the collection of true absence information improves the data set and allows the use of traditional statistical methods (Li et al. 2011). Further, true absence data is essential to producing accurate assessments within any species distribution model (Vaclavik and Meentemeyer 2009).

The USFWS Region 3 (R3) refuges in the Central Hardwood region (Illinois, Indiana, and Missouri) that are primarily forested include Big Oaks NWR (IN), Crab Orchard NWR (IL), Cypress Creek NWR (IL), Mingo NWR (MO), Muscatatuck NWR (IN), and Patoka River NWR (IN). In 2009, these refuges began investigating IPS infestations and identified the need to prioritize management actions. Further, managers and biologists recognized the need for coordination to effectively control multiple forest-adapted IPS. The U.S. Geological Survey (USGS) partnered with the refuges to utilize multi-resolution digital aerial color infrared photographs to map some infestations in the spring and fall when nonnative plants were most likely to be most distinct from surrounding native vegetation.[2] In 2011, staff from each refuge, R3 Division of Biological Resources, and collaborators from the Chicago Botanic Garden convened for a SDM workshop. The goals of the workshop

[2] U.S. Geological Survey. 2010. Examining the use of color-infrared digital photography to map non-native invasive plants on two Southern Indiana U.S. Fish and Wildlife Service National Wildlife Refuges. 13 p. Unpublished Administrative Report. On file with: Upper Midwest Environmental Sciences Center, 2630 Fanta Reed Road, La Crosse, WI 54603.

were to formulate and clarify the key components of AM, which included objectives, management alternatives, modeling, and monitoring approach (Gregory and Long 2009, Hammond et al. 1999, Keeney and Raiffa 1993, Nichols and Williams 2006, Williams et al. 2007). Through the SDM process, participants decided to: (1) focus on managing IPS; (2) reduce uncertainty in management effectiveness at two spatial scales (refuge scale and 1-ha grid scale); and (3) link management decisions at the grid scale to success at the refuge scale over 7 years. Participants determined that the 1-ha scale was the most appropriate scale to balance effort and resolution of inventories and was an effective scale for management actions and monitoring. Also, staff at most refuges would need 7 years to conduct inventories, apply management actions, and assess effectiveness. Ultimately, the Forest Invasive Adaptive Management (FIAM) project was developed and is presented here. FIAM incorporates a multi-step approach of inventory, prioritization, pretreatment monitoring, treatment, and effectiveness monitoring. FIAM is nearing completion of the setup phase of AM (*sensu* Williams et al. 2007), and pilot work and development of key components are highlighted. Data collected at Muscatatuck NWR using 0.25 ha grids (50 m by 50 m) is used to demonstrate the inventory and management prioritization. However, the other five participating refuges use a 1 ha (100 m by 100 m) grid system because the resolution was found to be adequate for project objectives and greatly reduced effort required to conduct surveys. The refuge-scale inventory phase guided prioritization and management decisions by providing highly detailed maps of the spatial extent and severity of approximately 40 IPS as well as maps of areas that are not invaded.

OBJECTIVES

The stated mission of the NWRS IPS Program is "Through partnerships, prevent, eliminate, or significantly reduce populations of aquatic and terrestrial IPS throughout the NWRS in order to protect, restore, and enhance native fish and wildlife species and associated healthy ecosystems" (U.S. Fish and Wildlife Service 2003). Goals of the program are to: (1) increase the awareness of IPS; (2) reduce impacts of IPS and more effectively meet fish and wildlife conservation goals; (3) reduce IPS impacts on NWRS neighbors and communities; and (4) promote and support safe and effective IPM techniques to combat IPS.

METHODS

Effective management of established IPS can be described as a general 3-step process.

1. Conduct an inventory to identify and prioritize management locations.
2. Apply management actions to those locations.
3. Monitor managed areas to evaluate effectiveness of the action.

Workshop participants developed objectives hierarchies for the refuge scale (Fig. 1) and grid scale (Fig. 2). The ultimate goal was to control IPS at the refuge scale by using actions at a 1-ha scale. Each objective hierarchy started with the NWRS fundamental objectives (i.e., the ultimate reason we seek to control IPS), and moved downward to means objectives (measurable objectives) and the metric that will be measured. An influence diagram was developed to conceptualize factors impacting our objectives and the predicted importance of management actions at the grid scale (Fig. 3). Many factors were considered when developing the influence diagram, but participants chose to focus on three factors of forest composition for monitoring and modeling. The influence diagram also

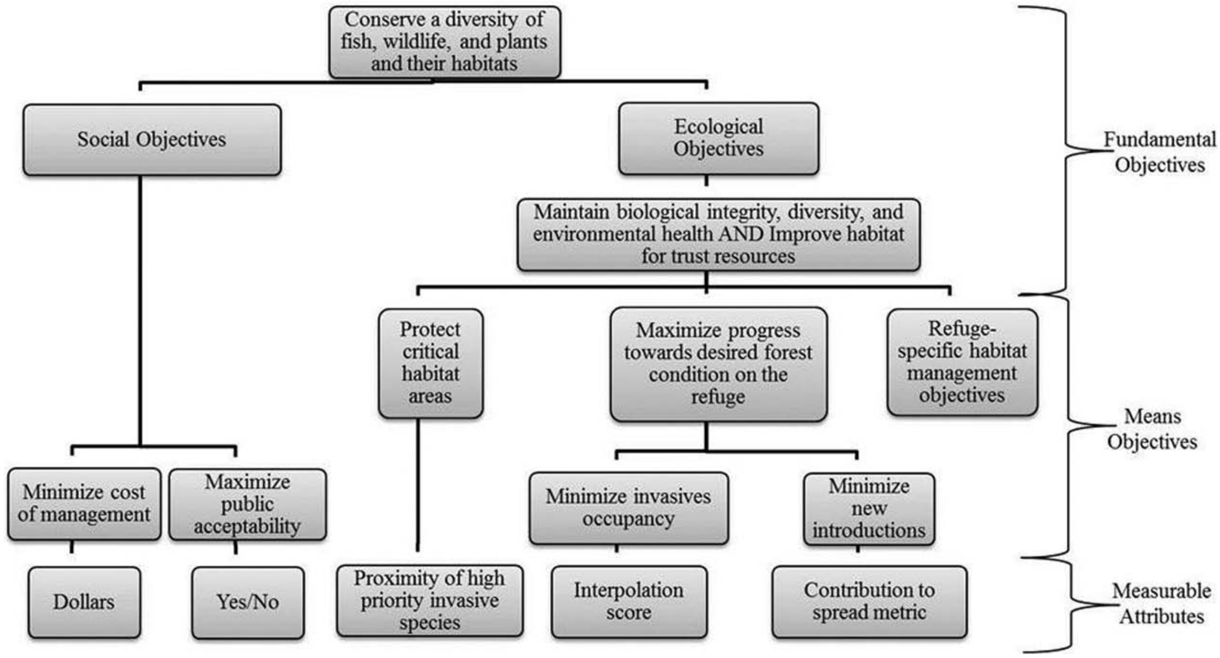

Figure 1.—The refuge-scale fundamental objectives, means objectives, and measureable attributes hierarchy describes the logic and ways to measure success for controlling invasive plant species on National Wildlife Refuges.

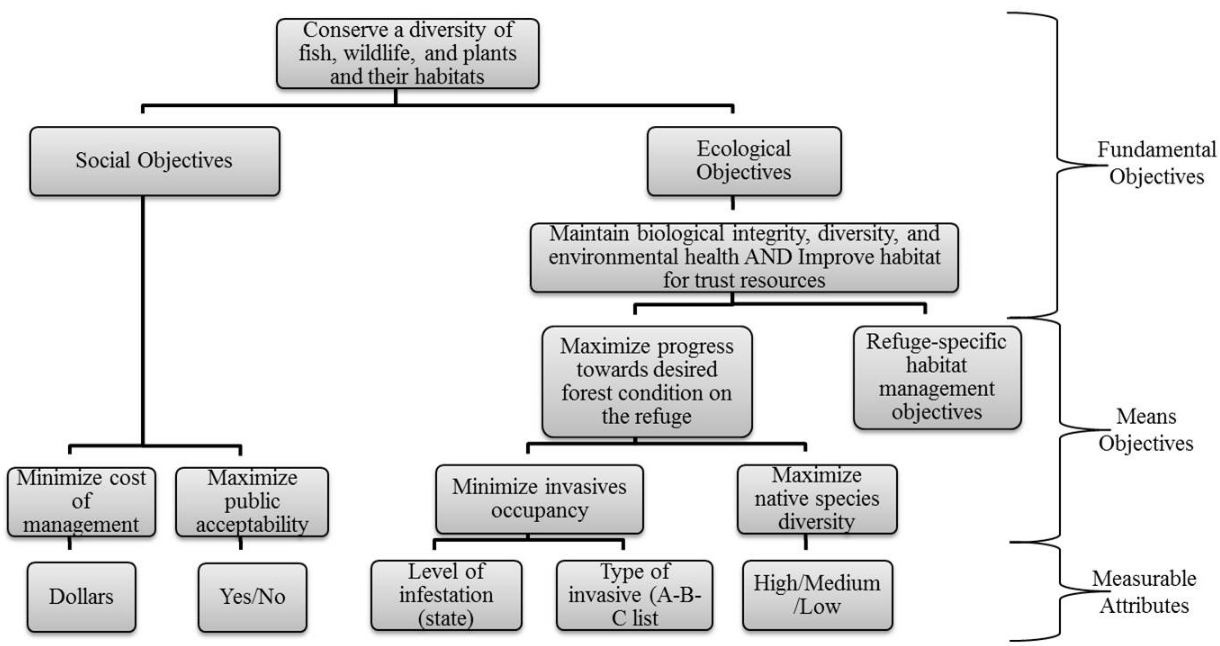

Figure 2.—Grid-scale objectives hierarchy for controlling invasive plant species on National Wildlife Refuges.

provided a visual reference communicating how new information from monitoring would be used to inform future management actions. The primary uncertainty was with how management interacted with the ecology of IPS. Adaptive management at the grid scale was intended to reduce this uncertainty by explicitly learning about the effects of treatments. Additionally, the distribution and potential for spread on the refuges was largely unknown, and the inventory process and prioritization model helped to reduce this uncertainty.

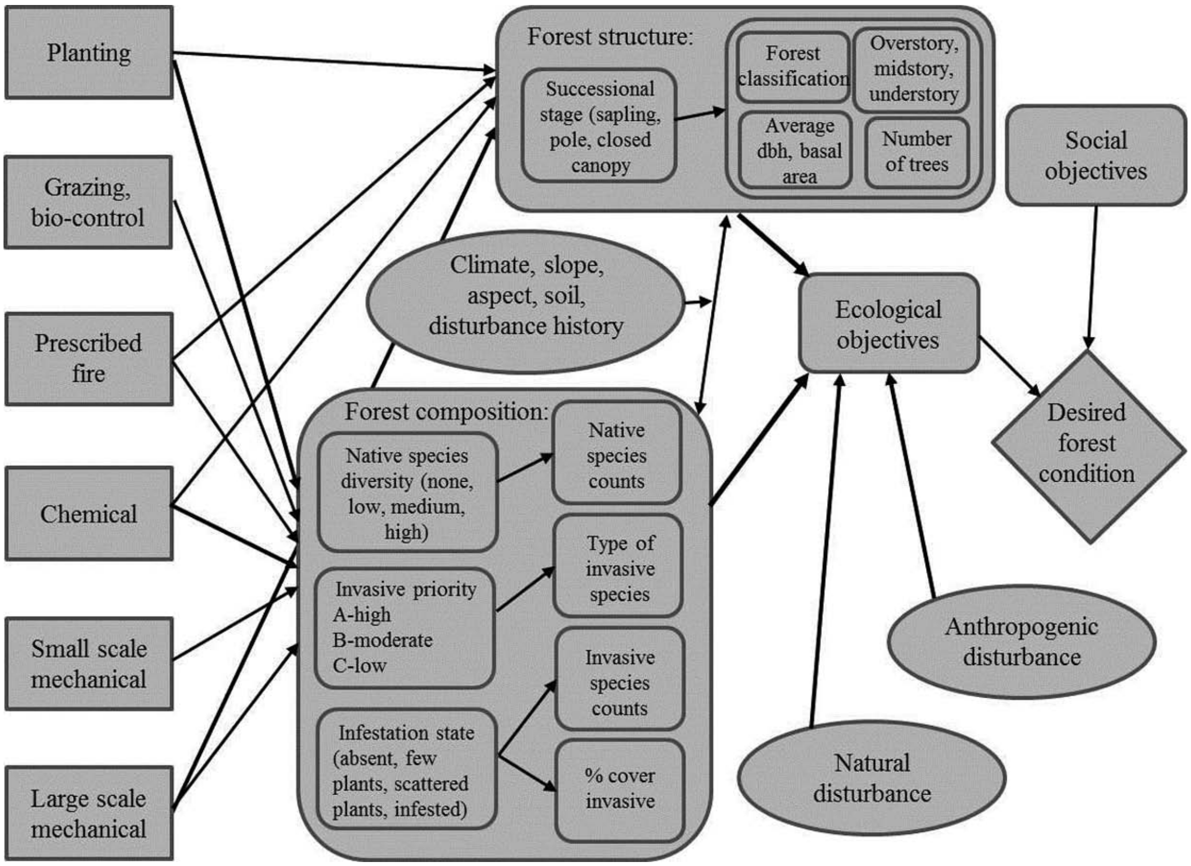

Figure 3.—The influence diagram shows the potential relationships among the management actions, variables outside of the control of managers, and variables controlled by management actions and measured by the refuge staff to assess success at controlling invasive plant species in individual grid cells on National Wildlife Refuges. Key to the influence diagram: diamond = fundamental objectives; rounded rectangles = a variable that is a function of other factors; ovals = uncertainties or chance variables; rectangles = decisions. The thickness of the arrow indicates the strength of the influence, with thicker lines indicating a stronger effect.

Invasive Plant Species Management Steps

Workshop participants formalized a step-by-step process for prioritizing actions at the refuge scale and applying management actions at the grid scale. These steps were built on the basic IPM steps and were useful for developing and revising the objectives hierarchies, monitoring protocols, and linking refuge-scale decisions about where to manage with grid-scale decisions about how to conduct management actions. Basic steps are listed below followed by a more detailed description of the process:

1. Place a grid of 1 ha square cells over the refuge and develop management units for inventory (Fig. 4).
2. Prioritize units for inventory based on site characteristics (e.g., ecological integrity, resistance to invasion, potential spread vectors, disturbance regime, restoration actions, presence of threatened and endangered species, and ease of management).
3. Inventory IPS at each grid across the refuge every 7 years.
4. Create maps based on IPS distribution and state of infestation.
5. Annually prioritize grid cells for management based on: (a) site-specific factors such as growth rate of IPS; (b) spread prioritization factors such as dispersal rate of IPS; (c) proximity to critical areas and potential vectors; d) proximity to public use areas; and e) cost.

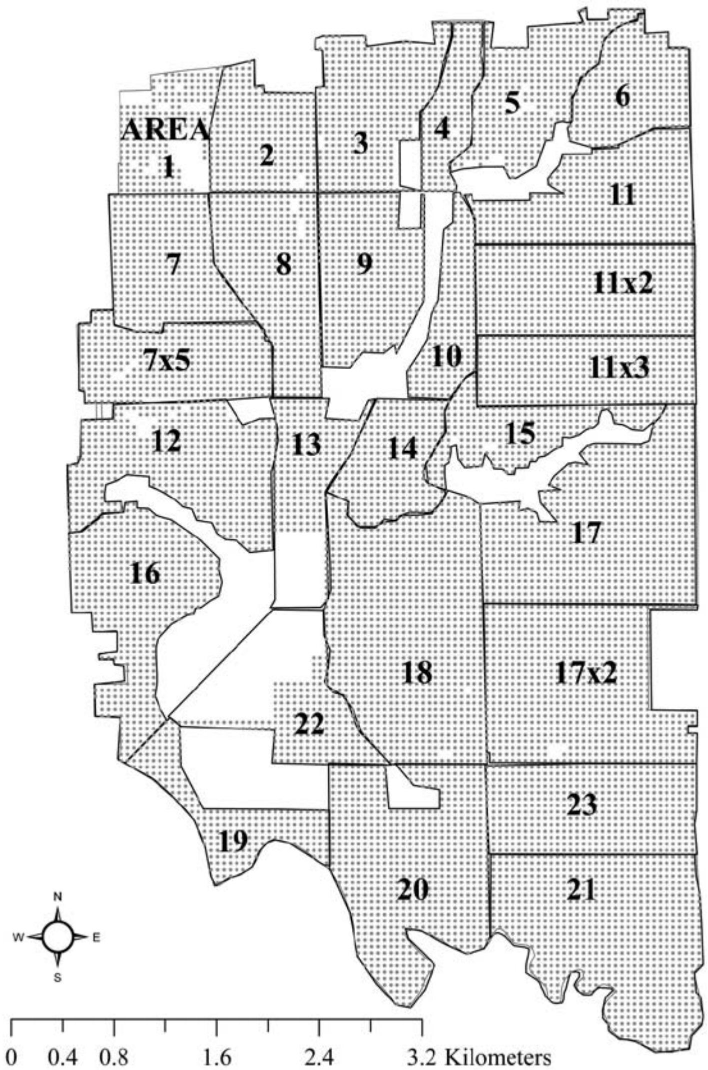

Figure 4.—Invasive plant species management units (areas) and inventory sample points on a 50 m x 50 m (0.25 ha) grid at Muscatatuck National Wildlife Refuge. The grid was overlaid on forested tracts, and most area boundaries consisted of roads, ditches, and wetlands.

6. Decide appropriate management actions.
7. Collect premanagement monitoring data at selected grid cells.
8. Take management action if inventory data and prioritization support action.
9. Collect postmanagement monitoring data to monitor effectiveness.
10. Annually repeat steps 5-8.

Inventory Protocol (Steps 1-3)

The refuge-scale inventory protocol was designed to specifically target project objectives (Lyons et al. 2008, Nichols and Williams 2006) and builds on a forest inventory conducted in 2009-2010. To simplify both inventory and monitoring, workshop participants classified species by their noxiousness (i.e., A-list, B-list, C-list; Table 1) (Morse et al. 2004) and categorized the state of the infestation as:

- Few plants—one plant to a few scattered plants that are not in distinguishable patches.
- Scattered plants—plants have a clumped distribution or are randomly scattered, but not a complete infestation.
- Infested—local area surrounding the sample point completely infested dense stand.

Table 1.—Select invasive plant species (IPS) detected on National Wildlife Refuge (NWR) forests in the Central Hardwood region categorized by level of priority for treatment

Scientific Name	Common Name	Priority rank[a]
Dioscorea bulbifera	air yam	A
Lonicera maackii	Amur honeysuckle	A
Elaeagnus umbellata	autumn olive	A
Dioscorea oppositifolia	Chinese yam	A
Ligustrum vulgare	European privet	A
Alliaria petiolata	garlic mustard	A
Phragmites australis	common reed	A
Berberis thunbergii	Japanese barberry	A
Lonicera japonica	Japanese honeysuckle	A
Polygonum cuspidatum	Japanese knotweed	A
Microstegium vimineum	Japanese stiltgrass	A
Sorghum halepense	Johnsongrass	A
Lonicera morrowii	Morrow's honeysuckle	A
Carduus nutans	nodding plumeless thistle	A
Celastrus orbiculatus	Oriental bittersweet	A
Lythrum salicaria	purple loosestrife	A
Phalaris arundinacea	reed canary grass	A
Lonicera tatarica	Tatarian honeysuckle	A
Euonymus fortunei	winter creeper	A
Populus alba	white poplar	A
Polygonum perfoliatum	Asiatic tearthumb	B
Cirsium vulgare	bull thistle	B
Lysimachia nummularia	creeping jenny	B
Dipsacus laciniatus	cutleaf teasel	B
Heracleum mantegazzianum	giant hogweed	B
Rubus armeniacus	Himalayan blackberry	B
Dipsacus fullonum	Fuller's teasel	B
Humulus japonicus	Japanese hop	B
Pueraria montana	kudzu	B
Rosa multiflora	multiflora rose	B
Paulownia tomentosa	princesstree	B
Lespedeza cuneata	sericea lespedeza	B
Ailanthus altissima	tree-of-heaven	B
Euonymus alatus	burningbush	C
Vinca minor	common periwinkle	C
Sesbania herbacea	coffee weed	C
Glechoma hederacea	ground ivy	C
Clematis terniflora	Japanese virgin's bower	C
Lonicera xbella	showy fly honeysuckle	C
Melilotus officinalis	white sweet clover	C
Salix alba	white willow	C

[a] A = high, B = medium, and C = low (Morse et al. 2004).

The refuge-scale inventory protocol was developed and pilot tested at Muscatatuck NWR during the 2011 field season. This protocol was amended from the Federal IPS Mapping Standards (North American Weed Management Association 2002) to more effectively meet AM project objectives. Information from Muscatatuck was used to refine the protocols and was used at other refuges during 2012–2013. The inventory was a rapid assessment of grid cells across the entire refuge based on five major metrics that affect prioritization:

- State of the infestation and type of IPS ranking based on priority for management (Table 1).
- Critical areas metric (distance to special communities, and threatened/endangered species).
- Spread metric (proximity to vectors for spread of IPS including roads, waterways, trails, and refuge boundaries).
- Public acceptability metric (public visibility of infestation).
- Cost metric (determined by logistics to access a grid cell).

At Muscatatuck NWR, ArcGIS 9.3 (Esri, Redlands, CA) geographic information system (GIS) was used to establish grid points with a 50 m spacing (other refuges used 100 m) to create 23 separate sampling areas delineated by wetlands, streams, ditches, roads, and refuge boundaries (Fig. 4). At each point, the IPS were recorded and the state of the infestation was visually estimated for each species. Visibility distance was also recorded as the categorical distance (0-5, 6-10, 11-20, or >20 m) that the observer could reliably identify vegetation. For each grid cell, GIS was used to measure the distance to critical areas, spread vectors, roads, and public use areas. The distance to road, which is correlated with management cost, was used to assess the relative cost to implement a management action.

Prioritization Decision Support (Steps 4-5)

Using a GIS point to raster conversion, a distribution map of autumn olive (*Elaeagnus umbellata*) was created based on survey data at Muscatatuck NWR (Fig. 5), and this procedure was repeated for each target species. If the species was not observed at a point, a 0 (absent) was recorded, therefore, areas that were not invaded were mapped. The procedure provided a layer that defined the approximate boundaries and the level of infestations. Maps of A-list, B-list, and C-list species were used to create a single map for the three priority levels, and the infestation scores were used in the prioritization tool.

Workshop participants developed a decision tool that prioritized management actions based on the state of each grid cell with regard to the prioritization metrics for each of the ecological and social objectives based on inventory data, the relative metric weights, and project budget. This tool was developed further and pilot tested using inventory data from Muscatatuck NWR (unpublished data[3]). Based on the five metrics from refuge-scale inventory, a management prioritization score was computed for each grid cell using a 5-step process:

1. Site-specific prioritization score assigned based on the probability of changing to another infestation state in the following year (Fig. 6).
2. Spread prioritization score estimated based on infestation state and invasive noxiousness of adjacent cells.

[3] Lonsdorf, E.V.; Blomquist, S.M.; Wood, D. Unpublished data. On file with: U.S. Fish and Wildlife Service, Muscatatuck National Wildlife Refuge, 12985 E. U.S. 50, Seymour, IN 47274.

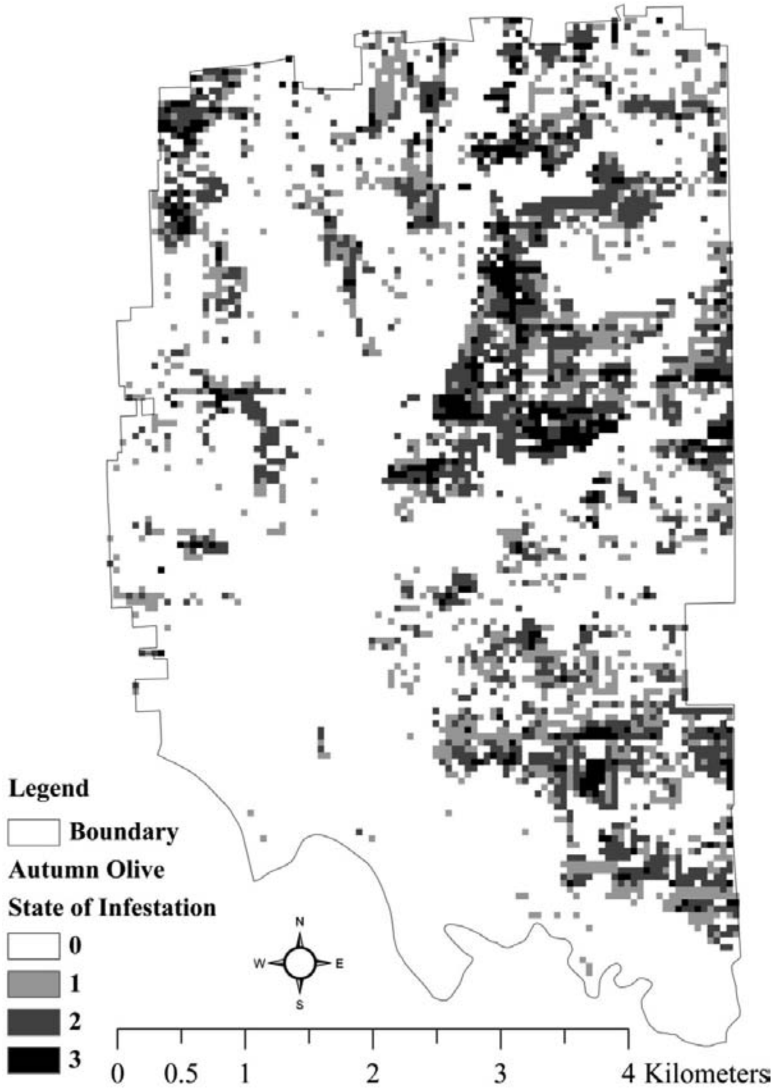

Figure 5.—Autumn olive distribution based on invasive plant species inventory during 2011 at Muscatatuck National Wildlife Refuge. The ordinal scale data for the state of autumn olive infestation were: 0= absent; 1= few plants; 2= scattered plants; 3= infested.

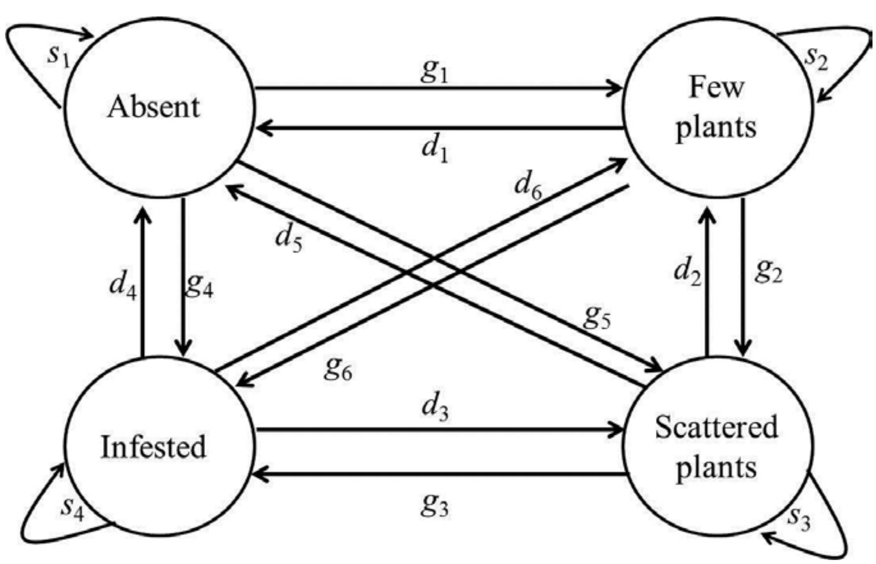

Figure 6.—Transition probabilities for a grid cell to remain in the current state or to change to another state from one year to another. The probabilities of infestation change are to grow (g), decrease (d), or stay (s).

3. Site-specific and spread prioritization score summed and weighted by the distance to spread vectors, critical areas, and public use areas.
4. Management cost estimated for each grid cell based on accessibility.
5. Grid cells selected for management based on the priority score and cost.

Management Actions (Step 6)

Management actions were categorized to reflect a general type of action to simplify the problem for modeling and decisionmaking purposes. Alternative management actions and techniques available for controlling IPS infestations on NWR include:

- No action
- Prescribed fire
- Small-scale mechanical (hand pull, girdle, chain saw)
- Large-scale mechanical (mow, mulch, bulldoze)
- Chemical spray (spot, broadcast)
- Tree planting

Within these categories, the decisionmaker chose the best management practice in each instance based on the species present, accessibility, management restrictions, cost, and other considerations. A challenge for AM projects was to reduce management alternatives to those that will be used at a high enough frequency to promote learning. Thus, categories were simplified based on the frequency of use in forested environments to a final action menu that included: no action, prescribed fire, mechanical, chemical, and planting, as well as selected combinations of these actions.

Grid-Scale Monitoring Protocol (Step 7)

Monitoring at the grid scale was intended to assess the effectiveness of the management actions as well as improve the refuge-scale inventory data. The current protocol collected data on habitat metrics to provide information necessary for state dependent decisionmaking, evaluate management performance, and facilitate improved management through learning. This protocol used a transect-based approach to sample approximately 20 percent of each grid cell selected for management, and thus increased detection of IPS (Chen et al. 2009, unpublished data[4]). Points were sampled on transects premanagement and postmanagement to assess three state-based metrics: (1) state of infestation, (2) invasive noxiousness, and (3) native species diversity in three categories based on species counts.

Management Action Decision Support (Step 8)

State-and-transition models, in which the transitions from one state to the other are unknown, were created to tie treatments to effectiveness monitoring. *A priori* transition probabilities were developed (Fig. 6) for how each category of plant (e.g., noxiousness levels, woody vs. herbaceous) changed with and without management based on staff experience, literature, and agency guidance. These transition

[4] Blomquist, S.M.; Wood, D. Unpublished data. On file with: U.S. Fish and Wildlife Service, Muscatatuck National Wildlife Refuge, 12985 E. U.S. 50, Seymour, IN 47274.

probabilities represented hypotheses that predicted how each species should respond to management and formalized our primary uncertainty about how our management affected the ecology of IPS. A critical aspect of the AM process is the development of credibility measures for each model, which represent relative beliefs or weights. Learning through AM occurs when each model's prediction is confronted with observations of the system, and these relative belief measures are updated through Bayes theorem (Williams et al. 2007). Stochastic dynamic programming is used to implement this Markov decision process framework (Bogich and Shea 2008). Such state-and-transition models are useful for determining an optimal policy of state-dependent actions and are recommended for land management modeling (Bestelmeyer et al. 2011).

Post-Management Monitoring (Step 9)

Postmanagement monitoring was conducted annually after taking management actions at the grid scale, and followed the same protocol as Step 7. The data on IPS distribution and state was also used to update the prioritization model (Steps 4-5).

DISCUSSION

We presented a systematic approach for IPS control on NWR lands in the Central Hardwood region, but the process can be used for lands managed for natural conditions. Although controlling IPS consumes incredible financial resources for many NWRs, managers rarely track the effectiveness of management actions. The primary reasons are a paucity of common protocols, data management structures, and a perceived lack of resources for monitoring. In most cases, it is unknown if resources used to combat IPS achieve the desired outcome. Before the development of FIAM, refuge managers had few options for prioritizing the control of IPS with various life forms and responses to management techniques. Managers were also challenged with assessing potential for spread beyond current infestations and boundaries. Additionally, the high diversity of habitats throughout much of the Central Hardwood region prevented the use of a single approach to effective IPS management.

The focus of FIAM is on established or recently invaded populations. Our project did not explicitly address early detection rapid response (EDRR) procedures which are effective for preventing IPS establishment and are an essential part of any IPM program (U.S. Fish and Wildlife Service 2004). However, the rapid inventory gave the field crews the opportunity to report EDRR species and give real time reporting of unusual vegetation. For example, during the inventory phase, several IPS were discovered that were unknown to occur on these lands.

Developing the grid system was a compromise between a systematic approach to rapidly inventory NWRs and an appropriate management scale. The 1-ha scale was small enough to put effective management on the ground and large enough to assess the effectiveness of those management actions. FIAM uses a systematic sampling approach to predict and learn about management. The grid-based approach comprehensively samples the management unit regardless of the current distribution, and such systematic approaches are ideal for supporting distribution modeling and long-term monitoring (Stadt et al. 2006).

The explicit structure of AM provided the guidance to elucidate goals, develop hypotheses, identify alternative management actions, and develop procedures to collect relevant data that can be evaluated and followed by reiteration (Williams et al. 2007). The objective hierarchies are decision analytic tools that were effectively used during the setup phase and can be modified through the implementation of FIAM with learning and shifting priorities. For example, workshop participants decided that forest structure was less influential than forest composition for making management decisions. This helped refine the objectives hierarchies to focus on forest composition and then build decision tools for prioritizing management actions. Ultimately, these hierarchies were useful to link the FIAM project to the NWRS mission, measuring progress toward achieving goals and other factors that may influence success.

This project highlighted the need for modeling capability for AM projects. The prioritization model was effective for deciding the most appropriate locations to focus management efforts and developing predictions about the spread of infestations. Large-scale AM projects with much uncertainty are likely to fail without substantial investment in personnel dedicated to modeling and data analysis.

We have completed pilot testing the inventory and monitoring protocols, but the project remains in setup phase for all refuges as we complete pilot testing during 2014. We anticipate FIAM will be fully implemented, providing feedback to refuge managers and being used for management guidance outside the NWRS by 2015.

FIAM is a good example of the requirements and benefits of developing and implementing the setup phase of an AM project for multiple NWRs. A key component of FIAM development was formalizing priorities for management and predicting effects of management actions used to deal with the high IPS diversity and management. This requirement of AM promoted collaboration and information sharing among refuge biologists and regional biological staff when developing and pilot testing standard protocols. Additionally, collaboration improved data management systems, which tend to be a major hindrance to tracking management actions on many NWRs. An additional key benefit was enhanced overall communication between multiple NWRs across a large region. The 10 management steps were critical to the participants when evaluating and tracking the development status of FIAM through the setup phase. These steps will continue to be used to ensure the project is implemented in an efficient and effective manner.

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