Simple Spatial Modeling Tool for Prioritizing Prescribed Burning Activities at the Landscape Scale

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Abstract: *Resources for prescribed fire are frequently insufficient to manage public lands for all conservation and resource management objectives, necessitating prioritization of the application of fire across the landscape within any given year. Defining tradeoffs when applying prescribed fire to large landscapes is problematic not only because of the complexity of weighing competing management objectives at the landscape scale, but also because of the difficult nature of independently applying need-to-burn criteria to large areas. We present a case study of a simple modeling process implemented at Eglin Air Force Base in the Florida Panhandle (U.S.A.) to prioritize the application of prescribed fire. In a workshop setting, managers and biologists identified key conservation criteria and landscape management objectives that drive the application of prescribed fire. Remote sensing and other spatial data were developed to directly or indirectly represent all these criteria. Using geographic information system software, managers and biologists weighted each criterion according to its relative contribution to overall burn prioritization, and individual values for the criterion were scored according to how they influence the need to burn. Subsequently, this process has been validated and modified through ecological monitoring. This modeling process has also been applied to the 77,400-ha Blackwater River State Forest, public land adjacent to Eglin Air Force Base, demonstrating its applicability to lands with varying management priorities. The advantages of this model-based approach for prioritizing prescribed fire include the reliance on accessible, inexpensive software, the development of spatially explicit management objectives, the ease of transferability, and clearly stated assumptions about management that may be tested and reviewed through monitoring and public comment.*

Key Words: Eglin Air Force Base, fire management, GIS, longleaf pine sandhills, modeling, prescribed burning, remote sensing

Herramienta Simple de Modelado Espacial para Priorizar Actividades de Quemas Prescritas al Nivel de Paisaje

Resumen: *Los recursos para las quemas prescritas frecuentemente son insuficientes para manejar tierras públicas para todos los objetivos de conservación y gestión de recursos, por lo que se requiere priorizar la aplicación de fuego en el paisaje en un año determinado. La definición de ventajas y desventajas de la aplicación de fuego prescrito a paisajes extensos es problemática no solo debido a la complejidad para valorar objetivos de manejo contrastantes al nivel de escala, sino también debido a la compleja naturaleza de la aplicación independiente de criterios de "necesidad de quema" en áreas extensas. Presentamos un estudio de caso de un proceso simple de modelado instrumentado en la Base Aérea Eglin en Florida (E.U.A.) para priorizar la aplicación de fuego prescrito. En un taller, administradores y biólogos identificaron criterios de conservación claves y objetivos de gestión de paisaje que rigen la aplicación de fuego prescrito. Se desarrolló la percepción remota y otros datos espaciales para representar todos estos criterios directa o indirectamente. Utilizando software de sistemas de información geográfica, los administradores y biólogos evaluaron cada*

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criterio según su contribución relativa a la priorización de quemas en general, los valores individuales para el criterio se clasificaron según la manera en que influyen sobre la "necesidad de quemar." Este proceso se ha validado y modificado posteriormente por medio del monitoreo ecológico. Este proceso de modelado también se ha aplicado en el Bosque Estatal Blackwater River de 77,400 ha, terreno público adyacente a la Base Aérea Eglin, con lo que se demuestra su aplicabilidad a terrenos con prioridades de manejo variables. Las ventajas de este enfoque basado en el modelo para priorizar quemas prescritas incluyen la confianza en software accesible y económico, el desarrollo de objetivos de manejo espacialmente explícitos, la facilidad de transferencia y suposiciones acerca del manejo claramente establecidas que pueden ser probadas y revisadas por medio del seguimiento y la opinión pública.

Palabras Clave: Base Aérea Eglin, gestión de fuego, Sistema de Información Geográfica, colinas arenosas con pinos, quemas prescritas, percepción remota

Introduction

Geographic information systems (GIS) and remote sensing tools have greatly enhanced the ability of conservation planners to view increasingly larger landscapes and to set conservation priorities more effectively (Breininger et al. 1991; Hoctor et al. 2000; Knight et al. 2000; Kautz & Cox 2001). There are, however, fewer tools that prioritize management actions at the landscape scale in a spatially explicit manner (McCarter et al. 1998), and existing tools are frequently too complicated or information-intensive to gather widespread acceptance among land managers.

In the southeastern United States, federal and state lands contain a significant percentage of remnant fire-dependent longleaf pine (*Pinus palustris* Mill.) communities (Outcalt & Sheffield 1996; Stein et al. 2000), and prescribed fire is critical to the maintenance of biodiversity and the recovery of federally listed endangered species (Kirkman et al. 1998*a*; Hiers et al. 2000; U.S. Fish & Wildlife Service 2000). The lack of frequent fire is cited as one of the greatest threats to biodiversity worldwide (Leach & Givnish 1996) and to the southeastern United States in particular (Hardin & White 1989; Robbins & Myers 1992; Kirkman et al. 1998*a*; Hiers et al. 2000). Too often on large tracts of public land, prescribed fire resources are insufficient, or political barriers that interfere with the application of prescribed fire are too numerous, to permit management of these landscapes with adequate fire frequency to sustain the ecosystem and meet conservation objectives. In addition, other management objectives that require prescribed fire, such as timber or recreation, also suffer.

To optimize resource conservation and meet multiple management objectives, managers must make tradeoffs in deciding which portion of the land receives fire within any given year. Defining the rules of tradeoffs among management objectives when applying prescribed fire to large landscapes is problematic because of (1) a lack of spatially explicit management objectives, (2) the complexity of balancing competing management objectives at the landscape scale, and (3) the difficult nature of independently assessing "need-to-burn" criteria across large landscapes.

Eglin Air Force Base (hereafter, Eglin), representing the largest public ownership of longleaf pine habitat, is a part of one of six hotspots for biodiversity in the United States (Stein et al. 2000), and it contains one of the largest populations of the federally listed Red-cockaded Woodpecker (*Picoides borealis*) (U.S. Fish & Wildlife Service 2000). Eglin does not have the management resources to maintain or restore all its fire-dependent communities. Nearly three-quarters of Eglin is composed of fire-dependent longleaf pine ecosystems, but the average annual prescribed-burn program totals <21,000 ha, resulting in an average 7-year fire-return interval. At Eglin, the challenges of resource management at the landscape scale have been compounded by decades of fire suppression, a chronic shortage of prescribed-fire resources, and widespread invasion of sand pine (*Pinus clausa* var. *immuginata* Ward) (McCay 2000).

Maintaining and restoring these imperiled conservation values necessitates the development of tools to prioritize management activities at the landscape scale, particularly in the application of fire to the land. Past modeling efforts for sandhill habitat developed at Eglin demonstrated that a long fire-return interval would likely result in the gradual degradation of the entire landscape and meet no management objectives (Peterson & Hardesty 1999). It also suggested that a targeted approach was necessary to maintain the conservation values of Eglin's sandhill ecosystem. We present a case study of a simple prioritization tool implemented at Eglin to target prescribed fire at the landscape scale by balancing complex management objectives. We also present the application of this tool to Blackwater River State Forest, a tract of public land adjacent to Eglin that has similar ecological habitat but different management priorities.

Methods

Study Site

Eglin is a 180,000-ha weapons testing installation in northwestern Florida. Xeric longleaf pine sandhills are dependent upon frequent, low-intensity surface fires that occur every 3–5 years (Christensen 1981) and dominate nearly three-quarters of the Eglin landscape (Rogers & Provencher 1999). Eglin's fire-management objectives are diverse, but, in general, fire resources are applied in descending importance to U.S. Air Force mission support, compliance with legal requirements for prescribed fire under the U.S. Endangered Species Act, maintenance of biodiversity, and management of timber and game resources (U.S. Air Force 2001).

Blackwater River State Forest (BRSF) is a 77,400-ha forest managed by the Florida Division of Forestry. It is the largest state forest in Florida and is located in the Florida Panhandle adjacent to Eglin's northern boundary. Like Eglin, BRSF faces many logistic challenges to the application of prescribed fire, and it is frequently difficult to meet prescribed burn goals. The BRSF is dominated by more productive longleaf pine-wiregrass (*Aristida beyrichiana* Trin & Rupr.) savannas than Eglin's xeric sandhill habitat, and its management objectives differ significantly from Eglin, with a greater focus on timber production and recreation. Through participation in the Gulf Coastal Plain Ecosystem Partnership, a regional effort coordinated by The Nature Conservancy, Eglin, BRSF, and other public and private landowners in the area share planning and resources to meet shared conservation goals across political boundaries.

Modeling Approach and Identification of Key Criteria

To target prescribed-fire application on the landscape, we used GIS software (ArcView Spatial Analyst Model Builder, Environmental Systems Research Institute, Redlands, California) to develop a spatially explicit burn-prioritization model. The approach required (1) the incorporation of the experience of managers into the model to identify and rank criteria according to the need to burn and (2) production of dynamic site rankings scalable to burn-unit boundaries. ArcView's Spatial Analyst Model Builder was chosen to generate the burn-prioritization model for its ease of use, scalability, cost, and availability.

At Eglin, several planning efforts have been used to identify criteria that drive the need to burn across the landscape. All key ecological criteria were identified through Eglin's participation in The Nature Conservancy's Site Conservation Planning Process (Sutter et al. 2001). This planning process used two workshops to produce long-term "desired future conditions" for all species, community conservation targets, and maps of habitat needed to maintain viable populations and communities of those conservation targets. At Eglin, all ecological criteria identified through the planning process reflect both the synthesis of current science on longleaf pine ecosystems and the accumulated experience of managers. The development of the Eglin Integrated Natural Resource Management Plan provided the remaining criteria that drive the need to burn, including timber and game management needs. Eleven criteria were used in the prioritization model and include habitat of current threatened and endangered species, long-term recovery goals for endangered species, biodiversity GIS layers, time since last fire, and forest cover type (Table 1).

Table 1. Burn-prioritization criteria that define the need to burn for Eglin Air Force Base and their overall influence in the prioritization model.*

Input criteria	*Overall model influence (%)*	*Value*	*Weight (%)*
Time since forest restoration harvest (years)	5	1	0
		2	50
		3	100
		4	75
		5	50
		6	25
		8	15
		>10	0
Site productivity			
mesic upland longleaf pine	8	restoration condition	100
		maintenance condition	50
longleaf pine flatwoods	8	restoration condition	100
		maintenance condition	50
longleaf pine sandhills	6	restoration condition	100
		maintenance condition	75
Fire-dependent wetlands			
seepage slopes	6	presence only	100
depressional wetlands	2	presence only	100
riparian zones	2	presence only	100
Time since last burn (years)	20	1	10
		2	15
		3	25
		4	55
		5	65
		6	75
		7–16	100
		>16	40
		no record of fire	0
Fire frequency (total no. burns)	6	8	35
		7	40
		6	50
		5	60
		4	70
		3	80
		2	90
		1	35
		no record of fire	0
Landcover classification	6	longleaf forest	100
		mixed pine forest	90
		deciduous oak forest	10
		sand pine forest	−10
		other	0
Deciduous cover	4	high	100
		medium-high	75
		medium	50
		medium-low	25
		low	0
Short-term endangered species goals	8	presence only	100
Long-term endangered species goals	6	presence only	100
Old-growth forest stands	8	presence only	100
Special natural areas	5	presence only	100

**Individual values of each criterion were also assigned a weight according to their influence in defining burn priority.*

Most of Eglin's criteria identified by planning workshops were directly represented by GIS or remote sensing data layers (Fig. 1a). For other criteria, such as biodiversity, we used surrogate GIS data layers to indirectly represent those management objectives across the landscape. We approximated species richness by including wetland features, such as seepage slopes and embedded depression wetlands, that contain fire-dependent ecotones known to possess a high number of species (Kirkman et al. 1998*b*). In addition, remote-sensing data were used to represent several criteria, including land-cover type (e.g., longleaf forest cover, sand pine cover), density of longleaf pine canopy, and density of deciduous oak (Fig. 1b).

Ranking Criteria and Value Scoring

Once represented by a discrete GIS data layer, managers and biologists assigned each criterion a weight according to its relative importance to overall burn prioritization (Table 1). In ArcView Spatial Analyst Model Builder, this process is simplified by requiring that the sum of criteria weights equals 100%. Although Eglin's model output represents a monotonic multiple-regression model, managers can increase the complexity of models by producing submodels to account for known interactions among model criteria.

We simultaneously scored individual values of each key criterion according to how they should influence the need to burn. For example, in Eglin's model, time since burn contributed 20% to the overall output; however, all values of time since burn did not influence priority with equal weight (Table 1). Managers at Eglin decided that within the xeric longleaf pine sandhills, time since burn should not exceed 6 years, but because annual fire was too frequent, areas with only 1 year since fire received no influence over the model output. Thus, the time-since-burn model input is scored as a sigmoidal curve with maximum values achieved at 6 years since burn and low values at 1–2 years since burn. If a value exceeds 16 years

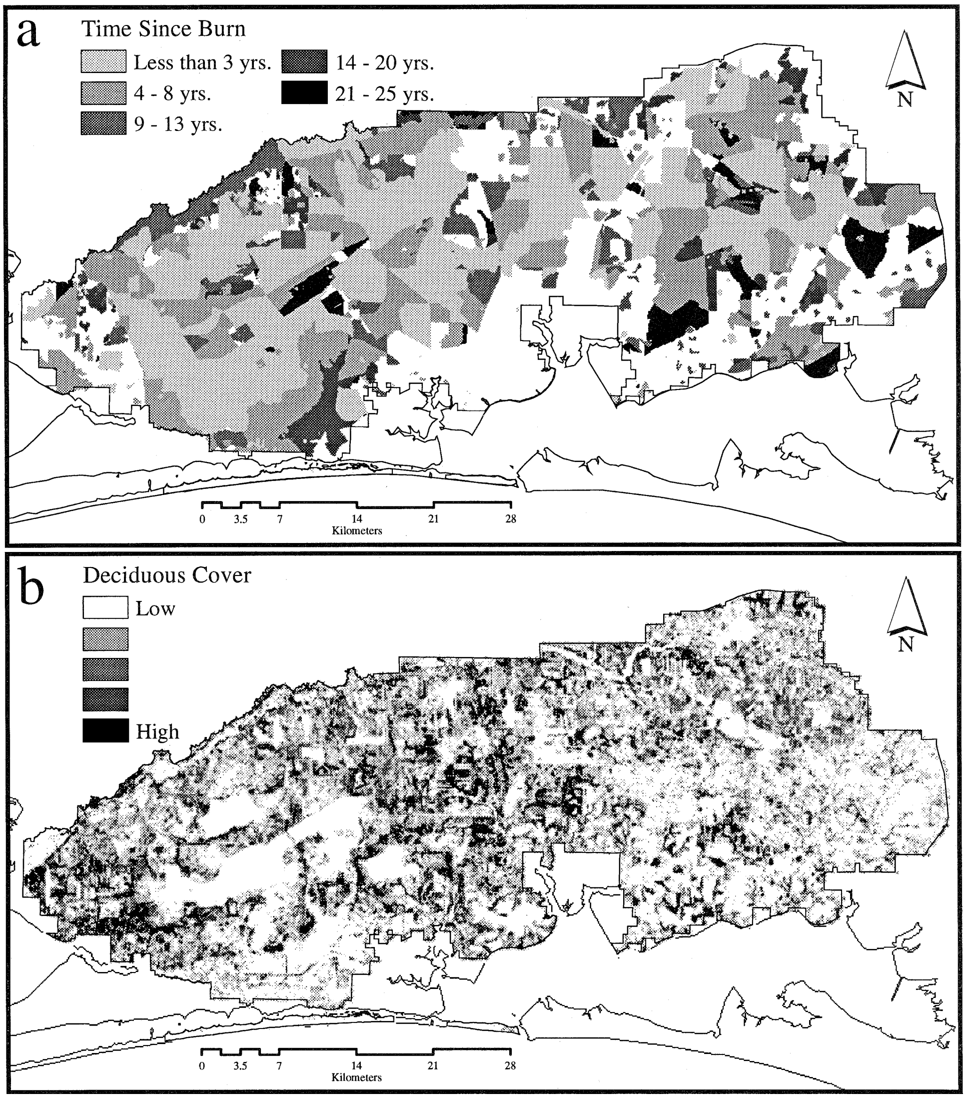

Figure 1. Example of spatial data layers used to represent criteria in the prioritization model: (a) time since burn and (b) deciduous oak density. The time-since-burn layer was generated from geographic information system records of historic fires from 1972 to the present. Deciduous hardwood cover was estimated through remote-sensing classification of Landsat thematic mapper satellite imagery. Weightings for individual values of example model inputs are listed in Table 1.

since fire, managers decided that priority should be reduced because fire becomes less effective in restoring those long-unburned sites.

Transferring the Burn-Prioritization Model

The transfer of the burn-prioritization model to an organization with differing management priorities was necessary to evaluate the utility of our approach and was accomplished through Eglin's participation in the Gulf Coastal Plain Ecosystem Partnership. Ecosystem similarities, combined with different management objectives, made BRSF an appropriate site for evaluating the burn-prioritization tool's ability to balance management priorities beyond Eglin.

The process used to build the burn prioritization at BRSF paralleled that of Eglin, but there were several notable differences. Rather than relying on multiple planning efforts to build the rules of management tradeoffs in the model, we conducted a single-day facilitated workshop expressly to develop the burn-prioritization tool. Prior to the workshop, all participants were asked to submit potential criteria to be used in defining the need to burn. This step facilitated the generation of GIS data layers to directly represent key criteria used as model inputs during the workshop. Recreation values—particularly gamebird management—aesthetics, and timber values ranked high among BRSF's objectives. The burn-prioritization output was displayed in real time at the BRSF workshop, which allowed participants to informally evaluate model results.

Model Validation

To verify the burn-prioritization model's ability to target fire to management-priority areas at Eglin, fire-return intervals were calculated before and after model implementation for individual management concerns, including the federally endangered Red-cockaded Woodpecker, fire-dependent seepage-slope wetlands, high-quality longleaf pine sandhill habitat, and longleaf pine plantations. The conservation targets analyzed represent a broad range of fire-dependent conservation and management concerns across Eglin. For longleaf pine plantations, the lowest-priority objective tested, the average return interval was calculated for plantations found in close proximity to the higher-priority objectives versus those plantations found in burn blocks that did not contain higher-priority objectives.

Results

The results of the burn-prioritization model were displayed as a grid across Eglin, with the overall acreage divided into groups of similar priority (Fig. 2). The grid size of the model output is user-defined and specified within the modeling software; however, the grid size selected is also scaleable to any landscape unit through a process of weighted averaging. The initial output produced at Eglin was a 30-m grid (Fig. 2a), but model results were scaled up to road-bounded polygons (Fig. 2b) and landscape-level burn blocks (Fig. 2c). The BRSF personnel chose to scale their model output to a polygon coverage of forest stands that represented defensible burn blocks bounded by roads and major streams (Fig. 3).

Since implementation, the model has shown significant improvement in achieving fire-return intervals appropriate to maintaining Eglin's highest conservation priorities, despite the fact that the average annual acres burned have not increased over that time. Since implementation in the 2001 burn season, the model has led to the application of fire in a 3.5-year average return interval for all active Red-cockaded Woodpecker clusters. This strategic application of fire is consistent with the fire regime necessary for maintaining this species in longleaf pine sandhill habitat. By comparison, between 1988 and 2000, Eglin averaged a 5.4-year return interval for active Red-cockaded Woodpecker clusters, which ultimately would have led to the deterioration of ecological condition in sandhill habitat required by that species (Peterson & Hardesty 1999). Eglin's highest-quality sandhill habitat, which had a high degree of overlap with Red-cockaded Woodpecker foraging area, averaged a 7.1-year return interval between 1988 and 2000 but has since received a 4.7-year return interval under the burn-prioritization model. Seepage-slope wetlands that depend on frequent fire averaged a 7.2-year fire-return interval prior to model implementation and a 4.5-year return interval since 2000. Longleaf pine plantations that were reforested between 1988 and 2000 averaged a 12-year fire-return interval, compared with a 5.6-year return interval since 2000. Since model implementation, those plantations in burn blocks with Red-cockaded Woodpecker foraging areas, high-quality sandhill habitat, and seepage slopes averaged 4.7-year return interval, whereas pine plantations that do not overlap with the higher priority objectives averaged a 6.1-year return interval.

Discussion

This model-based approach to prioritizing limited management resources at Eglin has eliminated subjective bias in applying prescribed fire to the landscape. Although resource limitations prevent all fire-management objectives from being fully accomplished, fire regimes are now applied at the appropriate return intervals for conserving the highest-priority objectives. Portions of the Eglin reservation that represent lower-priority objectives are burned based on their proximity to higher-priority sites within the landscape. Furthermore, the model-based approach allows for the balancing of competing management

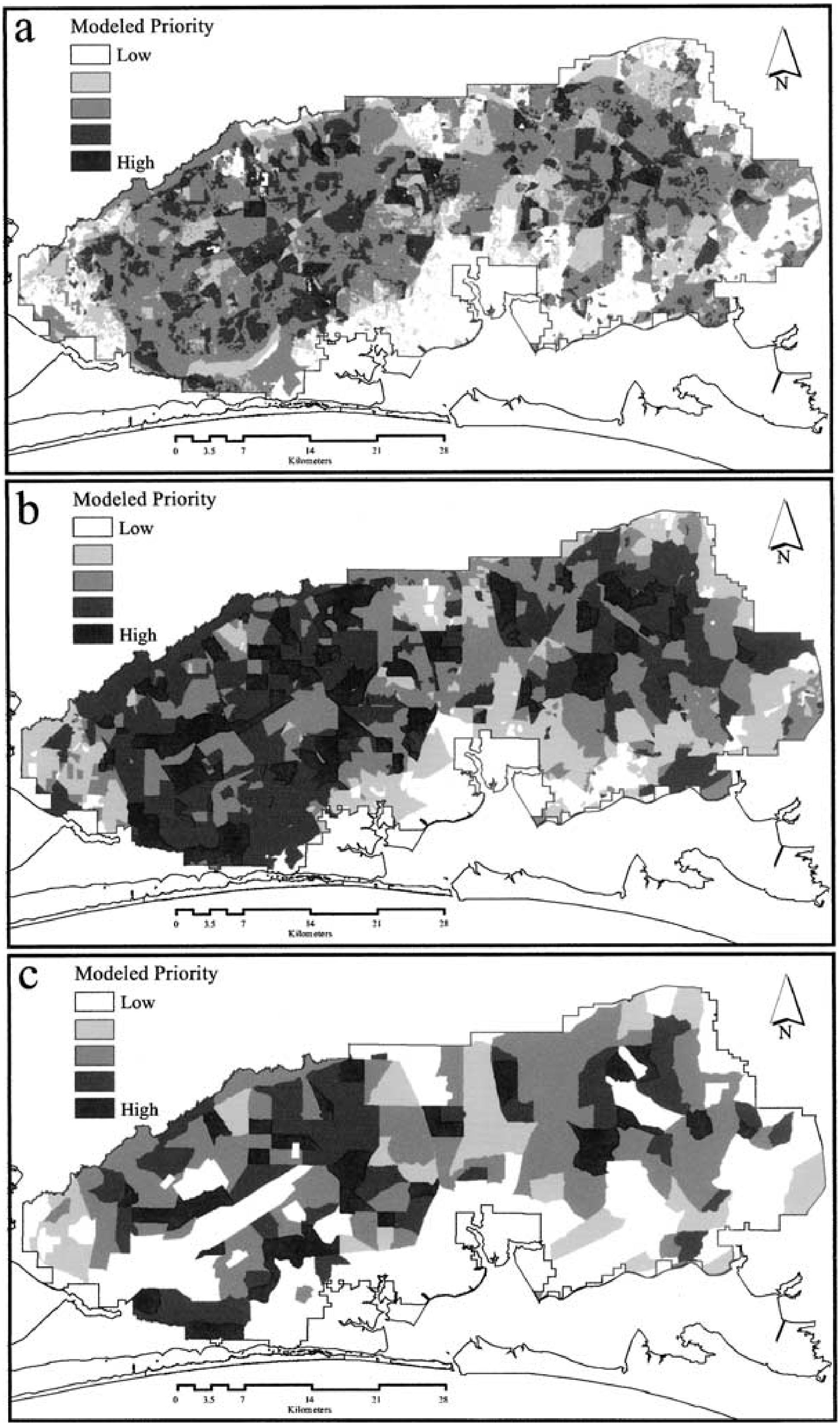

Figure 2. Burn-prioritization output scaled to management-relevant units: (a) 30-m grid, (b) road polygon grid, and (c) aerial-ignition burn blocks. Darker colors in grayscale legend indicate higher priority for fire. Although the grid size of the initial model is user defined, weighted averaging scales the output.

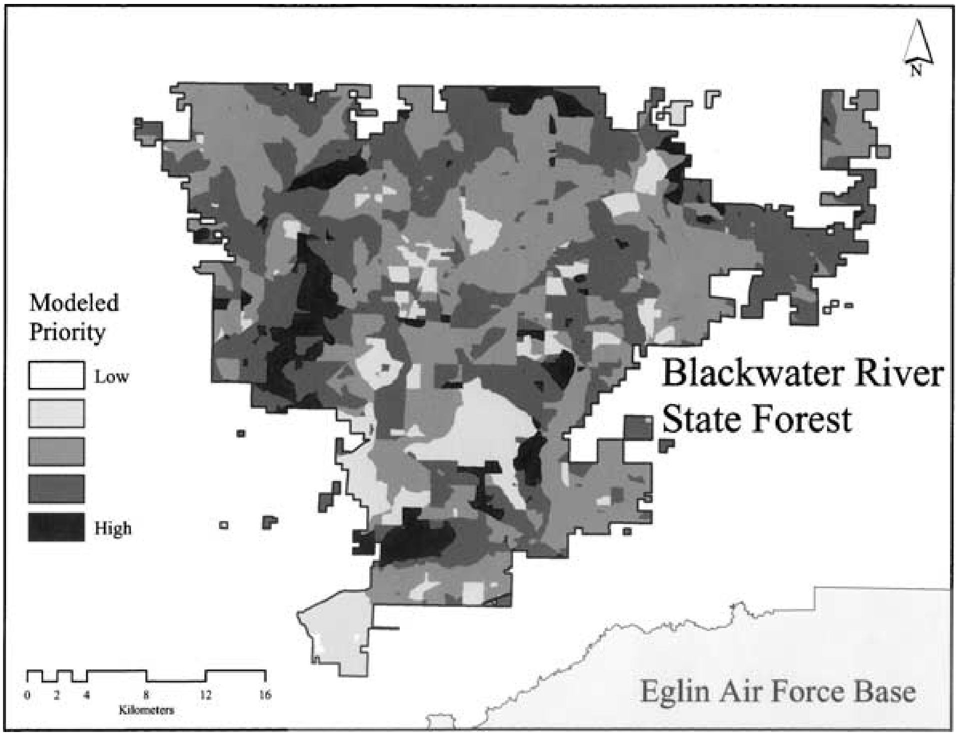

Figure 3. Blackwater River State Forest burn-prioritization output, produced at a 30-m grid and displayed using road- and stream-bounded polygon files that represent defensible-burn block boundaries. Darker colors in grayscale legend indicate higher priority for fire.

objectives without promoting a focus on a single species or particular management objective.

The model offers flexibility for modification as management objectives and landscape condition change. By relying on accessible software and GIS data layers, the model is easily updated as new information replaces old. Similarly, as management objectives change or new ecological research is made available, the scoring of the model is easily modified over time. In the most recent iteration of Eglin's burn-prioritization model, the relative weight initially assigned to deciduous oak density was decreased as a result of ecological monitoring that showed sand pine encroachment to be a greater threat to system health than deciduous oak cover (J.K., unpublished data).

A single facilitated workshop setting such as the one used by BRSF provided several improvements to the model-building process initially used by Eglin. First, participants were given the opportunity to suggest key burn criteria prior to the modeling workshop to ensure that a diversity of management objectives was represented. Second, scoring model inputs by consensus allowed participants to clearly understand how the model operated and how to modify future model iterations. Lastly, model results were displayed immediately for managers and biologists to review. This immediate review was critical to the validation and acceptance of modeled results by managers, and real-time results represent one of the greatest advantages of simple spatial modeling tools in prioritizing management actions. Through the facilitated workshop at BRSF, model results reflected a balance between the priorities of individual managers and the objectives of institutional resource management.

Although spatially explicit modeling is often perceived as onerous and complicated, simple tools developed from commonly available GIS software can make a significant contribution to conservation management, particularly at large scales when resources are limited. The burn-prioritization tool was transferred between agencies with varied management objectives and different GIS resources. By building on the foundation of managers' experience and the best available science, the burn-prioritization process has gained the acceptance of local resource managers and has generated interest in further development and wider application.

More complex tools, when available, may provide a significant improvement over simple spatial modeling, but this burn-prioritization model and the process described for its development represent a significant step that many resource managers can take with existing personnel and commonly available software. Furthermore, this concept has potential for application to management actions other than prescribed fire across large landscapes.

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