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A Multi-Criteria Decisionmaking Approach for Management Indicator Species Selection on the Monongahela National Forest, West Virginia

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Abstract

The management indicator species concept remains an appealing tool for land managers charged with monitoring and conserving complex biological diversity over large landscapes with limited available resources. However, selecting management indicator species that adequately represent the ecological composition, structure, and function of complex ecological systems is a daunting challenge. We used the analytical hierarchy process (AHP) to determine the best management indicator species (MIS) for three management objectives of the 364,225-ha Monongahela National Forest (MNF) in West Virginia. The criteria to our AHP analyses were sensitivity to management actions common on the MNF (sensitivity), monitoring efficacy and effectiveness (monitoring), species baseline information (documentation), and social, political, and economic importance (SPE). We compiled a set of alternative MIS, including current MNF MIS, for each objective based on a literature review of species-habitat relations in the Appalachian Mountain region. We used the AHP to determine local priorities, based on pair-wise comparisons for criteria and MIS alternatives. Among potential alternatives, total global priority scores for the ruffed grouse (*Bonasa umbellus*), pileated woodpecker (*Dryocopus pileatus*), and Virginia northern flying squirrel (*Glaucomys sabrinus fuscus*) contributed most to respective management objectives. We believe the AHP is an effective tool for MIS selection, particularly within complex Appalachian ecosystems, because it provides a formal structured decision procedure, has a strong theoretical foundation, accommodates incomplete ecological data, and offers transparency to the MIS decisionmaking process.

Cover Photo

Golden winged warbler. Photo by Jerry Kreiser, U.S. Geological Survey, Biological Resources Division, West Virginia Cooperative Fish and Wildlife Research Unit.

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INTRODUCTION

Public and scientific concern over altered or declining biodiversity and species extinction has led to the passage of several key pieces of Federal legislation over the past few decades designed to address these issues in the United States. Among these, the National Forest Management Act of 1976 directs the U.S. Forest Service to identify and actively monitor management indicator species (MIS) to assess impacts of forest management activities on native biota within national forest lands (Code of Federal Regulations 1985). As defined by the National Forest Management Act, MIS may include species listed as (1) threatened, endangered, or rare, (2) having habitat requirements sensitive to management activities, (3) having social or economic value, and (4) serving as monitors for environmental factors, population trends of other species, or habitat condition. However, the MIS concept has received much criticism, primarily because many selection criteria and processes are vague or lack scientific rigor. Moreover, the suite of indicators selected generally fails to consider the full complexity of ecological systems to be represented (Caro and O'Doherty 1999, Dale and Beyeler 2001, Landres et al. 1988, Niemi et al. 1997, Rolstad et al. 2002). In part, these criticisms have led to elimination of mandatory MIS designation in the proposed 2005 Forest Planning Rules for national forest lands (Federal Register 2005). Regardless, the MIS concept remains an appealing tool for land managers charged with monitoring and conserving the vast and complex biological diversity with limited available resources. However, selecting MIS that adequately represent the ecological composition, structure, and function of complex ecological systems is a daunting challenge (Karr 1991), especially when the number of MIS selected and their subsequent monitoring are limited due to budgetary constraints and incomplete ecological information (Caro and O'Doherty 1999, Dale and Beyeler 2001). Because complete knowledge of ecosystems will always be lacking, particularly for complex ecological regions such as the Appalachian Mountains, decisionmaking approaches that allow land managers to overcome knowledge gaps with expert judgment may provide a more robust MIS selection process.

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Although extensive time and effort are spent collecting information about natural resources, relatively little attention is given to the decisionmaking processes that integrate this information into rational choices (Schmoldt et al. 1994, 2001). Multiple criteria decisionmaking (MCDM) techniques allow land managers to incorporate available ecological information and expert judgment within an organized framework to determine the best alternatives (Mendoza and Martins 2006, Moffett and Sarkar 2006, Schmoldt et al. 2001). These techniques are generally comprised of three primary components: a decision objective, a list of criteria deemed important to reach the objective, and a list of alternatives wherein the best will be selected relative to the objective and based on the criteria (Mendoza and Martins 2006). One such technique, the Analytical Hierarchy Process (AHP), allows decisionmakers to assess several criteria and alternatives and give each a priority based on pair-wise comparisons of the relative importance of one over another relative to the objective (Saaty 1990). Although various aspects of the AHP have been criticized, such as subjective priority scores and possible rank reversal (Dyer 1990, Mendoza and Prabhu 2000), it has a strong theoretical foundation (Harker and Vargas 1987, Perez 1995, Saaty 2003). The AHP increasingly is being applied to complex natural resource management decisionmaking problems involving ecological, political, and economic aspects (Diaz-Balteiro and Romero 2008, Gomontean et al. 2008, Herath 2004, Kuusipalo and Kangas 1994, Regan et al. 2007, Villa et al. 2002). For example, Regan et al. (2007) used the AHP to prioritize criteria for determining biodiversity value of private lands planning units in California. Tran et al. (2002) ranked ecological health of watersheds in the mid-Atlantic region based on indicators using the AHP. Despite the potential use of AHP and other MCDM techniques in natural resources management, the vast majority of natural resources decisions, particularly those regarding biodiversity, still are determined using ad hoc procedures (Schmoldt et al. 2001).

Our objective was to apply the AHP as a more rigorous approach to MIS selection. Accordingly, herein we use the AHP to determine the best MIS among a suite of alternative species, including current MIS, for three Monongahela National Forest (MNF) management objectives: (1) maintenance of 20,250 ha of early successional habitat, (2) maintenance of >20,250 ha of >80-year-old mixed mesophytic and cove hardwood stands, and (3) maintenance of >8,100 ha of >80-year-old red spruce (*Picea rubens*) stands.

MATERIALS AND METHODS

Study Area

Located within the central Appalachians of eastern West Virginia, the MNF contains a diverse suite of flora and fauna (Ricketts et al. 1999). Occupying 362,225 ha, the forest occurs within portions of 10 counties of the state. Because of its latitudinal position and elevation gradients, the MNF contains aspects of temperate forest assemblages at lower elevations and more northern to boreal forest assemblages above 900 m. Most of the MNF is located in the Allegheny Mountains and Plateau physiographic province that is characterized by a series of high ridges, often with broad summits, running southwest-northeast and separated by elevated, narrow valleys. Lesser acreage of the forest on the eastern portion is located in the Ridge and Valley physiographic province, characterized by elongated, sharp-crested ridges running southwest-northeast (Stephenson 1993). Soil types throughout are primarily composed of Inceptisols, Ultisols, and Spodosols; soil pH decreases and organic matter content increases with increased elevation. The Allegheny Mountains can receive more than 150 cm of yearly precipitation and typically have a growing season of 90–160 days depending on elevation. Conversely, the Ridge and Valley lies within a precipitation shadow of the Allegheny Mountains and exhibits somewhat drier conditions of 115 cm or less of yearly precipitation with a longer, yet similarly variable growing season of 120-180 days.

Before establishment in 1920, most of the MNF was heavily cutover from the late 1890s through the 1920s (Stephenson 1993). For example, exploitative logging and subsequent wildfires during this period reduced red spruce-dominated montane boreal forests from an estimated 200,000+ ha to approximately 24,000 ha at present (Schuler et al. 2002). Many areas of high-elevation sites were maintained as livestock summer range by repeated burning for several decades following the initial anthropogenic disturbances (Stephenson 1993).

At lower- and mid-elevations, fire suppression policy after national forest establishment and extensive use of diameter-limit harvesting throughout much of the 20th century has resulted in increased dominance of shade tolerant, mixed mesophytic woody species and decline of oak (*Quercus* spp.)-dominated stands at lower- and mid-elevations (Schuler 2004). Currently, most forest stands in the MNF are mixed mesophytic assemblages consisting of sugar maple (*Acer saccharinum*), red maple (*A. rubra*), northern red oak (*Quercus rubra*), chestnut oak (*Q. prinus*), yellow-poplar (*Liriodendron tulipifera*), American beech (*Fagus grandifolia*), sweet birch (*Betula lenta*), black cherry (*Prunus serotina*), and basswood (*Tilia americana*; Madarish et al. 2002). Before the 1920s, American chestnut (*Castanea dentata*) also was a regular component of hardwood forests at these elevations, but was eliminated by chestnut blight (*Endothia parasitica*). At approximately 900-1,100 m elevation, and depending on aspect and landform position, the forest transitions to northern hardwood or northern hardwood-montane boreal assemblages of sugar maple, American beech, yellow birch (*B. alleghaniensis*), eastern hemlock (*Tsuga canadensis*), and red spruce (Stephenson 1993). Currently, about 93 percent of the MNF is forested. The small amount of non-forested area primarily consists of livestock grazing allotments, wildlife food plots or similarly maintained grassy openings, natural gas wells, abandoned surface mines and some upland and wetland areas such as the Dolly Sods Scenic Area that never fully recovered from logging and burning (U.S. Forest Service 2006a).

Criteria and Alternatives Selection

We used AHP to determine the best MIS alternative for forest management objectives on the MNF. Our analysis included three forest management objectives: (1) maintenance of 20,250 ha of early successional habitat, (2) maintenance of >20,250 ha of >80-year-old mixed mesophytic and cove hardwood stands (U.S. Forest Service 2006a), and (3) maintenance of >8,100 ha of >80-year-old red spruce stands (U.S. Forest Service 2006a). The relative ecological and management importance and rationale of each management objective to the overall MNF plan is beyond the scope of our study.

We determined four selection criteria characteristic of effective MIS based on existing reviews of the indicator species concept and its application (Carignan and Villard 2002, Dale and Beyeler 2001, Landres et al. 1988): (1) sensitivity—MIS alternatives should be sensitive to habitat alteration or parameters of management concern while having limited sensitivity to natural variation and should respond in a predictable manner that reflects disturbance intensity; (2) monitoring—MIS alternatives should be cost effective to monitor and population parameters accurately estimated; (3) documentation—MIS alternatives should have sufficient baseline information so that changes in population parameters can be related to specific environmental disturbances; and (4) social, political, and economic importance of MIS alternatives—such as game (legal hunting seasons) and threatened and endangered species (SPE).

We selected a suite of alternatives for each objective based on several factors including current and former MIS, species with viability concerns (U.S. Forest Service 2006b), and species believed to most satisfy our selection criteria.

For objective 1, our alternative MIS species included (1) golden-winged warbler (*Vermivora chrysoptera*)—a neotropical migratory songbird classified as "sensitive" on the MNF (U.S. Forest Service 2006a), associated with oldfields, power-line corridors, shrub bogs, reclaimed surface mines, and regenerating clearcuts with clumps of shrub and areas of abundant herbaceous vegetation adjacent to forest stands (Confer 1992, Confer and Pascoe 2003, Hamel et al. 2005, Hunter et al. 2001, Klaus and Buehler 2001, La Sorte et al. 2007); (2) ruffed grouse (*Bonasa umbellus*)—an important gamebird throughout its distribution, associated with a variety of forest habitats in the Appalachians, but greater reproductive success of grouse, invertebrate prey abundance, and predator avoidance have been linked to availability and spatial configuration of regenerating clearcuts, road rights-of-way, canopy openings with abundant herbaceous cover, and shrub-dominated oldfields (Dessecker and McAuley 2001; Fearer and Stauffer 2003; Jones and Harper 2007; Jones et al. 2008; La Sort et al. 2007; Tirpak et al. 2006; Whitaker et al. 2006, 2007; Wiggers et al. 1992); (3) yellow-breasted chat (*Icteria virens*)—a neotropical migratory songbird, associated with large forest openings dominated by herbaceous flora, power-line corridors, riparian thickets and regenerating clearcuts interspersed with shrub and sapling patches (Baker and Lacki 1997, Confer and Pascoe 2003, Crawford et al. 1981, La Sorte et al. 2007, Penhollow and Stauffer 2000); (4) meadow vole (*Microtus pennsylvanicus*)—associated with a variety of maintained or arrested early successional habitats such as fence rows, gas-well openings, powerline and gasline rights-of-way, emergent bogs, and wildlife food plots (Cranford and Maly 1986; Ford et al. 2007a; Francl et al. 2004, 2008; Litvaitis 2001) and (5) *Sylvilagus* spp.—comprised locally of both eastern cottontail (*S. floridanus*) and Appalachian cottontail (*S. obscurus*)—that occupy a variety of early successional habitat types including regenerating clearcuts, agricultural fields, oldfields, and open areas dominated by thick shrub growth such as mountain laurel (*Kalmia latifolia*) or *Rubus* spp. cover (Althoff et al. 1997, Boyce 2001, Chapman et al. 1980, Sommer 1997, Stevens and Berry 2002, Sucke 2002).

For objective 2, our alternative MIS species included (1) Indiana myotis (*Myotis sodalis*)—a federally endangered bat species. During spring and summer, male residents primarily roost in snags and live trees with exfoliating bark, particularly shagbark hickory (*Carya ovata*) and sugar maple locally, and forage along forested riparian corridors, whereas females form maternity colonies under exfoliating bark of dead or dying trees in open conditions within a variety of upland and bottomland forest types. During winter, both males and females occupy cave hibernacula within and near MNF (Brack 2006, Britzke et al. 2003; Ford et al. 2002a, 2006; Ford and Chapman 2007; Menzel et al. 2001, 2005); (2) Virginia big-eared bat (*Corynorrhinus townsendii virginianus*)—a federally endangered subspecies, day-roosts during spring and summer and hibernates during winter within and near MNF in caves also associated with karst geology locally and forages in open pastures and along forested ridgetops (Adam et al. 1994, Chapman 2007, Lacki et al. 1993, Sample and Whitmore 1993); (3) cerulean warbler (*Dendroica cerulea*)—a neotropical migratory sogbird classified as "sensitive" on the MNF (U.S. Forest Service 2006a), associated with ridgetops and convex cove landforms within large mixed mesophytic forest stands exhibiting a high degree of horizontal canopy heterogeneity and internal edge associated with canopy gaps (Buehler et al. 2006, Hamel and Rosenberg 2007, La Sorte et al. 2007, Robbins et al. 1989, Weakland and Wood 2005, Wood et al. 2006); (4) hooded warbler (*Wilsonia citrina*)—also associated with large patches of mature mixed mesophytic forest with abundant interior edge created by canopy gaps (Augenfeld et al. 2008, Crawford et al. 1981, Greenberg and Lanham 2001, La Sorte et al. 2007); (5) pileated woodpecker (*Dryocopus pileatus*)—associated with mature mixed mesophytic forest containing abundant large diameter trees for cavity excavation and foraging (Conner 1980, Conner et al. 1975, La Sorte et al. 2007, Penhollow and Stauffer 2000); and (6) red-backed salamander (*Plethodon cinereus*)—most abundant in mature mixed mesophytic forests with moist microhabitats, such as coarse woody debris (CWD) and emergent colluvium, but also occur within agricultural fields, golf courses, and forest/opening edge when suitable cover is available (Ford et al. 2002b,c; Marsh et al. 2004; Moseley et al. 2009; Petranka et al. 1993; Petranka 1998; Riedel et al. 2008; Russell et al. 2004).

For objective 3, our alternative MIS species included (1) Virginia northern flying squirrel (*Glaucomys sabrinus fuscus*)—a formally federally listed endangered subspecies of the northern flying squirrel classified as "sensitive" on the MNF, associated with forests dominated by red spruce or northern hardwoods with a substantial red spruce component (Ford et al. 2004, 2007b,c; Menzel 2003; Menzel et al. 2006; Odom et al. 2001; Smith 2007); (2) southern rock vole (*M. chrotorrhinus carolinensis*)—classified as "sensitive" on the MNF, associated with large emergent colluvium typically above 900 m elevation within mature red spruce, mixed spruce-northern hardwood, northern hardwood, and mixed mesophytic forest types (Healy and Brooks 1988, Kirkland and Jannett 1982, Orrock and Pagels 2003, Pagels and Laerm 2007); (3) hermit thrush (*Catharus guttatus*)—a short-distance migrant, associated with mid- to late-successional stage red spruce, mixed red spruce-northern hardwood, northern hardwood, and mixed mesophytic forests for breeding habitat (Brooks 1935; Dellinger et al. 2007a,b; Hall 1984; Stewart and Aldrich 1949); and (4) Cheat Mountain salamander (*P.*

nettingi)—a federally listed threatened species, primarily associated with emergent colluvium and abundant bryophytes at high elevations, primarily in red spruce forests (Brooks 1948; Dillard et al. 2008a,b; Pauley 1998).

Pair-wise Comparisons and Priority Assignment

We determined preference scores for MIS alternatives based on a literature review. Specifically, for each MIS alternative, we determined habitat associations in the Appalachian region, sensitivity to forest management, occurrence and abundance within the MNF, availability of baseline species information, and existing monitoring protocol. Similarly, we determined preferences of selection criteria based on a literature review of the indicator species concept. We assigned selection criteria and alternative MIS preference scores of the relative importance of one over another based on a nine-point scale (1 = equal importance, 3 = weakly more important, 5 = more important, 7 = strongly more important, 9 = absolutely more important; Appendices 1–4) as recommended by Saaty (1980). Using preference scores, we conducted pair-wise comparisons for criteria and MIS alternatives relative to each criterion. Pair-wise comparisons are used to create a matrix, whereby the number in the *i*th row and *j*th column represents the preference score for alternative *i* as compared with alternative *j*. We converted preference scores to local priorities using the eigenvector technique. For the eigenvalue technique, pair-wise comparisons are converted to local priority scores by calculating the eigenvalue of the normalized pair-wise comparison matrix (Saaty 1980). Criteria and alternatives with higher local priorities are more important relative to other criteria and alternatives in the comparison, with local priorities being scaled to sum to one (Saaty 1980, 1990). Additionally, we calculated a consistency value to determine the degree of inconsistency and coherence for pair-wise comparisons, with a consistency ratio ≤ 0.10 generally considered acceptable (Saaty 1980). Using local priorities for alternatives and criteria, we also created global priority values for each alternative relative to each selection criteria. Global priorities are calculated by multiplying the local priority score of a given alternative by the local priority score of the respective criterion. Global priorities are the contribution of an alternative, relative to a given selection criteria, to the overall management objective, with each management objective having a priority of 1 (Saaty 1980). The alternative with the greatest total global priority is considered to contribute the most to the overall management objective and thereby is the best alternative (Saaty 1980). Our analyses were performed using MultSync software (Moffett et al. 2005).

RESULTS

For our MIS selection criteria, monitoring (0.55) had the highest local priority, thereby contributing most to selection of the best MIS alternative for management objectives, followed by sensitivity (0.32), documentation (0.10), and SPE (0.04). The consistency ratio for criteria pair-wise comparisons was ≤ 0.10, suggesting consistency in preference assignments.

For objective 1, the ruffed grouse had the highest local priority for monitoring, documentation, and SPE selection criteria (Table 1). The meadow vole had the highest local priority for the sensitivity criterion (Table 1). Overall, the ruffed grouse had the highest global priority total, thereby contributing the most to this management objective, followed by meadow vole, *Sylvilagus* spp., yellow-breasted chat, and golden-winged warbler (Table 1).

For objective 2, the pileated woodpecker had the highest local priority for monitoring, sensitivity, and documentation, whereas the Indiana myotis and Virginia big-eared bat had the highest local priority for the SPE criterion (Table 2). Overall, the pileated woodpecker had the highest global priority total, thereby contributing most to this management objective, followed by the red-backed salamander, hooded warbler, cerulean warbler, Indiana myotis, and Virginia big-eared bat (Table 2). The consistency ratio for the SPE selection criteria was 0.14 (Table 3), suggesting minimal inconsistency in preference assignments.

For objective 3, the Virginia northern flying squirrel had the highest local priority for sensitivity and documentation, whereas the hermit thrush and Cheat Mountain salamander had the highest local priority for

Table 1.—Monongahela National Forest, West Virginia, objective 1, maintenance of > 20,250 ha of early successional habitat; local and global priority scores based on pair-wise comparisons for golden-winged warbler (*Vermivora chrysoptera*), ruffed grouse (*Bonasa umbellus*), yellow-breasted chat (*Icteria virens*), meadow vole (*Microtus pennsylvanicus*), and *Sylvilagus* spp. (*Sylvilagus*)[1]

	Criterion								
	Sensitivity		Monitoring		Documentation		SPE		
	Local	Global	Local	Global	Local	Global	Local	Global	Global total
Ruffed grouse	0.03	0.01	0.52	0.29	0.52	0.05	0.49	0.02	0.37
Meadow vole	0.47	0.15	0.04	0.02	0.15	0.02	0.03	0.00	0.19
Sylvilagus	0.06	0.02	0.22	0.12	0.25	0.03	0.29	0.01	0.18
Golden-winged warbler	0.22	0.07	0.11	0.06	0.03	0.00	0.14	0.01	0.14
Yellow-breasted Chat	0.22	0.07	0.11	0.06	0.05	0.01	0.06	0.00	0.14
Total	1.00	0.32	1.00	0.55	1.00	0.10	1.01	0.04	1.00

[1] Management indicator species alternatives based on four selection criteria: sensitivity to management actions (sensitivity), monitoring efficacy and effectiveness (monitoring), species baseline information (documentation), and social, political, and economic importance (SPE)

Table 2.—Monongahela National Forest, West Virginia, objective 2, maintenance of >20,250 ha of >80-year-old mixed mesophytic and cove hardwood forest; local and global priority scores based on pair-wise comparisons for Indiana myotis (*Myotis sodalis*), Virginia big-eared bat (*Corynorrhinus townsendii virginianus*), red-backed salamander (*Plethodon cinereus*), cerulean warbler (*Dendroica cerulea*), hooded warbler (*Wilsonia citrina*), and pileated woodpecker (*Dryocopus pileatus*)[1]

	Criterion								
	Sensitivity		Monitoring		Documentation		SPE		
	Local	Global	Local	Global	Local	Global	Local	Global	Global total
Pileated woodpecker	0.49	0.16	0.45	0.25	0.47	0.05	0.04	0.00	0.45
Red-backed salamander	0.03	0.01	0.23	0.13	0.28	0.03	0.02	0.00	0.16
Hooded warbler	0.26	0.08	0.11	0.06	0.05	0.01	0.08	0.00	0.15
Cerulean warbler	0.07	0.02	0.11	0.06	0.10	0.01	0.14	0.01	0.10
Indiana myotis	0.13	0.04	0.03	0.02	0.05	0.01	0.37	0.01	0.08
Virginia big-eared bat	0.03	0.01	0.07	0.04	0.05	0.01	0.37	0.01	0.07
Total	1.00	0.32	1.00	0.55	1.00	0.10	1.00	0.04	1.00

[1] Management indicator species alternatives based on four selection criteria: sensitivity to management actions (sensitivity), monitoring efficacy and effectiveness (monitoring), species baseline information (documentation), and social, political, and economic importance (SPE).

Table 3.—Consistency ratios for pair-wise comparison judgments of management indicator species alternatives for three Monongahela National Forest, West Virginia, management objectives[1]

	Criterion			
	Sensitivity	Monitoring	Documentation	SPE
Objective 1	0.04	0.07	0.08	0.08
Objective 2	0.05	0.06	0.05	0.14
Objective 3	0.06	0.09	0.01	0.11

[1]Judgments were based on four selection criteria: sensitivity to management actions (sensitivity), monitoring efficacy and effectiveness (monitoring), species baseline information (documentation), and social, political, and economic importance (SPE)

Table 4.—Monongahela National Forest, West Virginia, objective 3, maintenance of >8,100 ha of >80-year-old red spruce (*Picea rubens*); local and global priority scores based on pair-wise comparisons for Virginia northern flying squirrel (*Glaucomys sabrinus fuscus*), Cheat Mountain salamander (*Plethodon nettingi*), southern rock vole (*Microtus chrotorrhinus carolinensis*), and hermit thrush (*Catharus guttatus*)[1]

	Criterion								
	Sensitivity		Monitoring		Documentation		SPE		
	Local	Global	Local	Global	Local	Global	Local	Global	Global total
Virginia northern flying squirrel	0.58	0.19	0.29	0.16	0.62	0.06	0.23	0.01	0.42
Hermit thrush	0.09	0.03	0.08	0.32	0.27	0.03	0.04	0.00	0.38
Cheat Mountain Salamander	0.29	0.09	0.05	0.04	0.06	0.01	0.62	0.02	0.17
Southern rock Vole	0.04	0.01	0.58	0.03	0.06	0.01	0.12	0.00	0.05
Total	1.00	0.32	1.00	0.55	1.00	0.10	1.00	0.04	1.00

[1]Management indicator species alternatives based on four selection criteria: sensitivity to management actions (sensitivity), monitoring efficacy and effectiveness (monitoring), species baseline information (documentation), and social, political, and economic importance (SPE).

SPE (Table 4). Overall, the Virginia northern flying squirrel had the highest global priority total, thereby contributing most to this management objective, followed by the hermit thrush, Cheat Mountain salamander, and southern rock vole (Table 4). The consistency ratio for the SPE selection criteria was 0.11 (Table 3), suggesting minimal inconsistency in preference assignments.

DISCUSSION

Objective 1

The ruffed grouse serves as a designated MIS for national forests in eight states in the eastern United States (Moseley 2008). In our AHP analysis, ruffed grouse, which contributed most to the early successional habitat objective, had the highest local priorities for monitoring, documentation, and SPE categories. These weights partly reflect its status as a popular gamebird in the region. That, combined with recent population declines within the region (Dessecker and McAuley 2001), has generated much research attention in the Appalachians for this species (Devers et al. 2007; Fearer and Stauffer 2003; Tirpark et al. 2005, 2006; Whitaker et al. 2007). Consequently, the ruffed grouse received the lowest weight for the sensitivity criterion partly because of its status as a game species. Using game species as MIS has been criticized because of the difficulty in distinguishing between changes in habitat and potential additive mortality impacts to populations from hunting (Landres et al. 1988, Simberloff 1998). However, hunter-induced mortality below 20 percent is regarded as compensatory for Appalachian ruffed grouse populations (Devers et al. 2007). Hunting mortality for ruffed grouse ranges from 8 to 20 percent in the central Appalachian region (Devers et al. 2007). Furthermore, grouse abundance and reproductive success have been linked to availability and spatial configuration of early successional habitats within the Appalachians (Fearer and Stauffer 2003). In addition to the ruffed grouse's role as a suitable MIS for early successional habitats for the MNF, it may also serve as a partial indicator for mature mixed mesophytic and northern hardwood forest conditions. Some component of ruffed grouse reproductive success has been linked to hard mast forage availability in oak-hickory forests (Devers et al. 2007), CWD abundance, and large-diameter tree availability (Tirpak et al. 2006) in the central Appalachians within the Ridge and Valley Province. This may add to the ruffed grouse's effectiveness as an MIS by complementing other MIS representing mature mixed mesophytic and northern hardwood forest characteristics such as abundant canopy gaps and CWD.

The meadow vole had the highest local priority for the sensitivity criteria and ranked second overall for objective 1, reflecting its sensitivity to forest succession and dependence on grassy/meadow habitats, the most commonly maintained early successional habitat type in the MNF. For example, Moseley (2008) surveyed natural gas-well openings and surrounding forests in the MNF and found that meadow voles primarily were restricted to the natural gas-well openings. Despite a strong association with maintained old fields and meadow habitats locally (Ford et al. 2007a; Francl et al. 2004, 2008), the meadow vole was weighted lowest for monitoring and SPE criteria. Unlike ruffed grouse (Bookout 1996, Zimmerman and Gutierrez 2007) and neotropical migratory songbirds (Pollack 2006, Simons et al. 1999) few long-term, large-scale population monitoring protocols have been established for small mammal species not having State or Federal protection status. Additionally, small mammal population fluctuations can be cyclic (Getz et al. 2001) and sensitive to abiotic factors (Whittaker and Feldhamer 2005) such as precipitation, diminishing their utility as MIS due to the inability to discriminate between management-induced population changes and those resulting from climatic or other conditions (Odum 1971).

Currently, the MNF does not have a MIS representing an early successional management objective, although white-tailed deer (*Odocoileus virginianus*) and black bear (*Ursus americanus*) are used as indicators for comparing proposed alternative management actions on the MNF (U.S. Forest Service 2006a). Regenerating forest openings and other early successional woody habitats that represent the shrub-scrub sere are among the most rapidly declining habitats throughout the Appalachian Mountains (Litvaitis 2001). In the eastern United States, recruitment and maintenance of early successional woody habitats have declined as even-aged timber management and other anthropogenic forest disturbances are increasingly constrained due, in part, to negative public perception (Litvaitus 2001, 2003; Trani et al. 2001). Nonetheless, half of all bird species classified as sensitive on the MNF, such as the golden-winged warbler, Henslow's sparrow (*Ammodramus henslowii*), vesper sparrow (*Pooecetes gramineus*), and loggerhead shrike (*Lanius ludovicianus*; U.S. Forest Service 2006a), are associated with early successional woody habitat (King et al. 2001, King and Byers 2002). Furthermore, the central Appalachian location of the MNF has been identified as a conservation priority region for several declining or sensitive birds such as the golden-winged warbler, Bewick's wren (*Thryomanes bewickii altus*) and mammals such as the Appalachian cottontail (Dettmers 2003, Fuller and DeStefano 2003, Litvaitus 2001). In Appalachian landscapes, many managers assign higher priority to conservation of species associated with large tracts of mature forest. However, active management for early successional and mature forest habitats does not have to be mutually exclusive, especially when conducted within an adaptive management framework (Hamel et al. 2005).

Objective 2

The cerulean warbler, currently the MNF MIS representing maintenance of >80-year-old mixed mesophytic and cove forest assemblages, contributed little to management objective 2. The cerulean warbler's primary weakness as an MIS, relative to other alternative MIS species, is that its association with undisturbed mixed mesophytic forest in the Appalachian region has not been clearly established (Hamel et al. 2004, Weakland and Wood 2005, Wood et al. 2006), thereby compromising its value for guiding MNF management. Indeed, Buehler et al. (2006) found that habitat models based on cerulean warbler presence/absence data in the Cumberland Mountains, Tennessee, were somewhat inaccurate in classifying cerulean absence and suggested that this species may occur across a broader range of conditions than those defined by their model. Furthermore, cerulean warblers are long-distance neotropical migrants, spending winters in South America (Hamel et al. 2004). Therefore, it is still not known whether cerulean warbler population declines are attributable to reduced breeding habitat availability or are exacerbated by conditions at wintering grounds (Buehler et al. 2006, Rappole and McDonald 1994). Similarly, the hooded warbler received a lower priority for the sensitivity criteria weight because of its status as a neotropical migratory songbird (Peterson 1980). However, unlike those of the cerulean warblers, habitat associations and positive response of hooded warblers to some active forest management has been documented (Augenfeld et al. 2008, Baker and Lacki 1997, Greenberg and Lanham 2001). Currently, the hooded warbler serves as an MIS for national forests within five southeastern states (Moseley 2008). Although only ranked as second highest, the hooded warbler may complement the pileated woodpecker as a MIS for mixed mesophytic-cove hardwood forests, serving as an indicator for functioning canopy gap-phase dynamics (Baker and Lacki 1997, Greenberg and Lanham 2001, Kilgo 2005, Moorman et al. 2002).

The pileated woodpecker contributed the most to objective 2 and received the highest local priorities for sensitivity, monitoring, and documentation. The pileated woodpecker is non-migratory and occurs in mixed mesophytic and northern hardwood forests (Conner et al. 1975). Southeast of the MNF, on the Jefferson National Forest, Virginia, pileated woodpeckers prefer forest stands with high basal area containing large-diameter hardwoods (> 38 cm diameter at breast height) for cavity excavation (Conner et al. 1975). Because of its dependence on large snags and CWD for foraging and large snags for nesting and roosting (Conner et al. 1975, Renken and Wiggers 1989), the pileated woodpecker is used as a MIS in approximately 63 percent of the national forests within the U.S. Forest Service Southern and Eastern regions—primarily to indicate adequate presence of CWD and large snag availability (Moseley 2008). Indeed, because of their association with snags and ease of recognition in the field, woodpeckers (Family Picidae) have been used as reliable indicators of bird diversity within forested landscapes in Europe and elsewhere (Mikusinski et al. 2001, Roberge and Angelstam 2006). Pileated woodpeckers also may serve as keystone species in some forest types due to the importance of their cavities to secondary cavity nesters such as northern flying squirrels, northern saw-whet owls (*Aegolius acadicus*), and bats (Bednarz et al. 2004, Bonar 2000, Menzel et al. 2004).

The Indiana myotis and Virginia big-eared bat received the highest local priority for the SPE criterion, the lowest ranked criterion. Despite their high ranking for this category, these species received the lowest global priorities for objective 2. Although cave-dwelling bats can be monitored effectively either by direct counting of individuals in winter hibernacula or during cave emergence (Kunz et al. 1996), it is difficult to relate population changes from cave surveys to specific habitat changes within the surrounding landscape. Furthermore, following post-hibernation emergence, it is assumed that most female Indiana myotis migrate to warmer regions to the east or west of the Appalachians for maternity activity (Ford and Chapman 2007), further confounding local population estimates. In addition to monitoring difficulties, Indiana myotis and Virginia big-eared bat habitat use patterns in the Appalachians are not restricted to mature mixed mesophytic-cove hardwood forest (Chapman 2007, Ford et al. 2002a, Menzel et al. 2001, Sample and Whitmore 1993). For example, in eastern West Virginia, Virginia big-eared bats were observed foraging over pastures adjacent to cave roosts (Sample and Whitmore 1993). Use of large snags or live trees with exfoliating bark by Indiana myotis is somewhat independent of stand age and structure and often is more related to the periodicity of forest disturbance from flooding or fire (Carter 2006). Individuals, particularly summer resident males and those in maternity colonies, often prefer roost sites with low to moderate canopy cover to increase solar exposure (Brack 2006, Britzke et al. 2003, Ford et al. 2002a, Ford and Chapman 2007, Menzel et al. 2001). The only known maternity roost observed within the proclamation boundary of the MNF was in a fire-killed red maple snag within a stand that had been selectively harvested prior to burning (Keyser and Ford 2006). On the Fernow Experimental Forest portion of the MNF, an adult male Indiana bat was observed day-roosting in mid-summer in a residual shagbark hickory within a 6-year-old patch clearcut (Ford et al. 2002a). Accordingly, maintenance of mature >80-year-old mixed mesophytic and cove forest assemblages is somewhat contradictory to some aspects of Indiana myotis and Virginia big-eared bat habitat associations within the central Appalachians. The effectiveness of bats as MIS for objective 2, therefore, appears limited.

Objective 3

Our AHP analysis supports the MNF's selection of the Virginia northern flying squirrel as a MIS representing mature red spruce forests (U.S. Forest Service 2006a). The Virginia northern flying squirrel received the highest local priorities for sensitivity and documentation criteria. Although northern hardwood forests adjacent to red spruce stands are used for denning and to a lesser degree for foraging (Ford et al. 2004, Ford and Rodrigue 2007, Menzel 2003, Menzel et al. 2006, Smith 2007), large mature red spruce stands are believed to harbor greater food resources such as mycorrhizal fungi thereby providing higher quality habitat. In addition, these red spruce forests support few or no southern flying squirrels (*G. volans*) that compete with northern flying squirrels for den cavities (Loeb et al. 2000, Menzel 2003, Menzel et al. 2005, Mitchell 2001). Until its delisiting in 2008 (Federal Register 2008), the Virginia northern flying squirrel was a federally endangered subspecies of the northern flying squirrel (U.S. Fish and Wildlife Service 1985). The delisting was due, in part, to current protection of mature red spruce stands within the MNF along with a recently documented wider distribution than previously believed (Odom et al. 2001, U.S. Fish and Wildlife Service 2007). Long-term monitoring efforts for Virginia northern flying squirrels primarily involve placing nest boxes within known and possibly occupied forest stands (U.S. Fish and Wildlife Service 2007). These monitoring efforts can provide important population information, such as sex ratios and age distribution as well as detection probabilities and percent area occupied; such data could then be linked to natural or management-accelerated development of red spruce with older forest characteristics (Reynolds et al. 1999, Terry 2004, U.S. Fish and Wildlife Service 2007). Furthermore, its new legal status requires a long-term post-delisting monitoring of populations and habitats for the upcoming decade (U.S. Fish and Wildlife Service 2007).

Cheat Mountain salamanders primarily are associated with emergent colluvium within mature red spruce and red spruce-northern hardwood stands (Brooks 1948; Dillard et al. 2008a, b). The Cheat Mountain salamander is federally threatened (U.S. Fish and Wildlife Service 1991), limited to approximately 70 known isolated “populations” within an 1,800 km^2 area (Petranka 1998). Despite its listed status for two decades, only the work of Dillard et al. (2008a,b) quantitatively documents Cheat Mountain salamander habitat relations. Furthermore, investigation and monitoring of Cheat Mountain salamanders are inhibited partly by their cryptic, fossorial habits that make survey and sampling efforts difficult and inefficient (Petranka 1998, M. Crockett, U.S. Fish and Wildlife Service, pers. comm) as well as the difficulty of obtaining survey and handling permits from State and Federal authorities. Despite these issues, the Cheat Mountain salamander received the highest local priority for SPE. Additionally, the Cheat Mountain salamander constitutes a distinct species, whereas the Virginia northern flying squirrel (Wells-Gosling and Heaney 1984) and southern rock vole (Kirkland and Jannett 1982, Pagels and Laerm 2007) are recognized only as subspecies.

The hermit thrush received the highest local priority for monitoring, the highest ranked selection criterion. Despite established monitoring efforts, the Virginia northern flying squirrel was not ranked highest for this criterion because of its perceived low detection probability and nocturnal habits (Menzel 2003). Alternatively, because of the hermit thrush’s diurnal activity, distinct vocalizations, and ease of training personnel in field identification, hermit thrush populations can be monitored more effectively than secretive taxa, such as the Virginia northern flying squirrel and Cheat Mountain salamander. Although the hermit thrush often is associated with mature red spruce forests (Brooks 1935, Hall 1984, Stewart and Aldrich 1949), it is not as dependent on this forest type as the Virginia northern flying squirrel (Menzel 2003, Menzel et al. 2005), occurring in as high or higher densities in northern hardwood forests (Dellinger et al. 2007, Hall 1984). Similar to other migratory songbirds, however, it is difficult to determine whether population fluctuations are attributable to reduced breeding habitat availability and/or exacerbated by wintering ground conditions (Brown et al. 2002).

CONCLUSION

The AHP was used to determine the best MIS for MNF forest management objectives from a suite of alternative species. To our knowledge, this is the first application of a multiple-criteria decisionmaking technique to MIS species selection. Although we had some inconsistency in our pair-wise comparisons for the SPE criterion, we believe the impact on our overall results is negligible due to the low priority of the SPE criterion. We also believe that our criteria priorities and rankings for alternative MIS species are comprehensive and defensible. A major criticism of the AHP is that preferences and subsequent priorities are somewhat subjective (Mendoza and Prabhu 2000). We acknowledge that another group's preferences may produce results different from ours, particularly for national forests in other regions. Nonetheless, we believe application of the AHP to MIS selection provides several important advantages over currently employed informal selection procedures. First, the AHP provides an open and straightforward decisionmaking process that allows evaluation by outside parties (Mendoza and Prabhu 2000). Secondly, the AHP has a strong theoretical foundation (Harker and Vargas 1987, Perez 1995, Saaty 2003). Thirdly, the AHP allows land managers to account for insufficient or missing information by incorporating expert opinion (Mendoza 2006). Similar to the adaptive management paradigm, this stregthens the decisionmaking process through a cycle of evaluation, planning, action, monitoring, and implementation, where MIS and criteria can be reassessed as new information becomes available (Lindenmayer et al. 2000, Williams et al. 2007).

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APPENDIX

Appendix 1.—Management indicator species selection criteria judgments for the Monongahela National Forest, West Virginia

Pair-wise Comparison	Better	Intensity[1]
Sensitivity vs Monitoring	Monitoring	3
Sensitivity vs Documentation	Sensitivity	5
Sensitivity vs SPE	Sensitivity	9
Monitoring vs Documentation	Monitoring	5
Monitoring vs SPE	Monitoring	9
Documentation vs SPE	Documentation	4

[1]Selection criteria: 1 = equal importance, 3 = weakly more important, 5 = more important, 7 = strongly more important, and 9 = absolutely more important.

Appendix 2.—Monongahela National Forest, West Virginia, objective 1, maintenance of > 20,250 ha of early successional habitat, judgments for golden-winged warbler (*Vermivora chrysoptera*; GWWA), ruffed grouse (*Bonasa umbellus*; BOUM), yellow-breasted chat (*Icteria virens*; ICVI), meadow vole (*Microtus pennsylvanicus*; MIPE), and *Sylvilagus* spp. (*Sylvilagus*) management indicator species alternatives based on four selection criteria: sensitivity to management actions (sensitivity), monitoring efficacy and effectiveness (monitoring), species baseline information (documentation), and social, political, and economic importance (SPE).

	Criterion							
	Sensitivity		Monitoring		Documentation		SPE	
Pair-wise Comparison	Better	Intensity[1]	Better	Intensity[1]	Better	Intensity[1]	Better	Intensity[1]
GWWA vs BOUM	GWWA	7	BOUM	5	BOUM	9	BOUM	5
GWWA vs ICVI	–	1	–	1	ICVI	3	GWWA	3
GWWA vs MIPE	MIPE	3	GWWA	5	MIPE	7	GWWA	9
GWWA vs Sylvilagus	GWWA	5	Sylvilagus	3	Sylvilagus	7	Sylvilagus	3
BOUM vs ICVI	ICVI	7	BOUM	5	BOUM	9	BOUM	7
BOUM vs MIPE	MIPE	9	BOUM	9	BOUM	5	BOUM	9
BOUM vs Sylvilagus	Sylvilagus	3	BOUM	3	BOUM	3	BOUM	3
ICVI vs MIPE	MIPE	3	ICVI	5	MIPE	5	ICVI	3
ICVI vs Sylvilagus	ICVI	5	Sylvilagus	3	Sylvilagus	5	Sylvilagus	7
MIPE vs Sylvilagus	MIPE	7	Sylvilagus	3	Sylvilagus	3	Sylvilagus	9

[1]Selection criteria: 1= equal importance, 3 = weakly more important, 5 = more important, 7 = strongly more important, and 9 = absolutely more important.

Appendix 3.—Monongahela National Forest, West Virginia, objective 2, maintenance of >20,250 ha of >80-year-old mixed mesophytic and cove hardwood stands; judgments for Indiana bat (*Myotis sodalis*; MYSO), Virginia big-eared bat (*Corynorrhinus townsendii virginianus*; COTO), red-backed salamander (*Plethodon cinereus*; PLCI), cerulean warbler (*Dendroica cerulea*; DECE), hooded warbler (*Wilsonia citrina*; WICI), and pileated woodpecker (*Dryocopus pileatus*; DRPI) management indicator species alternatives based on four selection criteria: sensitivity to management actions (sensitivity), monitoring efficacy and effectiveness (monitoring), species baseline information (documentation), and social, political, and economic importance (SPE).

	Criterion							
	Sensitivity		Monitoring		Documentation		SPE	
Pair-wise Comparison	Better	Intensity[1]	Better	Intensity[1]	Better	Intensity[1]	Better	Intensity[1]
MYSO vs COTO	MYSO	5	COTO	5	–	1	–	1
MYSO vs PLCI	MYSO	5	PLCI	7	PLCI	5	MYSO	9
MYSO vs DECE	MYSO	3	DECE	5	DECE	3	MYSO	5
MYSO vs WICI	WICI	3	WICI	5	–	1	MYSO	7
MYSO vs DRPI	DRPI	7	DRPI	9	DRPI	7	MYSO	7
COTO vs PLCI	–	1	PLCI	3	PLCI	7	COTO	9
COTO vs DECE	DECE	3	DECE	3	DECE	3	COTO	5
COTO vs WICI	WICI	7	WICI	3	–	1	COTO	7
COTO vs DRPI	DRPI	9	DRPI	5	DRPI	7	COTO	7
PLCI vs DECE	DECE	3	PLCI	3	PLCI	5	DECE	7
PLCI vs WICI	WICI	7	PLCI	3	PLCI	5	WICI	5
PLCI vs DRPI	DRPI	9	DRPI	3	DRPI	3	DRPI	5
DECE vs WICI	WICI	5	–	1	DECE	3	DECE	3
DECE vs DRPI	DRPI	7	DRPI	5	DRPI	7	DECE	7
WICI vs DRPI	DRPI	3	DRPI	5	DRPI	7	WICI	5

[1]Selection criteria: 1= equal importance, 3 = weakly more important, 5 = more important, 7 = strongly more important, and 9 = absolutely more important.

Appendix 4.—Monongahela National Forest, West Virginia, objective 3, maintenance of >8,100 ha of >80 year old red spruce (*Picea rubens*) stands; judgments for Virginia northern flying squirrel (*Glaucomys sabrinus fuscus*; GLSA), Cheat Mountain salamander (*Plethodon nettingi*; PLNE), Southern rock vole (*Microtus chrotorrhinus carolinensis*; MICH), and hermit thrush (*Catharus guttatus*; CAGU) management indicator species alternatives based on four selection criteria: sensitivity to management actions (sensitivity), monitoring efficacy and effectiveness (monitoring), species baseline information (documentation), and social, political, and economic importance (SPE).

	Criterion							
	Sensitivity		Monitoring		Documentation		SPE	
Pair-wise Comparison	Better	Intensity[1]	Better	Intensity[1]	Better	Intensity[1]	Better	Intensity[1]
GLSA vs PLNE	GLSA	3	GLSA	5	GLSA	9	PLNE	5
GLSA vs MICH	GLSA	9	GLSA	7	GLSA	9	GLSA	3
GLSA vs CAGU	GLSA	7	CAGU	3	GLSA	3	GLSA	7
PLNE vs MICH	PLNE	7	PLNE	3	PLNE	1	PLNE	5
PLNE vs CAGU	PLNE	5	CAGU	9	CAGU	5	PLNE	9
MICH vs CAGU	CAGU	3	CAGU	7	CAGU	5	MICH	5

[1]Selection criteria: 1= equal importance, 3 = weakly more important, 5 = more important, 7 = strongly more important, and 9 = absolutely more important.

Moseley, K.R.; Ford, W.M.; Edwards, J.W.; Strager, M.P. 2010. **A multi-criteria decisionmaking approach to management indicator species selection for the Monongahela National Forest, West Virginia.** Res. Pap. NRS-12. Newtown Square, PA: U.S. Department of Agriculture, Forest Service, Northern Research Station. 22 p.

The management indicator species concept is useful for land managers charged with monitoring and conserving complex biological diversity over large landscapes with limited available resources. We used the analytical hierarchy process (AHP) to determine the best management indicator species (MIS) for three management objectives of the Monongahela National Forest (MNF) in West Virginia. We compiled a set of alternative MIS, including current MNF MIS, for each objective based on a literature review of species-habitat relations in the Appalachian Mountain region. We believe the AHP is an effective tool for MIS selection, particularly within complex Appalachian ecosystems, because it provides a formal structured decision procedure, has a strong theoretical foundation, accommodates incomplete ecological data, and offers transparency to the MIS decisionmaking process.

KEY WORDS: analytical hierarchy process, Appalachians, management indicator species, Monongahela National Forest, multi-criteria decisionmaking

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