Implementing Northern Goshawk Habitat Management in Southwestern Forests: A Template for Restoring Fire-Adapted Forest Ecosystems

James A. Youtz, Russell T. Graham, Richard T. Reynolds, and Jerry Simon

ABSTRACT

Developing and displaying forest structural targets are crucial for sustaining the habitats of the northern goshawk, a sensitive species in Southwestern forests. These structural targets were described in Management Recommendations for the Northern Goshawk in the Southwestern United States (MRNG) (Reynolds, et al., 1992). The MRNG were developed in a unique food-web approach that identified desired forest conditions for the goshawk. These desired conditions were based on syntheses of the habitats of both goshawks and the diverse suite of plants and animals in their food web. Not surprisingly, implementing these structural targets results in forests restored to conditions similar to our understanding of pre-European settlement forests.

Silviculturists are responsible for:

1) developing a silvicultural system,
2) documenting the system in a silvicultural prescription, and
3) establishing protocols for monitoring the development and perpetuation of the desired forest conditions.

We present spreadsheet tools to aid silviculturists with diagnosis and development of silvicultural prescriptions and tree-marking guides that produce the desired uneven-aged, heterogeneous forest structures that comprised historic forests, as well as goshawk habitats, in Southwestern ponderosa pine landscapes. These tools incorporated fire behavior and fuel considerations, rendering them appropriate for developing prescriptions for other management objectives (e.g., restoration of fire-adapted forest ecosystems) and biophysical situations.

Key words: forest management, marking guides, northern goshawk, reference conditions, restoration, silvicultural prescriptions, structural targets

This paper was published in: Deal, R.L., tech. ed. 2008. Integrated restoration of forested ecosystems to achieve multiresource benefits: proceedings of the 2007 national silviculture workshop. Gen. Tech. Rep. PNW-GTR-733. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 306 p.

James A. Youtz is a regional silviculturist, Southwestern Region, USDA Forest Service, 333 Broadway Blvd. SE, Albuquerque, NM 87102. **Russell T. Graham** is a research forester, Rocky Mountain Research Station, USDA Forest Service, 1221 South Main Street, Moscow, ID 83843. **Richard T. Reynolds** is a research wildlife biologist, Rocky Mountain Research Station, USDA Forest Service, 2150 Centre Ave. Bldg. A, Fort Collins, CO 80526. **Jerry Simon** is a forester, silviculturist, Southwestern Region, USDA Forest Service, 333 Broadway Blvd. SE, Albuquerque, NM 87102.

HISTORY OF GOSHAWK HABITAT MANAGEMENT IN THE SOUTHWEST

The northern goshawk (*Accipiter gentilis*) is a large forest raptor that typically occurs in old forests and feeds on birds and mammals such as tree and ground squirrels, rabbits, jays, woodpeckers, and grouse. Many of these prey species are more abundant in older forests (Squires and Reynolds, 1997). Over the last 30 years, considerable controversy has developed regarding the conservation of the goshawk (Greenwald, et al., 2005). It has been suggested that tree harvests negatively affect goshawks by altering the composition and structure of their habitats (Reynolds, 1971; Reynolds, et al., 1982; Moore and Henny, 1983), and Crocker-Bedford (1990) showed that territory occupancy and reproduction of goshawks in northern Arizona were lowered by tree harvests. These findings initiated a flurry of appeals and litigation aimed at reducing tree harvests in the Southwest and provided the basis for petitions to list the goshawk as threatened (Boyce, et al., 2006). In response to these challenges, the Southwestern Region of the Forest Service (FS) convened a scientific committee of goshawk biologists and silviculturists to develop forest management recommendations to protect and enhance habitats of the goshawk in the southwestern United States (Boyce, et al., 2006). The committee's recommendations were published in the Management Recommendations for the Northern Goshawk in the Southwestern United States (hereafter MRNG) (Reynolds, et al., 1992). In 1996, management standards and guides (hereafter "guidelines") were developed by the Southwestern Region based on the MRNG, which appeared in a Final Environmental Statement for amending National Forest Management Plans in Arizona and New Mexico (Boyce, et al., 2006). In 1996, a Record of Decision (ROD) amended the Forest Management Plans to implement the MRNG in all National Forests in the Southwest (USDA Forest Service 1996). The Plan Amendment directed National Forests to apply the goshawk guidelines in almost all vegetation manipulation projects (timber sales and fuels management treatments). An initial strategy was developed in 1993 (Higgins, 2003) for implementing the guidelines on the Kaibab National Forest (KNF), based on the concepts and desired forest conditions described in the MRNG. Despite this, there continued to be uncertainty in forest management applied in the Southwest regarding the MRNG desired forest conditions (Boyce, et al., 2006). Here we present tools to help managers with the process of prescription development, implementation layout, and monitoring. These tools facilitate understanding and application of the concepts outlined in the MRNG and meeting the guideline specifications outlined in the ROD.

GOSHAWK HABITAT MANAGEMENT: FOREST ECOLOGY

The MRNG described sets of desired goshawk breeding habitats for Southwestern forests based on syntheses of the life history and habitats of goshawks and 14 important Southwestern goshawk prey species and the ecology of dominant overstory and understory plants in each forest type (Reynolds, et al., 1992; Reynolds, et al., 2006). The MRNG described habitats at three spatial scales:

(1) a 12-ha (30-acre) nest area with relatively large trees and high canopy cover relative to forest type,

(2) a 168-ha (420-acre) post-fledging family area (PFA) surrounding the nest area providing a transition from forest structures similar to those in nest areas to structures suitable for goshawk foraging (see below), and

(3) a 2,160-ha (5,400-acre) foraging area surrounding the PFA comprised of structures suited for goshawk foraging and mosaics of prey habitats (Reynolds, et al., 1992) (Figures 1-2).

Goshawk foraging habitat included subcanopy flight space (lifted crowns), abundant tree perches, and available prey. Prey habitats included highly interspersed groups of mid-aged (140+ years) and old trees (230+ years) with interlocking tree crowns (for tree squirrels), small openings (typically <0.5 ha, 1.25 acre) around tree groups (for ground squirrels, rabbits, birds), decadent reserve trees and snags (for woodpeckers, tree squirrels), logs (for ground squirrels, rabbits, woodpeckers), and wood debris (for ground squirrels, rabbits, birds) (Reynolds, et al., 1992). Mid-aged, mature, and old forests provided the best habitat for most prey species, but small openings were also important (Reynolds, et al., 1992). Old forests also provide subcanopy flight space suited for goshawk hunting. Predator and prey habitats were synthesized into desired landscapes so that the distribution and interspersion of habitats optimized their availability to territorial goshawks and their prey with an objective of maximizing goshawk occupancy, reproduction, and survival (Reynolds, et al., 2006b). To

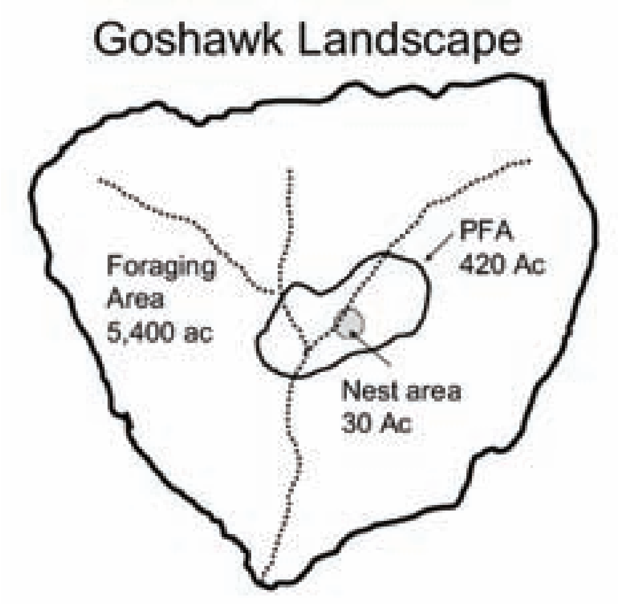


Figure 1. Conceptualized Goshawk Home Range

assure that the specific desired habitats were within the biophysical capabilities of a forest and could therefore be attained and sustained, the MRNG developed specific desired conditions for Southwestern ponderosa pine, mixed conifer, and spruce/fir forests by incorporating local and regional variations in vegetation composition and structure, tree development rates and longevity, natural disturbances and succession, the sizes, shapes, juxtapositions of plant aggregations, and site capabilities (Reynolds, et al., 1992, Reynolds, et al., 1996, Long and Smith 2000, Reynolds, et al., 2006).

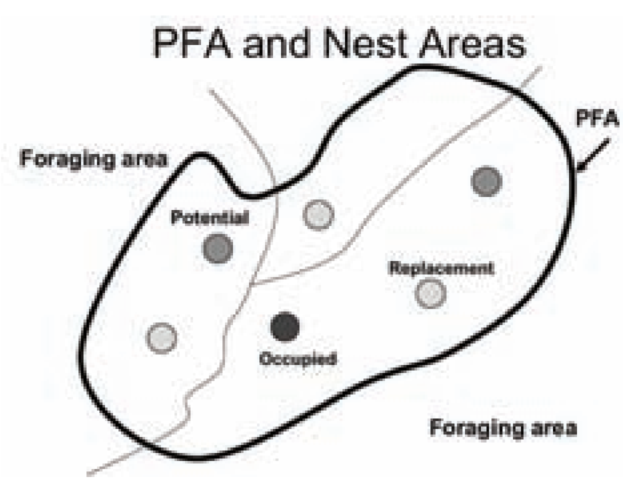


Figure 2. Conceptualized Goshawk PFA and Nest Areas

The intent of the MRNG was to maintain goshawk reproduction by sustaining predator and prey habitats on each home range and used vegetative structural stages (VSS) to describe the desired vegetation. VSS integrates the stages that vegetation complexes (e.g., composition, structure) go through beginning with regeneration through maturation and mortality (Oliver and Larsen 1990, Franklin, et al., 2002, Thomas et al. 1979). The MRNG defines 6 vegetation structural stages from forest initiation (VSS 1) to old forest (VSS 6) (Figure 3). Due to forest dynamics (e.g., resulting from vegetation growth, succession, natural disturbances) landscapes entirely of old forest (VSS 6) can not be sustained. Therefore the MRNG used maturation rates of Southwestern forests to estimate sustainable landscape proportions of old forest, and recommended that about 10% of a naturally forested landscape be in a grass/forb/shrub stage (VSS 1; to 20 yrs), 10% in the seedling/sapling stage (VSS 2, to 50 yrs), 20% in young forest (VSS 3; to 96 yrs), 20% in mid-aged forest (VSS 4; to 137 yrs), 20% in mature forest (VSS 5; to 183 yrs), and 20% in old forest (VSS 6; to 233+ yrs) (Reynolds, et al., 1992, Appendix 5, Table 1). Excluding grass/forb/shrub, each VSS comprised similarly-aged trees and elements such as live-tree decadence, snags, logs, and vertical and horizontal heterogeneity. Over time (≈ 250 years), the desired landscape consisted of a temporally shifting mosaic of highly interspersed VSS groups in the desired proportions of VSS (Reynolds, et al., 1992, Long and Smith 2000). Sizes of VSS groups approximated the natural (prior to tree harvests and fire suppression) conditions in these forests and contained 2 - 44 trees occupying 0.2-0.3 ha (0.5- 0.75 acre) (Cooper 1961, White 1985, Pearson 1950). At the coarse scale (landscape), ponderosa pine was all-aged, but trees within each group (fine scale) tended to be similar age (Pearson 1950). The desired within-group structure in the mid-aged to old classes (VSS 4-6) included open understories, interlocking tree crowns, abundant large limbs (goshawk hunting perches), and shade for mycorrhizal fungi (food of several prey species) (Reynolds, et al., 1992). Grass, herb, shrub habitat was interspersed in and around groups and provided habitat for rabbits, ground squirrels, and birds (e. g., grouse, doves) (Reynolds, et al., 1992). Additional desired conditions include retention of large live reserve trees within regeneration groups > 0.4 ha (1 acre) in size, snags, downed logs, and woody debris. An ideal MRNG landscape had home ranges spaced at about 4 km (2.5 mile) between centers (Reynolds, et al., 1992, Boal et al. 2001, Reynolds, et al., 2005, Reynolds and Joy 2006). Because

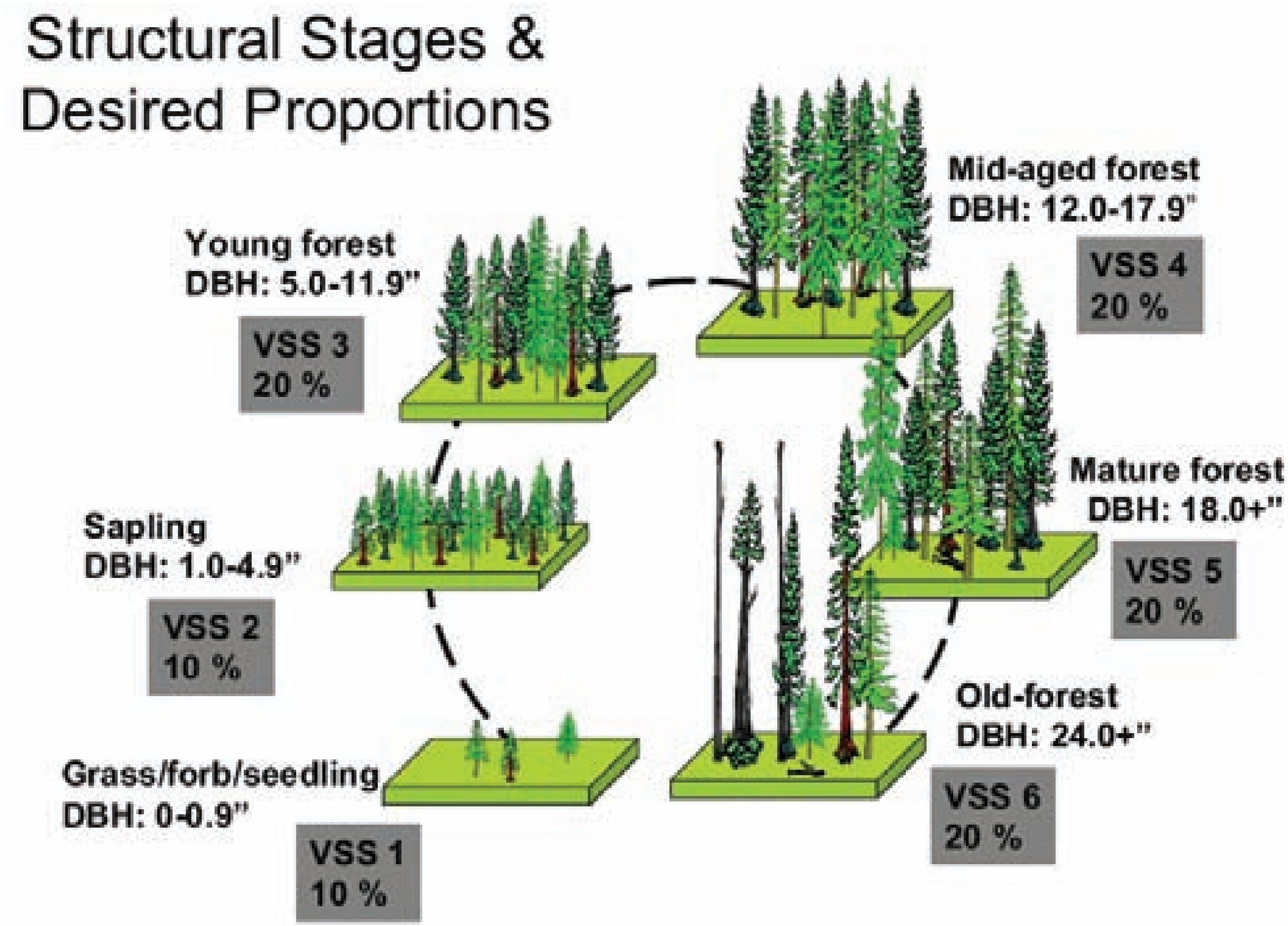


Figure 3. Forest Structural Stages

the desired MRNG condition for Southwestern ponderosa pine forests closely resembles the pre-European settlement (before grazing, fire control and major harvesting) conditions in this forest type (Cooper 1961, White 1985, Pearson 1950, Covington and Moore 1994, Fulé et al. 1997, Long and Smith 2000), implementation of the MRNG is a large step towards ecological restoration.

HISTORIC REFERENCE CONDITIONS: FOREST RESTORATION AND MRNG

Historic reference conditions (HRC) provides a framework for understanding forest conditions, ecological processes, and the historic range of variability prior to extensive European settlement (Moore and others 1999). Figure 4 shows historic forest patterns in the Fort Valley Experimental Forest near Flagstaff, Arizona (Covington, 1997). Note the similarity of historic forest tree group patterns to the desired conditions described under the MRNG. Such patterns are relevant for developing management strategies in Southwestern ponderosa pine and dry mixed-conifer forest types.

Following are some concepts related to MRNG and ecological restoration of historic reference conditions:

- Implementation of MRNG and other ecological restoration approaches based upon historic conditions will lead to restoration of forest resiliency to disturbances within the historic range of natural variability.
- Strict-sense ecological restoration involves restoration of historic reference conditions relative to forest structure, patterns, species and ecological processes. It is the end-goal of a process that provides for maintenance of desired conditions by re-introduction of or mimicking historic ecosystem processes (fire, insects,

etc.). It will hereafter be referred to as restoring historic reference conditions (RHRC). Some groups and individuals believe most, if not all, management actions on southwestern forests should be designed to restore HRC.

- MRNG is a strategy that provides for development, maintenance and sustainability of the desired forest structural conditions. These desired conditions are based on the habitat requirements of the goshawk and their prey species and are similar to the historic range of variability of natural forest conditions. Implementation of MRNG will result in forest landscape restoration (structure, patterns and species composition within this historic range of variability of natural forest conditions). But MRNG is a management system designed to provide sustainability within a management framework that recognizes multiple resource objectives. Resultant desired future condition of the MRNG strategy will be similar but not necessarily identical to RHRC, and the maintenance strategy may differ between the MRNG and RHRC.

The following are some implementation similarities and differences between MRNG and RHRC:

- Both approaches may utilize tree harvest as a tool for obtaining desired conditions. But some strict-sense RHRC advocates have suggested that desired conditions should be maintained by either prescribed fire or wildland fire use alone and tree cutting is not warranted. In contrast, MRNG utilizes tree cutting as a scheduled activity for maintaining desired forest conditions. Timber production isn't an objective, but rather is a by-product of maintaining structural composition. In addition, prescribed fire is the preferred method of treating surface fuels but mechanical and hand methods are not excluded. Because of this flexibility, implementing the MRNG appears to be more feasible than maintaining desired forest structures by prescribed fire alone.
- Grouped and single trees are interspaced within a grass/forb/shrub mosaic (see below) under both management approaches. This results in an irregular and discontinuous forest canopy with variable tree densities and discontinuous arrangement of fuels which minimizes the potential for crown fire and facilitates the use of low intensity prescribed fire. Therefore both MRNG and RHRC are applicable for decreasing fuels and crown fire hazard.
- Both RHRC and MRNG focus on development of clumps/groups of trees, surrounding root development zones, natural openings, and replacement trees arranged in fine scale mosaics [e.g., 0.04 to 0.8 ha (0.1 to 2.0 acre) in ponderosa pine forests].
- Depending on the setting, type and current forest condition, implementing the MRNG could tend to create and maintain even-aged groups of trees while the RHRC would tend to create uneven-aged groups. Nevertheless, depending on the frequency and intensity of treatments utilized by both approaches, a variety of forest compositions and structures could be maintained.
- The RHRC approach focuses on historic locations of tree groups and clumps based upon remnant evidence (stumps and logs representing pre-settlement trees) for determination of the number and location of replacement trees. Such pre-settlement evidence can also be used to develop desired forest structures identified in the MRNG. A key to using both historic reference conditions and the MRNG for treating forests is to use this information along with intrinsic site information such

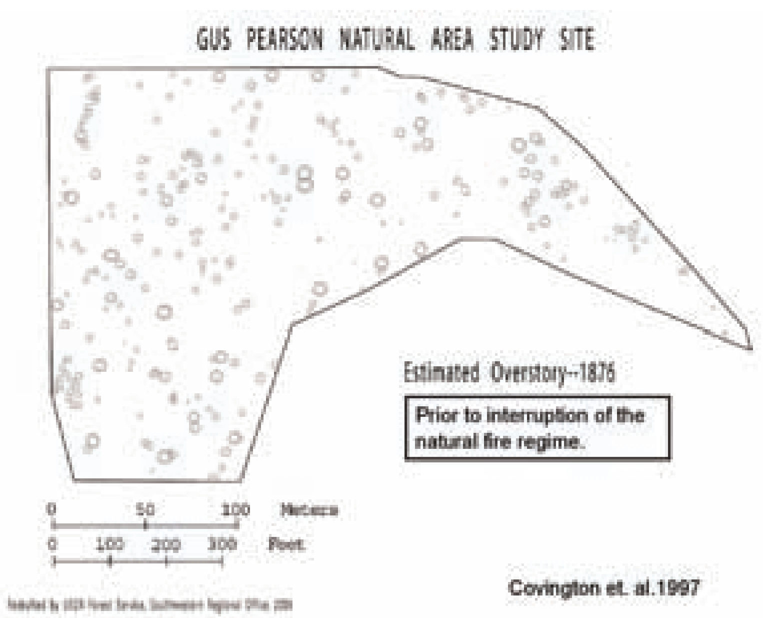


Figure 4. Historic Reference Conditions

Table 1. Forest Density and Structural Targets (Full Stocking Level, Ponderosa Pine PFA)

DESIRED FUTURE CONDITION Ponderosa Pine Forest Type - All Sites - Post-Fledging Family Area									
				Group basis				Per acre basis mean (average acre)	
VSS Class	DBH Class	% of Area	Mean DBH	SDI	Mean Trees/ acre	Basal Area (ft²/acre)	Canopy Cover (percent)	Trees/ acre	Basal Area (ft²/acre)
1	<1	10	0.1	0	203	0		20.3	0
2	1-4.9	10	3	28	193	9		19.3	1
3	5-11.9	20	8.5	105	136	54		27.3	11
4	12-17.9	7	15	137	72	88	60	4.8	6
4	12-17.9	13	15	130	68	83	50	9.0	11
5	18-23.9	20	21	127	39	93	50	7.7	19
6	24+	20	27	135	27	109	50	5.5	22
								93.9	69
	====== Note on per acre basis =======							Dq* =	13.11
								SDI* =	113.7
	Reserve trees and grass matrix areas are included in these figures. Trees are closely grouped, allowing for open rooting zone interspaces between groups.							*Quadratic mean diameter includes trees >= 1" dbh only.	

Modeling assumptions: Site Index = 78 (Minor), Stand Density Index (SDI) max = 450

Table 2. Forest Density and Structural Targets (Full Stocking Level, Ponderosa Pine FA)

DESIRED FUTURE CONDITION Ponderosa Pine Forest Type - All Sites - Foraging Area									
				Group basis				Per acre basis mean (average acre)	
VSS Class	DBH Class	% of Area	Mean DBH	SDI	Mean Trees/ acre	Basal Area (ft²/acre)	Canopy Cover (percent)	Trees/ acre	Basal Area (ft²/acre)
1	<1	10	0.1	0	203	0		20.3	0
2	1-4.9	10	3	28	193	9		19.3	1
3	5-11.9	20	8.5	105	136	54		27.3	11
4	12-17.9	20	15	89	46	57	40	9.3	11
5	18-23.9	20	21	100	30	73	40	6.1	15
6	24+	20	27	104	21	84	40	4.2	17
								86.5	54
	====== Note on per acre basis =======							Dq* =	12.29
								SDI* =	92.1
	Reserve trees and grass matrix areas are included in these figures. Trees are closely grouped, allowing for open rooting zone interspaces between groups.							*Quadratic mean diameter includes trees >= 1" dbh only.	

Modeling assumptions: Site Index = 78 (Minor), Stand Density Index (SDI) max = 450

Table 3. Forest Density and Structural Targets (Full Stocking Level, Mixed Conifer PFA)

DESIRED FUTURE CONDITION

Dry Mixed Conifer Forest Type - All Sites - Post-Fledging Family Area

VSS Class	DBH Class	% of Area	Mean DBH	Group basis: SDI	Group basis: Mean Trees/ acre	Group basis: Basal Area (ft^2/acre)	Group basis: Canopy Cover (percent)	Per acre basis mean (average acre): Trees/ acre	Per acre basis mean (average acre): Basal Area (ft^2/acre)
1	<1	10	0.1	0	203	0		20.3	0
2	1-4.9	10	3	29	200	10		20.0	1
3	5-11.9	20	8.5	140	182	72		36.3	14
4	12-17.9	20	15	145	76	93	60	15.2	19
5	18-23.9	20	21	153	47	112	60	9.3	22
6	24+	20	27	170	34	137	60	6.9	27
								108.0	84
								Dq* =	13.23
								SDI* =	137.4

====== Note on per acre basis =======

Reserve trees and grass matrix areas are included in these figures. Trees are closely grouped, allowing for open interspaces between groups.

*Quadratic mean diameter includes trees >= 1" dbh only.

Modeling assumptions: Site Index = 85 (Minor), Stand Density Index (SDI) max = 486, Species composition = 75% ponderosa pine, 25% Douglas-fir (actual species composition will be project-specific)

Table 4. Forest Density and Structural Targets (Full Stocking Level, Mixed Conifer FA)

DESIRED FUTURE CONDITION

Dry Mixed Conifer Forest Type - All Sites - Foraging Area

VSS Class	DBH Class	% of Area	Mean DBH	Group basis: SDI	Group basis: Mean Trees/ acre	Group basis: Basal Area (ft^2/acre)	Group basis: Canopy Cover (percent)	Per acre basis mean (average acre): Trees/ acre	Per acre basis mean (average acre): Basal Area (ft^2/acre)
1	<1	10	0.1	0	203	0		20.3	0
2	1-4.9	10	3	29	200	10		20.0	1
3	5-11.9	20	8.5	140	182	72		36.3	14
4	12-17.9	7	15	145	76	93	60	5.1	6
4	12-17.9	13	15	95	50	61	40	6.6	8
5	18-23.9	20	21	123	37	90	50	7.5	18
6	24+	20	27	149	30	120	60	6.0	24
								101.8	72
								Dq* =	12.69
								SDI* =	119.6

====== Note on per acre basis =======

Reserve trees and grass matrix areas are included in these figures. Trees are closely grouped, allowing for open rooting zone interspaces between groups.

*Quadratic mean diameter includes trees >= 1" dbh only.

Modeling assumptions: Site Index = 85 (Minor), Stand Density Index (SDI) max = 486, Species composition = 75% ponderosa pine, 25% Douglas-fir (actual species composition will be project-specific) as but not limited to potential vegetation type, soil type, climate, successional stage, insect and disease conditions, and fire regime condition class. This information should be incorporated in all silvicultural applications utilizing fundamental knowledge of tree silvics, growth patterns etc. and displayed and quantified where appropriate using metrics such as stand density index, site index, etc.

SILVICULTURAL METHODS AND SYSTEMS

Desired forest conditions for the goshawk food web are described in the MRNG and goshawk guidelines. Attainment and maintenance of these forest conditions can be achieved by applying appropriate silvicultural systems documented in a silvicultural prescription (Graham and Jain 2004). In general the desired forest conditions and suggested forest dynamics inherent within them can be created and maintained using selection systems (Pearson 1950, Long and Smith 2000, Graham and others 2007). However, even though selection systems and silvicultural methods necessary to create and maintain goshawk habitat are slightly different than those aimed at producing commercial timber, the principles and concepts are relevant to selection systems for sustaining goshawk habitat, such as:

- Maintenance of high-forest cover on landscapes at all times (forests and stands have no origin or end-point).
- Forest regeneration is established following each management entry (cutting cycle) on a scheduled basis.
- Structural regulation and sustainability is provided for at the local and landscape scale and smaller spatial scales (stand, group, clump) are integral to attaining desired landscape conditions (Long and Smith 2000).

The MRNG focuses on creating and sustaining a patchy forest of highly interspersed structural stages ranging from regeneration to old forest throughout a goshawk territory (≈ 2,400 ha, 6,000 acre landscape). These variable density tree groups can be comprised of 2-40 trees occupying up to 1.6 ha (0.1 to 4 acres) but tree groups are generally less than 0.3 ha (0.75 acres). Sufficient growing space between tree groups is required for producing the desired large trees and the canopy densities within tree groups. Depending on the biophysical setting and existing forest structure, occasional openings to 1.6 ha (4 acres) in size may be created, but each regeneration group larger than 0.4 ha (1 acre) must provide for retention of 3-5 mature reserve trees per 0.4 ha (1 acre). The discontinuous, irregular forest structural stage distribution is similar to that maintained by the mature selection system described by Pearson (1950) or the grade selection system described by Meyer (1934). Meyer (1961) perfected the use of "q" defined diameter distributions for sustaining the production of timber. In fact the structural stage distribution defined in the MRNG can be represented by a diameter distribution defined by a "q" of 1.16 (2 inch diameter class basis). Perhaps "individual/clump or clump selection" are appropriate terms that describe the silvicultural system used to sustain goshawk habitat. As Baker (1934) stated there are not four or five silvicultural systems but general classifications that contain a myriad of systems that can be developed to sustain forest conditions to meet management objectives.

The Forest Vegetation Simulator (FVS) is an excellent tool for planning and displaying either group selection or individual tree selection systems (Dixon 2002). It can be calibrated to local conditions and variants are available for most forests. FVS's default individual tree selection and group selection options readily project diameter distributions and tree densities through time; however, FVS has many other options for designing and projecting stand treatments. For example, trees can be selected to leave or remove by species, diameter, height, canopy cover, stand density index, basal area, trees/unit area, crown class, and from inventory plots to name a few. Stand dynamics (i.e., regeneration, growth, death) projected by FVS are readily displayed by the Stand Visualization System (SVS). Because the automatic default in SVS randomly distributes trees, the tree patterns and their juxtaposition will most likely differ from the desired goshawk forest structures displayed in the MRNG. Nevertheless, mapped tree locations or estimated tree locations can be input and used by SVS to display the group/clump distribution inherent to the MRNG. In addition, individual trees can be selected by location within the stand to be left or removed or trees can be selected by characteristics (e.g., diameter, species height etc.) This information can be used to schedule treatments in FVS (see Graham and others 2007, Appendix A for an example of using FVS and SVS for projecting and displaying complex stand structures). In addition the fire and fuel extension of FVS can readily be used to display fire behavior metrics such as torching and crowning index.

PROJECT PLANNING

Regional management priorities

> "The restoration of the ecological functionality of Southwestern forests and grasslands, with primary emphasis on fire adapted systems, has been identified as the central priority for this Region… Nationally, the Forest Service recently decided that each Region would develop a 5-year, integrated regional strategy outlining how they plan to address designing land management programs that achieve resource-specific objectives and work to create a landscape pattern that effectively lessens the likelihood of large wildland fires." (USDA Forest Service, Southwestern Region, 2004).

Management direction linking this central priority to implementation of the MRNG was stated in a transmittal letter from the Southwestern Regional Forester: "…we have come to understand there is a high level of compatibility between research findings for northern goshawk habitat, ecological restoration, sustainability, and the restoration of fire adapted ecosystems." (Forsgren, 2006).

Forest plan standards: Incorporation of MRNG

In the Southwestern Region, Land and Resource Management Plans (LRMPs) provide the management direction and Standards and Guidelines for the Mexican Spotted Owl (MSO) and other Threatened & Endangered species as well as the northern goshawk (MRNG). Under current Forest LRMPs, most forest types that are not classed as restricted habitat under MSO or management-limited by other specified requirements will be managed under the MRNG strategy. Additionally, 75-80% (depending upon geographic area) of the MSO restricted forest types may be managed under the MRNG strategy, but this is not required under Forest LRMPs. Cutting trees greater than 60 cm ≈ 24 inch diameter at breast height (dbh) is prohibited in Mexican spotted owl restricted habitat (mixed conifer and pine/oak forest types). Consultation with U.S. Department of Interior, Fish and Wildlife Service must be initiated to resolve conflicts when activities conducted in conformance with the MRNG may adversely affect other threatened, endangered, or sensitive species or may conflict with other established recovery plans or conservation agreements.

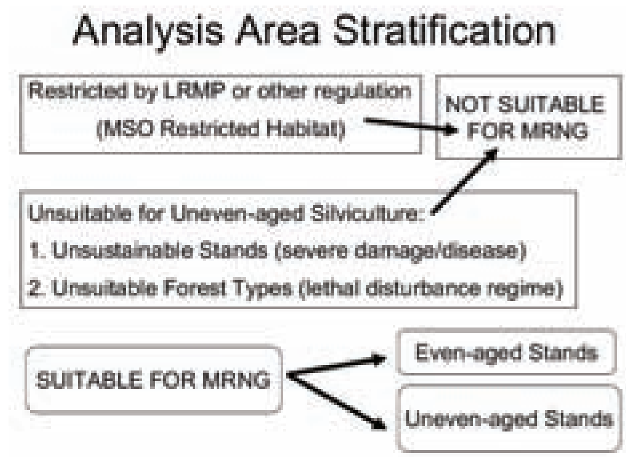


Figure 5. MRNG Forest Stratification Criteria

Project planning is initiated by stratification of an analysis area to classify both plan-level (MSO, other special areas), and bio-physical (forest types, structure, condition, etc.) management stratum. It is critical to identify existing forest conditions that are unsuitable for uneven-aged silvicultural treatments, and to recommend other management alternatives. Examples of unsuitable forest conditions include:

(1) those affected by severe insect, disease, or other damage;

(2) forest types that may experience windthrow damage if openings are created within the stand; and

(3) inappropriate forest types (characteristic lethal fire regime with ecologically-adapted even-aged forest development).

Some forest conditions may be permanently unsuitable for uneven-aged silvicultural treatments (i.e. characteristic lethal fire regime), while other conditions (severe insect, disease, or other damage) may be more appropriately managed with even-aged silvicultural methods during the initial treatment, but in the long-term these areas are suitable for uneven-aged management strategies (planning analysis and stratification flowchart, Figure 5). There are also multiple other decision criteria for selection of appropriate silvicultural systems and methods. Some of the most important are listed below:

- Biophysical setting and/or potential vegetation
- Current condition relevant to both short- and long-term desired condition
- Wildfire hazard/fire regime condition class
- Dwarf mistletoe/other insect-disease conditions

Uneven Aged Foraging Area Summary

Total Stratum

	Number	Acres
Stands in Stratum	87	6853

Based upon Proportional Acres

		Acres
Percent of Stratum in Commercial Conifer	92	5971
Percent of Stratum in Other Species	8	882

Commercial Conifer in Stratum 5971 Acres

(Averages)

VSS	Canopy Cover	Merch Volume - Board Feet	Merch Volume - Cubic Feet	Trees Per Acre	Basal Area	SDI	Proportional Acres	% of Total Comm. Conifer Acres
1	2	193	51	313	4	9	212	4
2	23	1744	400	2496	37	126	174	3
3	38	3345	1040	928	82	195	1033	17
4	46	6661	1475	722	84	178	1293	22
5	51	11370	2255	655	93	189	1938	32
6	54	18532	3300	691	108	210	1321	22

Figure 6. Plot by Plot Spreadsheet Summary, Example Project Analysis Area, Current Condition

- Operability, logging systems, economics, and feasibility of treating
- Regeneration of desired species
- Snags and woody debris

A specific need to manage a stand outside goshawk guidelines must be identified and discussed by an interdisciplinary planning team during project development. Managing outside the guidelines requires a site specific Forest Plan amendment for Southwestern Region National Forests.

Inventory and analysis

The MRNG recommends the targeted vegetative structural stages (VSS, 6 stages) proportions be managed with juxtapositions such that there is a high degree of interspersion of VSS at the sub-stand level. This implies an uneven-aged forest, regulated to provide landscape (2,400 ha ≈ 6,000 acre goshawk territory home range) sustainability.

Sub-stand structural classification of uneven-aged forests poses a challenge relative to stand inventory and analysis for prescription development and planning. Generally, structural stages are determined by which tree component represents the highest basal area. However, even though a big tree may dominate a group's basal area, a predominance of grass/forb/shrub, seedlings, or young forest may determine the VSS (i.e., VSS 1-grass/forb/shrub, VSS 2-seedling/sapling). "The area" in which VSS is determined can be as small as a group of 2 to 3 trees up to stand-sized areas if little diversity is present. As such, depending on the locale, inventory methods, and data needs, it may be more appropriate to classify the vegetation to VSS before quantifying the metrics (see Graham and others, (2007) for methods of classifying VSS). Typical stand exam data is collected at the plot scale and subsequently summarized to the stand. This homogenizes sub-stand structural variability such as VSS distributions and tree group characteristics, etc. A stand-level summary is adequate for one and two-storied stands that will be treated to initiate conversion to future uneven-aged structure, but is inadequate for stands currently composed of three or more VSS classes. One method for analysis of uneven-aged forest sub-stand characteristics is to classify and summarize each sample plot independently. In this way, all uneven-aged stands in the project area can be combined into a stratum and individual plots within a stratum can then be compiled to generate stratum statistics. This method may not perfectly determine VSS distribution but it does provide a sub-stand summary of forest characteristics sufficient for planning and prescription development. The use of fixed-area rather than variable-area sample plots will also provide a better representation of local structural characteristics. In addition, stand maps could be obtained for a few of these fixed area plots and displayed using both FVS and SVS, an excellent communication tool. Other inventory methods such as transects can also provide an overall summary of VSS distribution [see Graham and others (2007) for methods for quantifying and displaying VSS distributions].

The Southwestern Region has developed a methodology for project planning analysis. An analysis area is stratified according to previously-described criteria: forest types by structure/condition (e.g. even-aged/two-aged, uneven-aged, unsustainable stands) are classified and grouped into separate stratum. Standard stand-level summaries are computed to determine current condition for the even-aged/two-aged and unsustainable stands and summarized by stratum. The following process is used to develop current

VSS 5	Uneven Aged Foraging Area			
		Variation		
	Average	Minimum	Maximum	Range
Canopy Cover	51	15	82	67
Mech Volume - Board Feet	11370	1777	50064	48287
Mech Volume - Cubic Feet	2255	365	9548	9183
Trees per Acre	655	20	9733	9713
Basal Area	93	15	334	319
SDI	189	40	600	559

Species Composition (percentage) by Basal Area	
PP	95.38
DF	1.06
WF	0.00
WP	0.00
BS	0.00
ES	0.00
CB	0.00
WS	0.00
LM	0.00
OA	0.56
OH	0.61
CO	0.00
PI	0.91
RM	0.00
BC	0.00
PE	0.00
JU	1.19
AS	0.29
	100.00

Figure 7. Plot by Plot Spreadsheet VSS Classification Statistics, Example

condition statistics for uneven-aged stratum (USDA Forest Service. 2007b):

- Stands are sorted and grouped by goshawk habitat management emphasis (PFA, FA or nest), and each grouping of stands is then aggregated into separate stratum for analysis.
- The exam plot data for each stand are assigned to their respective stratum, and disassociated with individual stands.
- Data for each plot is expanded to a unit area basis, and grown to a common analysis year through the FVS model. Plots comprising a specific stratum are then batch run through FVS. FVS will summarize VSS classification, normal standard summary statistics and computed values for each plot independently.
- FVS individual plot summaries are exported to the PLOT_BY_PLOT excel workbook. Macros in this workbook are used to combine plots by VSS class and display summary statistics for each VSS class. Examples of these summaries are shown in Figures 6 and 7.

Target Stand Conditions

Figure 3 shows the six structural stages and their target distribution for sustaining goshawk habitat, or for that matter sustaining any vegetative community (Odum 1971).

Understanding canopy cover and how it is measured is required for developing the desired goshawk habitat. Moreover, canopy cover recommendations vary depending on goshawk home range components (i.e., nest area, PFA, FA). Canopy cover is defined in MRNG as: "the percentage of a fixed area covered by the crowns of plants delimited by a vertical projection of the outermost perimeter of the spread of the foliage" and is determined at the group or clump level for VSS 4 thru 6 (mid-aged through old forest).

The group and clump nature, especially of native ponderosa pine forests in the Southwest, not only encompasses the area occupied by tree boles and canopies but it also includes areas extending beyond tree crowns that are often occupied by tree roots (Pearson 1950). These areas (primary rooting zones) between tree clumps are free of trees and are occupied by roots of trees within the clump/group. These areas not only provide a rooting zone, they also provide growing space for crown expansion, needle development and other factors that allow trees within groups to develop while the desired relatively high canopy cover within the group is maintained (Figure 8). Therefore, a highly heterogeneous stand containing the entire suite

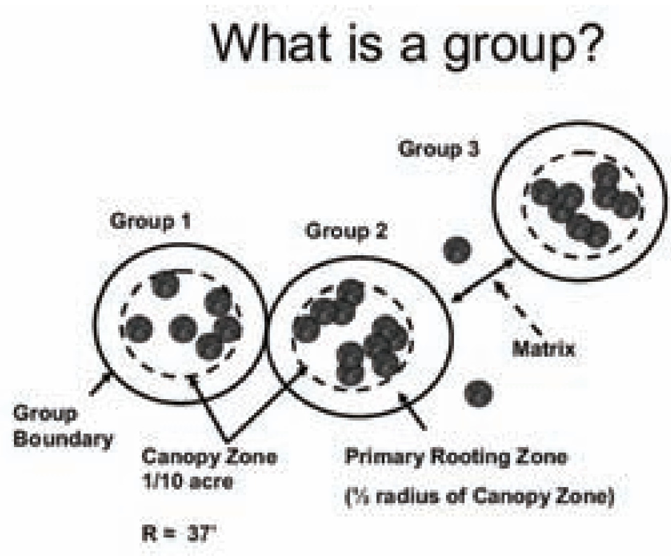


Figure 8. Groups and Group Spacing

of VSS (grass/forb/shrub through old forest) and the open areas occupied by tree roots would be at full site occupancy even though timber management metrics (e.g., stand density index, trees per unit area, basal area) may not indicate these conditions. In addition, by separating the crowns between tree groups and creating and maintaining highly variable forest structures with multiple tree juxtapositions, these conditions reflect the historic conditions and reduce crown fire potential as measured by crowning and torching index. Additional desired conditions include a scattering of large reserve trees (7.4-12.3 per ha ≈ 3- 5 per acre), large snags (4.9 per ha ≈ 2 per acre), large logs (7.4 per ha ≈ 3 per acre), and woody debris (2.2-3.1 Mg per ha ≈ 1965 to 2947 pounds/acre) through the landscape. The forest floor should retain a reasonable amount of down woody debris the amount of which should be commensurate with local site historic conditions and provide for the ability to restore frequent surface fires for ecosystem maintenance.

Prescription Targets

Various threshold target densities for structural groups are recommended in the MRNG for differing forest types and goshawk home range components. Based upon these recommendations, targets have been developed for goshawk PFA and FA for ponderosa pine and mixed conifer forest types. Determination of target canopy cover thresholds during field implementation has been problematic due to various methods used to measure canopy cover and natural variability of forest characteristics. There have also been misunderstandings of the recommended means for measuring canopy cover. Therefore target stocking levels for project implementation have been developed by using the FVS canopy cover model. With this model, stocking levels were developed based on canopy cover and translated to measurable variables such as trees per unit area and basal area (BA) and by VSS class (Tables 1-4). Growth modeling to develop target stocking levels was conducted using the following assumptions:

- The MRNG target canopy cover thresholds for VSS 4-5-6 would be achieved and maintained.
- Target stocking levels for VSS 1-2-3 were developed to provide necessary stocking levels of younger tree age classes to achieve future mid-aged to old tree target size classes/densities.
- Differing site indices were examined for ponderosa pine and dry mixed conifer forest types. No significant stand developmental differences were noted based upon an average site index range, so stocking targets were developed by forest type and goshawk home range component (PFA and FA). (Stocking levels may need to be adjusted for very dry or otherwise poor site locations.)
- Structure and density is maintained by mechanical treatments on a 20-year cycle, and prescribed fire on a 10-20 year cycle.

Projections based on the stand modeling process determined that threshold canopy cover densities could not be achieved nor maintained as a whole stand condition. Therefore, it is recommended that group size be limited to less than 0.2 ha (0.5 acre) on average to sustain the desired canopy cover levels. Primary rooting zones provided growing space necessary to develop and sustain the desired canopy cover within tree groups. Full-stocking level targets were developed with these concepts in mind and are a starting basis for project planning. In the context of MRNG, full-stocking levels are defined as the condition where the forest is patterned as shown in Figure 9. Note that full-stocking in this context is not equivalent to full-stocking as defined by traditional density measurements such as stand density index (SDI).

Many current Southwestern Region projects are focused on RHRC, since there has been a tremendous increase in the number of trees per unit area since the late 1800's. Historic reference conditions are generally less than the full-stocking level MRNG targets for average growing site conditions. On forest sites of above-average growth potential, the historic condition may be greater than the full-stocking level MRNG targets. Sometimes hazardous fuels reduction project objectives cannot be achieved at the full-stocking level. However, the broad objectives of the MRNG can be met at a wide range of forest densities; overall stand density can be reduced or slightly increased from the full-stocking level, while adhering to MRNG sustainability principles. During project implementation, canopy zone separation of tree groups may be adjusted from full-stocking, as long as forest structural sustainability and group canopy cover guidelines are met. If the desired conditions can not be met, a site specific Forest Plan amendment must be prepared. However in most cases, conditions suitable for both MRNG and project objectives can be met by creation of additional inter-group space (matrix) between rooting zones to achieve a desired average distance between tree canopy zones in adjacent groups (Figure 10). This inter-group space can be described as an additional open area composed of few or no trees. It may be desirable to retain a low density scattering of individual trees throughout this area, both to provide for natural forest patterns, and to provide for long-term development of other structural components (i.e., large/old reserve trees). To facilitate prescription development, a spreadsheet tool has been developed to calculate stand metrics at variable spacing distances between tree group canopy zones (USDA Forest Service, Southwestern Region, 2006). Figure 11 displays the spreadsheet summary data for a ponderosa pine forest type PFA at the full-stocking (100%) level. In this example, the spacing between canopy zones is 37.1 feet (11.3 meters) and the average acre mean target density is 69 square feet basal area (2.6 square meters/hectare). Figure 12 shows the summary data for an adjusted target condition with spacing between canopy zones of 55.5 feet (16.9 meters). In this example, the adjusted average acre mean density target is 51 square feet basal area (1.9 square meters/hect-are), representing a resulting stocking density of 74% of

Figure 9. Full-Stocking (Illustration)

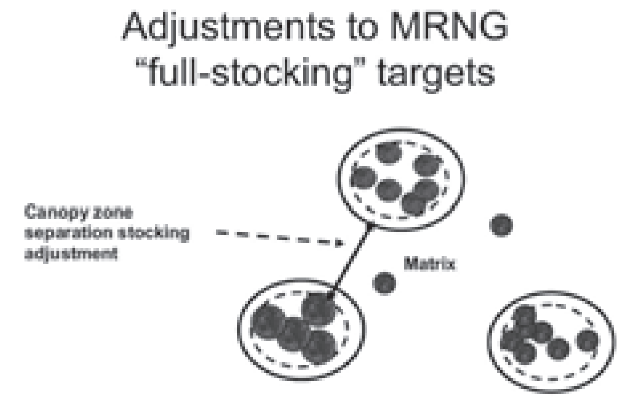


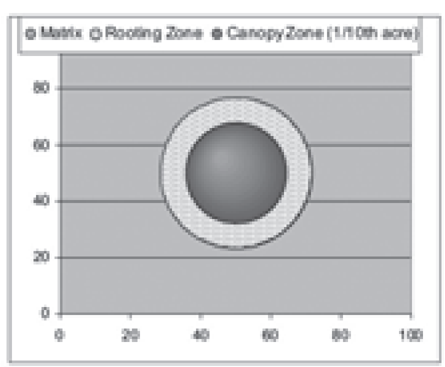
Figure 10. Groups and Stand Density Adjustments from Full-Stocking (Illustration)

MRNG "full-stocking" (PP PFA)

VSS Class	Per acre basis mean (average acre) tpa	BA/Ac
1	20.3	0
2	19.3	1
3	27.3	11
4	4.8	6
4	9.0	11
5	7.7	19
6	5.5	22
	93.9	69

Dq* = 13.11
SDI* = 113.7

*includes trees >= 1" dbh only.



Functional Area	Radial Spacing	Radial Factor
Canopy Zone (1/10th acre)	37.2	1.00
Canopy + Rooting Zone	55.8	1.50
Matrix	0	0
Canopy Zone Separation Distance		37.1
Stocking Multiplier		100%

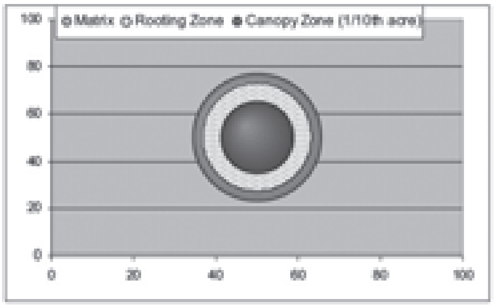
Figure 11. Full-Stocking– ponderosa pine PFA (Spreadsheet Summary)

MRNG Adjusted Stocking (PP PFA)

VSS Class	Per acre basis mean (average acre) tpa	BA/Ac
1	14.9	0
2	14.3	1
3	20.1	8
4	3.5	4
4	6.6	8
5	5.7	14
6	4.0	16
	69.2	51

Dq* = 13.11
SDI* = 83.8

*Includes trees >= 1" dbh only.



Functional Area	Radial Spacing	Radial Factor
Canopy Zone (1/10th acre)	37.2	1.00
Canopy + Rooting Zone	55.8	1.50
Canopy + Rooting Zone + Matrix	65.0	1.75
Canopy Zone Separation Distance		55.5
Stocking Multiplier		74%

Figure 12. Groups and Stand Density Adjustments from Full-Stocking (Spreadsheet Summary)

full stocking. Use of this spreadsheet tool facilitates rapid analysis of target stand conditions for project planning. The leave stand characteristics displayed by the spreadsheet can then accompany the marking guide templates to provide implementation instructions to field layout crews.

IMPLEMENTATION

Project Layout

Surveys for goshawks are made within the management analysis area prior to management activities, including an area 0.8 km (0.5 mile) area beyond the boundary. Survey requirements are spelled out in the MRNG. These surveys will help identify nest areas, PFAs, and foraging areas and a requisite spacing of territories across the landscape (3.2 to 4 km ≈ 2 to 2.5 mile). Goshawk Territories are made up of the following components (Figures 1-2):

1) PFA (168 ha ≈ 420 acres total), including 6 nest areas, each 12 ha (≈ 30 acres) in size; 72 ha (≈ 180 acres) minimum of nest areas should be identified within each PFA (six nest sites - three nests are suitable and three are replacements).
2) One Foraging Area = 2,160 ha (≈ 5,400 acres) surrounding the PFA.
3) Total Home Range Size = about 2,400 ha (≈ 6,000 acres).

In summary, planning and management of goshawk territories entails the map delineation of 6 nesting areas (3 potential, 3 replacements), a post-fledgling family areas that encompasses the six nesting areas, all surrounded by the foraging area. A territory with these components is established where there are known nest sites, old nest sites, areas where historical data indicates goshawks have nested in the past, and where goshawks have been repeatedly sighted over a 2-year period. When possible, all historical nest areas should be maintained. Human activity should be limited in nesting areas and PFAs during the breeding season (March 1 through September 30). The remainder of the 2,400 ha (6000 acre) management territory consists shall be managed as foraging areas, according to applicable guidelines

Tree Designation

This management strategy focuses on attainment and monitoring of residual forest characteristics. For these reasons, implementation of project prescriptions would be difficult or impossible without designation by leave tree marking.

General Guides for Marking Even-aged and Two-aged Stands

Stands with these structures cannot be regulated with uneven-aged management systems during initial treatment entries. The following guidelines outline a process for converting these types of stands to uneven-aged structures within the context of MRNG desired conditions.

Initial steps toward conversion to an uneven-aged forest structure:

1. Where some age class diversity is present, leave as many under represented VSS trees, in small groups, as possible.
2. Create openings for VSS 1 age class recruitment (including the primary rooting zones) on approximately 15-20% of project/stand area. Do this by removing entire groups of trees from the predominant age class, but only in those areas with trees of sufficient maturity and vigor to provide adequate seed for

natural regeneration. Diseased (e.g., mistletoe) and damaged trees may be targeted for regeneration, but because these trees are often important elements in forest ecosystems, some may be retained. It is recommended that diseased trees not be retained as seed trees for new VSS 1 groups. Diseased trees can be retained within larger VSS tree groups with other trees of similar height. Diseased trees can also be isolated from younger trees when the desired distances between tree groups is attained. Follow MRNG regarding tree group sizes, opening sizes, reserve trees, downed logs, woody debris, etc.

3. Thin trees to initiate development of greater forest diversity, to create desired forest structural characteristics, and as necessary to meet project-level resource objectives.
   a) Begin to create group structure, including both the canopy and primary rooting zone portions of the group. Initial creation of groups could be referred to as creating doughnuts. The doughnut is the primary rooting zone and the doughnut hole is the canopy zone that is left. These groups should generally be sized from 0.04 to 0.13 ha (≈ 0.1 to 0.3 acre) of various shapes. Once trees within identified primary rooting zones (and the inter-group matrix, if necessary) are removed, thinning of retained groups may be required to grow young trees (VSS 2 and 3) into large trees more rapidly.
   b) Thin VSS 2 and 3 groups to variable densities to accelerate their growth. However, thin VSS 2 and 3 commensurate with attaining the desired interlocking crowns when these tree groups grow into VSS 4-6.
   c) For high-density mid-aged groups that have not been previously thinned, only thin groups to the extent necessary to sustain group maintenance and development, taking care to maintain required canopy cover density. Do not thin VSS 6 groups, except to remove smaller young trees that pose a threat to sustainability of the mature tree group. Do not thin groups such that the structural attributes are altered. Suppressed and damaged trees that have developed with the group are important habitat elements for wildlife species. Squirrels, for example use overtopped trees for nesting. Only thin groups to the extent necessary to maintain desired current and future species composition, sustainability and development.
   d) Areas lacking adequate seed bearing trees will be difficult or impossible to regenerate naturally during an initial management entry. In this situation, accelerating tree growth to larger VSS classes is the primary management objective. Thinning should be prescribed to develop trees within groups that have full live crowns for viable cone production.
4. Create a matrix between tree groups (groups = canopy and primary rooting zones) if less than full stocking is desired, based upon project-level objectives. Maintain matrix (beyond rooting zones) with few or no trees. A matrix is designed to provide for additional spacing between high density canopy zones, beyond that provided by the primary rooting zones.

General Guides for Marking Uneven-aged Stands

Some project areas and ecosystem management areas presently have a mix of VSS classes. These areas can be managed to further develop and maintain desired VSS class diversity. Inventory data at the landscape level is desired to ensure the VSS distribution proportions and juxtapositions are known so the desired structural proportions on the landscape can be developed. By having a landscape view, prescriptions can be developed to ensure the landscape desired condition is planned for and being developed. In order to maintain desired structural proportions on the landscape, it's important to balance structural distribution at the local (stand scale) within larger landscapes. Some local areas could be managed to temporarily provide a disproportionately large percentage of a structural stage that is otherwise limited or lacking in the larger landscape. Any VSS in surplus of the desired percentage may be regenerated to create a future balance of VSS classes. Marking guide templates have been prepared for use as samples for different forest cover types and goshawk habitats in uneven-aged forest conditions, based upon full stocking density targets (USDA Forest Service, 2006b). As previously discussed, stocking levels can be adjusted to meet various management objectives and provide prescription parameters for residual stand desired conditions. A marker's tally form spreadsheet has been developed as a guide to measure attainment of desired structures during marking. Each marker tallies leave tree groups by VSS and group size (1/10 acre basis) during the marking process. This tool summarizes post-marking conditions to provide information on how many acres of each VSS class are being retained as well as the residual percentage of each VSS class over the entire

Marker's Talley Form Spreadsheet Summary

VSS Class	Group Equivalent Acres	Individual Tree Equivalent Acres	Total Equivalent Acres	Percent of Area by VSS Class
VSS 1	5	0	5	4
VSS 2	9	0	9	7
VSS 3	35	3	38	27
VSS 4	58	0	58	41
VSS 5	24	2	26	18
VSS 6	4	2	6	4
Total Acres	134	7	141	100

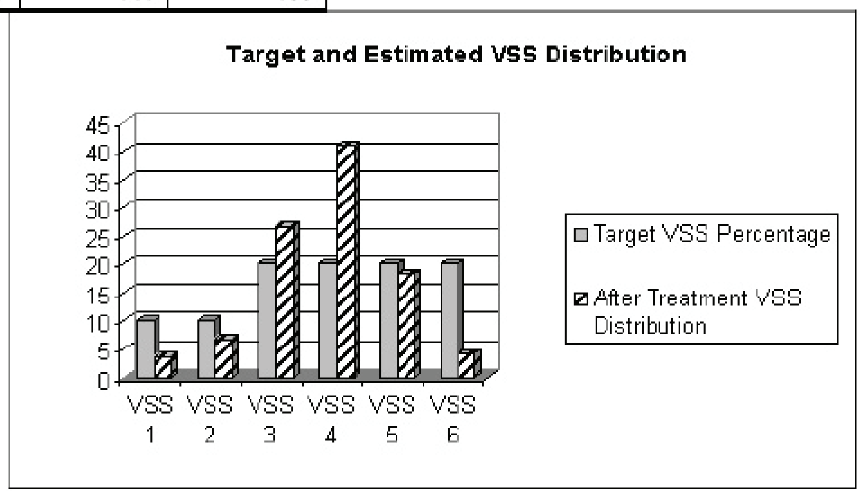


Figure 13. Marker's Tally Form Summary

project area (USDA Forest Service, 2006c) (Figure 13). As such, this tool can be used for both quality control and as monitoring documentation.

CONCLUSION

The goal of silviculture is to develop vegetation management strategies to meet desired conditions (silvicultural systems- a planned series of treatments through the life of a forest) and to document them in silvicultural prescriptions to meet management objectives. The Southwestern Region is committed to restore the historic resilience and function of fire adapted (ponderosa pine and dry mixed conifer) forests and is committed to develop and maintain habitat for both the Mexican spotted owl and the northern goshawk through a Regional Amendment of Forest Plans. Management recommendations for the northern goshawk, ecological restoration research, ponderosa pine management information, and fire hazard and fuel treatment information are only a partial list of science that can be used to inform the management actions (silvicultural treatments) in the Southwestern Region (Reynolds and others 1992, Covington and Moore 1994, Pearson 1950, White 1985). Through this effort we have been able to establish a strong link between restoring historic conditions and implementing the MRNG. However, this information in most circumstances is inadequate for planning and executing on-the-ground activities. Therefore the Southwestern Region developed tools that could help planners, silviculturists, fuels specialists, and others involved with designing and implementing treatments directed at restoring fire adapted forests of the Southwest. These tools and the MRNG both provide a template, a process, and approach that are adaptable to a wide variety of forests and a wide variety of management objectives. We do not postulate that the exact metrics in the MRNG or those presented in spreadsheet tools are precisely applicable to other locales. However, we argue the tools and procedures have sufficient flexibility to allow project planners to incorporate other objectives.

LITERATURE CITED

Baker, F. S. 1934. The principles of silviculture. New York: McGraw-Hill. 502 p.

Boal, C. W., and R. W. Mannan 1994. Northern goshawk diets in ponderosa pine forests on the Kaibab Plateau. Studies in Avian Biology 16: 97-102.

Boyce, Douglas A. Jr.; Reynolds, Richard T.; Graham, Russell T. 2006. Goshawk status and management: What do we know, what have we done, where are we going. In: Morrison, Michael. Ed. The northern goshawk: a technical assessment of its status, ecology and management. Cooper Ornithological Society. 312-325.

Cooper, C. E. 1961. Patterns in ponderosa forests. Ecology 42: 493-499.

Covington, W. W., and M. M. Moore 1994. Postsettlement changes in natural fire regimes and forest structure: Ecological restoration of old-growth ponderosa pine forests. Pp. 152-181 in Sampson, R. N., Adams, D. L., eds. Assessing forest ecosystem health in the inland west. New York, The Haworth Press, Inc.

Covington, W. W., P. Z. Fulé, M. M. Moore, S. C. Hart, T. E. Kolb, J. N. Mast, S. S. Sackett, and M. R. Wagner 1997. Restoration of ecosystem health in southwestern ponderosa pine forests. Journal of Forestry 95(4):23-29.

Crocker-Bedford, D. C. 1990. Goshawk reproduction and forest management. Wildlife Society Bulletin 18: 262-269.

Dixon, Gary E. 2002. Essential FVS: a user's guide to the Forest Vegetation Simulator. Internal Report. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Forest Management Service Center. 189 p.

Forsgren, Harv. November 20, 2006. Unpublished Document. Policy transmittal letter. USDA Forest Service, Southwestern Region, Albuquerque, NM.

Franklin, Jerry F.; Spies, Thomas A.; Van Pelt, Robert; Carey, Andrew B.; Thornburgh, Dale A.; Rae Berg, Dean; Lindenmayer, David B.; Harmon, Mark E.; Keeton, William S.; Shaw, David C.; Bible, Ken; Jiquan, Chen. 2002. Disturbances and structural development of natural forest ecosystems with silvicultural implications, using Douglas-fir forests as an example. Forest Ecology and Management 155: 399-423.

Fulé, O. Z., W. W. Covington, M. M. Moore. 1997. Determining reference conditions for ecosystem management of southwestern ponderosa pine forests. Ecological Applications 7: 895-908.

Graham, Russell T.; Jain, Theresa B. 2004. Past, Present and Future Role of Silviculture in Forest Management. In: Shepperd, Wayne D.; Eskew, Lane G., compilers. Silviculture in special places: proceedings of the National Silviculture Workshop. 2003 September 8-11; Granby, CO. Proceedings. RMRS-P-34. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 1-14.

Graham, Russell T.; Jain, Theresa B.; Sandquist, Johnathan 2007. Free selection: a silvicultural option. In: Powers, Robert. Ed. Restoring fire -adapted forested ecosystems. 2005 National Silviculture workshop. June 6-10, 2005, Lake Tahoe, CA. Gen. Tech. Rep. PSW-GTR-203. Albany, CA: U. S. Department of Agriculture, Forest Service, Pacific Southwest Research Station . 121-156.

Greenwald, D. N.; Crocker-Bedford, D. C.; Broberg, L.; Suckling, K. F.; Tibbitts, T. 2005. A review of northern goshawk habitat selection in the home range and implications for forest management in the western United States. Wildlife Society Bulletin 33: 120-129.

Higgins, B. J. 2003. Implementation and interpretations of management recommendations for the northern goshawk. USDA Forest Service, Kaibab National Forest, Williams, AZ. 16p.

Long, J. N., and F. W. Smith. 2000. Restructuring the forest: goshawks and restoration of southwestern ponderosa pine. Journal of Forestry 98: 25-30.

Marquis, D. A. 1978. Application of uneven-aged silviculture and management on public and private lands. Uneven-aged silviculture & management in the United States. Gen. Tech. Rep. WO-24. Washington, DC: U.S. Department of Agriculture, Forest Service, Timber Management. 25-61.

Meyer, H. A. 1943. Management without rotation. Journal of Forestry 41: 126-132.

Meyer, H. A.; Recknagel, A. B.; Stevenson, D. D.; Bartoo, R. A. 1961. Forest Management. New York, NY: The Ronald Press Co. 282

Meyer, Walter H. 1934. Growth in selectively cut ponderosa pine forests of the Pacific Northwest. Tech. Bulletin 407. U.S. Department of Agriculture, Washington, DC. 64 p.

Moore, K. R., and C. J. Henny 1983. Nest site characteristics of three coexisting accipiter hawks in northeastern Oregon. Journal Raptor Research 17:65-76.

Moore, Margaret M.; Covington, W. Wallace; Fulé, Peter Z. 1999. Reference conditions and ecological restoration: a southwestern ponderosa pine perspective. Ecological Applications 9(4): 1266-1277.

Odum, Eugene P. 1971. Fundamentals of ecology. Saunders, Philadelphia, PA. 555 p.

Oliver, C. D.; Larson, B. C. 1990. Forest stand dynamics. New York: McGraw-Hill Inc. 467 p.

Pearson, G. A. 1950. Management of ponderosa pine in the southwest. USDA Forest Service Agricultural Monograph No. 6.

Reynolds, R. T. 1971. Nest site selection of the three species of Accipiter hawks in Oregon. In: Proceedings Fish and Wildlife Habitat Management Training Conference (pp. 51-53). USDA Forest Service, Eugene, OR.

Reynolds, R. T., R. T. Graham, M. H. Reiser, R. L. Bassett, P. L. Kennedy, D. A. Boyce, G. Goodwin, R. Smith, and E. L. Fisher 1992. Management recommendations for the Northern Goshawk in the Southwestern United States. General Technical Report RM-217, 90 pp. USDA Forest Service, Rocky Mountain Forest and Range Experiment Station, Fort Collins, CO, USA.

Reynolds, R. T., W. M. Block, and D. A. Boyce, Jr. 1996. Using ecological relationships of wildlife as templates for restoring southwestern forests. Pp. 35-43 in Covington, W. and P.K. Wagner (tech coord.), Conference of Adaptive Ecosystem Restoration and Management: Restoration of Cordilleran Conifer Landscapes of North America. Gen. Tech. Rep. RM-GTR-278. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station.

Reynolds, R. T., J. D. Wiens, S. M. Joy, and S. R. Salafsky 2005. Sampling considerations for demographic and habitat studies of northern goshawks. Journal of Raptor Research 39: 274-285.

Reynolds, R. T., and S. M. Joy. 2006. Demography of northern goshawks in northern Arizona, 1991-1996. Studies in Avian Biology 31: 63-74.

Reynolds, R. T., R. T. Graham, and D. A. Boyce, Jr 2006. An ecosystem-based conservation strategy for the northern goshawk. Studies in Avian Biology 31: 299-311.

Schlich, W. 1906. Manual of forestry, Volume II. Silviculture. Bradbury, Agnew & Co, London. 393 pp.

Squires, J. R.; Reynolds, R. T. 1997. Northern Goshawk (Accipiter gentilis). In: Poole, A.; Gill, F. Editors. The Birds of North America. Philadelphia, PA, and Washington, DC: The Academy of Natural Sciences and The American Ornithologists' Union.

Thomas, J. W.; Miller, R. J.; Maser, C.; Anderson, R. G.; Carter, B. E. 1979. Plant communities and successional stages. In: Thomas, J. W., ed. Wildlife habitats in managed forests, the Blue Mountains of Oregon and Washington. Agriculture Handbook 553. Washington, DC: U.S. Department of Agriculture, Forest Service. 22-39.

USDA Forest Service 1996. Record of Decision for Amendment of Forest Plans for Arizona

USDA Forest Service 2004. Strategic Action Plan for Restoring the Functionality of Fire-Adapted Systems. USDA Forest Service, Southwestern Region, Albuquerque, NM.

USDA Forest Service 2006. Unpublished Document. Goshawk_Guidelines_Targets.xls. USDA Forest Service, Southwestern Region, Albuquerque, NM. Intranet: http://fsweb.r3.fs.fed.us/for/silviculture/tools.htm

USDA Forest Service 2006b. Unpublished Document. NGH_FA_PP_markguide template.doc, NGH_PFA_PP_markguide template.doc, NGH_FA_MC_markguide template.doc, NGH_PFA_MC_markguide template.doc. USDA Forest Service, Southwestern Region, Albuquerque, NM. Intranet: http://fsweb.r3.fs.fed.us/for/silviculture/tools.htm

USDA Forest Service 2006c. Unpublished Document. Goshawk_marking_talley_form.xls. USDA Forest Service, Southwestern Region, Albuquerque, NM. Intranet: http://fsweb.r3.fs.fed.us/for/silviculture/tools.htm

USDA Forest Service 2007. Unpublished Document. Northern Goshawk Standards and Guidelines, Implementation Guide. USDA Forest Service, Southwestern Region, Albuquerque, NM.

USDA Forest Service 2007b. Unpublished Document. PLOT_BY_PLOT.xls. Forest Vegetation Analysis for Project Planning for Implementation of the Management Recommendations for Northern Goshawk. USDA Forest Service, Southwestern Region, Albuquerque, NM. Intranet: http://fsweb.r3.fs.fed.us/for/silviculture/tools.htm.

White, Alan S. 1985. Presettlement Regeneration Patterns in a Southwestern Ponderosa Pine Stand. Northern Arizona University. Ecology Vol. 66(2).

Assessing the Ecological Benefits and Opportunity Costs of Alternative Stream Management Zone Widths for Eastern Hardwoods

Chris B. LeDoux and Ethel Wilkerson

ABSTRACT

Leaving buffer zones adjacent to waterways can effectively reduce the water quality concerns associated with timber harvesting. However, riparian areas are also some of the most productive sites and can yield high quality wood. The amount of unharvested timber left in SMZs (Streamside Management Zones) can represent a substantial opportunity cost to landowners. In this study we used computer simulation to integrate contemporary scientific data among disciplines to develop opportunity cost and ecological function protection tradeoffs that result from the implementation of alternative SMZ widths. We quantified the opportunity costs and ecological benefits of using different buffer zone widths. We used the principles of benefit/cost analysis to compare the results. Results suggest that benefit/cost ratios range from 5.89 to 1.49 depending on the buffer zone width, the species composition of the stand, and the logging technology used to harvest the timber. A literature review was used to score the ability of different buffers to protect riparian functions. Results show that to fully protect the riparian functions modeled, 45 meter buffers are needed. The study results should be of high interest to landowners, managers, loggers, land use planners, and other decision and policy makers who need to understand the opportunity costs and ecological benefits associated with implementing different widths of streamside management zones.

Keywords: ecological functions; capital recovery costs; simulation; optimization; riparian zones; benefit/cost ratio

This paper was published in: Deal, R.L., tech. ed. 2008. Integrated restoration of forested ecosystems to achieve multiresource benefits: proceedings of the 2007 national silviculture workshop. Gen. Tech. Rep. PNW-GTR-733. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 306 p.

Chris B. LeDoux is a supervisory industrial engineer, U.S. Department of Agriculture, Forest Service, Northern Research Station, 180 Canfield Street, Morgantown, WV 26505; **Ethel Wilkerson** is the headwaters stream project manager, Manomet Center for Conservation Sciences, 14 Maine Street, Brunswick, ME 04011.

INTRODUCTION

Streams, wetlands, and riparian areas are among our most valuable natural assets. From an ecological perspective, riparian zones are among the most productive wildlife habitats on the continent (Bisson and others 1987, Kentucky Department of Fish and Wildlife Resources 1990). In addition, riparian areas protect water quality and aquatic communities by reducing the amount of sediment entering the stream channel (Castelle and Johnson 2000), shading the stream channel from solar radiation (Brown and Krygier 1967), supplying organic material for food (Allan 1995), and contributing woody material that increases the hydraulic and structural complexity of the stream channel (Bisson and others 1987, Hilderbrand and others 1997). Removal of streamside vegetation during logging operations has been shown to increase the sediment load in the stream (Davies and Nelson 1994), increase water temperature (Brown and Krygier 1967), and change the food supply and condition of the habitat, altering the aquatic and riparian communities (Hawkins and others 1982, Hanowski and others 2002). Leaving buffer strips adjacent to waterways can effectively reduce the water quality concerns associated with timber harvesting.

Because of their ecological importance, the protection of riparian areas is a top priority for most state and federal conservation agencies (Blinn and others 2001). This goal is usually achieved by establishing streamside management zones (SMZs) adjacent to waterways and by adopting best management practices (BMPs), which are guidelines for locating haul roads, skid trails, log landings, and stream crossings. Recommendations for SMZs and BMPs vary among states (Huyler and LeDoux 1995, Shaffer and others 1998, Vasievich and Edgar 1998, Blinn and Kilgore 2001, Williams and others 2004) and are often voluntary. For example, a commonly suggested BMP includes no harvesting activities in 15-45m buffer strips adjacent to the waterway, sometimes with allowances for up to 50 percent removal of the volume of standing trees to leave an evenly spaced stand to protect the riparian function (LeDoux and others 1990, Phillips and others 2000).

Riparian areas also are some of the best sites for producing high quality wood products. The unharvested timber left in SMZs can represent a substantial opportunity cost to landowners (Shaffer and Aust 1993, Kilgore and Blinn 2003, LeDoux 2006). The opportunity costs are influenced by the species mix in the stand, by the logging technology used, the level of riparian protection desired (Peters and LeDoux 1984, LeDoux 2006), the stream network to be protected (Ice and others 2006), and the increasing proportion of isolated SMZ units within a watershed (Olsen and others 1987, University of Washington 1999). Simultaneous economic and environmental assessments have been reported addressing the consequences of alternative fuel management strategies (Mason and others 2003) and the layout and administration of fuel removal projects (Hauck and others 2005). Companion papers address the opportunity costs/capital recovery cost of managing for old growth forest conditions (LeDoux 2004), of alternative patch retention treatments (LeDoux and Whitman 2006), and of implementing streamside management guidelines in Eastern hardwoods (LeDoux 2006, Li et al 2006). In this study, we had two objectives:

1) to evaluate the opportunity costs of different SMZ protection options for two different stand types using four different logging technologies; and
2) to compare the opportunity costs with the ecological benefit of different SMZ widths using the principles of benefit/cost analysis.

The data and results summarized in this paper are borrowed heavily from LeDoux (2006) and LeDoux and Wilkerson (2006).

METHODS

Stand Data

The two 27.5-ha stands selected for this study were similar in age (120 years old), density, average diameter at breast height (d.b.h.), and volume. One stand represents a medium- to low- value species mix comprised predominately of yellow-poplar (***Liriodendron tulipifera*** L.) with some red maple (***Acer rubrum*** L.), black cherry (***Prunus serotina*** Ehrh.), and sycamore (***Plantanus occidentalis*** L.). This stand has 232 trees/ha, an average d.b.h. of 45.6cm, and a merchantable volume of 329m^3/ha. We refer to this stand as yellow-poplar or "YP."

The second stand represents medium- to high-value mixed hardwood species comprised of yellow-poplar, American beech (***Fagus grandifolia*** Ehrh.), shagbark hickory (***Carya ovata*** (Mill.) K. Koch), black cherry, red maple,

Table 1. Logging system configurations and costs used to simulate the harvest of the 27.5 ha tracts.

Logging Technology	Description	Cost/unit Yellow-poplar stand	Cost/unit Mixed hardwood stand
		$/m^3	$/m^3
A	Chainsaw felling with Ecologger I cable yarder	20.83	20.47
B	Timbco 445 Cut-to-length harvester with Valmet forwarder	17.65	17.30
C	Chainsaw felling with John Deere 640 cable skidder	16.24	16.24
D	Timbco 425 feller buncher with Valmet forwarder	15.88	15.88

cucumber tree (*Magnolia acuminata* L.), sugar maple (*Acer saccharum* Marsh.), red oak (*Quercus rubra* L.), white oak (*Quercus alba* L.), and eastern hemlock (*Tsuga canadensis* (L.) Carr.). This stand has 224 trees/ha, an average d.b.h. of 46.4cm, and a merchantable volume of 341m^3/ha. We refer to this stand as mixed hardwood or "MH."

These stands were selected because of their similarities, availability of detailed tree measurements, and a relatively low and high value species mix level. These stands are typical of the eastern hardwood region of the United States. Both stands were subjected via computer simulation to the same even-aged silvicultural treatment, all merchantable timber was harvested.

Logging Systems Evaluated

Computer simulations of four logging systems were used in this study (Table 1). These logging systems were selected because we have robust time and motion study data for each and they represent contemporary methods being used by loggers to harvest eastern hardwood stands. Machine capacities were matched to the size of logs to be removed. Machine configurations are ranked by their per-unit operating cost, with the Ecologger I1 cable yarder being the most expensive and the Timbco 425 feller buncher with the Valmet forwarder being the least expensive. The per-unit operating cost for logging system combinations C and D are very similar, but reflect different on-the-ground operating conditions since logging technology D is mechanized.

Models Used

Two computer software models were used. The first model, ECOST (LeDoux 1985), estimated the stump-to-mill logging costs for the logging technology configurations (Table 1). ECOST is a computer program that can estimate the stump-to-mill costs of cable logging, conventional ground-based skidding, cut-to-length, feller-buncher applications, forwarding, and several small farm tractors for logging eastern hardwoods. Stand data were input into ECOST to develop simulated estimates of the stump-to-mill costs. The cost information within ECOST comes from time studies and simulations conducted over the years. The cost information is part of the model and is updated yearly. All costs are in 2005 U.S. dollars and reflect new equipment.

The second model, MANAGE-PC (LeDoux 1986) computer program, provides the volume yield and volume/product estimates. MANAGE-PC integrates harvesting technology, silvicultural treatments, market prices, and economics in a continuous manner over the life of the stand. The simulation is a combination of discrete and stochastic subroutines. Individual subroutines model harvesting activities, silvicultural treatments, growth and yield projections, market prices, and discounted present net worth (PNW) economic analysis. The model can be used to develop optimal economic management guidelines for eastern hardwoods. Stand data were entered into MANAGE-PC to provide volume/production yield estimates. The

Table 2. Delivered prices for sawlogs and fuelwood/pulpwood by species

Species	Large[a] sawlogs	Medium[b] size sawlogs	Small[c] sawlogs	Fuelwood[d]/ Pulpwood
	Product			
	- - - - - - - - $/m^3	- - - - - - - -	- - - - - - - -	- - - $/cunit - - -
Sugar maple	135	103	58	45
Red maple	106	81	56	45
Sycamore	119	75	53	45
American beech	119	75	53	45
White oak	173	118	58	45
Yellow-poplar	119	75	53	45
Red oak	238	168	95	45
Cucumber tree	119	75	53	45
Shagbark hickory	71	61	56	45
Hemlock	64	64	64	45
Black cherry	119	75	53	45

[a]Minimum small-end diameter ≥ 33.02 cm, length ≥ 3.05 m.

[b]Minimum small-end diameter ≥ 27.44 cm, length ≥ 2.44 m.

[c]Minimum small end diameter ≥ 25.40 cm, length ≥ 2.44 m.

[d]Minimum small-end diameter ≥ 10.16 cm that will not make large, medium, or small sawlogs.

average delivered prices for sawlogs and pulpwood (Table 2) were obtained from forest products price bulletins (Ohio Agriculture Statistics Service 2007, Pennsylvania State University 2007, Tennessee Division of Forestry 2007, West Virginia University Division of Forestry 2007).

SMZ Protection Options

The stands were modeled identically and it was assumed they were bisected by a perennial stream (Fig. 1). Although riparian area cross-sections adjacent to streams can be quite variable, we assumed homogeneity of stand composition and consistent 20-25 percent sideslopes to simplify the simulations. The simulated harvesting plan removed timber from both sides of the stream to landings on truck haul roads located on both sides of the stream under the five SMZ treatment levels. SMZ protection options evaluated include:

1) no protection, harvest all 27.5ha without buffers;
2) unharvested 15m SMZ on both sides of the stream;
3) unharvested 30m SMZ on both sides of the stream;
4) unharvested 45m SMZ on both sides of the stream; and
5) a partially harvested 30m SMZ on both sides of the stream with approximately 50 percent of the timber volume removed from the SMZ.

Although commonly recommended riparian management zone guidelines call for partial volume removal (Blinn and Kilgore 2004), we wanted to evaluate the opportunity costs and ecological benefits for more restrictive treatments, such as options 3 and 4. For the no-protection option, we assumed that the operator could select where haul roads and skid trails would occur with no restrictions on soil distur-

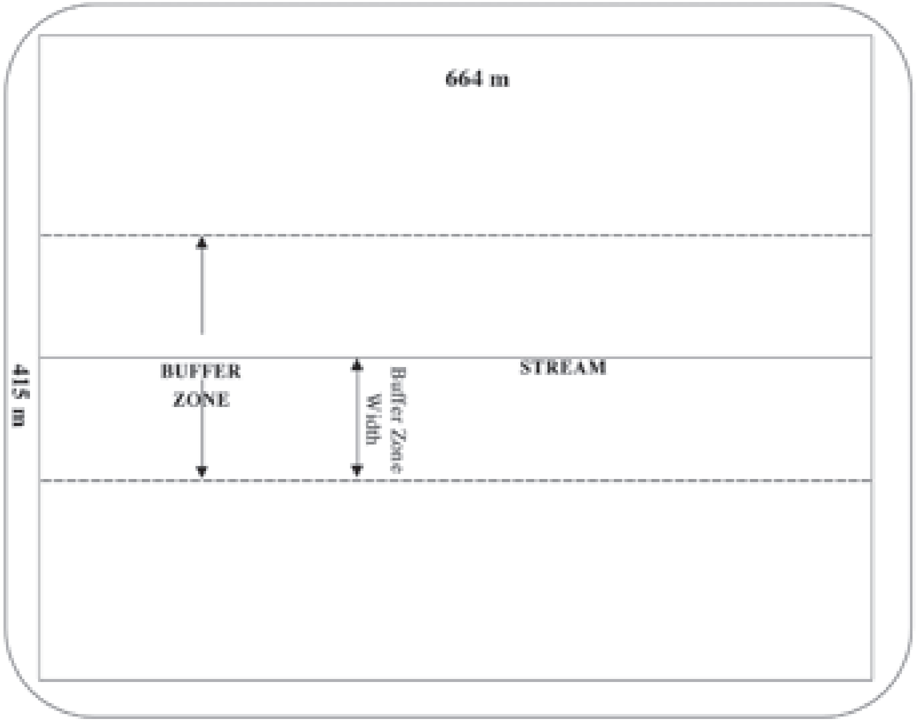


Figure 1— Diagram of modeled harvest area, stream, buffer zone, and buffer zone width.

bance or exposure. For all of the options, we assumed the volume and species mix removed would remain constant as we moved further away from the stream to simplify the simulations.

Riparian Protection Score

The ecological functions of riparian zones are numerous and range from stabilizing near-stream soil (Castelle and Johnson 2000) to providing travel corridors for large terrestrial mammals (Klapproth and Johnson 2000). Quantifying the full range of physical and biological functions that occur within riparian areas would be a daunting task. In this study, we focused on the processes and biota that are easily measurable and strictly dependent on and/or unique to riparian zones. We limited the various functions of the modeled riparian forests to the following five categories:

1) coarse woody debris supply;

2) shade/temperature maintenance;

3) sediment filtering;

4) maintaining aquatic communities (macroinvertebrates and periphyton); and

5) maintaining habitat for riparian-associated passerine birds.

We conducted a literature review to identify studies examining at least one of our five categories of riparian function. Studies with SMZ widths that did not correspond exactly to those used in our economic models were placed in the most logical category, while studies with large discrepancies in SMZ width or experimental design were excluded from this study. We found that few studies examined partial timber removal in SMZs (option 5 in this study) so this treatment was not evaluated for riparian protection. Research on the ecological assessment of SMZs does not exist in adequate quantities from a single region of the United States. To complete the analysis, we tried to focus on literature from the eastern United States, but as data was limited we included studies from other regions. The evaluation of SMZ protection was limited to no SMZ (option 1), and unharvested SMZs with widths of 15m, 30m, and 45m (options 2, 3, 4, respectively).

For each SMZ width (excluding the partial harvest treatment) we assessed the capacity of the SMZ to protect against post-harvest changes for each of the five categories of riparian function based on the following criterion: the SMZ does not protect the component resulting in large post-harvest changes (score = 0); SMZ results in moderate post-harvest changes (score = 1); SMZ results in small post-harvest changes (score = 2); or SMZ protects against measurable changes in the component (score = 3). Scores were determined by comparing the magnitude of change to other studies or other SMZ widths and the statistical significance/non-significance of post-harvest changes. Each SMZ width was given a numerical score (0-3) for each of the five categories of riparian function. An overall score for each SMZ width was calculated by summing the score of each category of riparian function. The overall scores had a minimum value of 0 and a maximum value of 15. The overall score was then converted into a percentage with 0 percent representing no protection of riparian functions

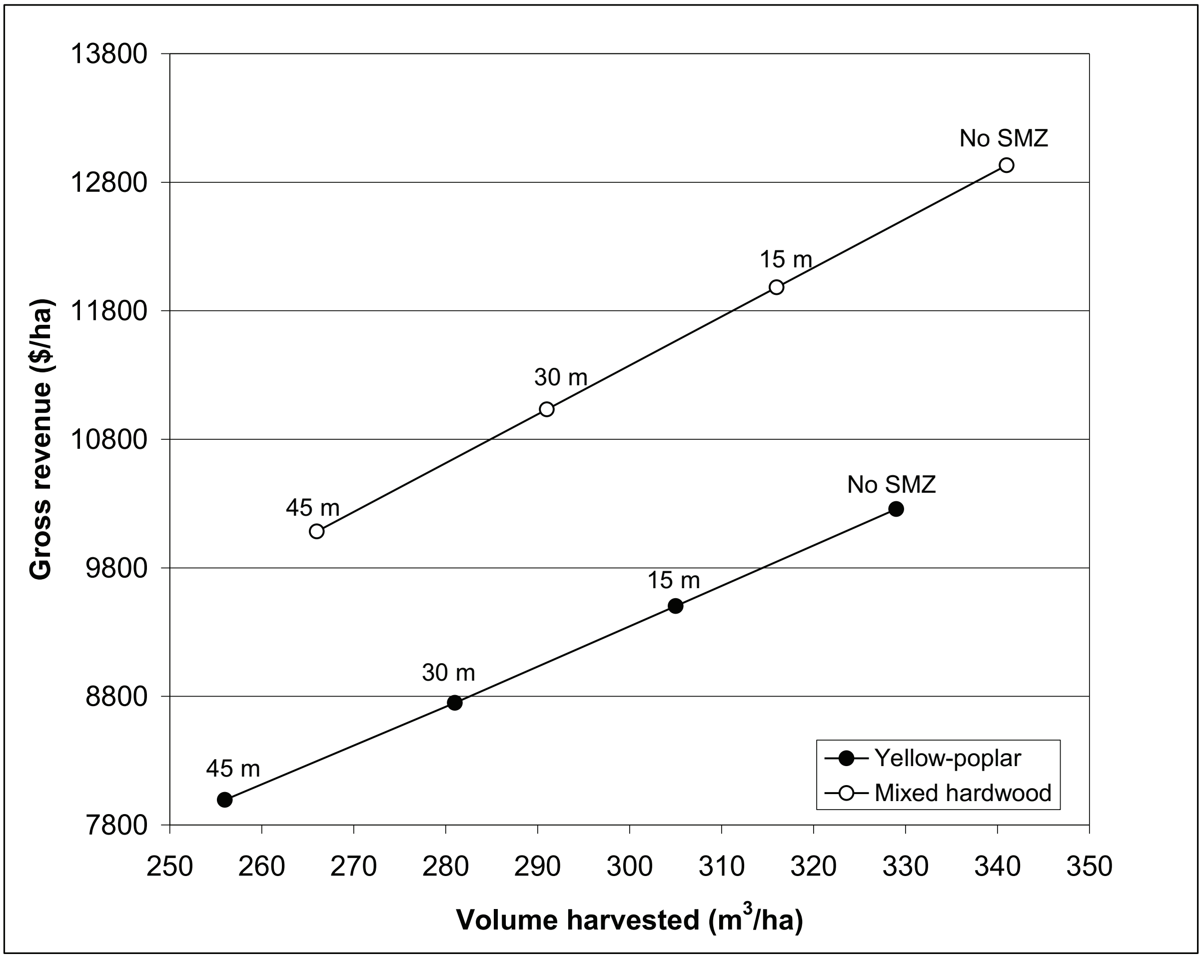


Figure 2— Gross revenue by timber volume harvested from yellow-poplar and mixed hardwood stands.

(value of 0) and 100 percent representing complete protection against measurable changes in riparian functions creating conditions similar to undisturbed riparian areas (value of 15). Each SMZ protection option has a score ranging from 0 to 100 percent and represented the effectiveness of the SMZ in protecting riparian functions. It is hereafter referred to as the SMZ protection score. Although the structure within the SMZ changes over the 120-year rotation, our SMZ protection score described above is based on the immediate condition of the riparian area. The canopy cover may recover quickly even for the completely harvested unit however, large wood recruitment may take much longer where the unit is completely harvested but it may be shortened for the partial harvest options (Zobrist and others 2005). We did not consider changing SMZ protection score over the 120-year rotation because we simply do not have the necessary data.

RESULTS AND DISCUSSION

Gross revenues from timber cutting depended on stand composition and the volume of timber volume harvested. The gross income from the yellow-poplar stand ranged from \$7,995/ha to \$10,257/ha, while the gross revenue of timber from the mixed hardwood stand ranged from \$10,084 to \$12,931/ha (Fig. 2).

Logging costs, which varied with the equipment used, are deducted from the gross revenue of the timber harvest to determine net income. Harvesting costs for yellow-poplar range from \$15.88 to \$20.83/m^3 and from \$15.88 to \$20.47/m^3 for a mixed hardwood stand (Table 1). While logging costs are comparable between the two stands (Fig. 3), they represent a larger percentage of the gross revenue in the yellow-poplar stand because of a greater profit margin for the mixed hardwood stand.

Only the cost of the logging system was considered as a treatment in this study. Cable logging systems may reduce the roads and landings needed to harvest a tract thus reducing the potential for erosion and sediment production. Mechanized track mounted systems, such as the cut-to-length and the feller buncher with forwarder, may result in less soil disturbance and compaction, and thus reduce roading and landing area. In this study we did not address the physical or ecological impacts of alternative systems because we lack the necessary data. Undoubtedly, managers must consider logging system options when making decisions on SMZs.

SMZ Protection Options

Leaving no SMZ generated the most revenue (gross and net) to the landowner (Fig. 4a and 4b) by providing the largest volume of wood (Table 3) and gross revenues of \$10,257 and \$12,931/ha for the low value yellow-poplar stand (Fig. 4a) and high value mixed hardwood stand (Fig. 4b), respectively. The net revenue ranges from \$3,415 to \$5,048/ha for the yellow-poplar stand (Fig. 4a) and \$5,903 to \$7,546/ha for the mixed hardwood stand (Fig. 4b) depending on the logging technology.

Compared to leaving no SMZ, a 15m unharvested buffer on both sides of the stream removed 24m3/ha less wood from the yellow-poplar stand and 25m3/ha from the mixed hardwood stand (Table 3). This scenario grossed \$754/ha less than leaving no SMZ for the yellow-poplar stand (Fig. 4a) and \$949/ha less for the mixed hardwood stand (Fig. 4b). The difference in net revenue can be viewed as the opportunity cost for retaining that width of SMZ. The cost of maintaining 15m SMZ ranges from \$252 to \$370/ha (yellow-poplar stand, Fig. 5a) and \$432 to \$553/ha (mixed hardwood, Fig. 5b), depending on the logging technology.

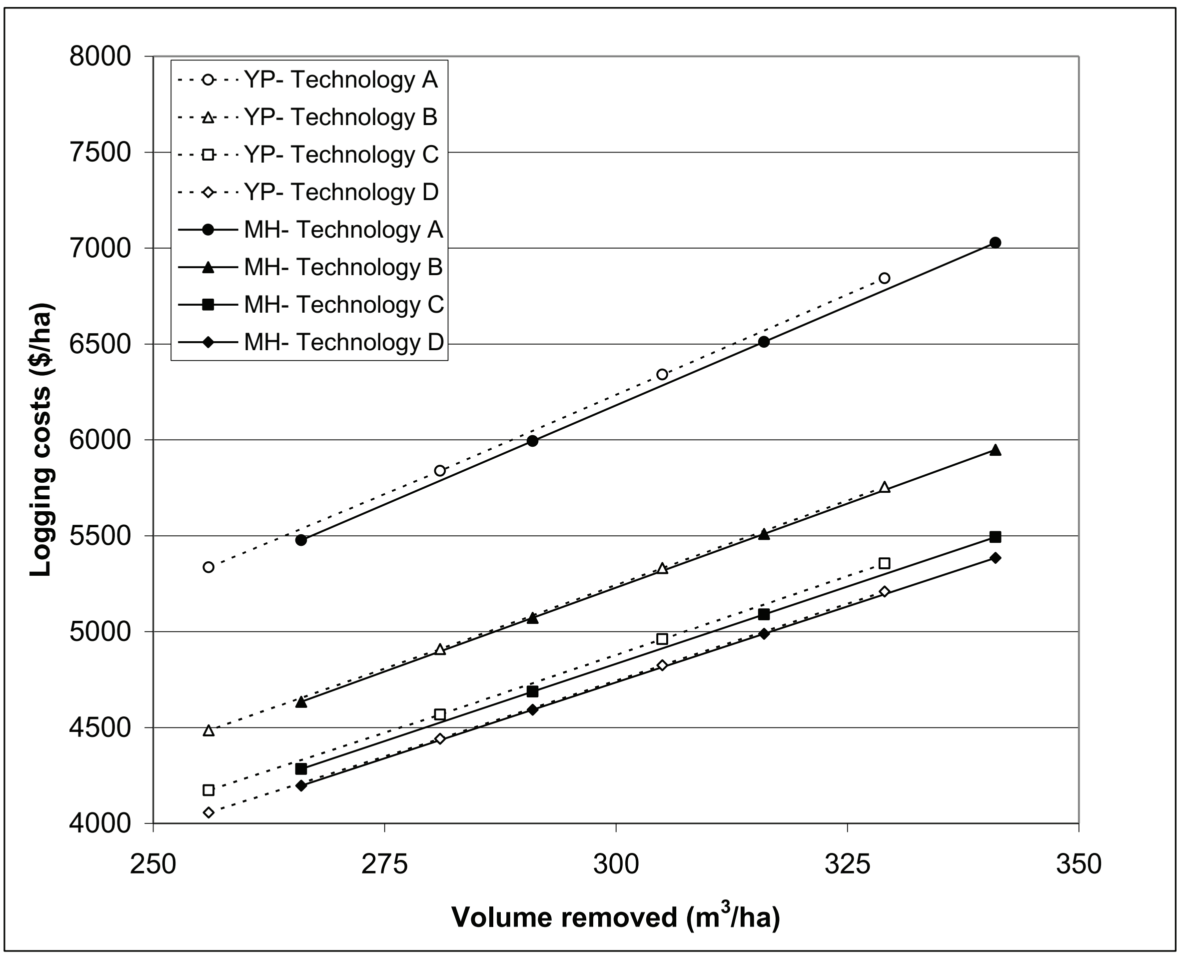


Figure 3— Logging costs by volume removed for mixed hardwood and yellow-poplar stands for four different logging systems (see Table 1 for description of technologies used).

Table 3. Volume of timber harvested and retained for each protection option in the yellow-poplar and mixed hardwood stands.

	Yellow-poplar		Mixed hardwood	
Protection Option	Volume Harvested	Volume Retained	Volume Harvested	Volume Retained
	---------- m^3/ha ----------			
No SMZ	328	0	341	0
15 m	304	24	316	25
30 m	280	48	291	50
45 m	256	72	266	75
30 m with partial harvest	304	24	316	25

Leaving a 30m SMZ on both sides of the stream removes 48m^3/ha and 50m^3/ha less merchantable wood than harvesting without an SMZ (Table 3) for the yellow-poplar and mixed hardwood stands, respectively. This level of SMZ protection decreases gross revenue from harvesting with no SMZ by $1,508/ha and $1,898/ha for the yellow-poplar (Fig. 4a) and mixed hardwood (Fig. 4b) stands, respectively. Leaving 30m buffers on both sides of the stream has a protection cost of $504 to $740/ha for yellow-poplar (Fig. 5a) and $864 to $1,106/ha for the mixed hardwood stand (Fig. 5b), depending on the logging technology.

A 45m SMZ on both sides of the stream removes 72 m^3/ha and 75 m^3/ha less merchantable timber for the yellow-poplar and mixed hardwood stand, respectively, as compared to harvesting with no SMZ (Table 3). Gross revenues decrease by $2,262/ha for yellow-poplar (Fig. 4a) and $2,847/ha for mixed hardwood (Fig. 4b) and protection costs range from $756 to $1,110/ha for yellow-poplar (Fig. 5a) and $1,296 to $1,659/ha for mixed hardwood (Fig. 5b) when compared to leaving no streamside buffer.

Removing 50 percent of the timber volume from a 30m SMZ results in removal of the same volume of timber as unharvested 15m buffers on both sides of the stream (Table 3). Compared to unharvested 30m buffers, harvesting 50 percent of the timber volume from the 30m SMZs can increase the gross revenue by $754/ha for yellow-poplar (Fig. 4a) and $949/ha for mixed hardwood (Fig. 4b) as well as decreasing the protection costs between $252 and $370/ha for yellow-poplar (Fig. 5a) and $432 and $553/ha for mixed hardwood (Fig. 5b).

Ecological Benefit

While maintaining SMZs represents a sizeable opportunity cost to the landowner, buffers provide a wide range of ecological benefits to riparian areas. SMZs that are too narrow cannot adequately protect all riparian functions, but

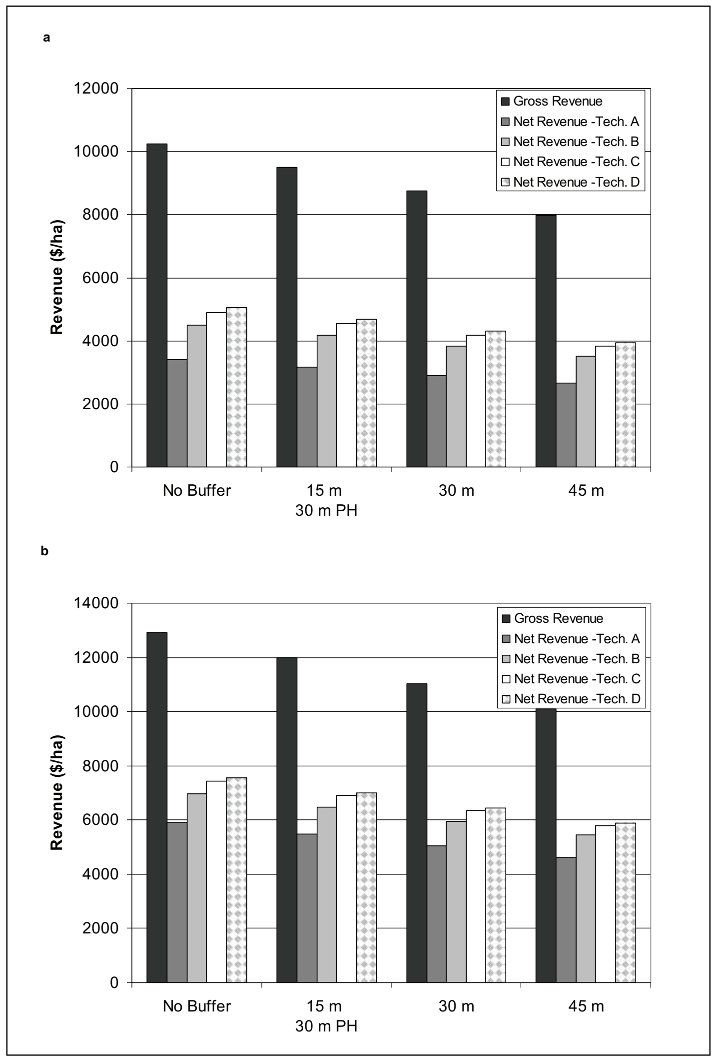


Figure 4— Gross and net revenues for different levels of SMZ protection for the (a) yellow-poplar and the (b) mixed hardwood stands under the four harvesting technologies (PH=partial harvest, see Table 1 for description of technologies used).

unnecessarily wide buffers produce an avoidable economic loss to the landowner (Castelle and Johnson 2000). The SMZ protection options (no SMZ, and unharvested 15m, 30m, 45m SMZs) resulted in varying levels of post-harvest change for the individual riparian functions (Table 4). The SMZ protection score increases with buffer width (Table 4). No SMZ results in a protection score of 0 percent; it did not protect any of the five categories of riparian function resulting in large changes following the harvest. A 15m SMZ has an SMZ protection score of 60 percent and a 30m SMZ has a protection score of 87 percent (Table 4). A 45m SMZ has a protection score of 100 percent; it protected against measurable changes in all five of the categories of riparian function (Table 4).

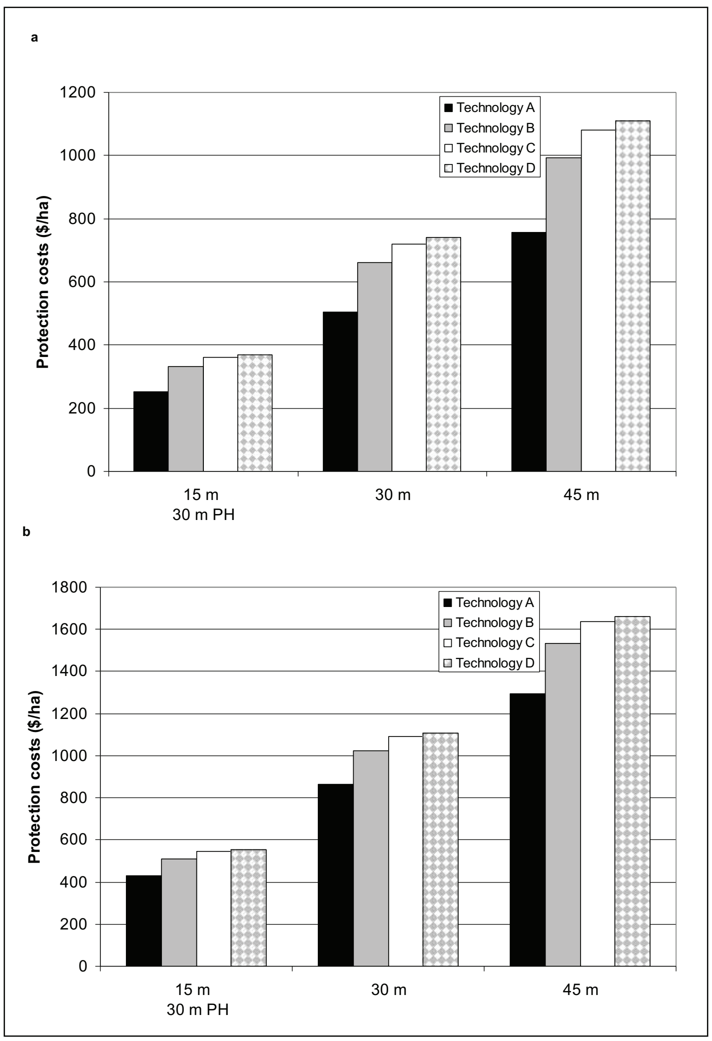


Figure 5— Costs for different SMZ protection options for the (a) yellow-poplar and (b) mixed hardwood stands (PH=partial harvest, See Table 1 for description of technologies used).

Comparing Financial Costs with Ecological Benefits

Forest landowners are responsible for protecting water quality and maintaining riparian habitat for the public good, but they also have other objectives that may include making a return on their investments. The challenge for landowners is to find a balance between financial sacrifice and ecologic protection. To find this balance, we must consider that the revenue reductions attributed to SMZ protection occur only once—at the time of timber harvest—but the ecological benefits of SMZ protection accrue after the harvest and continue through the next rotation. To compare the current costs with future ecological benefits, a capital recovery factor can be calculated to convert revenue reductions to a series of uniform annual costs that begin at the time of harvest and extend through the next rotation.

The capital recovery cost takes the protection costs of retaining an SMZ and, using a real interest rate of 4 percent, divides that cost into annual allotments. These calculations are the per-hectare cost to leave an SMZ for each year of a 120-year rotation. In an ecological context, capital recovery costs can be viewed as the annual monetary cost required to maintain a particular level of riparian function.

Benefit/Cost Analysis

We used the principle of benefit/cost ratios (Gregory 1972) to compare the ecological benefits with the opportunity costs. By comparing the capital recovery costs with the SMZ protection score, we can determine the benefit-cost ratio between ecological protection and SMZ width (Fig. 6a and 6b and Table 5). In summary:

- All B/C ratios were greater than or equal to 1. Thus, it is desirable to use SMZs.
- In all cases, B/C ratios are more robust for 15m SMZs.
- In all cases, B/C ratios are still very desirable for 30m SMZs
- B/C ratios, although still desirable for 45m SMZs, are not as robust as those from 15m and 30m SMZs, suggesting that the benefit produced is decreasing while costs are increasing.

SMZ protection scores increase with capital recovery costs for both stand types and all logging technologies. Harvesting without an SMZ leaves no

Table 4--SMZ protection scores for different SMZ widths for protecting against post-harvest changes in riparian functions for 2 to 4th order streams.

Riparian Function	Width				References
	No SMZ	15 m	30 m	45 m	
Coarse woody debris	0[a]	1	2	3	Murphy and Koski 1989, Harmon and others 1986, McDade and others 1990, Robinson and Beschta 1990, Van Sickle 2000, May and Gresswell 2003.
Shade/ temperature maintenance	0	2	3	3	Burton and Likens 1973, Moring 1975, Brown and Krygier 1967, Rishel and others 1982, Lynch and others 1984, Lynch and others 1985, Noel and others 1986, Beschta and others 1987, Budd and others 1987, Caldwell and others 1991, Kochenderfer and Edwards 1991, Davies and Nelson 1994, Jackson and others 2001, Kiffney and others 2003, Wilkerson and others 2006
Sediment filtering	0	2	2	3	Karr and Schlosser 1977, Moring 1982, Lynch and others 1985, Davies and Nelson 1994, Jackson and others 2001
Aquatic communities (macroinverte-brates and periphyton)	0	2	3	3	Newbold and others 1980, Noel and others 1986, Davies and Nelson 1994, Hetrick and others 1998, Kiffney and others 2003, Wilkerson and others in review[b]
Riparian bird communities (riparian associated passerines)	0	2	3	3	Triquet and others 1990, Whitaker and Montevecchi 1999, Pearson and Manuwal 2001
Total Score	0	9	13	15	
Percent SMZ effectiveness	0%	60%	87%	100%	

[a]Scoring: 0) Does not protect riparian function; 1) Results in moderate post-harvest changes in riparian function; 2) Results in small post-harvest changes in riparian function; 3) Completely protects against measurable changes in riparian function

[b]Wilkerson, Ethel; Hagan, John M.; Whitman, Andrew A. In review. The effectiveness of different buffer widths for protecting water quality and biotic communities of headwater streams in Maine. Freshwater Biology.

Table 5--SMZ protection scores, capital recovery costs, and B/C ratios by logging technology and stand type.

	Yellow-poplar		Mixed Hardwood	
SMZ Protection Score	Capital Recovery Cost	B/C Ratio	Capital Recovery Cost	B/C Ratio
-----% -----	----$/ha/yr----		----$/ha/yr----	
		Technology A		
0	0.00	0.00	0.00	0.00
60	10.18	5.89	17.44	3.44
87	20.36	4.27	34.88	2.49
100	30.54	3.27	52.32	1.91
		Technology B		
0	0.00	0.00	0.00	0.00
60	13.37	4.49	20.66	2.90
87	26.74	3.25	41.32	2.11
100	40.11	2.49	61.98	1.61
		Technology C		
0	0.00	0.00	0.00	0.00
60	14.55	4.12	22.04	2.72
87	29.10	2.99	44.08	1.97
100	43.65	2.29	66.12	1.51
		Technology D		
0	0.00	0.00	0.00	0.00
60	14.95	4.01	22.34	2.69
87	29.90	2.91	44.68	1.95
100	44.85	2.23	67.02	1.49

timber adjacent to the stream resulting in an SMZ protection score of 0 percent and no capital recovery costs. Retaining a 15m SMZ results in an SMZ protection score of 60 percent and costs between $10.18 and $14.95/ha/year for a yellow-poplar stand (Fig. 6a) and between $17.44 and $22.34/ha/year for a mixed hardwood stand (Fig. 6b), depending on the logging technology. A 30m SMZ results in an 87 percent SMZ protection score and cost between $20.36 and $29.90/ha/year (yellow-poplar, Fig. 6a) and between $34.88 and $44.68/ha/year (mixed hardwood, Fig. 6b). A 45m SMZ achieves a 100 percent riparian protection score but costs between $30.54 and $44.85/ha/year (yellow-poplar, Fig. 6a) and between $52.32 and $67.02/ha/year (mixed hardwood, Fig. 6b).

The relationship between increasing capital recovery costs and increasing SMZ protection score is not linear. This analysis shows that for SMZs wider than 15m, the rate of increasing SMZ protection begins to diminish while capital recovery costs continue to increase (Fig. 6a and 6b). Therefore, increasing streamside protection from a 15m SMZ to a 30m SMZ results in an increase in economic cost that is disproportional to the increase in ecological protection gained. However, if the goal is to completely protect riparian functions against measurable post-harvest changes (a 100 percent SMZ protection score), a 45m SMZ is required and landowners will pay an economic premium to achieve this level of protection. Although we could not calculate an SMZ protection score for the 30m partially harvested SMZ, the capital recovery costs are 50 percent less than the 30 m SMZ without timber removal. Landowners may chose partial removal of timber within the SMZ to reduce capital recovery costs while still maintaining a portion of riparian structure that can contribute to riparian function.

Considerations for Managers

Ultimately, landowners and managers and concerned public/outside interests must determine the appropriate balance between opportunity/capital recovery costs and SMZ protection. The level of riparian protection will vary between ownerships and even within different landscapes on a single ownership. On an ownership level, managers should consider state and local laws and BMPs, certification requirements, and their long-term strategies for

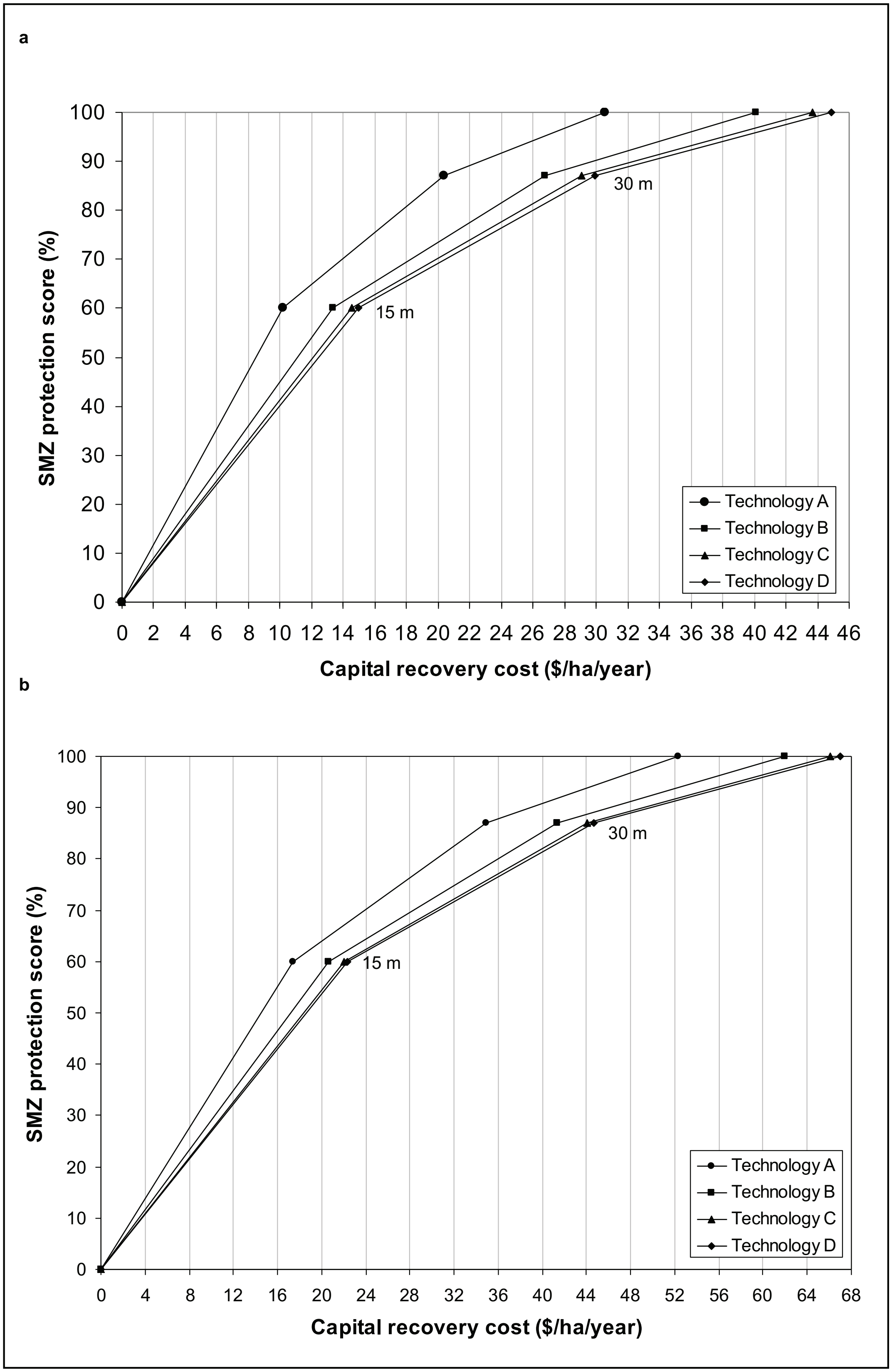


Figure 6--SMZ protection scores compared with capital recovery costs for the (a) yellow-poplar and (b) mixed hardwood stands under the four harvesting technologies. Symbols and lines represent different logging systems. SMZ protection scores are labeled on corresponding SMZ width (See Table 1 for description of technologies used).

maintaining and protecting fisheries and wildlife on their land base. At a smaller scale, managers should consider the slope and topography of the stand, the age class and disturbance history of the surrounding forests, and determine if there are species of special management concern within the watershed.

The decision on which logging system to use to harvest wood adjacent to and from within buffers requires careful consideration of the ecological functions that one wishes to protect. For example, cable logging systems usually require ridge top roads and landings, which may result in less erosion and sediment production. This could justify narrower buffer widths with partial volume removal if one was concerned with erosion and sediment production only. However, if the objective is to also provide habitat for breeding birds (Hanowski and others 2005), amphibians (Perkins and Hunter 2006) and use by some mammals, such as martens (Fuller and Harrison 2005), then wide (45m) buffers with no volume removed may be required.

Using computer simulations and the principles of benefit/cost analysis, we evaluated two stands, four logging technologies, five SMZ protection options, five riparian/ecological functions, a fixed real interest rate of 4 percent, and fixed market prices. The results reported here are specific to the conditions simulated and to the models and assumptions used and should not be generally inferred. However, the results provide an understanding of the costs and ecological benefits associated with alternative levels of SMZ protection.

ACKNOWLEDGEMENT

We are grateful to Andrew Whitman, Manomet Center for Conservation Sciences, for his suggestions and guidance in developing the riparian scoring criteria.

LITERATURE CITED

Allan, J.D. 1995. Stream ecology: structure and function of running waters. 1st ed. New York: Kluwer Academic Publishers. 400 p.

Beschta, R. L.; Bilby, R. E.; Brown, G. W.; Holtby, L. B.; Hofstra, T. D. 1987. Stream temperature and aquatic habitat: Fisheries and forestry interactions. In: Salo, E.O.; Cundy, T.W., eds. Streamside management: forestry and fishery interactions. Seattle, WA: University of Washington: 191-232.

Bisson, P. A.; Bilby, R. E.; Bryant, M. D.; Dolloff, C. A.; Grette, G. B.; House, R. A.; Murphy, M. L.; Koski, K. V.; Sedell, J. R. 1987. Large woody debris in forested streams in the Pacific Northwest: past, present, and future. In: Salo, E.O.; Cundy, T.W., eds. Streamside management: forestry and fishery interactions. Seattle, WA: University of Washington: 143-190.

Blinn, C. R.; Alden, A. M.; Ellefson, P. V. 2001. Timber harvester perceptions of costs and benefits from applying water quality BMPs in north-central USA. International Journal of Forest Engineering. 12(1): 39-51.

Blinn, C.R.; Kilgore, M.A. 2001. Riparian management practices: A summary of state guidelines. Journal of Forestry. 99(8): 11-17.

Blinn, C.R.; Kilgore, M.A. 2004. Riparian management practices in the Eastern US: a summary of state timber harvesting guidelines. Water, Air, and Soil Pollution: Focus. 4(1): 187-201.

Brown, G.W.; Krygier, J.T. 1967. Changing water temperatures in small mountain streams. Journal of Soil and Water Conservation. 22(6): 242-244.

Budd, W.M.; Cohen, P.L.; Saunders, P.R.; Steiner, F.R. 1987. Stream corridor management in the Pacific Northwest: determination of stream corridor widths. Environmental Management. 11: 587-597.

Burton, T.M.; Likens, G.E. 1973. The effect of strip-cutting on stream temperature in the Hubbard Brook Experimental Forest, New Hampshire. BioScience. 23: 433-435.

Caldwell, J.E.; Doughty, K.; Sullivan, K. 1991. Evaluation of downstream temperature effects of type 4/5 waters. Rep. No. TFW-WQ5-91-004. Olympia, WA: Washington Department of Natural Resources. 71 p.

Castelle, A.J.; Johnson, A.W. 2000. Riparian vegetation effectiveness. Tech. Bull. No. 799. Research Triangle Park, NC: National Council for Air and Stream Improvement. 26 p.

Davies, P. E.; Nelson, M. 1994. Relationships between riparian buffer widths and the effects of logging on stream habitat, invertebrate community composition and fish abundance. Australian Journal of Marine Freshwater Research. 45(7): 1289-1305.

Fuller, A.K.; Harrison, D.J. 2005. Influence of partial timber harvesting on American martens in north-central Maine. Journal of Wildlife Management. 69(2): 710-722.

Gregory, G.R. 1972. Forest resource economics. The Ronald Press Company, New York. 548 p.

Hanowski, J.; Danz, N.; Lind, J.; Niemi, G. 2002. Breeding bird response to riparian forest harvest and harvest equipment. Forest Ecology Management. 174: 315-328.

Hanowski, J.; Danz, N., Lind, J.; Niemi, G. 2005. Breeding bird response to varying amounts of basal area retention in riparian buffers. Journal of Wildlife Management. 69(2): 689-698.

Harmon, M.E.; Franklin, J.F.; Swanson, F.J.; Sollins, P.; Gregory, J.D.; Lattin, J.D., Andrews, N. H.; Cline, S.P.; Aumen, N.G.; Sedell, J.R.; Lienkaemper, G.W.; Cromack, K., Jr.; Cummins, K W. 1986. Ecology of coarse woody debris in temperate ecosystems. Advances in Ecology Research. 15: 133-302.

Hauck, L.M.; Ice, G.G.; Saheh, A.; Tanter, A. 2005. Challenges and opportunities for applying the comprehensive economic and environmental optimization tool (CEEOT) to forestry activities. In: Gassmann, P.W., ed. Watershed management to meet water quality standards and emerging TMDL (Total maximum daily load): Proceedings of the third conference; 2005 March 5-9; Atlanta, GA. ASAE-701-P0105. St. Joseph, MI: American Society of Agricultural Engineers: 88-92.

Hawkins, C.P.; Murphy, M.L.; Anderson, N.H. 1982. Effects of canopy, substrate composition, and gradient on the structure of macroinvertebrate communities in Cascade Range streams of Oregon. Ecology. 63(6): 1840-1856.

Hetrick N.J.; Brusven, M.A.; Meehan, W.R.; Bjornn, T.C. 1998. Changes in solar input, water temperature, periphtyon accumulation, and allochthonous input and storage after canopy removal along two small salmon streams in southeast Alaska. The American Fisheries Society. 127(6): 859-875.

Hilderbrand, R.H.; Lemly, A.D.; Dollof, A.; Harpster, K.L. 1997. Effects of large woody debris placement on stream channels and benthic macroinvertebrates. Canadian Journal of Fisheries and Aquatic Science. 54(4): 931-939.

Huyler, N.K.; LeDoux, C.B. 1995. Estimating the cost of applying Vermont acceptable management practices to logging on moderate slopes. In: Hassan, Awatif E.; Sherar, Jim; Swanner, Jack, eds. proceedings of the Council on Forest Engineering 18th annual meeting; 1995 June 5-8; Cashiers, NC. Raleigh, NC: North Carolina State University, College of Forest Resources: 165-171.

Ice, G.G.; Skaugset, A.; Simmons, A. 2006. Estimating areas and timber values of riparian management zones on forest lands. Journal of the American Water Resources Association. 42(01): 115-124.

Jackson, C.R.; Sturm, C.A.; Ward, J.M. 2001. Timber harvest impacts on small headwater stream channels in the coast ranges of Washington. Journal of American Water Resources Association. 37(6): 1533-1549.

Karr, J.R.; Schlosser, I.J. 1977. Impact of near stream vegetation and stream morphology on water quality and stream biota. EPA-600/3-77-097. Washington, DC: U.S. Environmental Protection Agency.

Kentucky Department of Fish and Wildlife Resources. 1990. Wildlife and wetlands. Kentucky Happy Hunting Ground. 46(1): 14-15.

Kiffney, P.M.; Richardson, J.S.; Bull, J.P. 2003. Reponses of periphyton and insects to experimental manipulation of riparian buffer width along forest streams. Journal of Applied Ecology. 40(6): 1060-1076.

Kilgore, M.A.; Blinn, C.R. 2003. The financial cost to forest landowners who implement forest guidelines: an empirical assessment. Journal of Forestry. 101(8): 37-41.

Klapproth, J.C.; Johnson, J.E. 2000. Understanding the science behind riparian forest buffers: effects on plant and animal communities. Publ. 420-152. Blacksburg, VA: Virginia Cooperative Extension. 20 p.

Kochenderfer, J.N.; Edwards, P.J. 1991. Effectiveness of three streamside management practices in the central Appalachians. In: Coleman, Sandra; Neary, Daniel G., eds. Proceedings of the 6th biennial southern silviculture research conference; 1990 Oct. 30 – Nov. 1; Memphis, TN. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station: 688-700.

LeDoux, C.B. 1985. Stump-to-mill timber production cost equations for cable logging eastern hardwoods. Res. Pap. NE-566. Broomall, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station. 6 p.

LeDoux, C.B. 1986. MANAGE: A computer program to estimate costs and benefits associated with eastern hardwood management. Gen. Tech. Rep. NE-112. Broomall, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station. 7 p.

LeDoux, C.B. 2004. Estimating the capital recovery costs of managing for old growth forests. Proceedings, eastern old growth forest conference; 2004 Sept. 23-26; Moultonborough, NH.

LeDoux, C.B. 2006. Assessing the opportunity costs of implementing streamside management zone guidelines in eastern hardwood forests. Forest Products Journal. 56(6): 40-44.

LeDoux, C.B.; Baumgras, J.E.; Miyata, E.S. 1990. Cost of wetland protection using a Christy cable yarder. ASAE Pap. 90-7573. St. Joseph, MI: American Society of Agricultural Engineers: 4-12.

LeDoux, C.; Whitman, A. 2006. Estimating the capital recovery costs of alternative patch retention treatments in eastern hardwoods. International Journal of Forest Engineering. 17(1): 21-30.

LeDoux, C.B.; Wilkerson, E. 2006. A case study assessing opportunity costs and ecological benefits of alternative streamside management zones and logging systems for eastern hardwood forests. Res. Pap. NRS-RP-1. Newtown Square, PA: U.S. Department of Agriculture, Forest Service, Northern Research Station. 16 p.

Li, Y.; LeDoux, C.B.; Wang, J. 2006. An economic assessment of implementing streamside management zones in central Appalachian hardwood forests. Forest Products Journal. 56(10): 73-79.

Lynch, J.A.; Corbett, E.S.; Mussallem, K. 1985. Best management practices for controlling nonpoint source pollution on forested watersheds. Journal of Soil Water Conservation. 40: 164-167.

Lynch, J.A.; Rishel, G.B.; Corbett, E. 1984. Thermal alteration of streams draining clearcut watersheds: quantification and biological implications. Hydrobiologia. 111: 161-169.

Mason, C.L.; Cedar, K.; Rogers, H.; Bloxton, T.; Comnick, J.; Lippke, B.; McCarter, J.; Zobrist, K. 2003. Investigation of alternative strategies for design, layout and administration of fuel removal projects. Seattle, WA: University of Washington, College of Forest Resources, Rural Technology Initiatives. Available at: http://www.ruraltech.org/pubs/reports/fuel_removal/fuel_removal.

May, C.L.; Gresswell, R.E. 2003. Large wood recruitment and redistribution in headwater streams in southern Oregon Coast Range, U.S.A. Canadian Journal of Forest Research. 33(8): 1352-1362.

McDade, M.H.; Swanson, F.J.; McKee, W.A.; Franklin, J.F.; Van Sickle, J. 1990. Source distances for coarse woody debris entering small streams in western Oregon and Washington. Canadian Journal of Forest Research. 20(3): 326-330.

Moring, J.R. 1975. The Alsea watershed study: effects of logging on the aquatic resources of three headwater streams of the Alsea River. Corvallis, OR: Oregon Dept. Fish and Wildlife. 23 p.

Moring, J.R. 1982. Decrease in stream gravel permeability after clear-cut logging: an indication of intragravel conditions for developing salmonid eggs and alevin. Hydrobiologia. 88: 295-298.

Murphy, M.L.; Koski, K.V. 1989. Input and depletion of woody debris in Alaska streams and implications for streamside management. North American Journal of Fisheries Management. 9(4): 427-436.

Newbold, J.D.; Erman, D.C.; Roby, K.B. 1980. Effects of logging on macroinvertebrates in streams with and without buffer strips. Canadian Journal of Fisheries and Aquatic Science. 37: 1076-1085.

Noel, D.S.; Martin, C.W.; Federer, C.A. 1986. Effects of forest clearcutting in New England on stream macroinvertebrates and periphyton. Environmental Management. 10(5): 661-670.

Ohio Agricultural Statistics Service. 2007. Ohio timber prices report. Columbus, OH: Ohio Department of Agriculture, Agricultural Statistics Service. 2 p.

Olsen, E.D.; Keough, D.S.; LaCourse, D.K. 1987. Economic impact of proposed Oregon forest practices rules on industrial forest lands in the Oregon coast range: a case study. Res. Bull. 61. Corvallis, OR: Oregon State University, Forest Research Laboratory. 16 p.

Pearson, S.F.; Manuwal, D.A. 2001. Breeding bird response to riparian buffer width in managed pacific northwest Douglas-fir forests. Ecological Applications. 11(3): 840-853.

Pennsylvania State University. 2007. Pennsylvania woodlands timber market report. University Park, PA: Pennsylvania State University. October-December. 3 pp.

Perkins, D.W.; Hunter, M.L. Jr. 2006. Effects of riparian timber management on amphibians in Maine. The Journal of Wildlife Management. 70(3): 657-670.

Peters, P.A.; LeDoux, C.B. 1984. Stream protection with small cable yarding systems. In Water Quality Symposium; 1984 March 13-14; University Park, PA: Pennsylvania State University: 53-69.

Phillips, M.; Swift, L. Jr.; Blinn, C. 2000. Best management practices for riparian areas. In: Verry, E.; Hornbeck, J.; Dolloff, A., eds. Riparian management in forests of the continental eastern United States. Washington, DC: Lewis Publishers: 273-286

Rishel, G. ; Lynch, J.A.; Corbett, E.S. 1982. Seasonal stream temperature changes following forest harvesting. Journal of Environmental Quality. 11(1): 112-116.

Robinson, E.G.; Beschta, R.L. 1990. Identifying trees in riparian areas that can provide coarse woody debris to streams. Forest Science. 36(3): 790-801.

Shaffer, R.; Aust, W.M. 1993. A cost/benefit comparison of voluntary and regulatory forestry BMP programs. In: Proceedings, 16th annual meeting of Council of Forest Engineering; 1993 Sept. 8-11; Savannah, GA. Corvallis, OR: Council of Forest Engineering.

Shaffer, R.M.; Haney, H.L. Jr.; Worrell, E.G.; Aust, W. M. 1998. Forestry BMP implementation costs for Virginia. Forest Products Journal. 48: 27-29.

Tennessee Division of Forestry. 2007. Tennessee forest products bulletin. Nashville, TN. October-December. 13 p.

Triquet, A.M.; McPeek, G A.; McComb, W.C. 1990. Songbird diversity in clearcuts with and without a riparian buffer strip. Journal of Soil and Water Conservation. 45(4): 500-503.

University of Washington. 1999. Economic and environmental impact assessment of forest policy: Western Washington. Fact sheet #3. Seattle, WA: University of Washington, College of Forest Resources. 4 p. Available at www.cfr.washington.edu/news_pubs/fact%20sheets/fact_sheets/03-assessWeWa-4pg.pdf.

Van Sickle, J. 2000. Modeling variable-width riparian buffers, with an application to woody debris recruitment. In: Wigington, P.J., Jr.; Beschta, R.L., eds. Proceedings, International conference on riparian ecology and management in multi-land use watersheds; 2000 August 27-31; Portland, OR. Corvallis, OR: American Water Resource Association: 107-112.

Vasievich, J.M.; Edgar, C. 1998. Economic implications of proposed forest management guidelines for Minnesota. Rep. SE-0998. St. Paul, MN: Minnesota Forest Resources Council. 85 p.

West Virginia University Division of Forestry. 2007. Timber Market Report. Morgantown, WV. 1st Quarter. 2 p.

Whitaker, D.M.; Montevecchi, W.A. 1999. Breeding bird assemblages inhabiting riparian buffer strips in Newfoundland: Canada. Journal of Wildlife Management. 63(1): 167-179.

Wilkerson, E.; Hagan, J.M.; Siegel, D.; Whitman, A.A. 2006. The effectiveness of different buffer widths for protecting headwater stream temperature in Maine. Forest Science. 52(3): 221-231.

Williams, T.M.; Lipscomb, D.J.; Post, C.J. 2004. Defining streamside management zones or riparian buffers. In: Connor, Kristina F., ed. Proceedings of the 12th biennial southern silviculture research conference; 2003 Feb. 24028; Biloxi, MS. Gen. Tech. Rep. SRS-71. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station: 378-383.

Zobrist, K.W.; Gehringer, K.R.; Lippke, B.R. 2005. A sustainable solution for riparian management: In: Deal, R.L.; White, S.M.; eds. Understanding key issues of sustainable wood production in the Pacific Northwest. Gen. Tech. Rep. PNW-626. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station: 54-62.