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A Case Study Assessing Opportunity Costs and Ecological Benefits of Streamside Management Zones and Logging Systems for Eastern Hardwood Forests

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Abstract

Forest landowners, managers, loggers, land-use planners, and other decision and policy-makers need to understand the opportunity costs and ecological benefits associated with different widths of streamside management zones (SMZs). In this paper, a simulation model was used to assess the opportunity costs of SMZ retention for four different logging systems, two mature hardwood stands, and five levels of streamside zone protection. Results from this assessment suggest that protection costs range from $252 to $1,659/ha depending on the SMZ width, the logging technology used to harvest the timber, and the species composition of the tract. A literature review was used to score the ability of different SMZ widths to protect riparian function. We quantified the economic costs and environmental benefits of SMZs. The results showed that to fully protect against post-harvest changes in riparian function, 45-m SMZs are needed. This protection will cost landowners between $30.54 and $67.02/ha/year depending on the stand type and logging technology.

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INTRODUCTION

Streams, wetlands, and riparian areas are among our most valuable natural areas. From an ecological/biological perspective, riparian areas are among the most productive wildlife habitat on the continent (Kentucky Dept. of Fish and Wildlife Resources 1990). In addition to providing habitat for a wide range of game and nongame wildlife species, 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), contributing woody material that increases the hydraulic and structural complexity of the stream channel (Hilderbrand and others 1997), and providing habitat for aquatic and terrestrial organisms (Bisson and others 1987). Removal of riparian vegetation during forestry 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/or habitat condition resulting in alteration of 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 with most state and federal conservation agencies (Blinn and others 2001). Protection of riparian areas is achieved by establishing streamside management zones (SMZs) adjacent to waterways and by adopting best management practices (BMPs), 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). An Internet website, Timbersource.com/bmp/html, allows easy access to BMPs and SMZ management information on a state-by-state basis. For example, the recommended BMP for most SMZs include no harvesting activities in 15-45 m buffer strips adjacent to the waterway and/or allowances for up to 50 percent removal of the basal area/volume of standing trees leaving an evenly distributed/spaced stand to protect the stream/wetland (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, Univ. of Washington 2003). 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). 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.

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Table 1.—Trees per hectare by size class for the yellow-poplar stand at age 120 years

	Midpoint of 5-cm d.b.h. class					
Tree species	36	41	46	51	56	Total
Black cherry	5	-	-	-	-	5
Red maple	15	-	-	-	-	15
Sycamore	7	-	-	-	-	7
Yellow-poplar	42	47	59	15	42	205
Total	69	47	59	15	42	232

Table 2.—Trees per hectare by size class for the mixed hardwood stand at age 120 years

	Midpoint of 5-cm d.b.h. class											
Tree species	21	26	31	36	41	46	51	56	61	66	71	Total
Black cherry	-	7	-	-	5	-	-	-	5	-	-	17
Shagbark hickory	-	5	-	-	-	-	-	-	-	-	-	5
Red maple	-	-	-	5	-	-	-	-	-	-	-	5
Red oak	-	-	-	10	5	10	-	-	-	-	-	25
White oak	-	-	-	5	2	10	-	-	-	-	-	17
Cucumber tree	-	-	-	5	-	-	-	-	-	-	-	5
Hemlock	-	-	-	-	5	-	-	-	-	-	5	10
Yellow-poplar	-	-	-	10	20	10	-	-	-	-	-	40
American beech	-	-	-	5	5	10	5	-	5	-	-	30
Sugar maple	5	-	5	10	-	15	10	10	-	15	-	70
Total	5	12	5	50	42	55	15	10	10	15	5	224

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 45.57 cm, and a merchantable volume of 328.83 m^3/ha (Table 1). 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.)), black cherry, red maple, cucumber tree (*Magnolia acuminata* L.), sugar maple (*Acer saccharum* Marsh.), red oak (*Quercus rubra* L.), white oak (*Quercus alba* L.), and hemlock (*Tsuga canadensis* (L.) carr.). This stand has 224 trees/ha, an average d.b.h. of 46.40 cm, and a merchantable volume of 341.09 m^3/ha (Table 2). 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.

Table 3.—Logging system configurations and costs used to simulate the harvest of the 27.5 ha tracts

Logging technology	Description	Cost/unit ($/m^3)	
		Yellow-poplar stand	Mixed hardwood stand
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

Logging Systems Evaluated

Simulations of four logging systems were used in this study (Table 3). 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 I[1] 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.

It might be worthwhile to look at whether the costs of cable yarding and the resulting reduction in soil disturbance and sediment production could be offset by reduced riparian management zones, but we do not have the data necessary to conduct such analysis. The current literature provides little insight into the impacts of alternative logging technology on ecological SMZ functions such as coarse woody debris supply, shade/temperature maintenance, sediment filtering, maintaining aquatic communities, and maintaining riparian bird habitat. To complete this analysis, we assume that logging equipment does not affect SMZ functions. However, managers must choose between numerous BMP options, including the logging system, road system, SMZ, and erosion control practices.

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 evaluated (Table 3). 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

[1]The use of trade, firm, or corporation names in this paper is for the information and convenience of the reader. Such does not constitute an official endorsement or approval by the U.S. Department of Agriculture or the Forest Service of any product or service to the exclusion of others that may be suitable.

Table 4.—Delivered prices for sawlogs and fuelwood/pulpwood by species

Species	Product			
	Large[a] sawlogs	Medium[b] size sawlogs	Small[c] sawlogs	Fuelwood[d]/ pulpwood
	- $/m³ - - - - - - - - - - - - - - - - - - -			- - - - $/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.

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 average delivered prices for sawlogs and pulpwood (Table 4) were obtained from forest products price bulletins (Ohio Agric. Stat. Serv. 2002, Pennsylvania State Univ. 2003, Tennessee Div. For. 2003).

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 27.5 ha without buffers; 2) unharvested 15 m SMZ on both sides of the stream; 3) unharvested 30 m SMZ on both sides of the stream; 4) unharvested 45 m SMZ on both sides of the stream; and 5) a partially harvested 30 m 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 some partial volume removed (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 disturbance or exposure. For all of the options simulated, 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

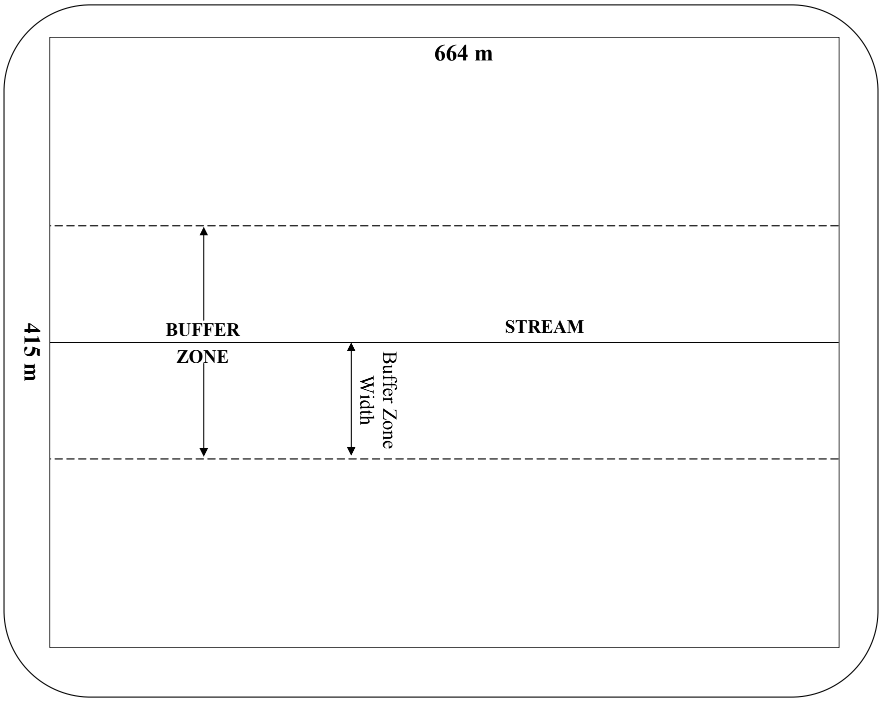


Figure 1.—Diagram of modeled harvest area, stream, buffer zone, and buffer zone width.

large terrestrial mammals (Klapproth and Johnson 2000). Quantifying the 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 riparian bird habitat (riparian associated passerines).

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 results 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 15 m, 30 m, and 45 m (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

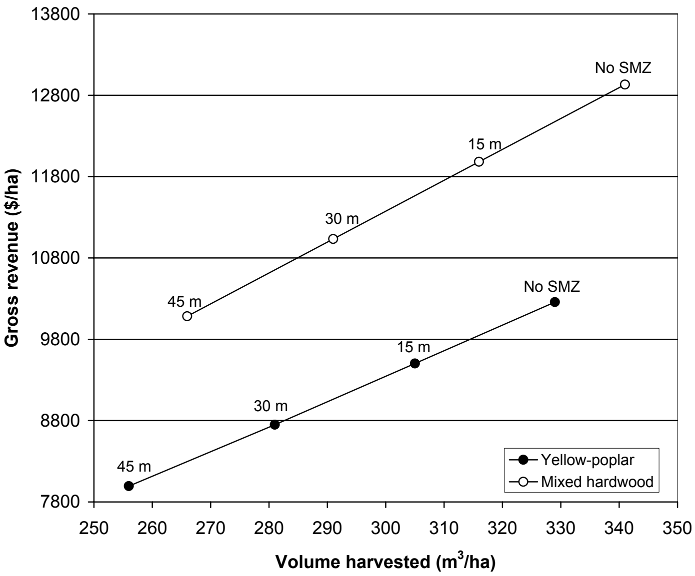


Figure 2.—Gross revenue by timber volume harvested from yellow-poplar and mixed hardwood stands.

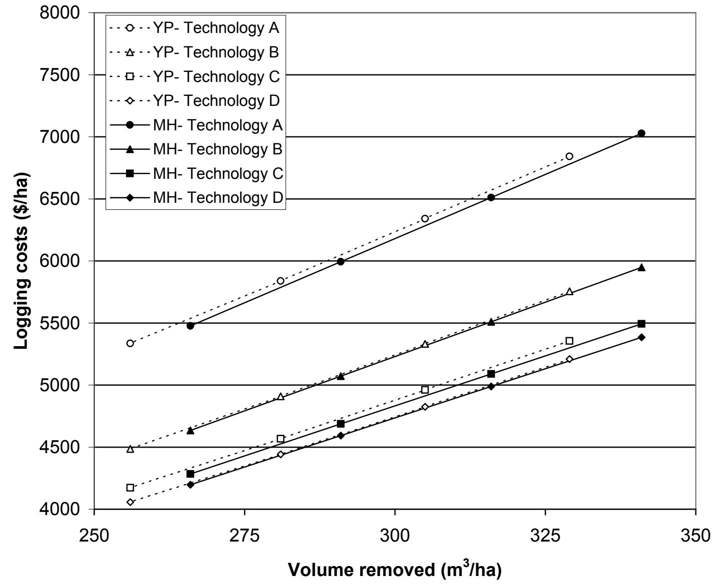


Figure 3.—Logging costs by volume removed for mixed hardwood and yellow-poplar stands for four different logging systems (see Table 3 and Page 3 for description of technologies used).

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 (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

The gross revenue ($/ha) from timber harvesting is dependent on stand composition. Depending on the timber volume harvested, the gross revenue from the yellow-poplar stand ranges from $7,995/ha to $10,257/ha while the gross revenue of timber from the mixed hardwood stand ranges from $10,084 to $12,931/ha (Fig. 2).

Logging costs ($/ha) are deducted from the gross revenue of the timber harvest to determine net income. Logging costs vary with the technology/equipment used. 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 3). The logging costs are comparable between the two stands (Fig. 3). Logging costs represent a larger percentage of the gross revenue in the yellow-poplar stand than in the mixed hardwood 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/ecological impacts of alternative systems because we lack the necessary data. Managers must consider logging system options when making decisions on SMZ management.

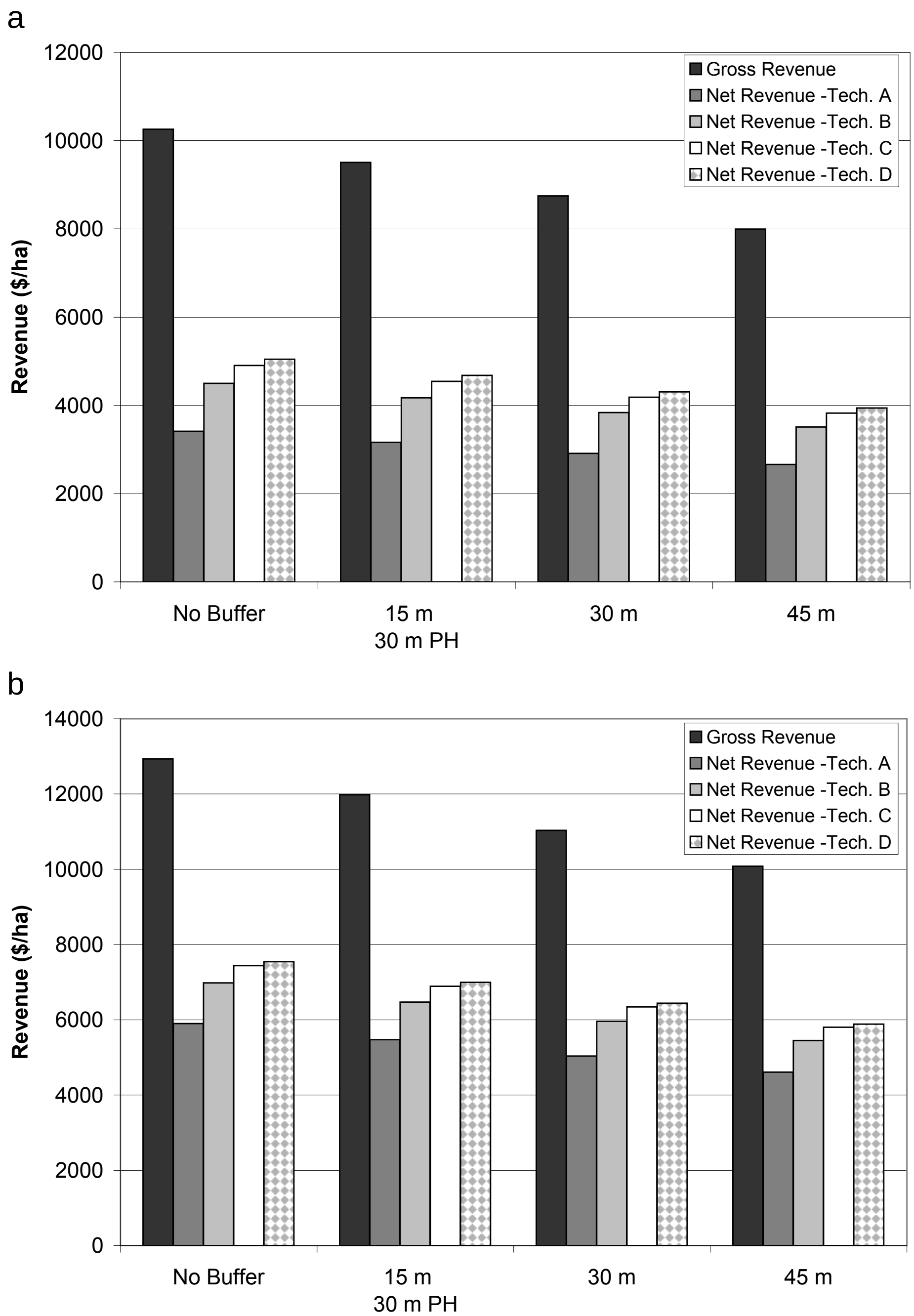


Figure 4.—Gross and net revenues for different levels of SMZ protection for the (a) yellow-poplar and the (b) mixed hardwood stands under the four harvesting technologies (PH=partial harvest, see Table 3 and Page 3 for description of technologies used).

SMZ Protection Options

Leaving no SMZ generates the most revenue (gross and net) to the landowner (Fig. 4a and 4b). This option provides the largest volume of wood (Table 5) 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.

Table 5.—Volume of timber harvested and retained for each protection option in the yellow-poplar and mixed hardwood stands

Protection option	Yellow-poplar		Mixed hardwood	
	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

A 15 m unharvested SMZ on both sides of the stream, removes 24 m^3/ha less wood from the yellow-poplar stand and 25 m^3/ha from the mixed hardwood stand (Table 5) as compared to leaving no SMZ. The gross revenue is $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 received from harvesting a stand with an SMZ and harvesting without an SMZ can be viewed as the opportunity/protection cost for retaining that width of SMZ. The protection cost for maintaining 15 m 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.

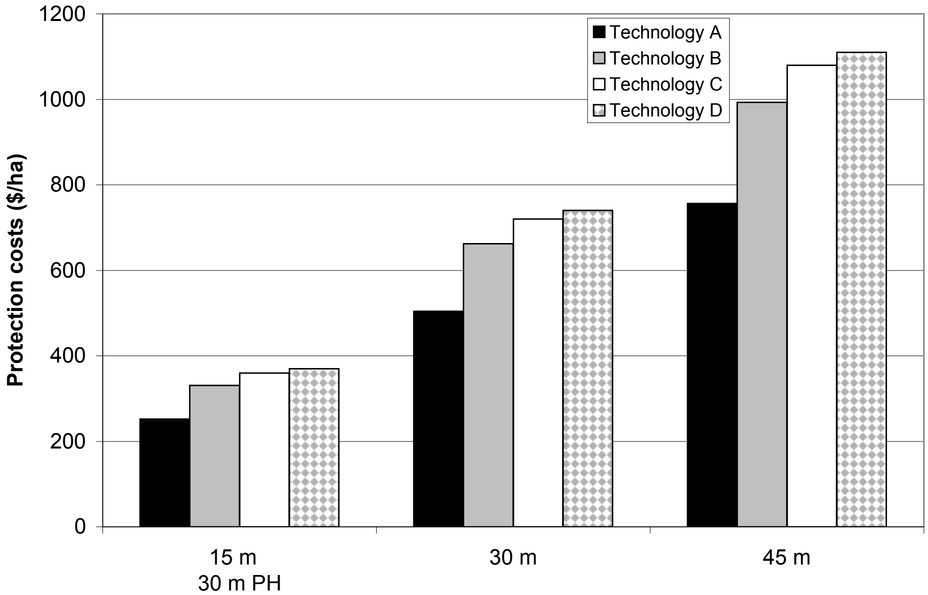
Leaving a 30 m SMZ on both sides of the stream removes 48 m^3/ha and 50 m^3/ha less merchantable wood than harvesting without an SMZ (Table 5) for the yellow-poplar and mixed hardwood stands, respectively. This level of SMZ protection decreases gross revenue by $1,508/ha and $1,898/ha for the yellow-poplar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

A 45 m 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 5). Gross revenues decrease by $2,262/ha (yellow-poplar, Fig. 4a) and $2,847/ha (mixed hardwood, Fig. 4b) and protection costs range from $756 to $1,110/ha (yellow-poplar, Fig. 5a) and $1,296 to $1,659/ha (mixed hardwood, Fig. 5b) when compared to leaving no streamside buffer.

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

Ecological Benefit

While maintaining SMZs can represent sizeable opportunity costs to the landowner, SMZs can provide a wide range of ecological benefit to streams and riparian areas. SMZs that are too narrow cannot adequately protect all riparian functions but SMZs that are wider than necessary result in unnecessary economic loss to the landowner (Castelle and Johnson 2000). The SMZ protection options (no SMZ, and unharvested 15 m, 30 m, 45 m SMZs) resulted in varying levels of post-harvest a



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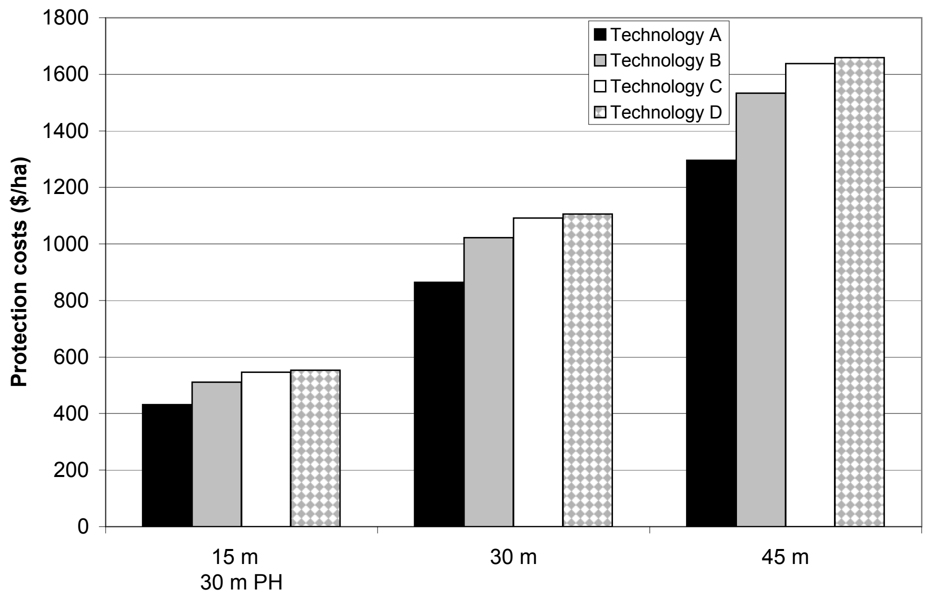

Figure 5.—Costs for different SMZ protection options for the (a) yellow-poplar and (b) mixed hardwood stands (PH=partial harvest, See Table 3 and Page 3 for description of technologies used).

change for the individual riparian functions (Table 6). The SMZ protection score increases with buffer width (Table 6). No SMZ results in a SMZ 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 15 m SMZ has an SMZ protection score of 60 percent and a 30 m SMZ has a protection score of 87 percent (Table 6). A 45 m SMZ has a protection score of 100 percent; it protected against measurable changes in all five of the categories of riparian function (Table 6).

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 the right to make a return on

Table 6.—SMZ protection scores for different SMZ widths for protecting against post-harvest changes in riparian functions for second to fourth 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 (macroinvertebrates 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.

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

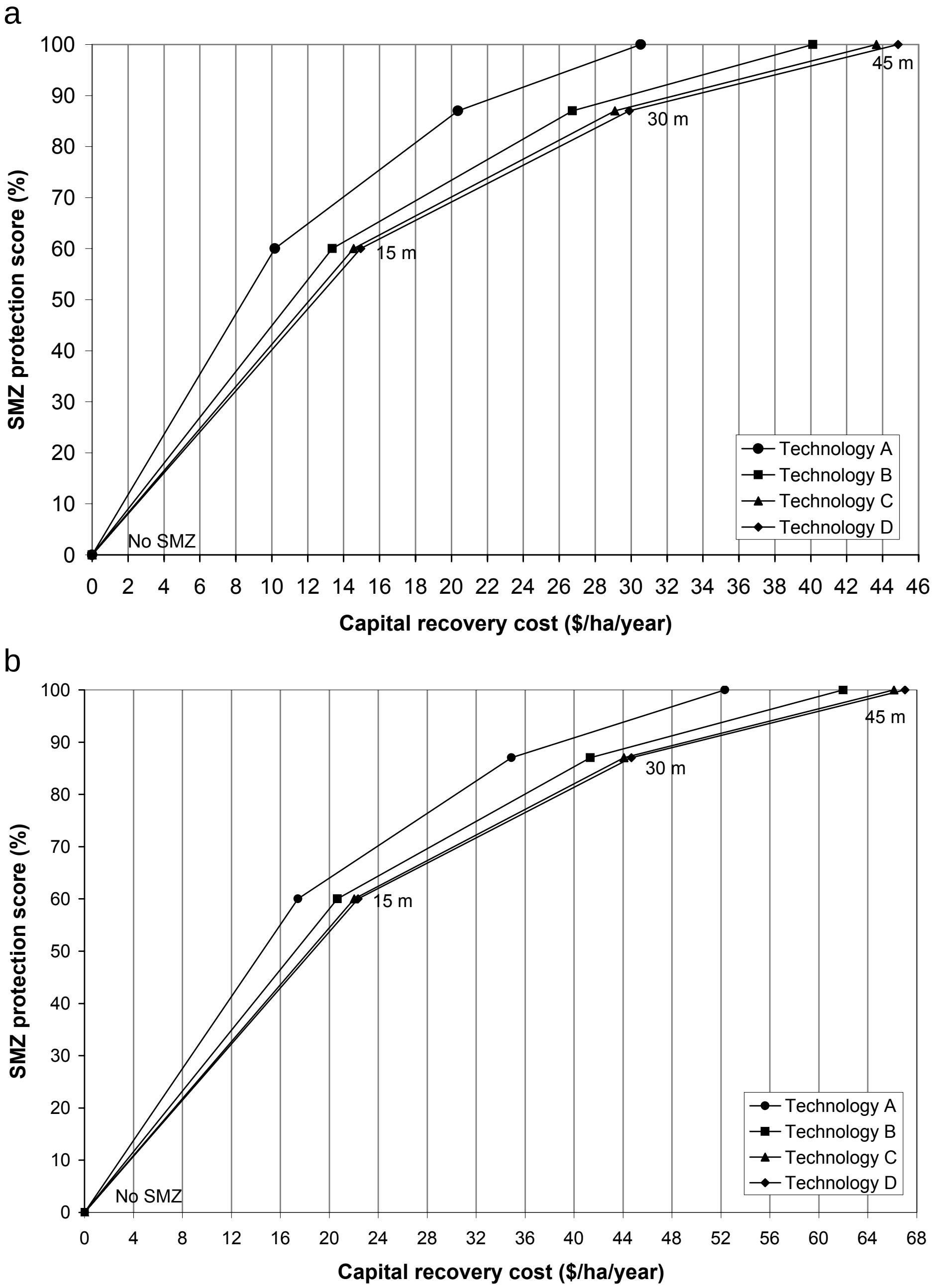

Figure 6.—SMZ protection scores compared with capital recovery costs for the (a) yellow-poplar and (b) mixed hardwood stands under the four harvesting technologies. Symbols and lines represent different logging systems. SMZ protection scores are labeled on corresponding SMZ width (See Table 3 and Page 3 for description of technologies used).

ecological context, capital recovery costs can be viewed as the annual monetary cost required to maintain a particular level of riparian function.

By comparing the capital recovery costs with the SMZ protection score, we can determine the cost-benefit ratio between SMZ width and ecological protection (Fig. 6a and 6b). SMZ protection scores increase with capital recovery costs for both stand types and all logging technologies. Harvesting without an SMZ leaves no timber adjacent to the stream resulting in an SMZ protection score of 0 percent and no capital recovery costs. Retaining a 15 m 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 30 m 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 45 m 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 15 m, 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 15 m SMZ to a 30 m 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 45 m 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 30 m 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 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 management strategies for 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 (45 m) buffers with no volume removed may be required.

Using computer simulations, 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.

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Forest landowners, managers, loggers, land-use planners, and other decision and policy-makers need to understand the opportunity costs and ecological benefits associated with different widths of streamside management zones (SMZs). In this paper, a simulation model was used to assess the opportunity costs of SMZ retention for four different logging systems, two mature hardwood stands, and five levels of streamside zone protection. Results from this assessment suggest that protection costs range from \$252 to \$1,659/ha depending on the SMZ width, the logging technology used to harvest the timber, and the species composition of the tract. A literature review was used to score the ability of different SMZ widths to protect riparian function. We quantified the economic costs and environmental benefits of SMZs. The results showed that to fully protect against post-harvest changes in riparian function, 45-m SMZs are needed. This protection will cost landowners between \$30.54 and \$67.02/ha/year depending on the stand type and logging technology.

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

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