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Harvesting Systems for the Northern Forest Hardwoods

Chris B. LeDoux

Abstract

This monograph is a summary of research results and environmental compliance measures for timber harvesting operations. Data are presented from the Northern Research Station's forest inventory and analysis of 20 states in the northern forest hardwoods. Harvesting systems available in the region today are summarized. Equations for estimating harvesting costs are documented. Safety considerations are compiled along with images of safety equipment and clothing engineered to protect the head, ears, eyes, face, hands, and legs. Mandatory and voluntary best management practices (BMPs) are discussed for streamside management zones (SMZs), patch/structural retention, invasive plant mitigation, and soil protection. Profitability and cost control are addressed. The importance of keeping machines working, exploiting machines' payload capacity, and matching machines to the size of wood being harvested is illustrated. The information offered in this text should be valuable to the harvesting industry and serve as a text for a course in timber harvesting.

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The author has attempted to provide photographs of each logging machine. Most of the photographs used were taken by the author over a period of years. Where photographs were used that were not taken by the author, permission was requested in advance. It is beyond the scope of this text to thank everyone for information and photographs that were used; however, the author robustly thanks all of those that contributed.

Cover Photo

The author observes a clambunk skidder transporting a load of logs to the landing. Photo courtesy of Andrew Whitman, Manomet Center for Conservation Sciences.

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INTRODUCTION

This four-part monograph has been written to help landowners, decisionmakers, and professional loggers understand and use the tools available today to harvest the northern hardwood resource. It is a collection and synthesis of numerous studies of harvesting systems conducted by the author over the years and by many researchers in the hardwood region and should serve as the basis for harvesting system selection, cost and production estimation, safety, environmental compliance, and on-the-ground implementation. It can also be used as a primary source for a course in harvesting systems.

Part I provides a basic review of important Forest Inventory and Analysis (FIA) information about the northern forest hardwood resource (Smith et al. 2004). The information provides a baseline of acreages, ownerships, terrain (percent sideslope), species, volumes, geography, and tree size distributions (diameter at breast height - d.b.h.). The text deals exclusively with the timber resource available in the FIA inventory to avoid complications caused by nonmarket products such as water, wildlife, nontimber products, and a wide array of other forest products and benefits. Transportation networks linking the timber inventory to sawmills, pulpwood, and other timber-consuming facilities are discussed. The current and historic timber consumption demands are addressed to provide the reader with some gauge of the demand versus the supply of northern forest hardwood resources. This type of information can help decisionmakers, landowners, and loggers select harvesting systems.

The harvesting systems commercially available in the region today are presented in Part II in terms of their applicability, cost and production, and environmental impact. The list of harvesting systems documented includes mechanized systems such as CTL (cut-to-length), feller bunchers, forwarders, and clambunk skidders. The list of nonmechanized systems includes traditional rubber-tired skidders, crawler and dozer tractors, small farm tractors, and other small systems such as horses, mules, and winches with chainsaw felling. In-woods chippers and chip transport are also addressed. Types of transportation including trucks and vans are documented. A section on how to estimate the production and cost of harvesting systems includes time study techniques, statistical methods, computer simulation, development of general cost and production equations, and development of user friendly computer software for the public.

Part III summarizes information on safety and environmental compliance—both safety concerns as well as safety equipment and its proper use. The author emphasizes chainsaw safety because most logging systems in use today require chainsaws and most workplace injuries involve chainsaws. Best Management Practices (BMPs) for riparian protection, structural retention, soil protection and disturbance, and invasive species mitigation are discussed. The section on BMPs is included in this text because various owners (including government, commercial industries, and private nonindustrial) require the implementation of BMPs to protect the numerous resources on their lands. Additionally, Sustained Forestry Initiative (SFI) and Certified Forestry Initiative (CFI) programs require the use of various BMPs for certification purposes. Loggers operating on these lands must be familiar with alternative BMPs; they must comply with these requirements safely and responsibly. In the case of BMPs for invasive plant mitigation, where the available guidelines and literature are limited, direction for future studies is provided. This section largely summarizes the safety equipment and regulations, BMPs available and required today, and is not intended to be the final word.

Part IV of the text provides considerations for managers, loggers, and decisionmakers who are involved or are considering becoming involved in the process of harvesting timber from the northern forest hardwood resource. The treatment is general and includes safety training, environmental compliance, legal issues, professional registration, and profitability and cost control. This section includes a discussion of timber sale appraisals and property boundary definitions.

PART I—FOREST INVENTORY AND ANALYSIS OF THE NORTHERN FOREST HARDWOOD RESOURCE

The most basic discussion of a harvesting operation begins with the definition of the tract in question. The tract(s) to be harvested are defined by the geography, terrain, ownership, species composition, volume of wood, tree size distribution, and several other variables including any special consideration for environmental compliance. Terrain will usually dictate the type of harvesting system that should be used on that site. For example, extremely steep terrain will require aerial systems such as helicopters or cable systems. Tracts on more gentle terrain can be harvested by ground-based systems such as cut-to-length machines, feller bunchers, skidders, dozers, and other small systems such as horses, mules, and winches. The tree size distribution will generally dictate the size of the machines needed to harvest the tract.

This section of the text summarizes important FIA inventory information about the northern forest hardwood resource (Smith et al. 2004). The FIA data summarized here provide a onetime snapshot of the current conditions as of the latest inventory. This summary is provided as a baseline example of the forest conditions that loggers, decisionmakers, and policymakers will encounter while planning harvesting operations in the northern forest hardwood resource. Special considerations of how a specific tract must be harvested or the surrounding resources protected may dictate the harvesting system that must be used on that specific tract. For example, a contract that requires that riparian areas or other resources such as shallow soil profiles be protected where the logs or trees to be extracted must be fully suspended as opposed to dragged may dictate the use of helicopters or cable systems.

The northern forest hardwood land base totals 170 million acres, includes 8 million reserve acres, covers 41 percent of the north, makes up 23 percent of the Nation's total forested land base, and has remained relatively stable over the past 40 years (Fig. 1). The majority of the forest is owned by private individuals, 75 percent of the total or 128 million acres. State and local governments manage 28 million acres while the National Forest System cares for another 11 million acres (Fig. 2). Family forest owners control 94 million acres (55 percent of the total), and most family forest land owners hold fewer than 10 acres each (Fig. 3). Hardwood forests predominate with 139 million acres. Maple-beech-birch and oak-hickory forests are the most common with more than 50 million acres each. Most of the softwood forests are spruce-fir; sawtimber-size stands predominate for both hardwoods and softwoods (Fig. 4). The growing-stock volume on the stump is about 218 billion cubic feet, most of it hardwoods; it supplies 17 percent of the Nation's total harvest but almost half (47 percent) of its hardwood saw log harvest (Fig. 5). This vast resource supports a forest products industry that employs more than 450,000 people and contributes more than $100 billion annually to the region's economy. The

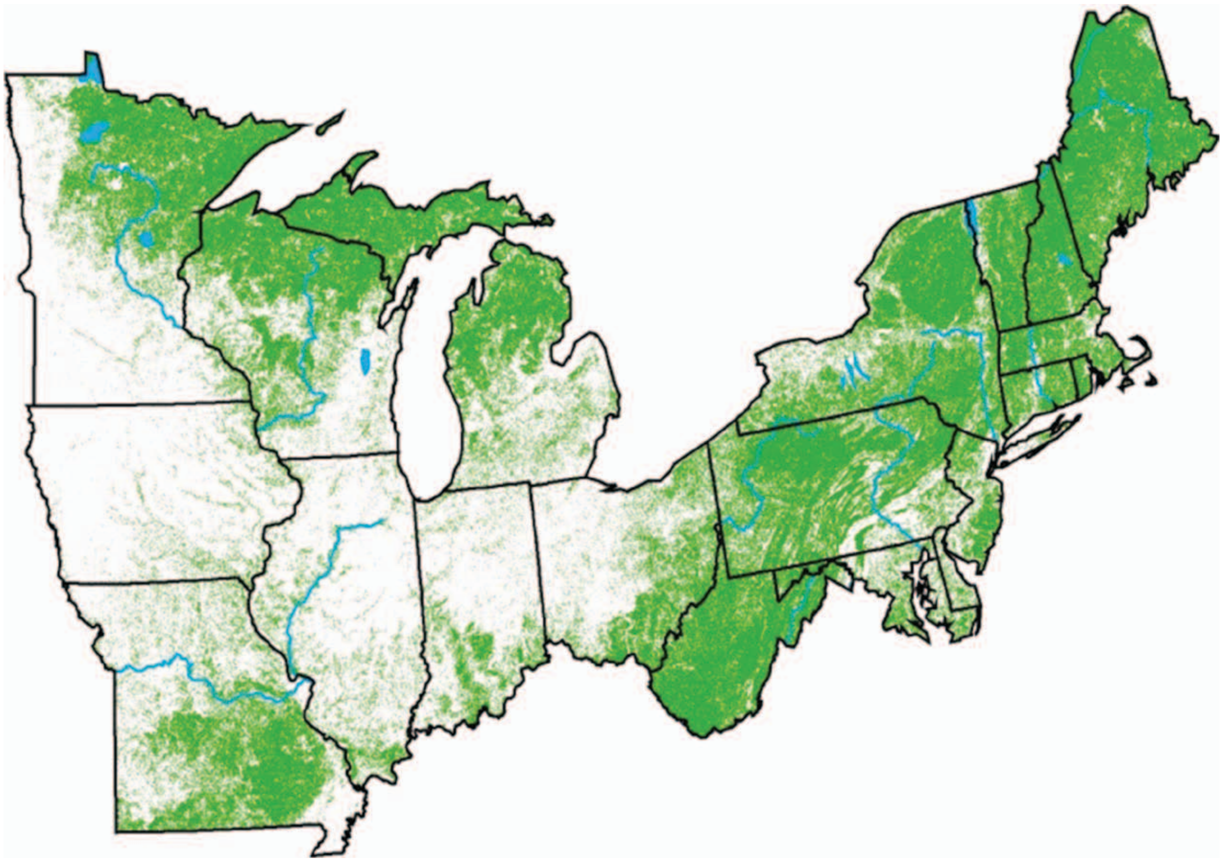

Figure 1.—Map of the northern forest hardwood resource (Smith et al. 2004).

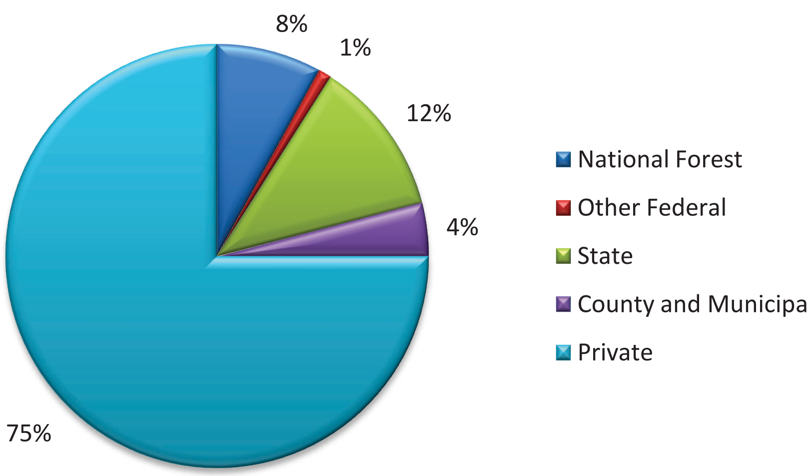

Figure 2.—Forest ownership in the northern forest hardwood resource (Smith et al. 2004).

region grows about twice as much wood as it harvests (Fig. 6). Figure 7 shows the percent of acres by stand diameter class size for the northern forest hardwood resource. The majority of the resource is in large trees 11 inches d.b.h. or more. Table 1 shows the acreage by state and percent sideslope. More than 16,508,300 acres or 9.73 percent of the total forest land is located on sideslopes of 30 percent or higher. Most of the forest land is located on gentle to moderate slopes of 29 percent or less.

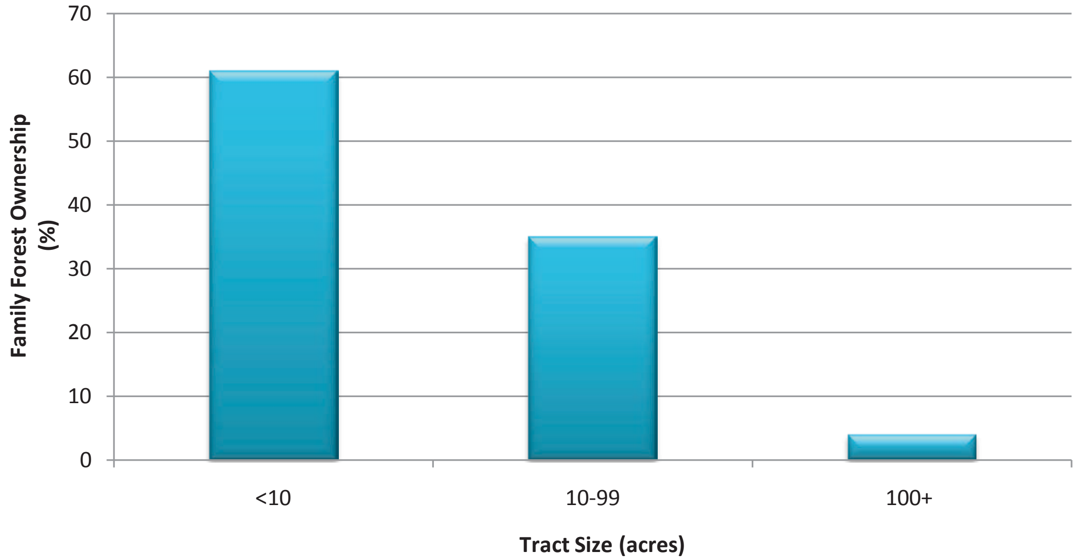

Figure 3.—Tract size of family forest ownerships in the northern forest hardwood resource (Smith et al. 2004).

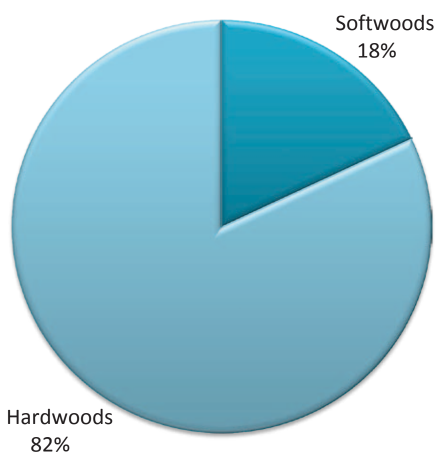

Figure 4.—Forest species composition in the northern forest hardwood resource (Smith et al. 2004).

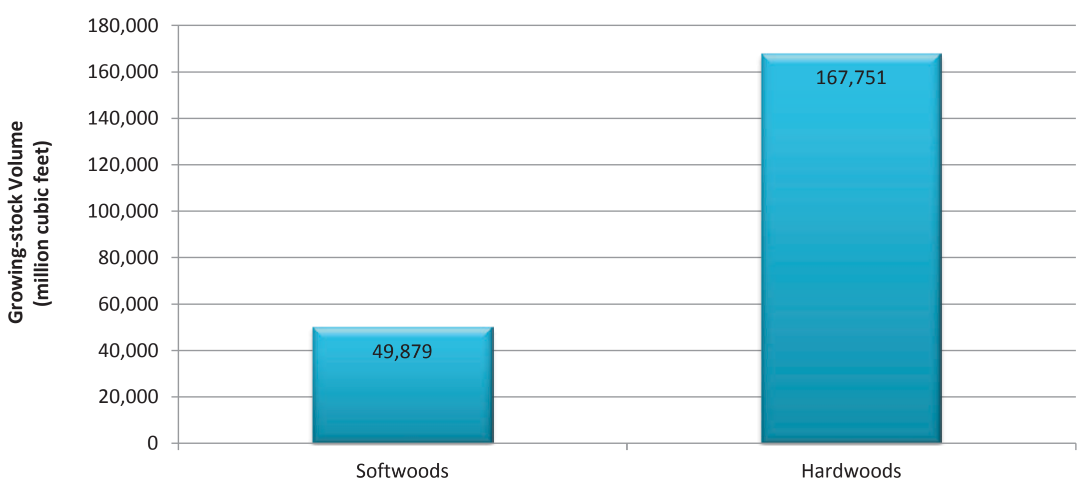

Figure 5.—Growing-stock volume of the major species groups in the northern forest hardwood resource (Smith et al. 2004).

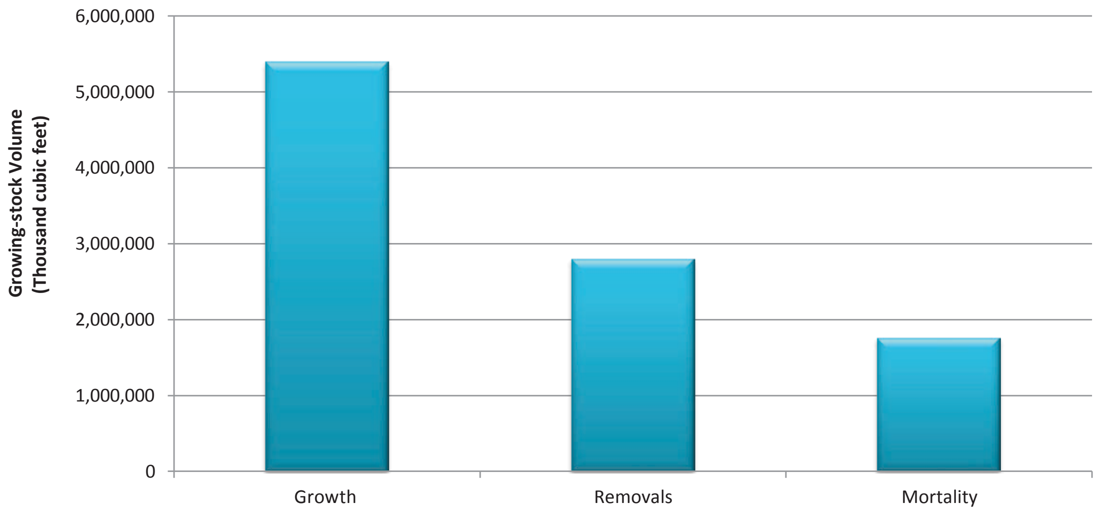

Figure 6.—Net annual growth, removals, and mortality of growing stock in the northern forest hardwood resource (Smith et al. 2004).

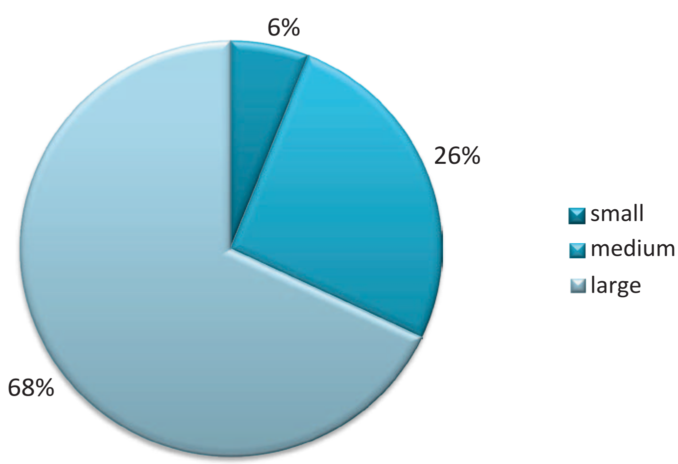

Figure 7.—Percent of acres by stand diameter class size for the northern forest hardwood resource; conditions: large-diameter trees >= 11 inch d.b.h.; medium-diameter trees >= 5 inch d.b.h.; small-diameter trees < 5 inch d.b.h. (Smith et al. 2004).

Table 1.—Acreage by state and percent sideslope intervals for the northern forest hardwood resource (Smith et al. 2004)

		Sideslope percent							
	Total forest land	0-5	5-10	10-15	15-20	20-25	25-30	30-35	35+
	(acres)								
Connecticut	1,859,292	852,630	346,965	236,101	167,900	132,764	40,662	20,159	62,111
Delaware	382,847	378,756	1,422	0	0	2,669	0	0	0
Illinois	4,330,770	2,050,158	796,097	507,903	382,158	208,236	121,931	125,892	138,395
Indiana	4,500,748	2,106,777	740,513	587,586	387,563	224,906	167,945	106,626	178,832
Iowa	2,050,200	759,200	273,300	253,000	240,200	140,300	124,000	102,200	158,000
Maine	17,699,410	11,364,093	2,738,889	1,544,332	770,639	483,559	343,015	171,624	283,260
Maryland	2,565,797	1,352,740	343,962	255,055	199,656	149,264	66,908	52,406	145,806
Massachusetts	3,126,003	1,558,956	566,807	364,753	234,731	151,157	87,920	37,613	124,066
Michigan	19,280,800	10,235,300	7,699,400	537,500	222,800	83,500	64,100	36,100	402,100
Minnesota	16,680,373	10,890,050	4,430,053	435,100	280,300	144,400	72,400	51,500	376,570
Missouri	13,991,968	4,372,906	3,052,274	2,454,972	1,685,480	1,051,464	685,476	327,996	361,400
New Hampshire	4,818,264	1,542,759	1,031,627	786,363	544,853	321,019	241,604	96,839	253,201
New Jersey	2,132,162	1,578,447	195,351	103,999	82,844	64,251	41,089	16,265	49,917
New York	18,431,988	6,992,548	2,606,854	2,214,426	1,421,871	884,729	706,186	454,125	689,197
Ohio	7,855,170	2,913,490	784,606	878,931	788,974	751,592	590,443	358,290	788,844
Pennsylvania	16,904,653	4,893,137	2,937,700	2,380,027	1,834,496	1,275,595	1,027,980	573,029	1,982,689
Rhode Island	385,364	233,816	64,433	49,814	14,647	957	11,076	0	10,620
Vermont	4,618,076	1,028,543	704,567	720,496	694,603	415,551	339,998	256,920	457,399
West Virginia	12,107,993	1,058,327	569,504	771,997	892,438	1,103,318	1,159,448	1,272,127	5,280,834
Wisconsin	15,963,026	10,570,757	2,268,181	1,083,391	684,786	378,033	272,508	216,535	488,835
Total	169,684,903	76,733,388	32,152,505	16,165,744	11,530,939	7,967,264	6,164,689	4,276,246	12,232,077

Figure 8.—Team of small horses with rigging attachments. Photo courtesy of North Carolina Outdoors.

PART II—HARVESTING SYSTEMS

The harvesting systems currently available to log the northern forest hardwood resource range from highly expensive helicopters and mechanized machines such as cut-to-length systems and feller bunchers to less expensive systems such as horses, mules, and small winches. In this section of the text, we discuss and document each of these systems. We begin with the nonmechanized and less expensive systems and work our way to the more complicated and expensive ones.

Figure 9.—Operator steering a team of small horses with rubber-tired bunk pulling some logs. Photo courtesy of Mountain Laurel Review.

Horses and other livestock have been used to transport logs from the stump to the landing for decades (Fig. 8). This approach generally couples chainsaw felling and bucking with livestock doing the skidding. The approach is somewhat labor intensive and requires that trees be felled, limbed, and bucked before skidding. The logs are skidded or dragged to the landing by a single horse or mule or by a team (Fig. 9) of animals depending on the size of the wood being harvested. One or more woods workers use rigging consisting of leather reins, metal chains, and hooks to steer and control the team of livestock during the extraction process. In many applications, a woods worker does the felling, steers, and controls the team as a one person operation. In some applications, a team of woods workers operate together, one person doing the felling, limbing, and bucking while the other person does the skidding, tends to the

Figure 10.—Small chainsaw-powered winch. Photo courtesy of Stihl and Lewis.

livestock, and takes care of the landing operations such as sorting and decking. Clearly, bigger logs require bigger animals or teams of animals to transport the logs to the landings. Although the system is associated with low productivity, it is relatively low cost, and makes minimal impact to the site with respect to soil disturbance, compaction, and residual tree damage. Horses, mules, and other livestock play a minor role in the harvesting of the hardwood resource.

Portable winches come in many forms and sizes and can be used for a variety of tasks, such as skidding logs, pulling trees over, loading and unloading logs, pulling rigging, bunching trees or logs, cleaning streams, and when coupled with blocks and additional rigging, they can be used to move equipment in the woods or at the landing (Fig. 10). They are relatively low cost, low productivity, low impact, and very labor intensive. Some winches can be powered by chainsaws or with small engines (LeDoux et al. 1987) that are part of the winch. Small portable winches play a small role in the harvest of northern forest hardwood resources.

Small farm tractors can be equipped with winches operating off the three-point hitch or with grapples that are attached to an arch mounted at the rear of the tractor (Figs. 11, 12). Small farm tractors are relatively inexpensive, low impact, low productivity, and somewhat labor intensive in that operators or their helpers move the rigging and hook and unhook the logs (Huyler et al. 1994; Huyler and LeDoux 1989, 1990). The trees in a small farm tractor operation are usually felled, bucked, limbed, and processed using chainsaws.

Rubber-tired skidders are the major workhorse used to log the northern forest hardwood resource. They come in a wide array of sizes, are articulated, four-wheel driven, with multiple options for tires and chains (Erickson et al. 1991b). They can be equipped with cable drum sets

Figure 11.—Small farm tractor with tire chains and blade in the front. Photo courtesy of Neil Huyler, U.S. Forest Service, retired.

Figure 12.—Large, rubber-tired, four-wheel drive farm tractor with rear-mounted double winch, remote control, and bucket in the front. Photo by Chris LeDoux, U.S. Forest Service.

and chokers (Fig. 13) or with grapples (Fig. 14) for skidding or dragging the trees or logs. Some applications require the use of wide or high flotation tires for operation in wet, soft soils, or swampy conditions (Fig. 15). Trees can be transported tree length or bucked into logs (LeDoux et al. 1993). This system requires a network of skid trails over the harvest tract so that the skidder can easily move within the stand or tract to build a turn of logs for transport to landings where the trees or logs can be further processed, sorted, and loaded onto trucks for transport to wood processing centers. Skidders are most applicable on gentle to moderately steep terrain, can create soil disturbance, and may cause several levels of soil compaction especially on skid trails that experience multiple passes (Wang et al. 2006, 2007). Some applications require

Figure 13.—Rubber-tired skidder with drum set, arch attachment, tire chains, and wire rope chokers at the landing (notice slash/debris mat on heavily used skid trail). Photo by Chris LeDoux, U.S. Forest Service.

Figure 14.—Rubber-tired skidder with grapple attachment, tire chains, and blade in the front with payload. Photo by Chris LeDoux, U.S. Forest Service.

Figure 15.—Rubber-tired skidder equipped with grapple and high flotation tires. Photo courtesy of Tigercat.

preplanned skid trails and roads where the skidder stays on the trail and the winch line is pulled to the trees or logs and hooked or choked, then winched back to the skidder and transported to landings (Erickson et al. 1991a). This approach is used primarily when the objective is to minimize soil disturbance and compaction. Logging operators are advised to match the machine size to the size of wood being extracted to minimize soil disturbance and compaction, keep residual stand damage to acceptable levels, and to minimize skidding costs (LeDoux 2000). Skidders can be equipped with a small blade in the front that can be used to push logs when building a turn or hitch or for maneuvering logs at the landing or for decking. Trees are generally felled, bucked, limbed, and processed using chainsaws in most cable-skidder applications but may be felled, bunched, and processed by feller bunchers when skidders equipped with grapples are used to transport the wood.

Figure 16.—Small, track-mounted crawler dozer with winch in back and blade in front working a log deck. Courtesy of Montgomery County Community College, PA.

Crawler tractors and bull dozers are also used to extract logs or trees that are chainsaw or feller buncher processed. Generally, if the trees are cut by a feller buncher and bunched, the dozer will be equipped with a grapple to maximize payload. These are generally track mounted and can be configured with winch drum sets and chokers (Fig. 16) or with grapples (Fig. 17). Many crawler systems also have a blade attachment in the front that can be used to excavate, build truck roads and skid trails, push logs, and sort and deck logs at the landing; it can be equipped with a trailing arch (Fig. 18). The additional advantage of the blade is that it can be used to stabilize the machine while winching logs on steep terrain. Dozers are generally slower than skidders, but they can be used for multiple purposes such as skidding, road building, clearing landings, and general road, deck,

Figure 17.—Medium, track-mounted crawler dozer with grapple in back and blade in front skidding a turn of logs. Photo courtesy of Caterpillar.

Figure 18.—Small, track-mounted crawler dozer with winch in back, blade in front, pulling a track-mounted arched bunk. Photo courtesy of International Tractor Co..

Figure 19.—Large, self-leveling, track-mounted cut-to-length machine with felling and delimbing head. Photo courtesy of Andrew Whitman, Manomet Center for Conservation Sciences.

and landing maintenance. Dozers and crawlers are generally used in gentle to moderately steep terrain but can be used in steeper terrain applications than skidders because they are track mounted and have a lower center of gravity than most rubber-tired skidders. They create about the same levels of soil disturbance and compaction as rubber-tired skidders, but in some cases may cause less soil compaction depending on the width of the track they are equipped with. Generally, with all factors equal (size of skidder versus crawler, length of skid distance, payload size, and terrain), rubber-tired skidders will outproduce crawler tractors simply because rubber-tired skidders can travel the same distance faster. Dozers and crawlers usually require a network of skid roads and trails like rubber-tired skidders, but because they can use the blade to move obstacles out of their path and because they are track mounted, they may in some cases require a less dense network of trails than rubber-tired skidders.

Mechanized systems such as cut-to-length and feller bunchers are also used to harvest the hardwood resource (Figs. 19, 20). These machines come in various sizes and can be configured with various choices for the felling, delimbing, and debarking heads (Figs. 21, 22) (Huyler and LeDoux 1996, 1997a, 1997b, 1997c, 1998, 1999; LeDoux and Huyler 1999, 2000,

Figure 20.—Large, self-leveling, track-mounted feller buncher with accumulating felling head. Photo courtesy of John Umstead, West Virginia University.

Figure 21.—Medium, track-mounted cut-to-length machine with felling, delimbing, and debarking head (notice log bundles behind and brush/debris mat in front). Photo courtesy of Kurt Gottschalk, U.S. Forest Service.

Figure 22.—Medium, track-mounted cut-to-length machine with felling, delimbing, and debarking head (notice log piles behind the machine). Photo courtesy of Kurt Gottschalk, U.S. Forest Service.

2001). These systems are generally coupled with rubber-tired skidders with grapples, dozers and crawlers with grapples, clambunk skidders, or forwarders to transport the logs or trees to landings or central processing areas (LeDoux 2010). These systems are best applied on gentle to moderately steep terrain, are expensive, and have high production rates. The cut-to-length system fells the tree, delimbs, bucks the trees into logs, debarks the stem, can sort the wood

Figure 23.—Small, track-mounted feller buncher with accumulating felling head. Photo courtesy of John Umstead, West Virginia University.

Figure 24.—Medium, rubber tire-mounted feller buncher with accumulating felling head felling a tree. Photo courtesy of John Deere.

as desired, and can build bunches according to the capacity of the machine that is going to be used for skidding. The feller buncher system fells the trees, can accumulate multiple stems in the head (Figs. 23, 24, 25), can be used to sort the wood as required, and builds bunches for future transport by the skidding machines. These machines are generally track mounted, with self-leveling cab, and are equipped with a boom that can extend the felling head a substantial distance beyond the machine itself. They are generally very ergonomic and highly

Figure 25.—Medium, rubber tire-mounted feller buncher with accumulating head in travel mode. Photo courtesy of John Deere.

maneuverable. They are low impact with respect to soil disturbance and compaction, residual stand damage, and overall impact to the site (LeDoux and Huyler 1999, Wang et al. 2005b). The cut-to-length system can use the limbs from the delimbing process to form a mat to travel on that further mitigates soil disturbance and compaction. These machines have an additional advantage in that both can fell the tree, eliminating a person on the ground with a chainsaw. Use of chainsaw felling is the most popular method for felling trees but can be very dangerous. Felling trees with these mechanized systems minimizes or eliminates most of the hazards and risks associated with manual chainsaw felling (Bell 2002). For example, manual felling of snow- or ice-ladened trees is extremely dangerous, if not impossible. However, such trees are no obstacle for mechanized systems such as feller bunchers or cut-to-length systems.

Figure 26.—Track-mounted clambunk skidder with boom attachment working on log deck. Photo courtesy of Andrew Whitman, Manomet Center for Conservation Sciences.

Clambunk skidders are commonly used in association with mechanized systems such as cut-to-length and feller bunchers (Fig. 26). They are generally track mounted and are equipped with a bunk and large grapple or clam attached to the back of the skidder. Some applications of this machine also have a boom that can be used to build loads, sort logs, build decks, and

Figure 27.—Small forwarder with tracks in the rear, rubber tires in the front with chains, and boom, loading in the woods. Photo courtesy of Neil Huyler, U.S. Forest Service, retired.

maintain landings. Generally, clambunk skidders are used to move the bunched logs created by the cut-to-length machine or feller buncher to landings or central log processing areas. They are moderately expensive, relatively low impact, and very productive. The major trails used to travel to and from the landing and log processing areas can be severely impacted. They can move large volumes of wood in a very short time period. They are suited for gentle to moderately steep terrain and can be used to transport logs long distances. They are limited somewhat in their ability to maneuver because of their size. One end of the log rests on the bunk and is held there during the skidding process while the other end of the log is dragged on the ground.

Forwarders are generally used to transport logs or trees in association with mechanized and non-mechanized systems (Fig. 27) when the logs or trees to be extracted have been prebunched in the woods. Forwarders come in various sizes with a range of payloads (Figs. 28, 29, 30). Forwarders can be equipped with rubber tires (Figs. 30, 31) and chains or track mounted and are usually equipped with a boom with a grapple attachment for self loading and unloading.

Figure 28.—Very small, self-propelled, track-mounted forwarder with operator and steering bar with control. Photo by Chris LeDoux, U.S. Forest Service.

Figure 29.—Small forwarder with rubber tires front and rear, boom, blade in the front, loading in the woods. Photo courtesy of Neil Huyler, U.S. Forest Service, retired.

Figure 30.—Large forwarder with rubber tires and boom, loading in the woods. Photo by Chris LeDoux, U.S. Forest Service.

Figure 31.—Small forwarder with rubber tires and chains in the front, tracks in the rear, boom, blade in the front, unloading and sorting at the landing. Photo courtesy of Neil Huyler, U.S. Forest Service, retired.

They are a good alternative to rubber-tired or dozer skidding when the skid distances are very long and the terrain is gentle to moderately steep (Erickson et al. 1992). They can sort logs or trees by species or product type in the woods while loading or at the landing while unloading (Fig. 31). They are slower than rubber-tired skidders, but they can transport bigger payloads than skidders or dozers. The wood is carried on bunks and not dragged on the ground as by horses, rubber-tired skidders, crawler tractors, or clambunk skidders. They range in cost from moderate to expensive, have relatively low impact on the site, but do create significant soil disturbance and compaction on the most heavily traveled skid roads and trails.

Figure 32.—Medium cable yarder with 30-foot tower mounted on rear-drive flatbed truck. Photo by Chris LeDoux, U.S. Forest Service.

Cable systems are generally used on steep terrain where ground-based systems would not be appropriate or where road construction is constrained by environmental or other concerns (LeDoux 1983; LeDoux and Butler 1981a, b). For example, contract requirements that require logs or trees to be fully suspended during the extraction process may dictate the use of cable systems (Baumgras and LeDoux 1985, 1995; Baumgras et al 1994; Huyler and LeDoux 1995; LeDoux 2006; LeDoux and Baumgras 1990; LeDoux and Whitman 2006, 2007, 2008; LeDoux et al 1990; Peters and LeDoux 1984, 1990). Cable yarders come in various sizes (Huyler and LeDoux 1997a, b; LeDoux 1984a, b, LeDoux 1985a, b; LeDoux 1986a, b; LeDoux 1987a, b; LeDoux 1989; LeDoux and Peters 1985; LeDoux and Starnes 1986; LeDoux et al. 1986, 1991, 1994, 1995a; Olsen et al. 1983; Sherar and LeDoux 1989;) with a range of payload capacities, yarding distances that can be achieved, and tower heights, and they can be mounted on rubber tires, tracks, on the bed of trucks, or on platforms that rest on sleds that can be moved from landing to landing (Figs. 32, 33). The machine generally rests on a landing area located on a road, and the wood is yarded uphill or downhill to these landings. The machine is generally accompanied by a shovel loader located at the landing that removes the yarded logs or trees from underneath the skyline; sorts, decks the wood;

Figure 33.—Medium cable yarder with 30-foot tower mounted on flatbed six-wheel-drive truck with remote control umbilical cord. Photo by Chris LeDoux, U.S. Forest Service.

and loads trucks that are headed to sawmills, pulp mills, or other wood processing centers. On some very narrow roadbeds where landings are too small to accommodate a shovel loader, a skidder or crawler is used to swing the yarded logs or trees from underneath the skyline to an alternative processing area. Cable logging systems are generally expensive, moderately to highly productive, and result in little to no impact to the site. Cable systems require a goodly amount of preplanning of roads, landings, corridors, guyline, and skyline anchors before any actual yarding of logs takes place. Trees are usually pre-felled and bucked before yarding operations.

Helicopters are generally used where road building or related disturbance is simply not acceptable and where the timber to be extracted is of high volume and value (LeDoux 1975, Wang et al. 2005c). For example, on very steep slopes or on sites where the soils are fragile or swampy, and where these conditions are matched by large volumes of wood of high value, it sometimes becomes economically feasible to extract the timber with helicopters. Helicopters are sometimes used where typical road building operations would impact the visual resource or where large volumes of wood must be extracted to prevent additional loss due to stain or decay. For example, following a major weather event such as a tornado or hurricane that blows down large volumes of valuable timber, helicopters are often used to extract the wood before stain or other value degrading agents move in before any road building can be accomplished. Helicopters come in a variety of sizes with alternative payloads (Fig. 34). They can transport high volumes of trees or logs quickly so it is crucial to plan landing operations so that logs or trees are handled as quickly as they arrive at the landing to avoid congesting the landing area and causing costly delays. The felling and hooking crews have to work closely together so that logs or trees are bucked and hooked to avoid exceeding the capacity of the helicopter being used. It is common practice to pre-fell and buck the timber and pre-choke several loads at the hooking site ahead of extraction operations. Helicopters are very expensive to own and operate, are highly productive operations, and result in little to no impact to the logging site. Helicopter operations require a substantial amount of planning prior to any on-the-ground event.

Figure 34.—Helicopter with large payload capacity. Photo by Chris LeDoux, U.S. Forest Service.

Production and Cost Estimation

Clearly, loggers and logging contractors must know what their logging machines can produce and at what cost if they are to compete in the timber harvesting environment for logging chances and make a profitable return on their investments. Having a good handle on what machines are capable of producing and what the related cost is per unit produced for the range of on-the-ground operating conditions allows loggers to bid on logging sales, make a profit, and stay in business. Many operators rely on their experience over time to develop estimates of production and cost for their machines. Many operators only work on tracts with large valuable saw logs or veneer type timber products, pulpwood, firewood, or fiber products exclusively, while others work on tracts where the product mix ranges from low value firewood to high value prime and veneer logs. In any case, loggers must have a good idea of what their machines are capable of producing and at what cost.

An excellent method for estimating production and cost is to conduct time studies of the respective machine(s) and operating(s) conditions. Time study techniques are well developed and have been used in many industrial settings for years to develop estimates of production and cost. The basic procedure involves defining the work elements that are involved in the process and then simply observing and using a stopwatch to record the time it takes to complete a given task. For example, the process of forwarding logs from the stump to the landing may be segmented into the following discrete components: traveling out unloaded, sorting in the woods, loading, traveling back loaded, unloading, decking, and sorting at the landing. Delays may be segmented, observed, and timed as desired. For example, the forwarder may need to move obstacles such as trees out of the travel path on its way to the landing or on its way to the woods. The forwarder may need to wait at the landing for other machines to move out of its way before it can proceed to unload or return to the woods. Then there is always an array of mechanical delays such as a failure of a hydraulic hose or the need for the operator to take a break. Once the element components and delays are defined, it may be useful to define variables that are independent of the respective component but that may influence or affect the time consumed in that segment. For example, the time required to complete the travel loaded task may be influenced by the distance that the loaded machine must travel between the loading point and the landing, the size of the load being transported, the conditions of the skid trail, the slope of skid trail, and the other traffic using the same trail. Although many time studies have been conducted and numerous variables have been investigated, several variables have proven to have a direct statistical correlation to the time required to complete a given task. These variables include the distance traveled, lateral distance traveled, logs per turn, volume per turn, volume per log, percent sideslope, volume per tree, average d.b.h. of the material cut, and volume per acre removed. Distance traveled is simply the distance that a machine must travel empty or loaded during the extraction process. For ground-based systems, this distance is measured along the skid trails traveled to and from the landing. For cable systems, this distance is measured along the skyline corridor being used as the extraction path. The lateral distance can be the distance the boom must reach out to cut a tree as in the case of feller bunchers and cut-to-length harvesters. In the case of cable systems, this distance is measured as the distance that chokers and mainline must be pulled laterally from the skyline or carriage to hook a turn of logs. Logs per turn are defined as the number of logs that form a given turn/hitch/load for both ground-based and cable systems. The volume per turn is defined as the sum total of the board-foot or cubic-foot volume of the logs that form that turn. Volume per log is defined as the average volume of the logs that form a turn. Volume per tree or piece size is defined as the volume of the tree being processed. The d.b.h. is the average diameter of the trees being harvested. The volume per acre is the board-foot or cubic-foot volume that is being removed per unit area.

For a forwarder, this series of events and the variables involved can be expressed as a mathematical relationship (LeDoux and Huyler 1992). This relationship could be expressed as the travel loaded time being the dependent variable and distance, load size, trail condition, and trail slope being the independent variables. In other words, the time to travel loaded is dependent on the randomly occurring distance, load, trail slope, trail and condition. In mathematical terms, these relationships may be expressed as $y = f(x_1, x_2, x_3, x_4)$ where y= the time it takes to travel loaded, x_1= distance traveled, x_2= load, x_3= trail slope, and x_4= condition of the skid trail. After many cycles are observed and timed, we have a database of times and causal variables that lend themselves to modeling using statistical techniques such as regression theory. Generally, a regression equation is fit to the data and we are then able to predict or estimate the time or production for the set of modeled conditions.

It is virtually impossible to time study or sample every combination of machine and operating condition. Operating on-the-ground conditions are extremely variable and subject to change as the terrain, tree size, and other variables vary from site to site. Computer simulation becomes a valuable tool that allows us to simulate conditions that are beyond the limited sample size (Baumgras and LeDoux 1992a, b, c; Baumgras et al. 1993; LeDoux 1983, 2002; LeDoux and Baumgras 1989; LeDoux and Butler 1981a; Wang and LeDoux 2001; Wang et al. 2003, 2005a). For example, time study data may be available for a limited set of terrain, stand conditions, and log sizes. Simulation techniques may be used to explore, simulate, and develop production and cost estimates for sets of conditions that are outside the available data sets of terrain, stand conditions, and log sizes. Simulation has been used for many years to develop estimates/estimators for a wide range of machine(s) and stand combination(s).

Each simulated result is generally considered an individual data point and as such the results from multiple simulation runs can be expressed mathematically in equation form and used to predict production and cost for a wide range of machines and operating conditions. Time study data blended with simulation techniques become a powerful tool that can be used to estimate production and cost for multiple combinations of machines and operating conditions. Tables 2 to 9 summarize the results of such equations for estimating the stump-to-mill cost of harvesting for multiple sets of conditions and machines. Table 2 contains equations for estimating costs for chainsaw felling, bucking, limbing, hauling, forwarding, and loading. The hauling cost can

Table 2.—Equations for loading, hauling, forwarding, and chainsaw felling, bucking, and limbing components

Variable	Equation	Variable Limits
Loading	$\$/ft^3 = -0.04282 + 1.02238 * (1 / DBH)$	DBH: 6-22
Hauling	$\$/ft^3 = (-0.71667 + 0.08333 * TC^a + 0.37629 * RC^b) / 100 * Mileage$	
Forwarding	$\$/ft^3 = 110 / (408.9482 + 0.00241 * TP^c * SYD - 0.0006 * SYD^2)$	
Felling, Bucking, & Limbing	$\$/ft^3 = 0.43744 - 0.11407 * LN(DBH)$	DBH: 6-24

[a]TC = Truck Class, see Table 4
[b]RC = Road Class, see Table 3
[c]TP = turn payload (ft^3) = 400
DBH = average diameter at breast height (in.)
SYD = slope yarding distance (ft)

Table 3.—Road class by design speed

Class	Design speed (miles/hour)
2	35+
3	25
4	16
5	8
6	4

Table 4.—Truck class by body type

Class	Body Type
5	Flat bed, 4x2, single axle
4	Flat bed, 6x4, tandem axle
3	Truck tractor, 4x2, single axle with tandem trailer
2	Truck tractor, 6x4, tandem axle with tandem trailer
1	Truck tractor, 6x4, tandem axle with tandem 30- to 35-foot trailer w/additional 15- to 20- foot trailer

be estimated for several road class (Table 3) and truck type (Table 4) combinations. Table 5 contains equations for estimating the cost of ground-based skidding with several different skidders and small farm tractors. The skidders range in horsepower from 60 to 120. The farm tractors include small tractors such as the Pasquali 993, medium tractors such as Holder A60F, and large tractors such as the Massey Ferguson. Table 6 contains an equation for estimating the cost of a grapple skidder. Table 7 contains equations for estimating the cost of felling and bunching for a small and large feller buncher. Table 8 contains equations for estimating the cost of a small and large cut-to-length machine. Table 9 contains equations for estimating the yarding cost for several cable yarders. The choice of yarders includes some very large machines such as the Skylok 78 and some very small machines such as the Bitterroot with a range of machines in between. The limits of the variable equations should be observed religiously or the equations may produce estimates that are mathematically sound but unreliable from a practical standpoint. The results from these time studies, statistical analysis, computer simulation, and development of production and cost estimators can be packaged in user friendly computer software programs for mass distribution and use such as WCOST (Fight et al. 1984) and ECOST (Baumgras and LeDoux 1992a, b, c; LeDoux 1985b, 1986a, 1987a, 1988, 1989; LeDoux and Baumgras 1989; LeDoux and Kosir 1989; LeDoux et al. 1986; Wang and LeDoux 2003). For users who wish to develop their own algorithms, the equations in this text may be incorporated into spreadsheet software or other methods as desired. In either case the variable limits must be observed for the equations to produce reliable results. These programs can be run on just about any type of computer and can be linked with other software programs to develop integrated software that can be used for forest planning and optimization of integrated decisions such as MANAGEPC (LeDoux 1986c), PROFITPC (LeDoux et al. 1989), FOREX (LeDoux et al. 1995b), and THINEX (LeDoux et al. 1998, 2003). The programs MANAGEPC, PROFITPC, FOREX, and THINEX were developed primarily

Table 5.—Simulated, delay-free, ground-based, skidding cost equations by skidder/tractor

Skidder/Tractor	Equation	Variable Limits	
Pasquali 993	$\$/\mathrm{ft}^3 = 0.1804113 + 0.0146528 \ast DBH + 0.000001948 \ast VOAC - 0.0021978 \ast VPL + 0.0000635 \ast SYD - 0.0058381 \ast VPT + 0.0073219 \ast LPT$	DBH:	7 to 24
		SYD:	446.4 to 1511.5
		VOAC:	334 to 4121
		VPL:	5.82 to 20.01
		VPT:	25.4 to 38.2
		LPT:	2.05 to 5.04
Holder A60F	$\$/\mathrm{ft}^3 = 0.4067681 - 0.0103927 \ast DBH + 0.0000008024 \ast VOAC + 0.0022703 \ast VPL + 0.0000577 \ast SYD - 0.0058798 \ast VPT + 0.006546 \ast LPT$	DBH:	5 to 29
		SYD:	494.2 to 1554.2
		VOAC:	334 to 5160
		VPL:	5.82 to 30.8
		VPT:	29.1 to 65.3
		LPT:	1.93 to 6.71
Massey Ferguson	$\$/\mathrm{ft}^3 = 0.2210557 + 0.0002437 \ast DBH + 0.0000002598 \ast VOAC + 0.0001181 \ast VPL + 0.0000438 \ast SYD - 0.0024174 \ast VPT + 0.0039977 \ast LPT$	DBH:	5 to 32
		SYD:	494 to 1554.3
		VOAC:	334 to 10599
		VPL:	5.82 to 75.07
		VPT:	29.9 to 75.1
		LPT:	1.0 to 6.69
Samé Minitaurus	$\$/\mathrm{ft}^3 = 0.2757052 - 0.0010672 \ast DBH - 0.0000006278 \ast VOAC - 0.0002746 \ast VPL + 0.00003963 \ast SYD - 0.0028276 \ast VPT - 0.0040634 \ast LPT$	DBH:	5 to 32
		SYD:	493.9 to 1603.3
		VOAC:	334 to 10599
		VPL:	5.82 to 76.16
		VPT:	29.7 to 78.1
		LPT:	1.0 to 6.69
JD 440C	$\$/\mathrm{ft}^3 = 0.1654157 + 0.0137012 \ast DBH + 0.0000008906 \ast VOAC - 0.001362 \ast VPL + 0.00004815 \ast .SYD - 0.0027067 \ast VPT + 0.0024094 \ast LPT$	DBH:	5 to 32
		SYD:	486.9 to 1612
		VOAC:	334 to 10600
		VPL:	5.82 to 113.98
		VPT:	28.9 to 128.2
		LPT:	1.08 to 6.64
JD 540B	$\$/\mathrm{ft}^3 = 0.43486 - 0.0201429 \ast DBH + 0.0000005772 \ast VOAC + 0.002606 \ast VPL + 0.00004743 \ast SYD - 0.0015778 \ast VPT - 0.0145491 \ast LPT$	DBH:	5 to 32
		SYD:	480.4 to 1616.3
		VOAC:	334 to 10599
		VPL:	5.82 to 127.77
		VPT:	29.4 to 168.1
		LPT:	1.27 to 6.64
JD 640D	$\$/\mathrm{ft}^3 = 0.3415523 - 0.0072889 \ast DBH + 0.000001086 \ast VOAC + 0.0012704 \ast VPL + 0.0000495 \ast SYD - 0.001875 \ast VPT - 0.0058284 \ast LPT$	DBH:	5 to 32
		SYD:	457.7 to 1627.4
		VOAC:	334 to 10599
		VPL:	5.82 to 127.77
		VPT:	29.44 to 186.6
		LPT:	1.27 to 7.82

DBH = average diameter at breast height (in.)
SYD = slope yarding distance (ft)
VOAC = volume per acre (ft^3)
VPL = volume per log (ft^3)
VPT = volume per turn (ft^3)
LPT = logs per turn

for research purposes. ECOST, a computer program developed by the author for estimating stump-to-mill costs of cable logging, conventional ground-based skidding, cut-to-length, feller-buncher systems, forwarding, and several small farm tractors for logging a wide range of eastern hardwoods, incorporates the results from Tables 2 to 9 and is now available for downloading at: http://www.nrs.fs.fed.us/tools/software/.

Table 6.—Simulated, delay-free, grapple skidding equation (LeDoux and Wang, in review)

Machine	Equation	Variable Limits
Timberjack 460	$\$/ft^3 = 0.65 * ((82.17 / (466.49 – (0.13*SYD^a) + (3.76*Pl^b) – (0.003*Pl^2) – (0.36*BS^c) + (0.003*BS^2))))$	SYD: 400 to 1800 Pl: 50 to 250 BS: 30 to 270

[a]SYD = slope yarding distance (ft)
[b]Pl = pay load (ft^3)
[c]BS = bunch size (ft^3)

Table 7.—Simulated, delay-free, felling and bunching cost equations by feller buncher (LeDoux and Wang, in review)

Machine	Equation	Variable Limits
Timbco 425	$\$/ft^3 = 119.17 / (1087.1828 + 38.0275 * TreeVol^a + 0.1865 * VOAC)$	DBH: 4 to 30 VOAC: 334 to 10600
Timbco 445	$\$/ft^3 = 138.33 / (633.3737 + 63.9942 * TreeVol + 352162.052 * (1 / VOAC))$	DBH: 4 to 30 VOAC: 334 to 10600

[a]TreeVol = tree volume (ft^3)
If DBH = 4 then TreeVol = 1.76; If DBH = 5 then TreeVol = 2.37; If DBH = 6 then TreeVol = 4.72 Else TreeVol = -32.0924 + 5.529*DBH
VOAC = volume per acre (ft^3)

Table 8.—Simulated, delay-free, cut-to-length cost equations by harvester

Machine	Equation	Variable Limits
Timbco T425	$\$/ft^3 = 146.7 / (7830 + 270.77 * DBH - 1.88 * DBH * HT^a - 642.51 * DC^b + 11.44 * DC * DC)$	DBH: 5 to 20
JD 988	$\$/ft^3 = 115.0 / (-440.25 + 201.74 * DBH - 1.85 * DBH * HT)$	DBH: 5 to 14

[a]HT = total height (ft) = 34.95428248+2.672088601*DBH
[b]DC = ground travel distance of harvester/cycle (ft) = 22
DBH = average diameter at breast height (in.)

Here is an example of how these equations can be used to estimate costs. Suppose a logger wishes to estimate the cost of using CTL + Forwarding to harvest a tract. The tract attributes are average tree d.b.h. (DBH) = 12 in., volume cut/acre (VOAC) = 2,000 ft^3, slope yarding distance (SYD) = 1,200 ft. Using the equation from Table 8 for the JD 988 and the forwarding equation from Table 2, we have:

For the JD 988

$$\$/ft^3 = 115.0 / (-440.25 + 201.74 * DBH - 1.85 * DBH * HT)$$
$$\$/ft^3 = 115.0 / (-440.25 + 201.74 * 12 - 1.85 * 12 * 67.02)$$
$$\$/ft^3 = 0.23$$

Table 9.—Simulated, delay-free, cable yarding cost equations by yarder

Yarder	Equation	Variable Limits
Skylok 78	$\$/ft^3 = 0.090775 + 0.594844 * (1 / DBH) + 0.000071 * SYD + 739.473795 * (1 / (VOAC * DBH))$	DBH: 7 to 24 SYD: 50 to 950 VOAC: 780 to 6871
Urus 1000-3	$\$/ft^3 = 0.203908 - 0.000387 * DBH^2 + 0.000144 * SYD + 13.160361 * (1 / VOAC)$	DBH: 7 to 24 SYD: 50 to 950 VOAC: 780 to 6871
Koller-K300	$\$/ft^3 = 0.167004 - 0.000343 * DBH^2 + 0.000146 * SYD$	DBH: 7 to 16 SYD: 50 to 950 VOAC: 780 to 6871
RadioHorse 9	$\$/ft^3 = -0.1264 + 1.1965 * (1 / DBH) + 0.00023 * SYD + 235.30853 * (1 / (VOAC * DBH))$	DBH: 4 to 12 SYD: 50 to 150 VOAC: 334 to 700
Berger 25Y	$\$/ft^3 = 0.09587038 + 0.00007867 * SYD + 458.98997156 * (1 / (VOAC * DBH))$	DBH: 6 to 24 SYD: 50 to 1500 VOAC: 780 to 6871
Appalachian Thinner	$\$/ft^3 = -0.089289 + 1.535553 * (1 / DBH) + 0.000269 * SYD + 81.991053 * (1 / VOAC) - 496.820821 * (1 / (VOAC * DBH))$	DBH: 7 to 24 SYD: 50 to 950 VOAC: 780 to 6871
Bitterroot	$\$/ft^3 = 0.161995 - 0.000783 * DBH^2 + 0.000172 * SYD$	DBH: 7 to 9 SYD: 50 to 950 VOAC: 780 to 6871
Ecologger I	$\$/ft^3 = 0.707187 - 0.050285 * DBH + 0.001089 * DBH^2 - 2.095831 * (1 /DBH) + 0.000168 * SYD + 33.101018 * (1 /VOAC)$	DBH: 7 to 24 SYD: 50 to 950 VOAC: 780 to 6871
Clearwater	$\$/ft^3 = 0.12577 - 0.00328 * DBH + 0.000048 * SYD + 623.08404 * (1 / (VOAC * DBH))$	DBH: 4 to 16 SYD: 50 to 950 VOAC: 780 to 6871

DBH = average diameter at breast height (in.)
SYD = slope yarding distance (ft)
VOAC = volume per acre (ft^3)

For the Forwarder

$$\$/ft^3 = 110 / (408.9482 + 0.00241 * TP * SYD - 0.0006 * SYD^2)$$

$$\$/ft^3 = 110 / (408.9482 + 0.00241 * 400 * 1200 - 0.0006 * 1200^2)$$

$$\$/ft^3 = 0.16$$

Combined total $\$/ft^3$ for the JD 988 and forwarder = .39 or about $34.81/cord; $42.45/cord adjusted for 18-percent delay/down time; $55.19/cord adjusted for 18-percent down time and 30 percent profit and risk.

Logs and Wood Hauling

In this text, the process of moving logs or wood from the stump to the landing is defined as primary transportation. The process of moving logs or wood from the landing to sawmills, pulpwood mills, sort yards, or other processing facilities is defined as secondary transportation and is generally done by large trucks (Figs. 35a, b, 36). Although logs or wood can be transported by railroad, barge, airline, or floated as a raft down a river, they are generally transported by truck. Trucks of various sizes are used to haul logs sometimes configured with one or more trailers (Figs. 37, 38) that are loaded at landings or log decks with a log loader (Figs. 39a, b). Other applications call for log trucks with multiple rear axles that are equipped with a self-loading mechanism on board (Figs. 40, 41, 42). Where trucking weights are relaxed such as on private haul roads, trucks may be equipped with as many as four trailers.

Figure 35.—Large log truck with (a) continuous flatbed trailer with logs loaded across the bed, equipped with a moose bumper; and (b) large log truck with second trailer loaded piggyback. Courtesy of Forestry Equipment Sales in Minnesota.

Figure 36.—Large log truck with trailer loaded piggyback. Courtesy of Whit-Log Trailers in Oregon.

Figure 37.—Small single-axle log truck with cab protector. Courtesy of Truck Paper.

Figure 38.—Pup pole trailer. Courtesy of Forestry Equipment Sales in Minnesota.

Secondary transportation networks are well established and usually consist of well-developed and heavily traveled public rural and freeway and interstate roads. These roads experience heavy traffic volumes and generally have very well defined haul load limits, loads must be secured and covered, and load weights and speeds must be observed. It is not unusual to be traveling down the interstate and to be passed by or encounter log trucks hauling a wide array of raw logs as they travel to sawmills, pulp mills, sort yards, or other wood-processing facilities. High quality veneer logs, prime saw logs, and select species peeler logs may be transported by truck in excess of 100 miles to their final destination. In some regions, where winter conditions lend themselves to such, loggers will take advantage of frozen lake surfaces to form ice bridges they can travel on, often saving 2 or 3 hours of travel time. Generally speaking, log trucks equipped with trailers designed for hauling saw logs or pulpwood will be able to negotiate even the narrowest, tightest horizontal and vertical curves, with just about any type of road surface. Mud, snow, and ice present a totally different set of challenges, but these trucks with good aggressive tires and skilled drivers can usually keep the wood flowing. Although equations and procedures are presented in this text in the stump-to-mill cost estimation section, the author's principal emphasis is on the primary transportation process because the secondary transportation process, networks, and trucks are well established and defined. The haul mileage is the primary cost and limiting factor involved in transporting logs or wood with trucks.

Figure 39.—Large log truck with (a) two trailers at landing ready to be loaded; and (b) large log truck with Douglas-fir logs in two-trailer mule train. Courtesy of Vannatta Forestry and Logging, Oregon.

Figure 40.—Dual rear-axle log truck with self loader in the rear. Courtesy of Truck Paper.

Figure 41.—Medium multiple rear-axle log truck with self loader in the rear. Courtesy of Forestry Equipment Sales in Minnesota.

Figure 42.—Large log truck with one-piece continuous trailer and self loader in the middle. Courtesy of Forestry Equipment Sales in Minnesota.

Chippers and Chip Hauling

Some operations call for the trees or stems to be chipped in the woods and transported via chip vans to their final destinations. Here the logs or trees are extracted to roadside, processing area, or landings by skidders, dozers, clambunk skidders, or forwarders and then processed by portable chippers. Chippers come in many sizes and capacities (Figs. 43, 44) in their ability to chip trees of alternate sizes, production rates, and costs to operate. Clearly, bigger horsepower chippers cost more to purchase and operate, but they also have the capacity to handle bigger dimension stems and produce more chips per unit time than smaller machines. These portable chippers are generally stationed at landings or near log decks where the flow of wood coming into the chipper and the flow of chip van traffic arriving to load and turn around do not create congestion or delays. A smooth well-planned operation is desirable where the amount of idle

Figure 43.—Large portable chipper. Photo courtesy of Mainka Enterprises, WI.

Figure 44.—Medium portable chipper. Photo courtesy of Mainka Enterprises, WI.

time is eliminated primarily around the chipper. In other words, the chipper ideally should not have to wait for wood being brought in to feed it and should not have to wait for chip vans to blow the chips into. Chip transport vehicles or vans come in various sizes with alternate payloads (Figs. 45, 46). The transportation network becomes more critical for large chip vans than for trucks hauling saw logs and pulpwood. Chip vans generally ride low to the ground and have solid walls to hold the chips in. Roads with sharp vertical curves or low dipping drainage structures can become problematic for chip vans in that the low belly of the van can scrape the bottom of the vertical curve or dip damaging the trailer. Vans can literally get hung up on some vertical curves. The vans may have difficulty negotiating sharp horizontal curves. The road network should also be cleared of large overhanging branches that may come in contact with the van walls damaging the van sides. Trucks hauling saw logs that would come in contact with these overhanging branches would simply push the branches out of the way, but a chip van cannot do this without damaging the sides. The road network must be ergonomic to large chip van traffic, or smaller vans that can negotiate the road must be used for in-woods chipping operations to work. Another option would be to truck the materials to be chipped to a central processing area where the chipper and large van traffic would be accommodated, but this adds more cost to the operation than may be justified. Limiting chipping operations to small vans that can negotiate the road network sharply reduces the amount of payload that can be transported, cutting the profit margins. Another variable for large chip vans is the combination of road grade and the surface finish on the road. For example, on road segments with steep uphill pulls and adverse grades that are surfaced with loose gravel, the truck may spin out and never get up the hill. Trucks equipped for hauling saw logs usually get around this challenge by redistributing the trailer load or having the trailer ride piggyback on the front trailer (Figs. 35b, 36). In some small operations and in an urban setting, it is desirable to have a small chip truck that also tows the chipper (Fig. 47). The author directs readers to search the published literature for their region for studies on production and cost for alternate chippers and transport vehicles that may match their conditions. Users may wish to conduct their own studies to determine such information.

Figure 45.—Small chip truck with dumping capability. Photo courtesy of Mainka Enterprises, WI.

Figure 46.—Large chip van trailer with open top. Courtesy of Pinnacle Trailers, NC.

Figure 47.—Small chip truck with dumping capability and medium chipper in tow. Photo courtesy of Mainka Enterprises, WI.

PART III—SAFETY AND ENVIRONMENTAL COMPLIANCE

Safety Considerations

Harvesting or logging of timber products is one of the most hazardous occupations with more frequent and serious injuries and fatalities than many other industries. Most time-consuming and expensive logging accidents occur when woods workers are struck by a falling or flying object or get tangled or caught and crushed or killed between objects or machines. Woods workers such as loggers (including fellers, buckers, rigging slingers, hook tenders, delimbers, choker setters, and chasers), general laborers, machine operators, truck drivers, and landing personnel are injured or killed most often. Woods workers have to be alert to ever changing conditions being created by the activities during the harvesting operation and must also be aware of changing conditions brought on by weather events such as rain, snow, ice, and wind. Work areas, whether for felling, bucking, delimbing, skidding, unloading, sorting, loading, or related tasks, must constantly be evaluated for hazards. Retreat zones must be identified, and workers must be trained in first aid and must be prepared to evacuate themselves or injured workers quickly. Accordingly, OSHA and other safety organizations have developed guidelines, rules, and laws for each phase of the logging operation to help prevent accidents and to protect woods workers. Loggers who manually fell trees with chainsaws are exposed to the most frequent and greatest logging risks. OSHA requirements that remedy some of these risks are presented for the following categories (www.osha.gov):

1. Required Training and Qualifications for Loggers
2. Personal Protection Equipment
3. Head Protection
4. Hearing Protection
5. Eye and Face Protection
6. Leg Protection
7. Foot Protection
8. Hand Protection
9. Chainsaw
10. Other Hand Tools and Equipment

It is beyond the scope of this monograph to capture all of the guidelines, rules, and laws available; however, the author finds it useful to summarize some of the most important ones. Proper training gives loggers the tools and skills necessary to perform their work safely and efficiently. Employers are required to properly train their employees and to ensure that they are performing their jobs in a safe manner. Properly trained workers should be able to anticipate, recognize, and mitigate job hazards as they develop or are encountered. Training must be provided without cost to all employees on their initial tasks and assignments and when new work tasks, tools, equipment or vehicles are assigned. This training must include work procedures, practices, and requirements of the work site, to include recognition, prevention, and control of general safety and health hazards encountered in logging and to perform assigned work tasks safely, including safe use, operation, and maintenance of tools. All training must be conducted by a knowledgeable person and must be presented in a manner that all employees can comprehend. Employees that require training must be closely supervised until they demonstrate mastery of their training, and monthly meetings must be held to alert workers of the hazards and safety considerations of the job. Additionally, a written certification record must be maintained by the employer with the names of the employees trained, the dates of the training, the signature of the trainer, and the date when the employer determined that the training given the employee was adequate.

Figure 48.—Hardhat combination that protects head, face, eyes, and ears. Photo courtesy of Makita.

Personal protection equipment for the head, ears, eyes, face, hands, and legs is designed to prevent or lessen the severity of injuries. All personal protection equipment must be inspected before each work shift, and except for foot protection, must be provided by the employer at no cost to the employee. Hardhats must meet safety standards and be worn when overhead hazards are present. Most commercially available hardhats offer adequate protection. Hearing protection must be worn when noise levels are at a point where hearing damage may result. Most chainsaw hard hat and mesh screen and ear muff combination protection devices available on the market will provide adequate hearing protection (Fig. 48). Additionally, ear plugs may be used. Eye and face protection must be worn when there is potential for injury to the eyes or face. Logger type mesh screens are considered adequate eye and face protection for chainsaw operators. Leg protection is required primarily for chainsaw operators and should extend from the upper thigh down to the top of the shoe. Leg protection is available in a variety of forms, including chaps (Fig. 49a), logger pants, and leggings (Fig. 49b). The protective matter must contain cut resistant material and can include ballistic nylon, protective Kevlar®, Engtek®, or other cut-resistant materials. Foot protection must ensure that heavy duty boots are waterproof, cover the ankle, and offer some type of anti-slip sole. If the boots are going to be worn by chainsaw operators, it may be necessary to require steel toes and cut-resistant material to protect from contact with running chain. Hand protection may be required by employees who handle wire rope and other abrasive materials where there is a potential hazard for cuts, scrapes, and puncture wounds such as from jaggers from wire rope. A wide

(a)

(b)

Figure 49.—Chaps (a) and leggings (b) with varying types and layers of protection against running chain. Photos courtesy of Ben Meadows and Clark Engineering.

(a)

(b)

(c)

(d)

Figure 50.—Gloves offering different types of hand protection: (a) protection from running chain and vibration absorbing capacity; (b) protection for fingers, palm, knuckles; (c) protection for handling wire rope; (d) vibration absorbing capacity. Photos courtesy of Amick's Superstore, Clark Engineering, North Star Gloves, and Ben Meadows.

array of hand protection is available on the market including gloves with built-in ballistic nylon (Fig. 50a), heavy leather palm and knuckles (Fig. 50b), heavy duty cloth for handling wire rope or setting chokers (Fig. 50c), and special vibration-absorbing gloves for timber fallers or users of chainsaws (Fig. 50d).

Chainsaws are extremely powerful tools for felling, bucking, limbing, and additional processing of trees into wood products. Table 10 shows that the majority of the harvesting systems dealt with in this text require a chainsaw to be fully operational. When used properly, chainsaws can be very productive and useful in many applications including brush clearing and general cutting jobs. Chainsaws can also be extremely dangerous tools when used carelessly. More people are killed when felling trees than any other logging activity. Most of these fatalities can be avoided.

Table 10.—Harvesting system applicability matrix

Harvesting system	Chainsaw required	Terrain	Initial cost	Productivity	Labor intensity	Environmental impact	Ease of moving in/out	Setup time required
Horses/Livestock	Yes	Gentle	Low	Low	High	Low	High	Low
Portable Winches	Yes	Gentle-steep	Low	Low	High	Low	High	Low
Small Farm Tractors	Yes	Gentle-moderate	Low	Low	High	Medium to high	Medium	Medium
Cable/Grapple Skidders	Yes	Gentle-moderate	Medium	Medium	Medium	Medium to high	Medium	Medium
Bulldozers/Crawler Tractors	Yes	Gentle-moderate	Medium	Medium	Medium	Medium to high	Medium	Medium
Feller Bunchers	No	Gentle-steep	High	High	Low	Low	Low	Medium
Cut-to-Length Systems	No	Gentle-moderate	High	High	Low	Low	Low	Medium
Forwarders	No	Gentle-moderate	High	High	Low	Medium to high	Medium	Medium
Clambunk Skidders	No	Gentle-moderate	High	High	Low	Medium to high	Medium	Medium
Cable Yarding Systems	Yes	Gentle-very steep	High	Medium	Medium	Low	Low	High
Helicopters	Yes	Gentle-very steep	High	High	Medium	Low	Medium	High

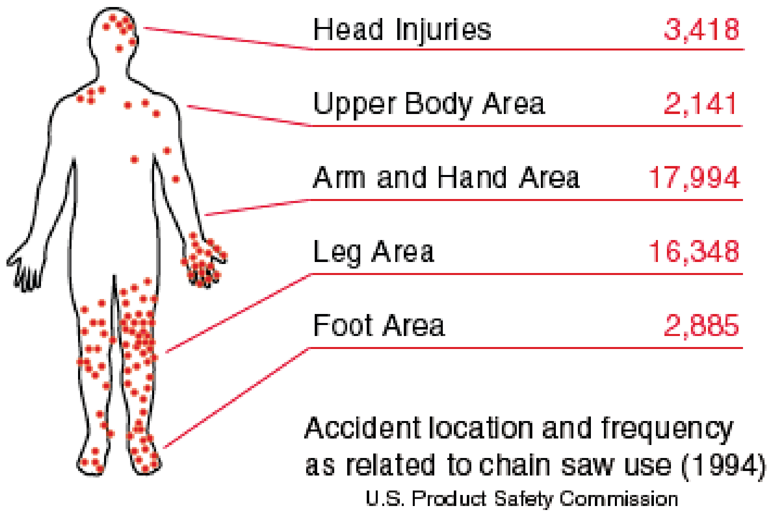

Figure 51.—Accident location and frequency due to chainsaw injuries. Diagram courtesy of OSHA.

Many guidelines, rules, and laws exist to help operators minimize, eliminate, or reduce the hazards involved. Chainsaws come in many sizes, configurations, and safety and ergonomic features. For example, chainsaws can be equipped with chain brakes and anti-kickback chains to help mitigate kickback and to stop the running chain should the operator lose control of the saw. Some saws are equipped with a chain-catching device that catches the chains if it is thrown off the bar during operation. As mentioned above, chainsaw operators can use protective gear from head to toe to protect themselves from some of the hazards associated with running a chainsaw. Figure 51 illustrates where most of the chainsaw injuries occur on the human body. Clearly most of the injuries occur in the hand, arm, and leg area. These areas can be protected by using hand and leg protection devices such as gloves and chaps, logger pants, or leggings. Careful attention should be directed to chainsaw use, maintenance, safety, and the protective equipment available to mitigate injuries because so many of the harvesting systems in use today to harvest the northern hardwood resource require the use of chainsaws (Table 10). Several independent organizations and contractors offer a wide array of chainsaw safety training as well as the Game of Logging series.

Other hand tools and equipment that timber fallers may require include axes, wedges, winches, gas and oil containers, saw files, screw drivers, jacks, and a variety of other useful items. As with all devices, safety must be a major consideration in the transport, storage, and use of these tools. Again, many guidelines exist for the proper use, storage, and transport of these items.

OSHA generally divides safety considerations into those for manual and mechanical operations. In this text, all safety is considered as being equally important regardless of the type of operation. However, manual operations where there is a person on the ground performing a function clearly have more safety hazards than a machine performing the same function (Bell 2002, National Institute for Occupational Safety and Health 2005).

Best Management Practices (BMPs)

The idea of best management practice (BMP) asserts that there is one technique, method, process, activity, incentive, or reward that is more effective at delivering a particular outcome than any other technique, method, process, etc. The idea is that with proper processes, checks, and testing, a desired outcome can be delivered with fewer problems and unforeseen complications. In this text, the author will consider best management practices for protecting riparian areas and streamside management zones (SMZs), for retaining structural and patch retention, for protecting soil erosion and soil properties, and for mitigating the invasion of undesirable plants following harvesting disturbances. This section will include summaries of BMPs by subject category as available in the contemporary literature and a dusting of the author's personal experiences from working in this field for many years.

BMPs for Streamside Management Zones (SMZs)

The discussion of SMZs will focus on specific areas associated with a stream, lake, wetland, or other body of water that is designated and maintained during silviculture or harvesting operations. The purpose of the SMZ is to protect water quality and riparian functions by reducing or eliminating forestry or harvesting related outputs of sediment, nutrients, logging debris, chemicals, and water temperature fluctuations that could adversely affect aquatic communities. SMZs provide shade, stream bank stability and erosion control, as well as detritus and woody debris that benefit the aquatic ecosystem in general (Fig. 52). The SMZ is also designed to maintain certain forest attributes that provide specific wildlife habitat values such as snags, den and cavity trees as well as mast-producing trees required by several species of wildlife. SMZs provide habitat for many species of wildlife for resting, breeding, raising their

Figure 52.—Stream with riparian protection on both banks with complement of woody component on banks and in the stream. Photo courtesy of Karen Sykes, U.S. Forest Service.

Table 11.—Recommended widths, in feet, for streamside management zone (www.state.hi.us/dlnr/dofaw/wmp/bmps.htm)

Soil type	Percent slope	SMZ width (each side)
Slightly erodible	0-5	35
Slightly erodible	5-20	35-50
Slightly erodible	20+	50-160
Erodible	0-5	35-50
Erodible	5-20	80 minimum
Erodible	20+	160 minimum

young, being safe, protection from predators, roosting, and for feeding. The SMZs can have variable widths, definitions of size and length, and operational restrictions with respect to the harvest of timber and traffic ability by harvesting machines. SMZs are generally implemented on both sides of a stream or wetland. The width of any one SMZ that is necessary to protect a given area is largely determined by general guidelines or based on judgment that relies on local experience. Some SMZ guidelines are based on the slope of the land adjacent to the stream, soil erodibility, precipitation, and sensitivity of the stream. The following table is an example of guidelines that consider soil type and slope of the adjacent land for Hawaiian forests, see Table 11 (www.state.hi.us/dlnr/dofaw/wmp/bmps.htm). In this set of guidelines partial harvest is acceptable where 50 percent of the original forest crown cover or 50 ft^2 of basal area, evenly distributed, must be retained in the SMZ. Clearcutting is prohibited within the SMZ. Although this text is largely about the northern forest hardwood resource, the author found the Hawaiian SMZ guidelines useful because they are based on percent sideslope and soil erodibility only.

The State of West Virginia, for example, passed a logging sediment control act in 1992 that has stipulations for logger licensing, logger certification, timber operation notification, logging operation posting, enforcement for activities causing erosion, and/or sediment, and reclamation to be completed within 7 days of the planned completion of the logging job. This act also provides guidelines for SMZs so that buffer zones should be at least 100 feet wide on each side of perennial or intermittent streams and 25 feet wide on each side of ephemeral streams. Perennial streams flow year round, intermittent streams flow only a portion of the year, and ephemeral streams flow only during wet periods when the surrounding ground is saturated. Equipment operation in these zones should be limited; however, cutting and pulling trees from within the area is permitted (West Virginia Division of Forestry 2005).

Recommendations also vary among national forests; for example, the Mark Twain uses riparian management zones (RMZs) and watershed protection zones (WPZs). The WPZ extends 100 feet (horizontal distance) on either side of the channel. Some activities are prohibited in the WPZ such as log landings, road and skid trail construction, and construction of wildlife ponds. Timber harvesting is allowed, but trees cannot be cut within 25 feet of the stream channel unless necessary to move the area toward the desired condition or to facilitate designated crossings. By contrast, the Green Mountain and Finger Lakes National Forests use 25-foot equipment-free zones on either side of the channel where logging equipment is prohibited. However, trees may be cut in this 25-foot strip but must be winched out (LeDoux and

Wilkerson 2008). LeDoux and Wilkerson (2006) developed a methodology that simultaneously considers the protection of multiple riparian functions and computes the opportunity costs involved with implementing SMZs of alternative widths. They applied the methodology to a case study for northern forest hardwood resource conditions for SMZ widths of 50, 100, and 150 feet. Their study concluded that 150-foot SMZs were required to fully protect the following riparian functions: coarse woody debris recruitment, shade and temperature maintenance, sediment filtering, aquatic communities (macroinvertebrates and periphyton), and riparian bird communities (riparian associated passerines). The study also quantified the capital recovery costs associated with alternative SMZ widths. Clearly, the use of SMZs to protect riparian functions is important, can be expensive, and requires vast variability in the widths required depending on the immediate conditions to be protected. It is beyond the scope of this text to deal with the vast array of combinations of conditions and SMZ widths needed; however, managers, loggers, landowners, policymakers, and decisionmakers need to consult their local laws and guidelines to arrive at SMZ widths that best accomplish their objectives. The methodology provided by LeDoux and Wilkerson (2006) can be used to compute the opportunity and capital recovery costs involved with implementing alternative SMZ widths.

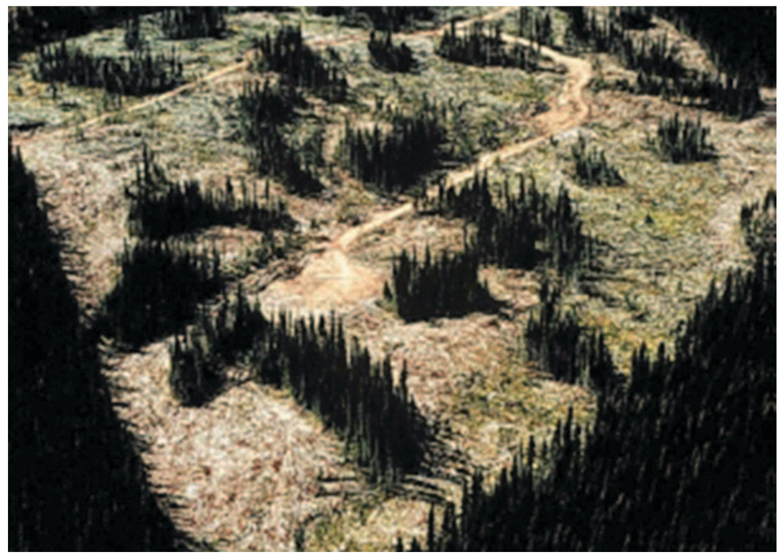

Figure 53.—Multiple patches of variable size and shape. Photo courtesy of Forest Science, Prince Rupert Forest Region, British Columbia.

BMPs for Patch or Structural Retention

Patch or structural retention harvesting can be used as a habitat or biodiversity management strategy (LeDoux and Whitman 2006). Patch retention calls for retaining about 5 to 20 percent of a harvest unit in discrete patches or islands of mature or immature trees (Forest Sciences 1994) (Fig. 53). These patches of standing timber are retained to provide post-harvest habitat for many plants, wildlife, insects, microorganisms, biological and ecological processes, and in some cases to protect the visual resource (Fig. 54). Managers need to plan for unharvested patches within harvest units and loggers must be careful to protect the patch from disturbance and do so in a safe manner. For example, many safety regulations prohibit workers from operating in the danger zone of snags that might be left in patches. Larger patches can incorporate snags in the center and thus allow workers to safely

Figure 54.—One-fourth-acre patch retention with vernal pool. Photo courtesy of Andrew Whitman, Manomet Center for Conservation Sciences.

Table 12.—Some criteria for selecting patches and stands for retention

Biodiversity/Wildlife Considerations	Silvicultural/Operational Considerations
1. adjacent to wetlands and riparian areas	1. advanced regeneration or trees suitable for release and further growth
2. rock outcrops/bluffs	2. suitable seed trees for natural regeneration
3. diverse tree species and canopy layers	3. gullies or other difficult terrain
4. less common tree species	4. deciduous and/or brush patches
5. large snags, or potential snags	5. wind firmness of residual trees
6. evidence of present wildlife use (e.g., nests, feeding activity)	6. visual screening is desired
7. unusual or rare plant communities	7. low disease/pest spread potential
	8. broadcast burning not prescribed

Table 13.—Patch retention objective for each landscape cell

	% Landscape Available for Harvest									
% Harvested	100	90	80	70	60	50	40	30	20	10
10	11	10	09	08	07	06	05	04	03	02
20	12	11	10	09	08	07	06	05	04	03
30	13	12	11	10	09	08	07	06	05	04
40	14	13	12	11	10	09	08	07	06	05
50	15	14	13	12	11	10	09	08	07	06
60	16	15	14	13	12	11	10	09	08	07
70	17	16	15	14	13	12	11	10	09	08
80	18	17	16	15	14	13	12	11	10	09
90	19	18	17	16	15	14	13	12	11	10
100	20	19	18	17	16	15	14	13	12	11

operate on the periphery of the patch, or "no work zones" can be established around smaller patches or where individual trees are retained. Mechanized systems such as feller bunchers or cut-to-length harvesters work very effectively and safely to create patches. The British Columbia Forest Service (Forest Sciences 1994) lists some useful criteria for selecting patches and stands for retention (Table 12). It also provides a formula and table for determining the minimum area (percent) that should be retained as a function of the percent area that is available for harvest and the percent of available area that has been harvested for a grid size of 248 acres (Table 13). For example, if 60 percent of the landscape is available for harvest, and only 10 percent of the available area has been harvested, the minimum retention objective in a 248-acre grid would be 7 percent. In contrast, if 60 percent of the landscape is available for harvest and 90 percent has been harvested, then the objective would be to retain 15 percent of the remaining area. The authors suggest these figures as BMPs and guidelines of what should be retained when considering structural retention.

BMPs for Invasive Plant Mitigation

There is no question that invasive native and nonnative plant and other organism species are a major threat to forested ecosystems and the general balance of nature. It is beyond the scope of this text to go into any detail on individual species, threats, or consequences of any one invasion or invader or the spread of such. The author's intent is to present state-of-the-art voluntary BMPs that may mitigate the spread of invasive plant species that are particularly associated with logging and forest operations that create the type of disturbance suitable for invasion or spread of certain plants. The focus is on the types of disturbance associated with logging and forest operations only as opposed to disturbance caused by recreational activities, moving of wood products, or other types of events. Forest operations such as road and skid trail construction, removal of trees during harvest, landing construction, skidding of logs, and movement of machinery in and out of different operating sites create conditions and opportunities for invasive plants to invade or spread within or from site to site. For example, the removal of trees during a harvest creates conditions where more sunlight is reaching the forest floor—conditions favorable for invaders to get established or spread. The construction of roads, skid trails, landings, along with the skidding of logs, creates soil disturbance where mineral soil is exposed, creating conditions favorable for invaders. Moving equipment from one logging site to another or moving equipment that has operated in areas that have invasive plants established within a single logging chance provides a vehicle where seeds or other plant parts can be transported into areas that were void of invaders. Currently, there are no mandatory BMPs for logging and forest operations that are designed to mitigate the spread or invasion of invasive plants.

Loggers protect themselves by disclosing what they see to the landowner, and this information could become part of the contract. An invasive species inspection by the landowner or by the logger would document what the circumstances are, and both parties would sign and date this document. This text provides proposed voluntary scientific guidelines on what loggers and landowners could do to mitigate "invasion" or spread during harvesting operations (Fig. 55). The Invasive Plant Council of British Columbia lists additional T.I.P.S. for Forestry Operations (Table 14).

The voluntary BMPs described in this text are general and state of the art. They are grounded in scientific principles but may not be substantiated in rigorous studies in the literature. As such, they should be viewed and used as a starting place for developing more rigorous BMPs for invasive species mitigation. However, a logger would be prudent to follow these guidelines and share this information with the landowner to further mitigate any actions taken against the logger by the landowner to account for any invasive plants or conditions created by the logging operation. The logger would be wise to survey, document, and inform the landowner of any invasive plant infestations or communities of invasive plants within the proposed harvest tract before any harvesting operations. The logger would also be wise to follow these voluntary BMPs, document them, and disclose them to the landowner. This approach would inform the landowner and establish a record of prior conditions and precautions the logger took to avoid aggravating the situation.

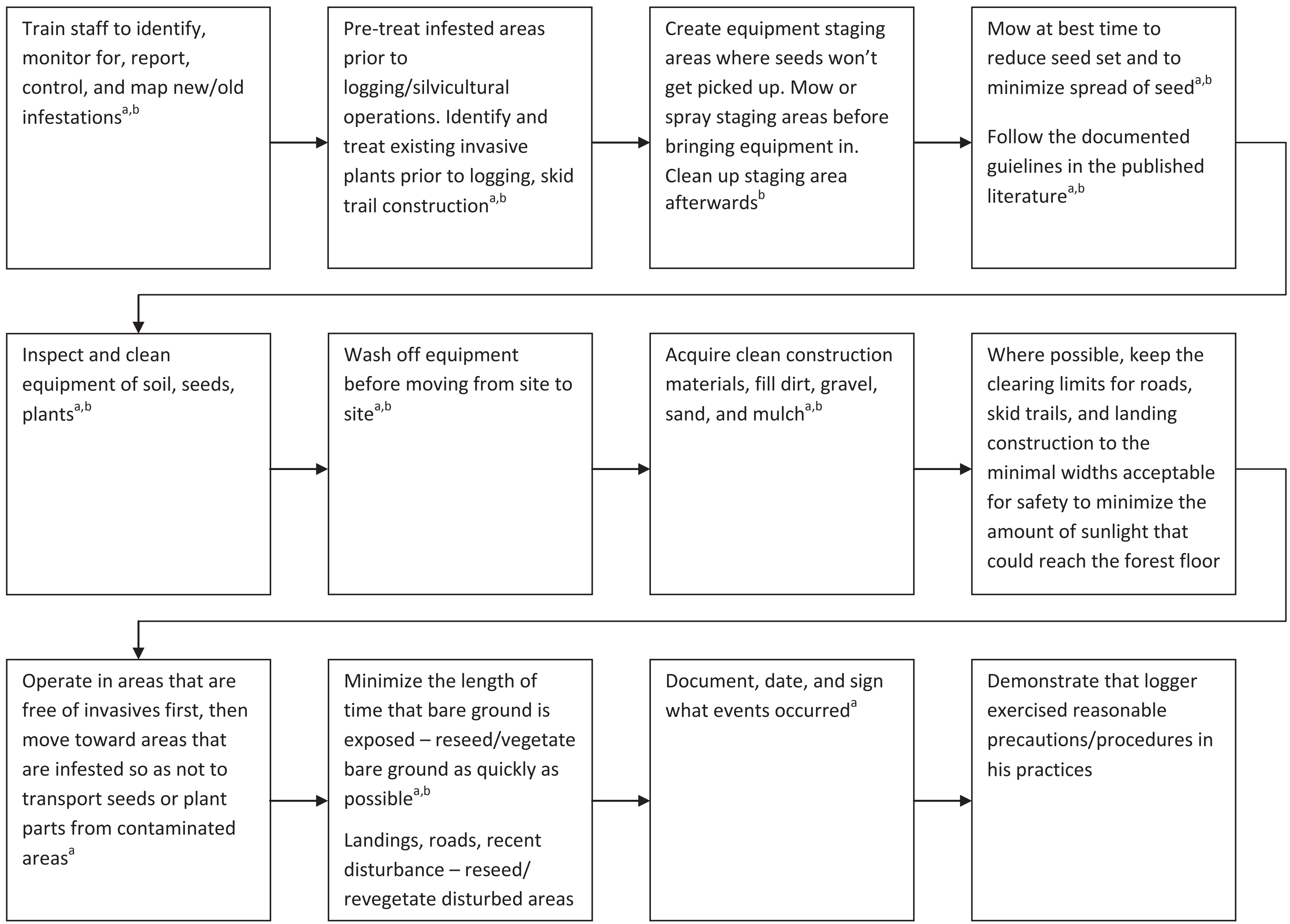

Figure 55.—Flow diagram of proposed voluntary BMPs for invasive species mitigation during harvest operations. ([a]Invasive Plant Council of BC 2007; [b]Kearns and Chapin 2008).

Table 14.—Targeted Invasive Plant Solutions for forestry operations (Invasive Plant Council of BC 2007)

T.I.P.S. for Forestry Operations	
OPERATION	TARGETED INVASIVE PLANT SOLUTIONS
General	These practices are always applicable, regardless of the operation, and are not limited to specific operations listed here. 1. Determine priority invasive plant species within your operating area. 2. Stay informed through collaborations with regional experts, and assist staff and contractors to identify and minimize spread of invasive plant species within your operating area. 3. Carry out regular detection surveys and record the locations of invasive plants in your operating area. 4. Keep equipment out of areas infested by invasive plants and keep equipment yards and storage areas free of invasive plants. 5. Regularly inspect the undercarriages of vehicles and remove any plant material found. 6. Dispose of plant material at the site of the infestation (if no flowers are present), or bag the plant material and dispose of it (locally) in the garbage (if flowers are present). 7. Wash plant seeds and propagules from personal gear, equipment, vehicles and machinery at designated cleaning stations before leaving infested sites. Ensure soil that is being moved does not contain invasive plant seeds or propagules. 8. Minimize unnecessary soil disturbance during road, landing, skid trail and site preparation. Ensure soil that is being moved does not contain invasive plant seeds or propagules. 9. Re-vegetate disturbed areas as soon after disturbance as possible using an appropriate combination of scarification, seeding, fertilizing and/or mulching. Ensure that seed used to re-vegetate will meet site objectives. Use Canada Common #1 Forage Mixture or better. 10. Treat infestations of invasive plants prior to disturbance (pre-treatment). 11. Monitor treatment sites for several years to ensure efficacy. Re-treat as necessary to ensure spread does not continue.
Silviculture & Reconnaissance Surveys	1. Consult the Invasive Alien Plant Program (IAPP) Application database to determine locations of high-risk infestations. 2. Incorporate IAPP spatial data into planning maps (www.nric.ca/). 3. Incorporate detection surveys into existing survey procedures. 4. When an invasive plant is encountered: record the species, date of observation, location (UTM coordinates), and estimated area of infestation (ha or m^2). IAPP field cards are available for use. Provide this information to the regional invasive plant committee coordinator or MFR invasive plant specialist, or enter the data independently.
Road Building & Maintenance	1. Inspect gravel pits and material sources for invasive plants, and remove invasive plant seeds and materials prior to use. 2. Where possible, begin work in un-infested areas and move toward infested areas. 3. Promptly re-vegetate disturbed areas along roadsides, landings, and cleaned culverts. 4. All machinery and equipment capable of carrying invasive plant propagules should be cleaned prior to moving on and off site. 5. Grade roads in directions that do not encourage spread of seeds away from known, priority invasive plant sites.
Harvesting & Site Preparation	1. Re-vegetate all harvested openings by re-establishing an appropriate stand of trees following the stocking standards prescribed in the Forest Stewardship Plan. 2. Minimize disturbance and the duration of time the site is left un-vegetated. Consider seeding if there is a delay in re-vegetation. 3. All machinery and equipment capable of carrying invasive plant propagules should be cleaned prior to moving on and off site.

BMPs for Soil Protection

There is no question that silvicultural practices and machinery used in the process of harvesting trees or achieving future desired forest conditions can result in various degrees of soil disturbance and compaction. Some silvicultural prescriptions require machines to be on the site and to travel throughout the tract in question to achieve the stated objective. Clearly, most harvesting operations require some type of machinery to be used in felling and extracting trees. These machines and processes can result in soil disturbance, soil erosion, sedimentation, rutting, and compaction. These soil impacts can have a cascading effect. For example, soil disturbance can lead to soil erosion; soil erosion can lead to loss of valuable topsoil and nutrients. Soil erosion can also lead to sedimentation in streams and riparian areas, impacting fisheries, animal and plant diversity, and it may change ecosystems. Heavy machinery in combination with wet saturated soils can lead to severe rutting. Rutting is caused when soil is displaced from underneath the machine tire or track and moved sideways, allowing the tire or track to sink into the subsoil. Rutting can also have a cascading effect in that ruts can channel water, accelerating erosion or soil movement. Rutting can also result in ponding where water is captured and held within the rut. Ponding of water may be undesirable for tree and root growth and may in some cases create microsites altering the ecosystem. Soil compaction may impact the infiltration rate of water, alter soil properties, reduce soil porosity, and impede root growth. For example, heavy harvesting equipment can harm existing trees and future regeneration by compacting soils. Good soil should contain about 50-percent pore space for aeration and moisture retention. Tree roots need oxygen to function. Heavy equipment can compact soil, reducing oxygen and inhibiting root growth. Multiple loaded and unloaded machine passes over the same skid trail can severely compact the soil in the skid trail. Not too much can be done to minimize or mitigate soil disturbance and compaction on the most heavily used skid trails. Several things can be done, however, to minimize soil disturbance and compaction by following some well-established BMPs. Controlling soil erosion protects and maintains water quality. Table 15 lists some commonly accepted BMPs that can be used to mitigate soil disturbance and compaction during harvesting operations.

Preplanned skid trails require the skidding machines to remain on the trail, and operators must pull the bull or winching line to the trees or logs. The logs or trees are then winched back to the machine. Tracked vehicles spread the weight of the machine over a wider footprint and have better traction, leading to less spin and churning of the soil. Skyline, cable, and aerial systems

Table 15.—Commonly accepted BMPs for protecting soil during harvesting operations

1.	Require the use of preplanned skid trails
2.	Require the use of tracked vehicles
3.	Require the use of cable or aerial systems
4.	Restrict operations on wet/saturated soils
5.	Require skidding on frozen ground
6.	Require skidding on deep snow pack
7.	Use mats of limbs and branches to travel on
8.	Require skidding/winching across the slope as opposed to up and down the slope
9.	Require the use of wide/high flotation tires

such as helicopters fully suspend some or all of the log or tree during the extraction process. Restricting operations when soils are wet and saturated prevents compaction and rutting. Skidding on frozen ground or on deep snow pack also prevents compaction and rutting. Use of limbs, branches, and vegetation on the skid trails during the extraction process also helps reduce compaction, disturbance, and rutting. Using a heavy layer of tree limbs, branches, and vegetation along the most heavily used skid trails, especially where the trails meet the landing area along with frozen ground or deep snow packs, can greatly reduce the impact of multiple machine passes on skid trails (Fig. 13). For machines such as feller bunchers and cut-to-length processors, the limbs and branches from the trees being processed can be used ahead of the machine as a mat to travel on thus protecting soil properties (Fig. 21). Winching across the slope when practical and safe as opposed to skidding or winching straight up and down the slope can also be effective in reducing soil disturbance and rutting. Wide and high flotation tires may be used to extend the operating season in wet and saturated or flooded areas. Such use may not actually protect soil properties but in fact may actually harm soils by churning and mixing soil into soup-like consistencies. These soupy and churned up soils may take decades to recover to their original conditions, if ever. In some applications, wide and high flotation tires may spread out the weight of the machine's footprint in a desirable way. The author's focus in this discussion has been on the BMPs that can be used to mitigate soil impacts on the site and on the lesser used skid trails.

Multiple objectives may be accomplished by selectively using one or more of the BMP guidelines. For example, leaving wide buffer zones adjacent to a stream may protect the stream and associated ecological functions; serve as a filter to minimize erosion, sedimentation, and nutrient movement; serve as a form of patch or structural retention; and, by not allowing harvesting or equipment traffic within the zone, may eliminate or minimize the spread or invasion of native and nonnative plant species. Many states have used these BMP guidelines successfully in the past (Vermont Department of Forests, Parks & Recreation 1999), and some foreign countries have developed their BMP practices based on what many states use here in the U.S. (Warkotsch et al. 1994). These BMP guidelines are based in science and they work when properly applied. Many states have logger and landowner training programs such as LEAP (Logger Education to Advance Professionalism) and PLP (Professional Loggers Program) where the methods are communicated to landowners and loggers. It is beyond the author's capacity in this document to list every example and reference for use of these techniques. However, many of these methods have been around for a long time, training programs abound, and the procedures have been proven to work. The challenge to the logger and landowner is to become familiar with these methods and to successfully implement them. Successful implementation of these principles will pay dividends in healthy forest lands, water resources, and ecosystems for future generations.

Figure 56 is a decision flowchart that can be used to identify the respective BMP guidelines needed for specific applications.

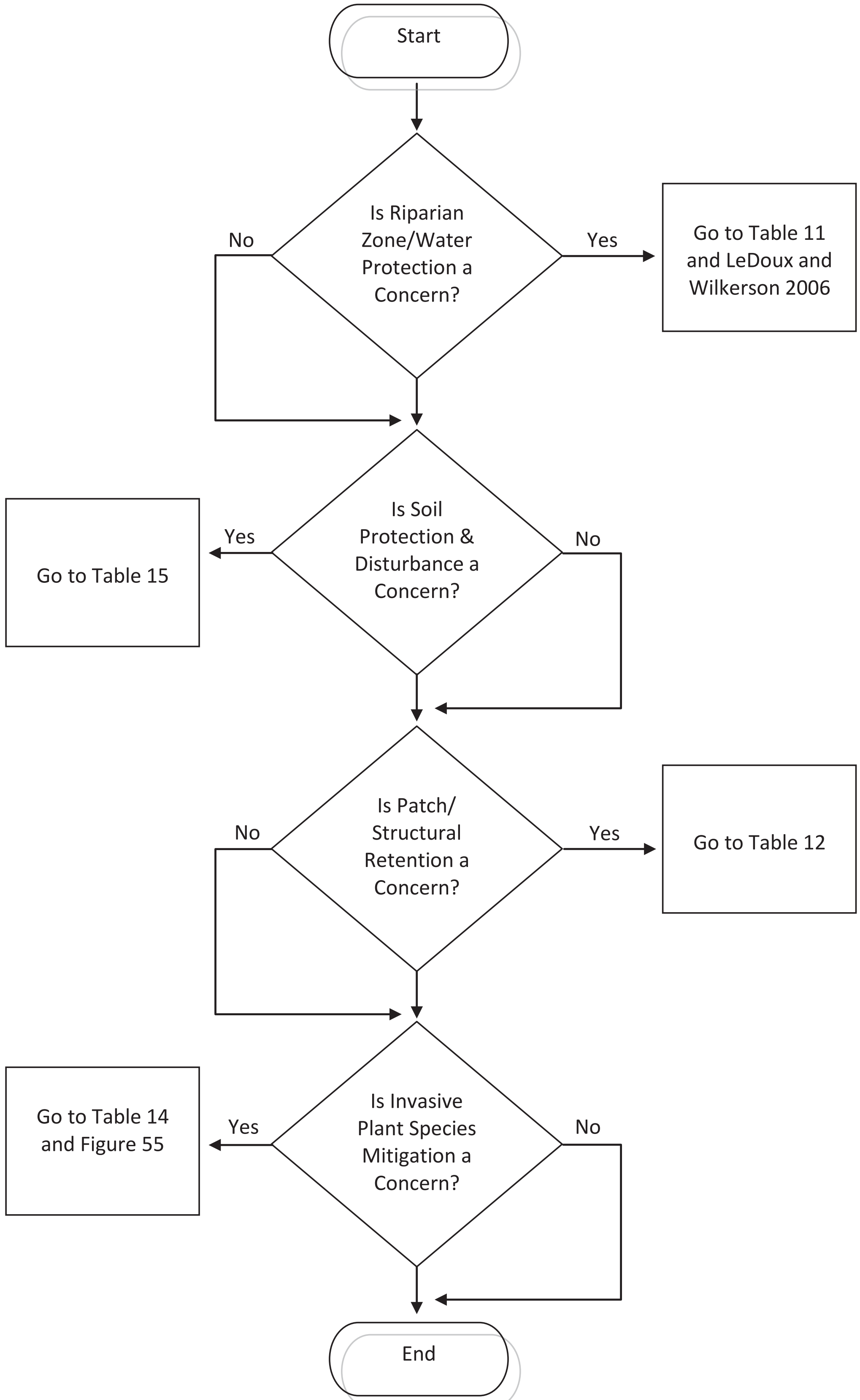

Figure 56.—BMP compliance decision flow diagram.

PART IV—CONSIDERATIONS FOR MANAGERS

Using the Harvesting System Applicability Matrix

Table 10 shows a harvesting system applicability matrix with respect to chainsaw requirement, terrain, initial cost, productivity, labor intensity, and environmental impact, ease of moving in and out, and setup time and planning required. The rankings are in general range terms as opposed to exact numerical rankings. Chainsaw required means that for that system to operate chainsaws are required on site. The terrain column suggests the terrain the system is best suited for, considering safety and productivity. The initial cost column simply ranks the initial investment needed to purchase that system new. The productivity column ranks the systems by their net hourly production rate. The labor intensity column ranks the harvesting system by the amount of labor required to make that system work. The environmental impact column ranks the system by its soil disturbance, soil compaction, and residual stand damage. The ease of moving in and out column ranks the harvesting system by the degree of difficulty encountered in moving that system from one site to another. The setup time and planning required column ranks the system by the amount of time and difficulty in setting up and the planning required prior to any operations. For example, the portable winches are ranked gentle-steep in the terrain column. This implies that portable winches can be used safely on gentle terrain but can also be used on steep terrain. In contrast, small farm tractors have a gentle-moderate ranking in the terrain column, suggesting that small farm tractors would not be safe or very productive on steep terrain. Small farm tractors are low production (see productivity column) anyway, and trying to use them on steep or very steep terrain would simply not be safe or practical. The environmental impact column attempts to capture the impact to the logging site from the perspective of soil disturbance and compaction and residual stand damage. For example, a ranking of low would suggest the system application results in low levels of residual stand damage, little soil disturbance, and minimal soil compaction. In contrast, medium to high level rankings for the clambunk skidder and the forwarders would imply such levels of soil disturbance and compaction primarily on the most heavily traveled skid trails that experience multiple passes loaded and unloaded. The clambunk and forwarders may experience low levels of residual stand damage because they largely stay on the skid trails, yet the overall impact to the soil environment would be medium to high. The applicability matrix blends information from the literature and personal experience from the author's many years in harvesting research and application on the ground. As such, the matrix is based on science and observation, but users may encounter difficulty in finding results from well-designed experimental long-term scientific studies to match or substantiate all that is captured in the matrix. The author's intent is to provide managers, decisionmakers, policy formers, and loggers with a starting point on selecting harvesting systems for logging the northern hardwood resource. As more and new knowledge is obtained, the matrix should be updated.

Managing People and Machinery

Logging managers must manage their machinery and production quotas or goals, but they also must be people and employee managers. There is no substitute for hiring and retaining the best qualified and hardest working employees. A well-balanced team approach where employees are paid well, safety is stressed daily, and crews maintain a positive outlook and strive to communicate among themselves and with landowners will pay dividends in the long run. Being honest with landowners and treating them with respect goes hand in hand with operating in an environmentally friendly manner. Taking that extra time to satisfy landowner objectives and to simultaneously protect the environment will pay dividends for generations to come. With respect to the laws and rules, if hauling permits are required to move oversized equipment from job site to job site, obtain them and follow the procedures during moves. Some delays and expenses can be avoided by scouting the routes to be followed before any move. For example, getting stuck in a bridge crossing that is too narrow or low for the oversized load may result in unnecessary delays, fines, and expenses. Not recognizing that a sharp horizontal curve cannot be negotiated by the tracking mule trailer that is hauling the oversized equipment and result in lost time and costly adjustments. Trying to negotiate a steep vertical curve with a lowboy mule train trailer can result in the mule train getting hung up literally and lead to delays, breakdowns, and headaches. Wiping out a row of mailboxes or someone's prize yard tree while negotiating a tight horizontal curve with the lowboy and the oversized load with the feller buncher or skidder in tow can be expensive and create a lot of ill feelings about loggers in general. Alternate routes may be necessary or the moving of equipment during non-peak traffic hours could solve the challenge of getting from one job site to another. Sometimes equipment must be dismantled and hauled in separate loads to satisfy legal haul limits and tricky road conditions. Accidents cannot be totally eliminated, but many can be avoided by a little preplanning and pre-scouting.

Weather and Hauling Regulations

If job site or individual registration is required for a particular job or employee, by all means loggers should comply. Training in job task and safety should be a top priority for all involved. Loggers and landowners should make property boundary definition a major objective to be met before any logging crews or machinery is allowed on job site. Environmental compliance required by the law or the landowner should be understood, communicated, and followed. Special considerations to protect water resources, wildlife habitat, visual resources, and future crop trees must be understood and communicated to all involved. Figure 57 is an example of a Timber Sale Agreement/Contract that could be used to capture what needs to be done and how. A well-written contract protects the landowner and the logger both. Provisions E, H, I, J, K, and L are examples of how special considerations can be incorporated into the contract. Although Figure 57 spells out special considerations that need to be observed, it is only an example of what a contract might look like. Daily or timely inspections by the side rod or supervisor in charge should be conducted and any modifications or shortcomings should be communicated, corrected immediately, and/or the contract modified. To some extent, the logging manager must be a bit of a weather forecaster to anticipate and deal with ever changing weather events. Certain weather events can affect productivity and safety, and they can create undesirable environmental impact. For example, although frozen roads and frozen ground are generally desirable for trucking and skidding (Stone 2002), too much snow or too much ice can create all kinds of problems that can impact trucking and skidding productivity when log trucks simply cannot negotiate deep snow or where skidding and cutting crews either cannot see the base of trees to fell them or skidding crews cannot find the logs to choke them or grapple them. For example, trees heavily ladened with snow or ice are extremely dangerous if not impossible for manual felling crews to deal with. However, they are no obstacle for mechanized systems such as feller bunchers or cut-to-length systems. Muddy conditions can create loss of traction in hauling, skidding, and maneuvering equipment in general, can lead to severe or unacceptable rutting, can alter soil properties if soil is churned and mixed or compacted, and can result in equipment getting stuck or hung up. Excess rain can lead to muddy conditions, soft spongy ground, poor visibility, flooding, and runoff leading to erosion where debris and rocks are washed out on the roadbed. Ice storms and freezing rains can be extremely dangerous to operate in. The ice accumulation on trees along haul roads and skid trails can lead to trees and limbs leaning into the running surface of the road and skid trail and can come in contact with chip vans, log trucks, and skidding machines, resulting in damage to equipment or posing a safety hazard to wood workers. The ice load on standing trees can create an explosive situation where tree tops are snapping and breaking and trees are uprooting or where freezing rain makes road conditions so treacherous that the roads are literally impassable even with the best drivers operating with the best combination of chains and tire tread. The secret to dealing with snow, ice, mud, and rain is to try and keep the roads open and operable. In some of these cases, the logging crews may need to stay out of the woods and off the roads and simply wait this out. Most of the time, these events can be dealt with by simply being aware of potential changing weather conditions and making adjustments as required. In some cases the woods are shut down to operations for the time required until conditions are favorable for logging. To the extent possible, all members of the team or crew should meet daily and discuss near misses and success stories; alert each other to existing and newly created safety hazards, changing weather conditions; discuss problems with equipment or with meeting production quotas; and reassure each other they are doing a good job and are looking out for each other's backs. Loggers would be miles ahead to invest in a set of portable scales because most of the haul regulations deal with weight limits.

Profitability and Cost Control

Controlling costs and ensuring that operations are profitable are major objectives of any logging venture. Operating costs can spiral out of control quickly and can lead to huge losses. For example, excessive idle and down time (nonproductive time) can result in low production levels that may literally shut down a business. There are cost factors that the logger or contractor has some control over, and there are some cost factors that are beyond the control of the operator. The generation of profit is imperative to any operation for the operator to remain in business. Profit is defined as any net return above and beyond all operating and fixed costs. In this section the author will address some of the cost factors and variables that the operator has some control over and provide some elementary concepts on profitability.

Machine availability and utilization is one of the primary cost factors that can be controlled by the logger and that have the greatest impact on productivity and costs. The best way to illustrate the impact of utilization rate on production costs is by the following example. Using the equation for the Timbco T425 CTL from Table 8, with DC=22, DBH=13, HT=69.69, and utilization rates of 100 percent, 90 percent, 80 percent, and 60 percent, we developed Figure 58. We have values of $12.46, $13.79, $15.58, and $20.74/cord for the utilization rates mentioned above, respectively. The difference between an achievable 90-percent rate ($13.79/cord) and a 60-percent rate ($20.74/cord) is $6.95/cord. Figure 58 tells us that the cost/ft^3 has leveled off at 13 inches d.b.h. In fact, $/$ft^3$ starts to level off at about 9 inches d.b.h. for all utilization rates. A utilization rate of 90 percent and higher is a reasonable goal. According to

TIMBER SALE AGREEMENT

This agreement is entered into on this the _________________ day of _________________, 19___ between Joe Bag of Donuts Logging of 543 Wiseman Road, Morgantown, WV 26505 hereinafter called the Buyer and ____ of ____ phone number (___) ___________________ hereinafter called the Seller.

Witnesseth:

1. The Seller does hereby sell all the trees described as follows: __________________________
____
____
____
____
____

2. The timber to be cut is located on the property as shown on the map attached hereto and made a part hereof and described as follows: ____
____
____
____

3. The Seller covenants to and with the Buyer that: Seller is the lawful owner of the land and timber; they are free from all encumbrances: Seller has good right to sell the same as afore said; and Seller will warrant and defend the sale of said property, goods and chattels as hereby made unto the Buyer against the claims and demands of all persons whomsoever.

4. The Seller agrees to allow the Buyer to have ingress, egress, and regress upon said premises as described on the attached map to remove the designated timber and to perform other operations that are necessary in conjunction with the removal of said timber, which includes the right to establish clearings for log landings and loading operations and to establish access and skid roads necessary for the removal of said timber.

5. The Buyer agrees to cut and remove said timber in accordance with the following provisions:

(A.) Young trees shall be protected against unnecessary injury.
(B.) No cut, broken or uprooted trees shall be left hanging in standing trees.
(C.) The Buyer shall use due care to prevent fire.
(D.) Stream courses will be kept free of tops, boundary lines will be kept open, roads will be free and open at the completion, and mechanized cut-to-length with forwarder logging practices will be used to harvest said timber.
(E.) 25 foot buffer zones will be left on both sides of streams. No timber will be harvested from these buffer zones.
(F.) Upon completion of the harvesting, the Buyer will smooth the ruts of the main haul skid road, truck roads, and landings where necessary. Also diversion ditches will be built where necessary on steep skid trails.
(G.) All stumps will be cut to within twelve (12) inches of the ground, measured on the uphill side.

(H.) The landings will be seeded at the completion of harvesting as follows:

____

____

(I.) An invasive species plant inventory will be conducted by the logger and landowner prior to any logging operations.

(J.) The logger will follow voluntary BMPs for invasive species mitigation as outlined by LeDoux 2011 in the publication "Harvesting Systems for the Northern Forest Hardwoods"

(K.) One quarter acre patches of timber will be retained and protected as marked by the landowner.

(L.) The logger and landowner will jointly survey the subject property for safety hazards and will flag such.

(M.) The Buyer will have until ____________________, 19__, within which to harvest the timber hereby conveyed.

6. The Buyer agrees to furnish the Seller with a Certificate of Insurance evidencing his having General Liability Insurance, in force, with submission of this contract.

7. The Seller shall be relieved of all claims, damages, or suits arising from the actions of the Buyer, his agents, servants, or employees during the period of this agreement. Likewise, the Buyer shall be relieved of all claims, damages, or suits arising from the actions of the Seller, his agents, servants, or employees during the period of this agreement.

8. The Buyer agrees to pay for said timber as follows: ___________________________________

____

____

____

____

____

9. This agreement and all terms, provisions, and conditions shall be binding on both parties, their legal representatives, heirs, and successors.

IN WITNESS WHEREOF, Seller and Buyer have set their hands and seals to these presents this the _____________day of ____, 19___.

Signed, sealed and delivered in the presence of:

_________________________________ _____________________________ (seal)

Witness Owner

_________________________________ _____________________________ (seal)

Witness Owner

Signed, sealed and delivered in the presence of:

_________________________________ _____________________________ (seal)

Witness Buyer, Joe Bag of Donuts Logging

Figure 57.—Example of a Timber Sale Agreement. Courtesy of Chris LeDoux.

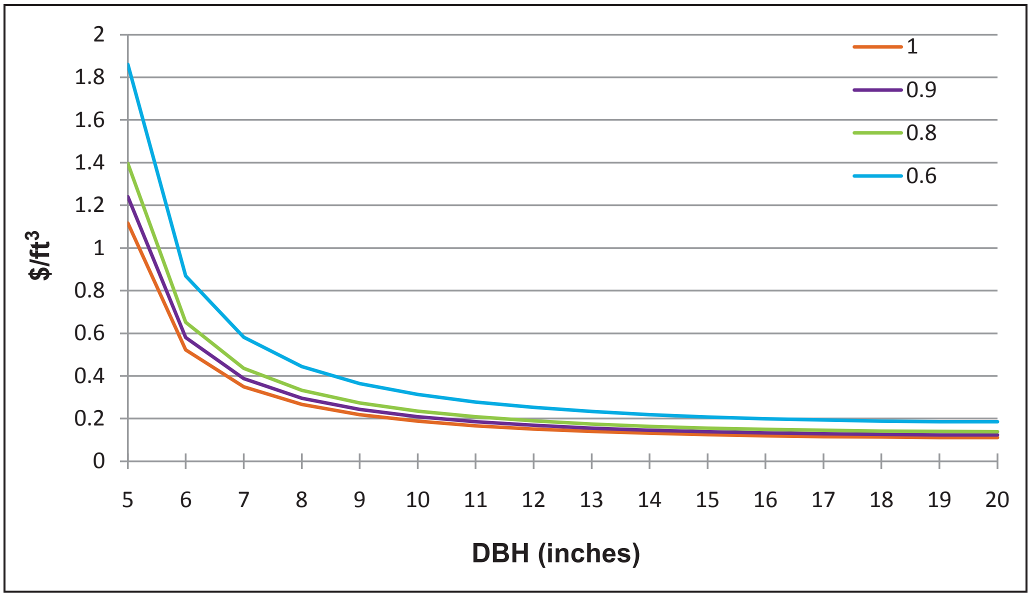

Figure 58.—Delay-free $/ft^3 by DBH for a Timbco 425 cut-to-length machine. Conditions: DC=22, utilization rates = 100, 90, 80, and 60 percent.

the author's observation, many operators achieve utilization rates that exceed 80 percent. Figure 58 can also be used to further explain the impact of utilization rate on the type (size) of stands that an operator would break even in if the CTL cost was constrained at $0.20/ft^3 ($17.80/cord). The logger should operate in 9-inch d.b.h. stands at 100-percent utilization, 10-inch d.b.h. stands at 90 percent, 11-inch d.b.h. stands at 80 percent, and 15-inch d.b.h. stands at 60 percent. Although 100-percent utilization rates are not practical, 80- to 90-percent utilization rates are achievable. Utilization rate is something we have control over. Machines must be kept in good operating condition so that idle time due to breakdown and repairs is minimized. A broken machine will simply not be able to produce any wood. Downtime due to machine failure and repairs should be kept to a minimum. Repairs and maintenance should be scheduled during non-working shifts, if possible. Equipment operators should get to know their machines and detect when components need repair or maintenance and do that immediately instead of waiting until a major component fails. Equally important is controlling and minimizing idle time due to machines having to wait on each other or on woods workers for wood. For example, ideally, chippers should be fed wood at a rate to keep them busy as opposed to having to wait on the arrival of wood for chipping. The helicopter should not have to hover and wait for the hooker to choke a turn of logs. The logs should be pre-choked and turns or loads should be pre-selected in advance of the hook and tag line being lowered. The grapple skidder should not have to wait on the feller buncher for wood. Clearly, some machine and component failures cannot be anticipated, but keeping a sharp eye on periodic maintenance and scheduling repairs at the first sign of need can go a long way toward keeping machines at the highest availability and utilization levels.

Machine operators should exploit the capacity of their machines whenever possible. For example, the skidder, forwarder, clambunk, helicopter, yarder, etc., should be loaded to safe working payloads every trip. Notice in Figure 59 how the load is configured on the clambunk skidder. The bottom layer of stems lies 2 to 3 feet behind the middle layer and the middle layer lies 2 to 3 feet behind the upper layer in the load. In other words, a grapple skidder running

Figure 59.—Clambunk skidder with multiple axles, dual tires on each side, and a balanced payload. Photo courtesy of Tigercat.

back to the landing with one-fourth or one-half of its load capacity is only losing the contractor money. The best way to illustrate the impact of payload on costs is by using an example. Using the equation for the grapple skidder (Table 6), we developed Figure 60. Cost/ft^3 decreases as payload increases. A 300-percent increase in payload (going from 50 ft^3 to 200 ft^3) results in a 47-percent decrease in cost (going from \$.105/ft^3 to \$.05/ft^3). Although the concept of exploiting a machine's capacity cannot be stressed enough, it is not always possible to maximize payload. In some cases it is relatively easy to fill forwarder bunks to capacity. Similarly the

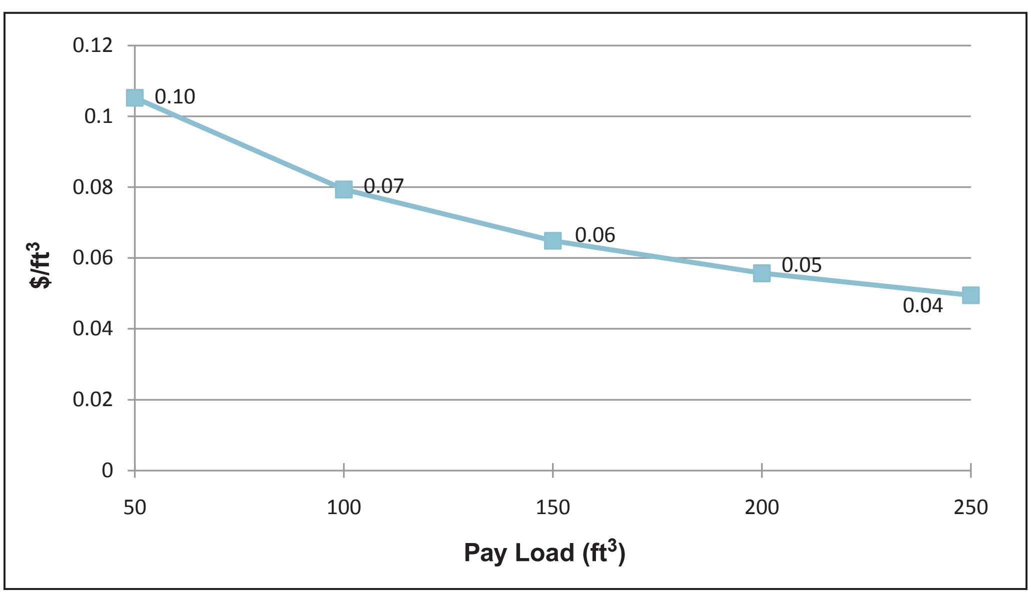

Figure 60.—Delay-free \$/ft^3 by payload for the Timberjack 460 grapple skidder. Conditions: ASD = 740, BZ = 135.

Figure 61.—High capacity forwarder with a payload. Photo courtesy of Tigercat.

grapple on the skidder, clambunk, or dozer can usually be loaded to capacity especially if the wood has been prebunched. In the case of loading a helicopter's hook, hooking a turn of logs for a cable system, or building turns for tractors and skidders, reaching capacity is more challenging. The machine operator may have to hook and winch logs, moving them about the stand in the process of collecting enough logs to reach the capacity of the machine. Many times when the log population is scattered within a harvest block, the operator does best by taking what is available versus spending excessive time and energy trying to hook a bigger turn.

When we studied the impact of log population and distribution in Douglas-fir cable thinning (LeDoux 1981), we found that the number of chokers to fly depended on the log population distribution. We also studied when to prebunch wood in cable thinning (LeDoux and Butler 1981b). We found that prebunching logs to decks within a stand using a small winch was more effective than yarding alone. Prebunching, directional felling, and loading machines to capacity really work and are things that the operator has some control over.

There is a fine line between exploiting the load capacity of the machines and abusing the machine to where it fails. For example, hooking too heavy a load on a helicopter may result in the pilot having to abort the load (resulting in delays to rehook the turn); hook failure, load or tag line failure may "pull" the helicopter into the surrounding trees or to the ground or cause machine and engine or component failure. Feller bunching machines with accumulating felling heads should be exploited to accumulate the maximum number of stems per cycle to maximize production. Notice in Figure 25 how multiple stems are accumulated in the felling head. Machine operators should always accumulate as many stems as safely possible to maximize the productivity of the machine without having to move to alternate locations. Figure 61 shows how a large forwarder can be loaded to its maximum safe operating capacity. Skyline carriages should be loaded to capacity by choking the maximum number of logs per cycle. Log and chip vans or trucks should be loaded to their safe and legal working limits. Wood or logs or stems should always be prebunched or bundled in the woods before any extraction operations. Equally important is the practice of matching the machine size and capacity to the size of wood they will be operating in (Fight et al. 1984; LeDoux 1985a, 2000). For example, in the first entries into a young stand, a small machine may be required, while in final entries or final harvests of older stands, larger machines would be the way to go (LeDoux 1986c, LeDoux and Brodie 1982, LeDoux and Butler 1981b). Suppose a logger plans to add a skidder to his equipment fleet. The skidder will operate in tracts where: average DBH = 12 in., volume cut/acre = 2,500 ft^3, slope yarding distance = 800 ft, volume/log = 20 ft^3, logs/turn = 4, and the volume/turn = 80 ft^3. Because the numerical values of the stand attributes are within the variable limits (Table 5), the JD 440C, JD 540B, and the JD 640D could all be selected to harvest these tracts. The logger could use the equations in Table 5 for the three machines as follows:

JD 440C

$$\$/ft^3 = 0.1654157 + 0.0137012 * DBH + 0.0000008906 * VOAC - 0.001362 * VPL + 0.00004815 * SYD - 0.0027067 * VPT + 0.0024094 * LPT$$

$$\$/ft^3 = 0.1654157 + 0.0137012 * 12 + 0.0000008906 * 2500 - 0.001362 * 20 + 0.00004815 * 800 - 0.0027067 * 80 + 0.0024094 * 4$$

$$\$/ft^3 = .1364$$

JD 540B

$$\$/ft^3 = 0.43486 – 0.0201429 * DBH + 0.0000005772 * VOAC + 0.002606 * VPL + 0.00004743 * SYD - 0.0015778 * VPT - 0.0145491 * LPT$$

$$\$/ft^3 = 0.43486 – 0.0201429 * 12 + 0.0000005772 * 2500 + 0.002606 * 20 + 0.00004743 * 800 – 0.0015778 * 80 - 0.0145491 * 4$$

$$\$/ft^3 = .1002$$

JD 640D

$$\$/ft^3 = 0.3415523 – 0.0072889 * DBH + 0.000001086 * VOAC + 0.0012704 * VPL + 0.0000495 * SYD - 0.001875 * VPT - 0.0058284 * LPT$$

$$\$/ft^3 = 0.3415523 – 0.0072889 * 12 + 0.000001086 * 2500 + 0.0012704 * 20 + 0.0000495 * 800 - 0.001875 * 80 - 0.0058284 * 4$$

$$\$/ft^3 = .1485$$

Based on these estimates, the selection would be the JD 540B or something in the same capacity. The JD 440C is likely reaching its maximum capacity range with the logs from a 12-inch stand (LeDoux 2000). The JD 640D may have too much capacity for the stand conditions. Too large or small a machine for the operating conditions required will only result in unused capacity, delays, and machine or component failure. Obviously, operators cannot always exploit the capacity of the machine or exactly match the machine to the operating wood size, but some attention to these principles can go a long way toward controlling costs and increasing productivity.

To run a profitable operation, contactors or loggers must not only attempt to control the cost factors they can, but also understand and account for the costs involved and allow for a profit and risk margin. For example, the cost to fell, buck, limb, skid, load, and haul the products must be summed along with the road and landing construction expenses. Any expenses for special environmental compliance such as protection of SMZs or survey and procedures to mitigate the control and spread of invasive plant species must be factored in. The author cannot stress enough the need to keep accurate and detailed records of all costs, production, repairs, etc. A good accurate and detailed paper trail not only serves as a benchmark for identifying bottlenecks or areas where changes or improvements must be made but also comes in handy in case of audits or litigation. Costs involved with contract preparation, site visits and cruises or surveys, and/or post harvest treatments such as seeding, renovating roads and landings, or putting skid trails to bed must also be summed. After all costs are accounted for, the author's guidance to students and practitioners is that the contractor should adjust the sum of all costs by a margin for profit and risk (this is the net return to the logger or contractor). For example, if the sum of all costs comes to $45/cord and the loggers' or contractors' margin for profit and risk is 30 percent, then the final bid price should reflect $58.50/cord. Clearly, many costs need to be considered in the process and each logging chance has its own set of operating conditions. The author's treatment of this subject is not exhaustive but should provide an elementary introduction into profitability and cost control.

The author cannot stress enough the importance of having a solid relationship with good reliable repair and maintenance support that respond quickly when needed. Although most loggers and crews become very proficient at repairing and maintaining their equipment, many tasks can be handled only by the repair shop.

In closing, simply stated, do a good job, keep good employees, pay them well, work hard, stay positive, be environmentally friendly, be safe, be honest, treat landowners with respect, follow the rules and laws, and you will succeed.

Many of the papers cited are available for downloading at: http://nrs.fs.fed.us/people/cledoux

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LeDoux, Chris B. 2011. **Harvesting systems for the northern forest hardwoods.** Gen. Tech. Rep. NRS-91. Newtown Square, PA: U.S. Department of Agriculture, Forest Service, Northern Research Station. 65 p.

This monograph is a summary of research results and environmental compliance measures for timber harvesting operations. Data are presented from the Northern Research Station's forest inventory and analysis of 20 states in the northern forest hardwoods. Harvesting systems available in the region today are summarized. Equations for estimating harvesting costs are documented. Safety considerations are compiled along with images of safety equipment and clothing engineered to protect the head, ears, eyes, face, hands, and legs. Mandatory and voluntary best management practices (BMPs) are discussed for streamside management zones (SMZs), patch/structural retention, invasive plant mitigation, and soil protection. Profitability and cost control are addressed. The importance of keeping machines working, exploiting machines' payload capacity, and matching machines to the size of wood being harvested is illustrated. The information offered in this text should be valuable to the harvesting industry and serve as a text for a course in timber harvesting.

KEY WORDS: BMPs, timber harvesting, cost, safety, logging systems, simulation

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