4.0 Harvesting Systems

A harvesting system typically consists of four phases: falling and bucking, yarding, loading, and hauling.

A harvesting system typically consists of four phases: falling and bucking, yarding, loading, and hauling. Because the capabilities and limitations of methods and equipment used in the yarding phase are critical in attaining variable-retention silvicultural objectives, they are the focus of this chapter.

Three major categories of factors affect the selection of harvesting systems in Clayoquot Sound:

Yarding methods are critical to attaining variable-retention silvicultural objectives.

- characteristics of the physical environment, including climate and hydrology, terrain and topography, and soils (Section 2.1);
- timber characteristics, including tree species, size, age, and condition, and the prescribed silvicultural system (Chapter 3); and
- other factors, such as mill requirements, public perceptions, and regulatory requirements, including roading constraints (Chapter 5).

4.1 Current Harvesting Technology and Equipment

4.1.1 Description of Yarding Methods[76]

There are four major categories of yarding methods.

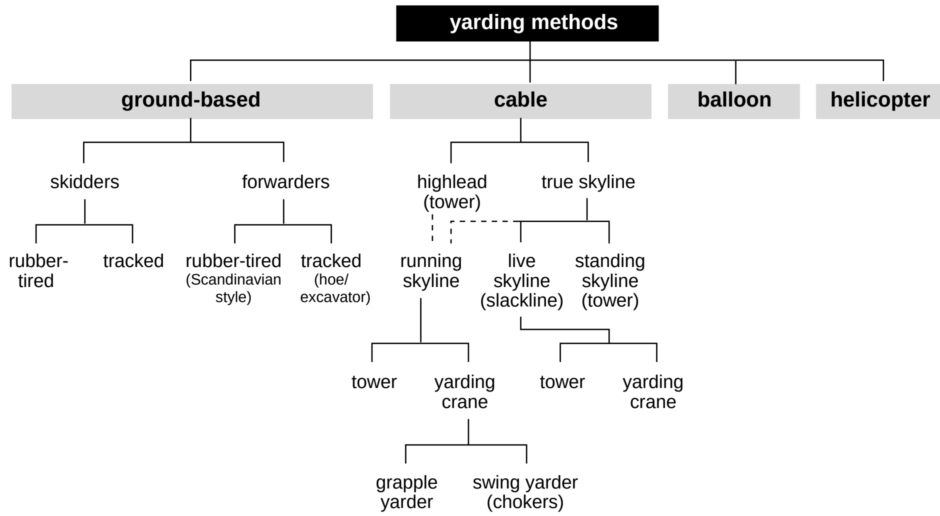
Yarding methods can be grouped into four categories, based on machinery used for moving logs from where trees are felled to the road, landing, or other point at which they are loaded for further transport:

- ground-based yarding (e.g., skidders, hoe forwarders, crawler tractors);
- cable yarding (e.g., highlead, skyline);
- balloon yarding (a hybrid between cable and aerial yarding); and
- helicopter yarding (commonly referred to as helicopter logging or heli-logging).

Figure 4.1 illustrates this classification of yarding methods; many innovative variants and adaptations exist. The requirements and range of applications of each yarding method are discussed following Figure 4.1 and summarized in Table 4.1.

[76] Illustrations of yarding methods in this section are from Binkley and Studier (1974).

Figure 4.1 Classification of yarding methods.



Ground-Based Yarding

In ground-based yarding, the machine travels to the log, then moves it to a landing.

In ground-based yarding, the machine travels to the log, then moves it to a collection point (landing). "Skidders" move on tracks or wheels to the logs and skid or drag them, usually with one end raised above the ground, to the landing. "Forwarders" transport logs without dragging them. Rubber-tired (Scandinavian style) forwarders carry relatively short logs in bunks. "Hoe forwarders" (or "hoe chuckers") use a modified backhoe or hydraulic loader to lift, then swing or slide logs to a yarding or skidding corridor,[77] to roadside, or to a landing.

Because skidders pull logs, they are constrained by slope and slope configuration, and can cause high soil disturbance. Rubber-tired forwarders are more constrained by slope than skidders. Hoe forwarders remain stationary as they swing logs and can operate on steeper slopes (up to 30–35%) with lower potential for soil disturbance. While both skidders and forwarders are sufficiently manoeuvrable to remove logs from the site with limited damage to residual standing timber, their potential to damage tree roots and soil during yarding must be considered.

Applicability of ground-based methods is limited by slope, soil, and weather conditions.

Ground-based methods, especially skidders, are weather sensitive. During heavy or prolonged rain their operation may be suspended because the soil loses strength, resulting in increased potential for soil and / or root damage.

[77]Yarding corridors (also called yarding "roads") refer to the roughly linear paths that logs travel as they are pulled by cables (lines) from the location of felling and bucking to the landing, or other area where logs are collected for loading. Skidding corridors are analogous but refer to designated routes used by ground-based equipment.

Cable Yarding

Cable yarding methods are characterized by stationary yarders which move logs by cables from where the trees were felled, along yarding corridors to a landing or to roadside. The amount of soil disturbance from cable yarding is a function of the extent to which logs remain in contact with the ground as they travel from the cutblock to the landing. This extent of contact ranges from full suspension to partial suspension to ground lead.[78]

Two basic types of cable yarding can be differentiated: highlead and skyline.

Highlead

The highlead method, where chokers are attached directly to the mainline, can provide no more than partial suspension of logs as a consequence of tower height and topography (Figure 4.2). The method has no lateral yarding capability[79] beyond the length of the chokers.

Highlead yarding has no lateral yarding capability beyond the length of the chokers.

Highlead yarding is usually limited to yarding distances of 200–300 m (dependent on log lift[80]). Log lift, log control, and production rate decrease rapidly with increased yarding distance. Typical production values range from a low of 100 m^3/shift for poor lift and long distances, to about 220 m^3/shift for short distances and good lift.[81] Highlead systems usually require a crew of five to six people. Highlead towers access fan-shaped to roughly circular areas with yarding corridors radiating out from a central landing (Figure 4.3).

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[78]With “full suspension,” logs are suspended in the air as they travel from where they are hooked up (in the cutblock) to the landing. With “partial suspension,“ one end of the log is in contact with the ground while the logs are yarded (dragged) to the landing. With “ground lead,” little or no lifting force is applied where the chokers attach to the logs; there is insufficient clearance between the ground and the loaded cable path to lift the end of the logs off the ground. Logs then commonly hang up behind stumps, and ground disturbance can be severe.

[79]Lateral yarding (also referred to as lateral reach or lateral reach capability) refers to the ability to yard logs from the stand into a main yarding corridor.

[80]Lift refers to the lifting force applied to a log by a cable yarding system. Lift varies continuously along the path travelled by the yarded log.

[81]Production figures (m^3 of logs yarded to a landing) are for a regular 8-hour shift less travel time.

Figure 4.2 Highlead yarding with chokers attached to the mainline via butt rigging.

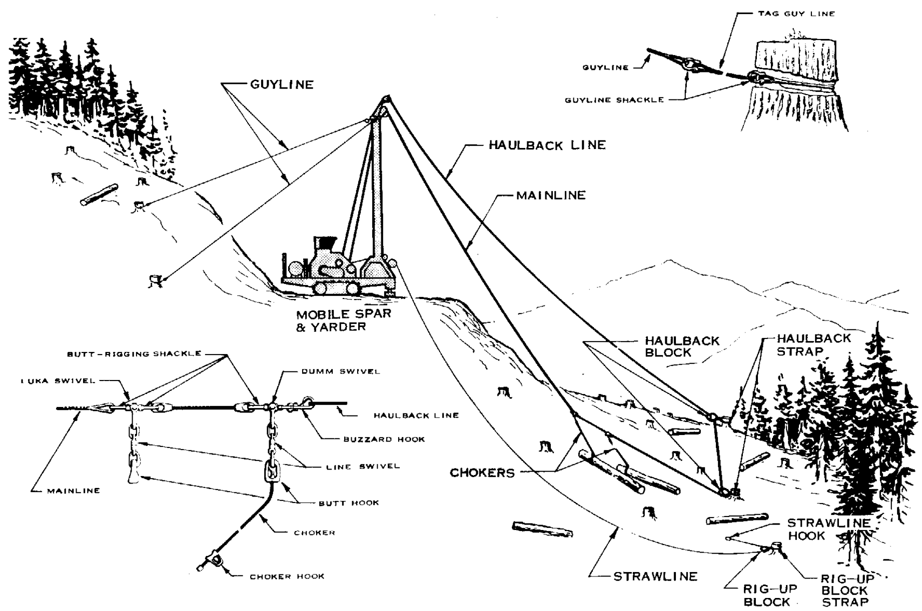
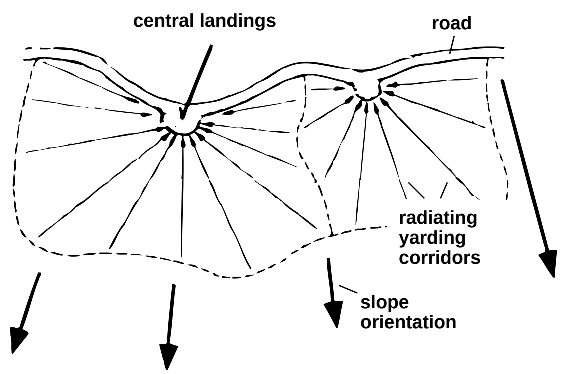
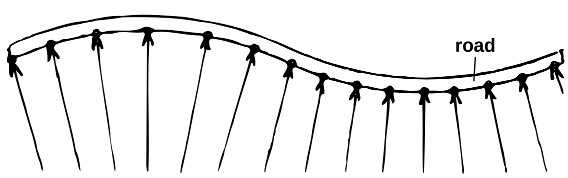


Figure 4.3 Yarding corridor patterns: radiating versus parallel.



Central landings require a large decking area or a dedicated log loader to prevent excessive congestion in the landing. Typical for highlead or skyline towers.



Parallel (to sub-parallel) yarding corridors allow logs to be decked along the road. The corridor orientation varies somewhat in response to concave and convex slope forms. Yarding and loading phases can be undertaken at different times. Typical for yarding cranes.

Skyline

Skyline yarding can be divided into "true" skylines and running skylines. True skylines include both live skyline (slackline) and standing skyline. Running skylines, like highlead, have two main operating lines: a mainline and a haulback line. However, in a running skyline configuration, the haulback doubles as a skyline to support a carriage or log grapple thus providing additional log lift. The configuration and movement of the cable and carriage define the type of skyline (Figures 4.5, 4.6, and 4.7).

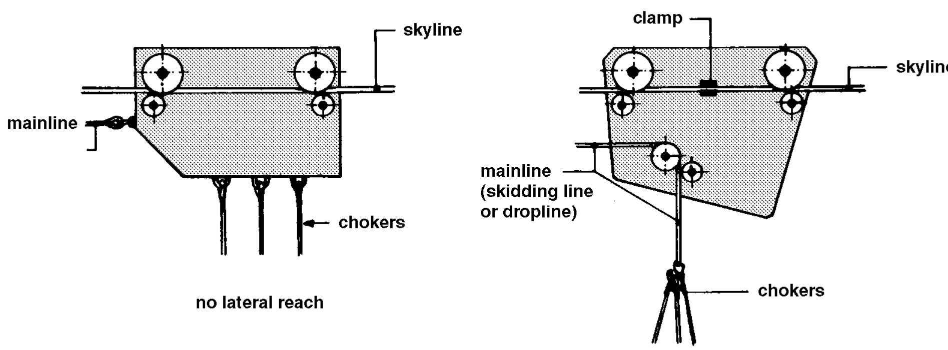
Skyline systems can yard up to 1000 m or more, given appropriate topography.

Skyline systems can use a relatively short crane (15–17 m) built on an excavator-like undercarriage (called a yarding crane or swing yarder) or a 27–30 m steel tower (called tower skyline). Either machine can yard up to 1000 m or more, given appropriate topography. Yarding cranes, which were developed in the 1960s, are very mobile, require two to four guylines, and can rotate without affecting these lines. By comparison, tower skylines require six to eight guylines, are stationary, require a larger crew to operate, and take more time to move. However, the taller towers have two advantages over yarding cranes: they permit higher log payloads and make yarding possible in broken terrain or other difficult topography.

Attaching chokers to a dropline or skidding line allows for lateral yarding.

Carriages are available in a range of types and sizes; they can be mechanically operated from the yarder or radio-controlled by the yarder and rigging crews. The carriage determines the ability of the skyline to yard logs laterally from the adjacent forest as well as from within the yarding corridor. Simple carriages with chokers directly attached, an uncommon configuration now, do not have lateral yarding capability. Carriages with chokers attached to a dropline[82] or skidding line, which can itself be pulled out (Figure 4.4), have lateral yarding capabilities typically ranging up to 30 m. Both tower skylines and cable cranes can use these carriages.

Figure 4.4 Simple carriages with and without lateral yarding capability.



Grapple yarding is best suited to clearcuts with short yarding distances where roads are not constrained.

A running skyline can operate either with chokers or with a log grapple. The grapple yarder is a configuration of running skyline that uses a relatively short yarding crane (swing yarder) equipped with a log grapple (rather than chokers) to grasp and yard logs (Figure 4.5).[83] The grapple yarder has no lateral yarding capability. Grapple yarding corridors are parallel and narrowly spaced; logs are landed at the roadside, or on the road where slopes exceed about 45%. By incrementally moving the yarding equipment along the road, yarding corridors can be kept nearly perpendicular to the road and slope contours. Where a mobile backspar machine (e.g., a modified hydraulic excavator) is used to speed movement between corridors and to increase lift, backspar trails are required. Grapple yarders are normally used to yard logs across distances of less than 150–200 m. Grapple yarding is best suited to clearcuts with short yarding distances where roads are not constrained.

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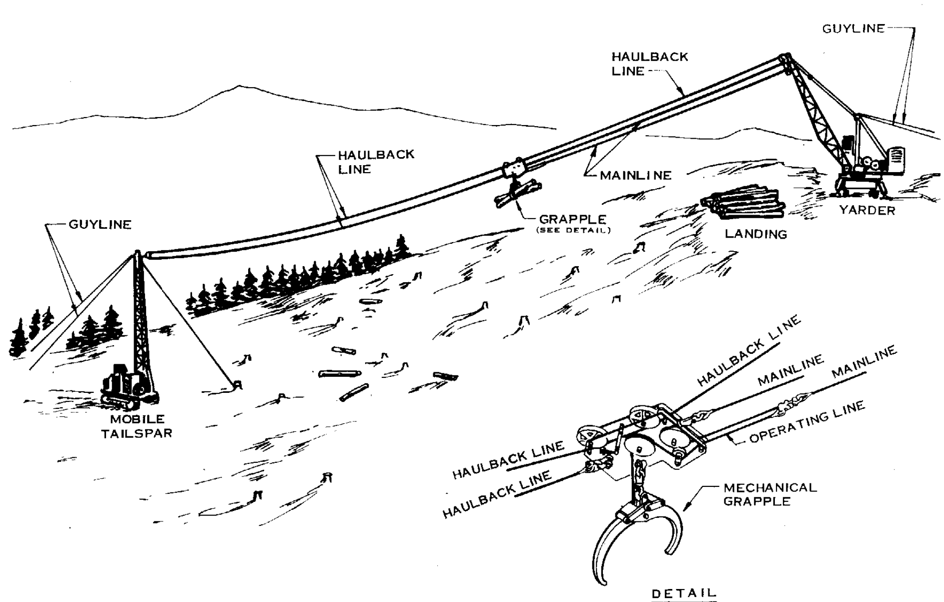
[82] A dropline is a skidding line that can be pulled out (dropped) from below the carriage to extend the lateral reach of the chokers. The dropline can be an extension of the mainline (Figure 4.4) or be wound on the drum in the carriage (Figure 4.6).

[83] Grapple yarding refers to a cable-based method of yarding logs with a grapple (or grapple tongs) from where they are felled and bucked, to a roadside. This method employs a yarder with a 15- to 17-m crane built on a hydraulic excavator-like chassis. In British Columbia coastal operations, the chassis is commonly on tracks.

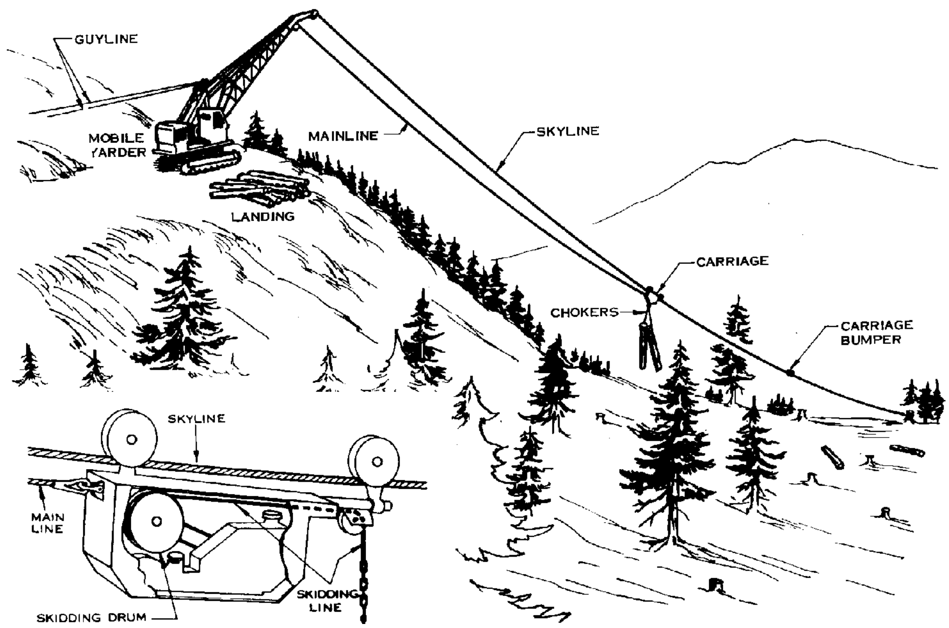
Figure 4.5 Grapple yarder.



When a running skyline is configured for chokers rather than a grapple, a lightweight carriage can be used (Figure 4.6). Depending on the type and capabilities of the carriage, lateral yarding of up to 30 m is feasible. This allows for retention cuts, where some or all of the retained trees are dispersed throughout the cutting unit.

With true skyline yarding, both live and standing skylines use a stationary cable (“skyline”) suspended between a yarding tower and a backspar. The mainline attaches to a carriage that travels along the skyline by gravity or by controlling mainline and haulback movement at the yarder.

Figure 4.6 **Live skyline with a radio-controlled slackpulling carriage showing full log suspension.**



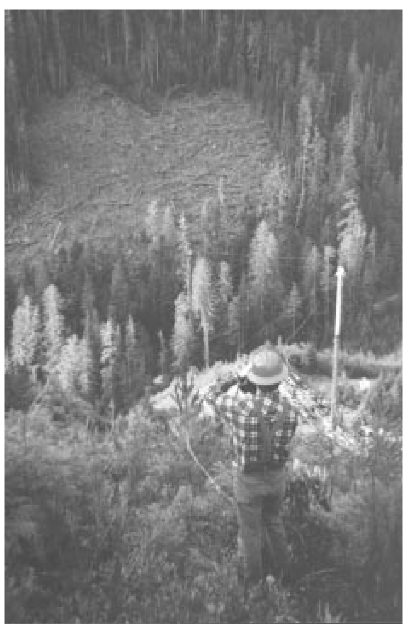


Photo 4.1

In this example, a live skyline with a tower is being used to yard logs over a forested riparian corridor.

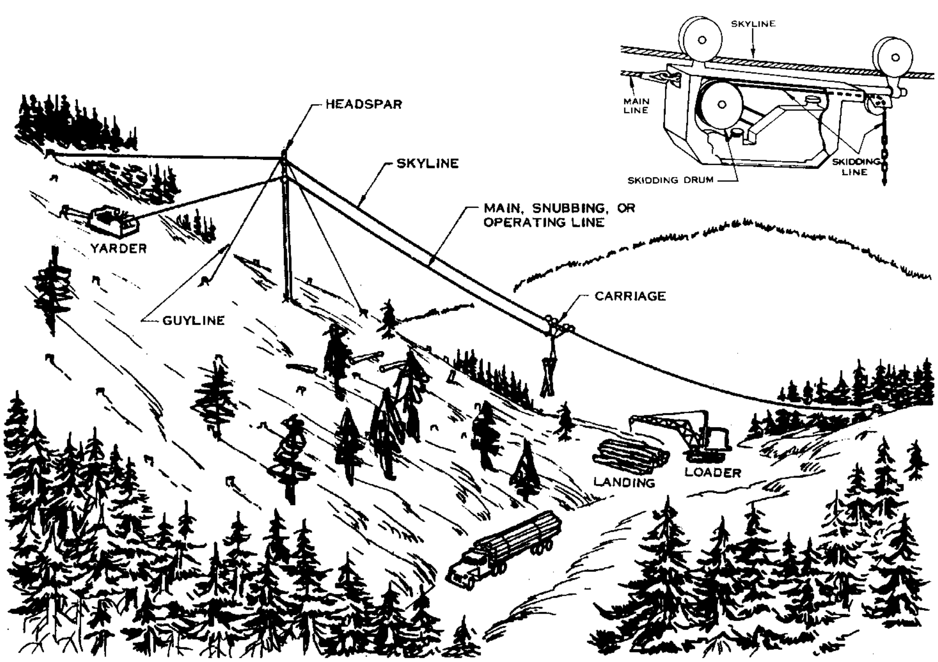
Live skylines are typically used where road access is constrained and long yarding distances (greater than 300 m) are required.

The “live skyline” is suspended between the yarder and a backspar (usually a tree), with one end of the cable anchored to tail-holds and the other wound on a drum so that the skyline can be lowered and raised during yarding (Figure 4.6). A carriage rides on the skyline with chokers attached directly to the carriage or to a dropline. In the latter case, chokers can be pulled laterally into the stand. Logs are commonly yarded with partial suspension, although full suspension is possible in suitable topography. Live skylines are typically used where road access is constrained and long yarding distances (greater than 300 m) are required.

Standing skylines are used where full suspension of logs is desired or for yarding long distances— of up to 1500 m.

In the “standing skyline,” both ends of the skyline cable are secured and the skyline cannot be raised or lowered during yarding (Figure 4.7). Chokers are attached to a dropline which can be lowered to the ground; logs are attached and pulled up to the carriage. Standing skylines are used where full suspension of logs is desired (e.g., to move logs from one side of a stream to the other, where roads are not possible or permitted, or for yarding long distances—up to 1500 m). With appropriate topography the system can carry logs over standing trees or regeneration; otherwise, narrow yarding corridors must be cut through standing timber. Multi-span configurations are sometimes feasible with standing skylines.[84]

Figure 4.7 Standing skyline with a radio-controlled carriage.



[84]Multi-span configurations involve two or more spans of the skyline by using intermediate supports.

Balloon Yarding

Balloon yarding overcomes some of the limitations of cable systems (e.g., yarding distance, payload, and lift) in unfavourable topography. Balloon yarding uses cables to move logs to a stationary yarder at the landing, in much the same way as traditional cable systems. However, lift is provided by the balloon rather than as a consequence of topography and tower height.

Balloons are inappropriate for retention silvicultural systems.

Balloons can yard up to 1500 m, thus reducing road access requirements. Their vertical lift capability (15 000–18 000 kg) enables full suspension of logs. Balloons are best suited to larger clearcut operations because of the high log volumes needed to offset high set-up costs. Balloons are inappropriate for retention silvicultural systems because imprecise manoeuvring and positioning of the balloon reduces control of the operating lines (cables).

Helicopter Yarding

Helicopters are typically used to yard logs in sensitive or otherwise inaccessible terrain.

Helicopters are typically used to yard logs in sensitive or otherwise inaccessible terrain. Optimal flight distance is typically 600–1000 m although maximum yarding distances can extend to 2000 m, with high value timber. Level to downhill flight paths are preferred to take advantage of gravity. Widened roadsides or water, rather than constructed landings, can be used as unloading sites (drop sites) for logs.

Compared to ground-based and cable yarding methods, helicopter logging has both higher operating costs (\$45–60 / m^3) and higher yarding production rates (500–1500 m^3 / shift). Because of high production rates, safe, efficient movement of workers and equipment requires careful planning. If central landings are used, they must be relatively large to accommodate log storage and segregate work activities for adequate worker safety. For such reasons, pre-harvest planning and organization are critical to the success of helicopter logging operations. Because helicopters have specific, limited payload lifting capacity,[85] and very high operating costs, logs—especially large logs—must be bucked precisely so that helicopters carry near to maximum payload and log value on each trip. Helicopters with heavy-lift payload capacity (e.g., Sikorsky S-64 and Boeing Vertol) are more suitable for higher levels of retention than medium-lift machines (e.g., Sikorsky S-61), because of their greater ability to lift logs almost vertically through remaining forest canopy.

Helicopter yarding is more sensitive to weather than cable yarding. Winds and landing location need to be considered. Fog, low cloud, and wind speeds above 50 km / hr usually suspend helicopter operations.

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[85] "Payload lifting capacity" refers to the weight that a helicopter can safely lift and transport. Helicopters can be classified as "low-lift" (up to 5000 lbs), "medium-lift" (5000–10 000 lbs), and "heavy-lift" (greater than 10 000 lbs).

Table 4.1 summarizes the basic characteristics and capabilities of each yarding method.

Table 4.1 Characteristics of common yarding methods.

Yarding method		Yarding distance	Limiting slope %	Applicability to different silvicultural systems	Yarding corridor arrangement	Potential for detrimental soil disturbance	Comments
Ground-based	Skidders (rubber-tired or tracked)	Uphill 120 m; downhill and flat 60–600 m	30–40%	Flexible; clearcuts, partial and retention cuts	Flexible	Moderate to high	Best suited to drier and/or cold climates, and strong soils (coarse-textured, dry, or frozen); potential for root damage
	Hoe forwarder	Uphill 20–70 m; downhill 20–120 m	Uphill 15–30%; downhill 35%	Flexible; clearcuts, partial and retention cuts, and thinning	Flexible	Low (<5%) if measures taken to protect soils	Allows full separation of yarding and loading; low labour requirement
	Scandinavian-style forwarders	150–600 m	15–20 %	Flexible; clearcuts, retention cuts, thinning	Flexible	Low to moderate	Potential for future use in managed stand harvest
Cable	Highlead	Uphill 100–300 m; downhill 30–100 m (recommended), 30–200 m (typical); no lateral yarding	Determined by falling and bucking safety	Clearcuts, apart from strips or wedges in the outer half of setting	Radiating	Low to moderate, depends on lift; locally high in ground-lead situations or in broken or gullied terrain	Lift is limited by tower height and slope configuration; partial suspension in favourable topography
	Grapple yarder	Uphill 100–200 m; downhill 50–150 m; no lateral yarding	Determined by falling and bucking safety	Most effective for clearcuts or strip cuts due to lack of lateral yarding capability	Parallel; at right angle or slightly angled to road (downhill yarding)	Low with adequate log suspension	15–17 m crane; uses road as landing; mobile backspar improves efficiency; only 2–4 guylines; fast yarding corridor changes
	Yarding crane (swing yarder) with dropline carriage	Uphill 100–700 m; downhill 100–400 m; 10–30 m lateral yarding	Determined by falling and bucking safety	Flexible; clearcuts, partial and retention cuts	Parallel; at right angle or angled to road; and radiating	Low with adequate suspension	15–17 m crane; uses road as landing; mobile backspar improves efficiency; only 2–4 guylines, fast yarding corridor changes
	Live skyline (tower)	Uphill, up to 1000 m; downhill, up to 700 m; lateral yarding to 30 m	Determined by falling and bucking safety	Flexible; clearcuts, partial and retention cuts, thinning	Radiating	Minimal with adequate suspension	6–8 guylines; accesses large area, may stay in place for one to several weeks; large volume accumulates at the landing; requires sound anchors for guylines and tail-holds; usually for single-span operations
	Standing skyline (tower)	Uphill or downhill up to 1500 m; lateral yarding to 30–60 m	Determined by falling and bucking safety	Flexible; clearcuts, partial and retention cuts, thinning	Radiating	Minimal; full suspension system in suitable topography	Used where full suspension is required (e.g., moving logs over a stream); requires sound anchors for guylines and tail-holds; has multi-span potential
Balloon		Up to 1500 m	Determined by falling and bucking safety	Limited to large clearcuts due to lack of line control	Radiating	Minimal; full suspension system	Requires large volumes to be economical; very sensitive to wind /heavy rain
Helicopter		Up to 2000 m where timber value allows	Determined by falling and bucking safety	Very flexible; clearcuts, partial, and retention cuts	No corridors	None	Road as landing or water drop; snags and other danger trees must be removed above and around hook-up areas; high operating costs; must run at near capacity; weather sensitive

4.1.2 Factors Affecting Choice of Harvesting System

As previously noted, harvesting systems are selected based on site variables and management objectives. Specific factors affecting the choice of harvesting system include:

- topography (slope steepness and variability);
- soil (composition, sensitivity to disturbance);
- silvicultural system (level of retention, number of harvest entries);
- timber characteristics (log size and volume per hectare);
- potential road access and roading constraints (Chapter 5); and
- yarding distance and direction; if cable yarding, desired log suspension (full or partial) is based on risk of detrimental soil disturbance, damage to retained trees, and protection of other resource values.

The selection of harvesting system follows a decision matrix (Figure 4.8).

Topography and soil characteristics are the key factors in determining if ground-based yarding methods are appropriate.

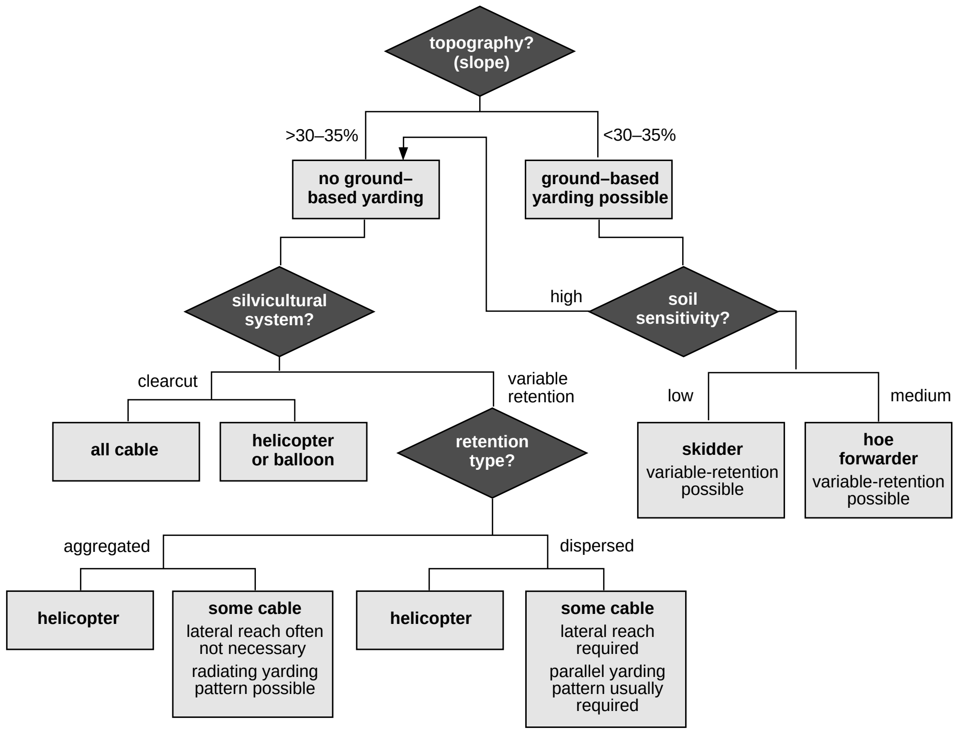
Topography and soil characteristics are the key factors in determining if ground-based yarding methods are appropriate. Ground-based yarding equipment is limited to slopes of less than about 35%, and is further constrained by soil type in relation to weather (i.e., rain, soil water content, soil-bearing strength).

For all yarding methods, stand and timber characteristics, such as volume per hectare and log size, influence choice of machine size and power, production rates, and operating costs. In general, an inverse relationship exists between harvest unit costs ($\$/m^3$), and log size and timber volume per hectare. Indirect costs such as minimizing damage to soil or aesthetic values also influence profitability of harvesting operations. Capital, operating, and labour costs are significantly higher for cable yarding and heli-logging than for ground-based systems. The feasibility of locating and constructing roads determines how close yarding equipment can get to the timber and may be an overriding determinant.

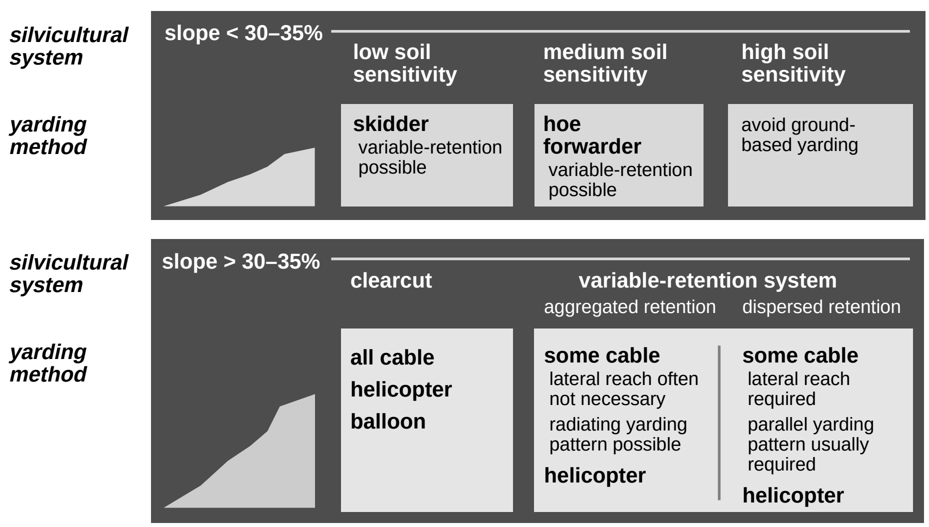
Yarding distance and direction also affect harvesting options.

Yarding distance and direction also affect harvesting options. Tower skyline yarding requires central landings with radiating yarding corridors. These corridors tend to accumulate large volumes of timber in the landing and, because of corridor overlap close to the landing (Figure 4.3), cannot retain trees near the landing. Radiating corridors may also require cross-slope yarding with attendant difficulty in controlling logs, and consequent potential for increased ground disturbance and damage to the residual stand. In such situations, full suspension may be required to keep corridor width, ground disturbance, and residual tree damage within acceptable levels (Figure 4.9).

Figure 4.8 **Harvesting systems decision matrix.**



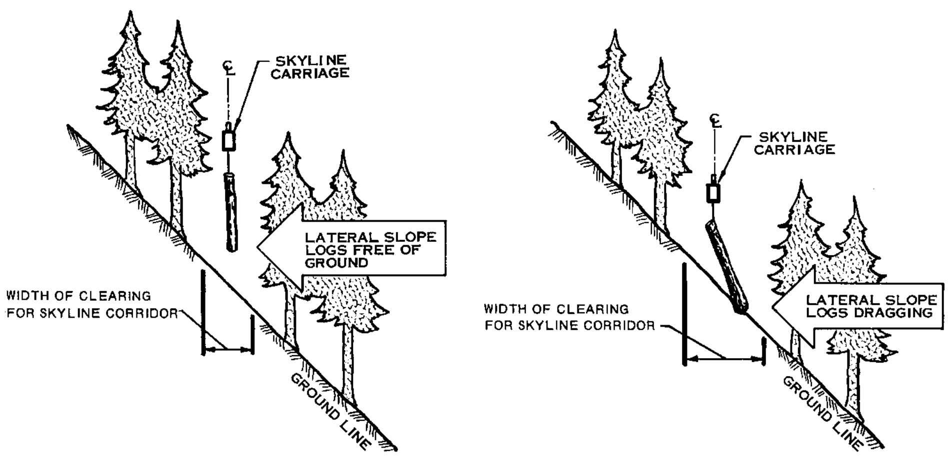
Summary



Highlead and grapple yarding are best suited to clearcutting where logs do not need to manoeuvre around standing trees.

In thinning and partial cuttings, including retention, the degree to which logs can be controlled during yarding affects residual tree damage, ground disturbance, and yarding productivity. Silvicultural systems that retain a significant number of trees will favour yarding methods with partial or full suspension and lateral yarding capabilities. Highlead and grapple yarding are best suited to clearcutting where logs do not need to be manoeuvred around standing trees, and lateral yarding is unnecessary. Running or live skyline methods using yarding cranes with dropline carriages are suited to retention cuts on steep slopes if yarding distances are less than 250–300 m. For longer yarding distances, tower skylines (standing or live) or helicopters are possibilities.

Figure 4.9 The effect of log suspension on corridor width when cross-slope yarding.



The final considerations in selecting a harvesting system are operational, such as specific features of timber and terrain, accessibility, and costs.

4.2 Harvesting in Clayoquot Sound

4.2.1 Historical Overview

Early logging in Clayoquot Sound concentrated on the gentle to moderate topography.

Early logging in Clayoquot Sound generally concentrated on the gentle to moderate topography of the Estevan Coastal Plain near Ucluelet and Tofino, and on steeper slopes close to tidewater.

Past harvesting activity in Clayoquot Sound was shaped by an even-aged management regime (clearcutting) and the operating constraints of the west coast environment (steep slopes, high precipitation, and sensitive soils). Like much of British Columbia's west coast, a clearcutting silvicultural system based on large old trees favoured handfelling and bucking, and highlead yarding to a central tower and landing. This changed with the advent of grapple yarding in the late 1970s.

Rising wages in B.C. encouraged a move to mechanized yarding operations as a means of reducing costs.

In the mid- to late 1970s, rising wages in British Columbia encouraged a move to mechanized yarding operations as a means of reducing costs. Highlead yarding operations, with crew sizes of five to six, were increasingly replaced by grapple yarding operations which required a crew of only two to three people. In 1985, about 90% of the 165 highlead towers operating in coastal British Columbia were 11 years or older; few new highlead machines were being purchased (two highlead towers in two years). By comparison, about two-thirds of the 125 operating running skylines were less than 11 years old (Sauder 1988). Yarding cranes, most of which were being used as grapple yarders, had become the machine of choice.

Past logging in Clayoquot Sound can be summarized as follows:

- The most readily accessible higher-value timber was harvested first. The current merchantable timber distribution is skewed to more difficult topography and more sensitive terrain. Immature timber is found on more moderate topography at lower elevations.

- Harvesting systems were designed for the prevailing silvicultural system—clearcutting.

The popularity of grapple yarding in the 1980s resulted in a denser road network.

- The popularity of grapple yarding in the 1980s resulted in a denser road network in the logged portion of the landscape. The bare cutslopes and fillslopes associated with these and earlier roads, plus any subsequent road-related slides, increased the visual impact of clearcuts, reduced forest productivity, and damaged aquatic ecosystems.

- Prior to the advent of grapple yarding, cutblocks typically involved multiple highlead settings. This, in combination with little control on cutblock adjacency, except for a short period of logging guidelines in the early to mid-1970s (*Coast Logging Guidelines* 1972), produced large clearcut landscapes. Many of the cutblocks deferred (left unlogged, between logged blocks) under the 1972 guidelines were logged when rules were relaxed in response to the economic recession of the early 1980s. At this time, a short-lived operation using a standing skyline (European Wyssen system) was employed to avoid roads on steep slopes; it produced a very large, highly visible clearcut opening.

The rate of harvesting, and policies regulating cutblock size, shape, and sequence have changed recently (Section 3.2.2). In the 1980s, more than 1000 ha was logged annually in Clayoquot Sound; by the early 1990s this had declined to less than 600 ha.

The *Clayoquot Sound Land Use Decision* (April 1993), identified 117 400 ha (45%) of Clayoquot Sound for general integrated resource management, with timber harvesting as a major use, and estimated the long-term harvest level from this area at 600 000 m^3/yr. The decision also stated:

> Throughout Clayoquot Sound, timber harvesting plans will be required to incorporate smaller dispersed cutblocks…Lower road densities and a corresponding increase in skyline and helicopter harvesting systems will be a key principle of future forest development plans. (British Columbia 1993a:13)

Smaller, dispersed cutblocks will likely result in a higher density of active roads.

This statement is an apparent contradiction in that "smaller dispersed cutblocks" will likely result in a higher density of *active* roads, the roads that produce the highest level of suspended sediment, often at rates of the same order as sedimentation resulting from landslides (e.g., Cederholm and Reid 1981; Haydon *et al.* 1991).

The area and means by which timber is extracted from Clayoquot Sound will continue to change as public values further influence decisions related to harvesting on Crown land.

4.2.2 Standards for Harvesting

The choice of harvesting system is recognized as an operational decision.

Existing standards applied in most of the Vancouver Forest Region and the proposed *British Columbia Forest Practices Code Standards with Revised Rules and Field Guide References* do not specify harvesting systems. The choice of harvesting system is recognized as an operational decision based on topography, ground conditions, timber type, machine availability, and economics. The harvesting system must be specified in the Pre-harvest Silviculture Prescription (PHSP). Where two or more systems are planned, they must be indicated on PHSP maps along with operating details such as season of logging and the location of planned backspar trails. This prescription is reviewed by government agencies and, upon approval, becomes a contractual obligation of the licensee to the province.

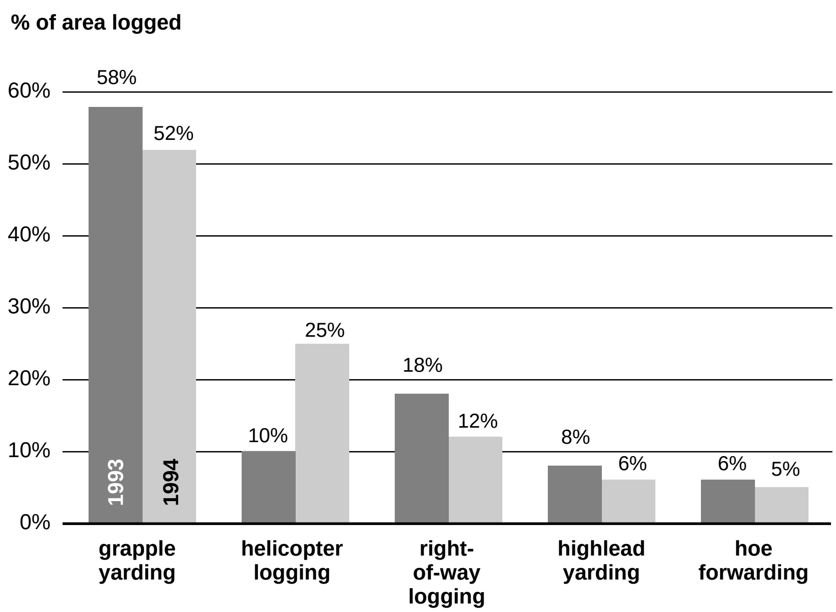
The *Clayoquot Sound Forest Practices Standards* (June 1993), and the *Interim Measures Agreement* (IMA) (March 1994) refer to specific harvesting systems. The *Clayoquot Sound Forest Practices Standards* state that "emphasis will be placed on the use of skyline and helicopter yarding methods to reduce road densities and eliminate the need for midslope roads on steep or unstable slopes," specifically in the upper Sydney and upper Clayoquot rivers (B.C. Ministry of Forests 1993a:6). The IMA restricts harvesting systems to "longline and full suspension aerial cable yarders and / or helicopter / balloon type systems" for areas covered by Total Resource Plans within part of the Clayoquot River Valley and on Flores Island, with provision for exceptions by the Central Region Board (British Columbia and the HawiiH 1994:12).

4.2.3 Recent Harvesting in Clayoquot Sound

Four main yarding methods have been used recently in Clayoquot Sound.

Four main yarding methods have been used recently in Clayoquot Sound (see Figure 4.10). Grapple yarding represented 58% of the volume harvested in 1993, followed by helicopter logging (10%), highlead yarding (8%), and hoe forwarding (6%).[86] Right-of-way logging, which involves clearcutting of linear strips prior to road construction, accounted for the remaining 18% of the logged volume. The width of right-of-way logging is often increased to more than that required for the construction of roads; the increase permits efficient yarding by modified line loaders or "long snorkels" operating from the road running surface. The volume of right-of-way logging is a direct function of the length of road built. Consequently, the proportion of right-of-way logging can be expected to drop as road densities are reduced.

Figure 4.10 Yarding methods used in Clayoquot Sound in 1993 and 1994.



Grapple yarding has dominated harvest operations in Clayoquot Sound since the 1980s.

Grapple yarding has dominated harvest operations in Clayoquot Sound since the 1980s for two reasons:

- it was, and is, more cost-effective than highlead or skyline yarding because of its relatively small crew size, short yarding cycle, and ability to change yarding corridors rapidly; and
- it could be widely applied to the topography of Clayoquot Sound provided road development was little constrained by policy and road costs could be recovered through stumpage allowances.

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[86] Data supplied by B.C. Ministry of Forests, Port Alberni Forest District. "Highlead yarding" for 1994 apparently includes a tower skyline operation in Cypre River. Data for 1994 are preliminary.

Grapple yarding will be less suited to near-future harvesting conditions in Clayoquot Sound where topography and slope stability constrain road development, thereby requiring longer yarding distances and partial or full suspension of logs; and the variable-retention silvicultural system requires flexibility to move around retained trees.

Most remaining merchantable timber in Clayoquot Sound is located on the steep slopes of the Vancouver Island Mountains. In general, these areas require greater retention of trees (Section 3.4, R3.6), and midslope roads are undesirable (Section 5.1.3, R5.1). Slopes in the western, outer portions of the Vancouver Island Mountains tend to be relatively long and uniform, with some potential for ridge road locations. In appropriate terrain, ridge road location can be coupled with single- or multi-span skyline yarding. Ridgetop roads, however, are not always desirable. Montgomery (1994) has documented cases of surface drainage from ridgetop roads initiating debris slides in gullies below the ridge. To the east, well within the Vancouver Island Mountains, relatively uniform slopes are found primarily at lower to midslope positions; these, however, are commonly dissected by V-notch gullies which hinder some yarding methods. Upper slopes tend to be characterized by irregular, broken slopes with considerable bedrock outcrop.

Proposed operations presented a significant increase in non-conventional harvesting systems.

Of the anticipated 450 000 m^3 harvest in Clayoquot Sound during 1994, approximately 100 000 m^3 was expected to be yarded by helicopter and tower skyline operations. A skyline operation of about 20 000 m^3 was approved in Cypre River using a tower skyline rigged with a carriage and chokers to reach across the valley. Helicopter operations were planned for areas in Stewardson Inlet (about 30 000 m^3), Kennedy Lake Division (about 10 000 m^3), and Tranquil Creek (about 30 000 m^3). The proposed and / or approved operations represented a significant increase in non-conventional harvesting systems. In addition, permits are pending for non-clearcut silvicultural systems using grapple yarding, alone or in combination with hoe forwarding, on the Kennedy Flats and near Fortune Channel.

Application of harvesting systems must continue to change to meet the requirements of a variable-retention silvicultural system.

4.2.4 Yarding Methods Appropriate to a Variable-Retention Silvicultural System

Current cable yarding can be successfully applied to silvicultural systems other than clearcutting.

The selection of silvicultural system greatly influences the selection of yarding methods. Of the existing yarding methods, only balloon yarding cannot be used in anything but clearcut operations. Most cable yarding methods, as well as ground-based equipment and helicopters, can be used in non-clearcut silvicultural systems. Their effectiveness, however, depends largely on careful matching of specific yarding methods with the prescribed silvicultural systems and thorough cutblock design. Experience in the U.S. Pacific Northwest and in British Columbia shows that current cable yarding can be successfully applied to silvicultural systems other than clearcutting. For example, the Plum Creek

Timber Company has successfully applied current harvesting equipment and methods in aggregated retention (patch and wedge) silvicultural systems (B.C. Ministry of Forests 1993e).

A variable-retention system requires harvesting methods that are:

- efficient and safe;
- flexible to accommodate different levels and distributions of retention; and
- appropriate to steep slopes and require low road densities.

Ground-based systems are flexible and can be readily adapted to various silvicultural systems, provided their impact on the soil and damage to the residual stand is not excessive.

For example, on the Montane Alternative Silvicultural Systems (MASS) trial site near Courtenay, B.C., a hoe forwarder and tracked skidder were used in old growth on gentle slopes (15–20% or less) to implement three silvicultural systems retaining forest cover: patch cutting (1.5 ha clearcuts), clearcutting-with-reserves (25 trees / ha retained),[87] and shelterwood (30% of the basal area of the stand, or about 150 stems greater than 17.5 cm dbh,[88] retained) (Beese 1994). Most unlogged slopes in Clayoquot Sound are greater than 20%, but ground-based systems have been used elsewhere on Vancouver Island where alternatives to clearcutting have been implemented (Moore 1994).

Highlead yarding is poorly suited to a variable-retention silvicultural system.

Highlead yarding is poorly suited to a variable-retention silvicultural system and totally unsuited to dispersed retention. Some pie-shaped aggregates could be retained between the far ends of yarding corridors. This initially would produce a more ragged edge rather than an isolated aggregate but could become an isolated aggregate when the adjacent area is logged. These aggregates could be oriented to improve windfirmness.

Grapple yarding can be used with aggregated retention where the aggregates are linear strips.

Grapple yarding also is poorly suited to a retention silvicultural system, especially if the trees to be retained are dispersed. Grapple yarding can be used with aggregated retention where the aggregates are linear strips between logged yarding corridors. This approach has been combined with some dispersed retention (25 trees / ha) in a recent cutblock at McTush Creek. Higher levels of aggregated retention may be feasible with grapple yarding if narrow cut strips are interspersed with linear retained aggregates.

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[87] The Panel would term these trials “dispersed retention”; if the 30% basal area is retained in the “shelterwood” cutting, the Panel would term that an “intermediate“ level of retention (Chapter 3, Figures 3.1 and 3.2).

[88] Dbh refers to “diameter breast height,” the stem diameter of a tree measured at “breast height,” about 1.3 m above the point of germination.

Skyline yarding is the cable yarding method best suited for retention.

Maintaining log control during yarding is critical in variable-retention silvicultural systems to minimize soil disturbance and damage to residual trees, and to maximize yarding productivity. Because of this, skyline yarding is the cable yarding method best suited for retention, particularly with dispersed retention.

With skyline yarding, log control is determined by:

- height of skyline above the ground;
- lateral yarding distance;
- ability to reposition the carriage during lateral yarding; and
- log lengths.

Where lateral yarding into a yarding corridor is involved (e.g., with dispersed tree retention), falling patterns must be integrated with the planned yarding. "Herringbone" patterns, which allow easier movement of logs into the main yarding corridor, require precise location of the skyline corridors, the spine of the pattern. Because of the importance of yarding corridor location in relation to the felled trees, fallers must be aware of corridor locations. As a result, corridor locations cannot be changed once falling has started.

Medium to large yarders will continue to be required for the variable-retention system.

Horsepower ratings for yarder engine sizes commonly used in Clayoquot Sound range from 350 hp to over 600 hp. Table 4.2 shows yarder sizes (in hp requirements) for typical combinations of log sizes and yarding distances in clearcut operations. Medium to large yarders will continue to be required to maintain line speed and yarding productivity for the variable-retention system and anticipated log sizes, particularly with longer yarding distances.

Table 4.2 The effect of yarding distance and log size on yarder engine size.

Yarding distance	150 m	250 m	300 m
Average log size (m^3/log)		Equipment size [1]	
0.4	small	medium	medium-large
0.8	small	medium	medium-large
1.5	medium	medium-large	large
3.0	medium-large	large	large

[1] Small refers to yarders less than 350 hp, medium from 350 to 550 hp, and large to greater than 550 hp.
Source: Conway (1982).

Some helicopters can be used efficiently in cutting systems that retain tree cover.

Although helicopter yarding has been used predominantly with clearcut operations to date, a helicopter yarding trial with a selection system was undertaken at Cat's Ears Creek in 1992. Trial results emphasized the importance of layout, planning, and payload capacity of the helicopter for successful helicopter operations. Despite high costs and manoeuvrability limitations, some helicopters can be used efficiently in cutting systems that retain tree cover.

The conditions under which helicopter yarding is practicable are significantly limited for the proposed variable-retention silvicultural system. The pilot must be able to see personnel on the ground to safely lower the load line[89] and must be able to lift the load without hanging up in the remaining trees. These concerns preclude logging of single trees but allow the logging of small patches or groups of trees. Retention or partial cutting systems require a significantly longer load line than is required in clearcut systems. Total load line length is the sum of the dominant tree height plus clearance between helicopter and canopy. As a rule, a minimum clearance of about 15 m between tree crowns and helicopter is required. For production and safety, a load line length of about 75 m should not be exceeded. Table 4.3 summarizes the potential of current yarding methods under a variable-retention silvicultural system.

[89]Load line is the line or cable that hangs from the helicopter to which the chokers are attached.

Table 4.3 Yarding methods – potential application with a variable-retention silvicultural system.

Yarding method		Limiting factors for application with a retention silvicultural system	Future applicability
Ground-based		Limited by the extent of suitable topography and soil conditions	In the short-term, limited by lack of merchantable timber on moderate slopes; expect increased application as managed stands become viable for commercial thinning and harvest
Cable	Highlead	Limited by lack of lateral yarding capability	Limited future use in small clearcuts and in aggregated (pie-shaped) retention cuts
	Grapple yarder	Limited by lack of lateral yarding capability, and short yarding distances	Some potential for narrow strip cuts interspersed with linear retained strips
	Yarding crane (swing yarder) with slackpulling carriage	Limited to medium yarding distances; rarely capable of full suspension because of machine and line wear	Considerable potential future use, especially on relatively uniform valleysides
	Tower skylines (live and standing)	Limited somewhat by specific requirements for topography, yarding distance, landings and solid anchors (for both guylines and tail-holds)	Most suited to demanding topographic conditions, including long yarding where roads are constrained, and cross-stream yarding while retaining riparian reserves
Balloon		Limited to clearcutting because of lack of control over moving lines	None
Helicopter		High levels of retention will be limited to cutting of small groups of trees rather than single trees because of safety concerns (visibility, rotor wash); limited on steep slopes because of the need to safely permit precise bucking	Considerable future potential, particularly on sensitive sites (stability, riparian, visual) requiring high levels of retention

4.3 Findings Regarding Harvesting Systems

Because of the inherent relations among silvicultural, harvesting, and transportation systems, many findings presented in this section are implications deriving from recommendations concerning silvicultural systems (Section 3.4) or roads (Section 5.1.3).

Implications of Past Harvesting in Clayoquot Sound

Past harvesting focused predominantly on low-elevation areas with moderate topography.

F4.1 Past harvesting in Clayoquot Sound focused predominantly on low-elevation areas with moderate topography. Much of the remaining, unlogged forest in Clayoquot Sound is on steeper, more difficult terrain.

F4.2 More than 80% of the older forests in the General Integrated Management Area of Clayoquot Sound is located on slopes steeper than 30° (approximately 60% slope). Yarding methods on these areas will be largely determined by the degree of retention prescribed and constraints on roads.

F4.3 Harvesting systems appropriate for future commercial thinning or harvesting in currently immature, managed stands will be determined by slope and soil sensitivity, in combination with log sizes. Because much of the earliest harvest was on gentle to moderate slopes, constraints of slope, as on ground-based equipment, will be less than for most presently mature stands.

Current Yarding Methods

Grapple yarding requires the greatest road density of all yarding systems currently used in Clayoquot Sound.

F4.4 Grapple yarding, because of its short yarding distances and lack of lateral reach, requires the greatest road density of all yarding systems currently used in Clayoquot Sound (Table 4.4). The high percentage of forest land converted to roads to support grapple yarding results in significant disruption to surface and subsurface drainage patterns. Ground disturbance can be even greater in situations where backspar trails are constructed.

Table 4.4 Area occupied by haul roads, landings, and backspar trails with various yarding methods.

Yarding method	% area occupied by:[1]			Total area (%)
	Haul roads	Landings	Backspar trails	
Grapple	9.5	0.5	1.8	11.8
Highlead	7.4	1.6	0.2	9.3
Skyline	3.5	0.9	0.1	4.5

[1]Area occupied is not equivalent to area of site degradation as defined by the Vancouver Forest Region (B.C. Ministry of Forests 1991b, 1992c, 1992d).

Source: Krag *et al.* (1993).

Skyline and helicopter yarding require lower road densities and result in less soil disturbance during yarding, thereby reducing the environmental impact of harvesting. Helicopter yarding requires no on-block roads, landings, or backspar trails. However, if logs will be dropped on land (rather than water), existing landings may be enlarged or new landings constructed to handle the high volume of logs produced by helicopter logging operations.

F4.5 Recent and currently planned alternatives to clearcutting involve low levels of retention, the so-called "clearcut-with-reserves." This system uses mostly well-established yarding methods—hoe forwarding, grapple yarding, and heli-logging. Very little experience has yet been gained in coastal British Columbia with retention cuts using cable yarding with lateral yarding capability, particularly at high levels of retention.

Harvesting Implications of a Variable-Retention Silvicultural System

F4.6 The variable-retention silvicultural system proposed for Clayoquot Sound (Section 3.4) will continue to produce logs with dimensions comparable to those currently produced (typically more than one cubic metre). Medium to large yarding equipment will continue to be needed to handle such logs (Table 4.2). Depending on the age at which thinning takes place, thinning operations may use smaller equipment.

The variable-retention silvicultural system requires flexible yarding methods that can efficiently and safely remove timber.

F4.7 The variable-retention silvicultural system requires flexible yarding methods that can efficiently and safely remove timber from a stand without damaging either the trees retained or the soil.

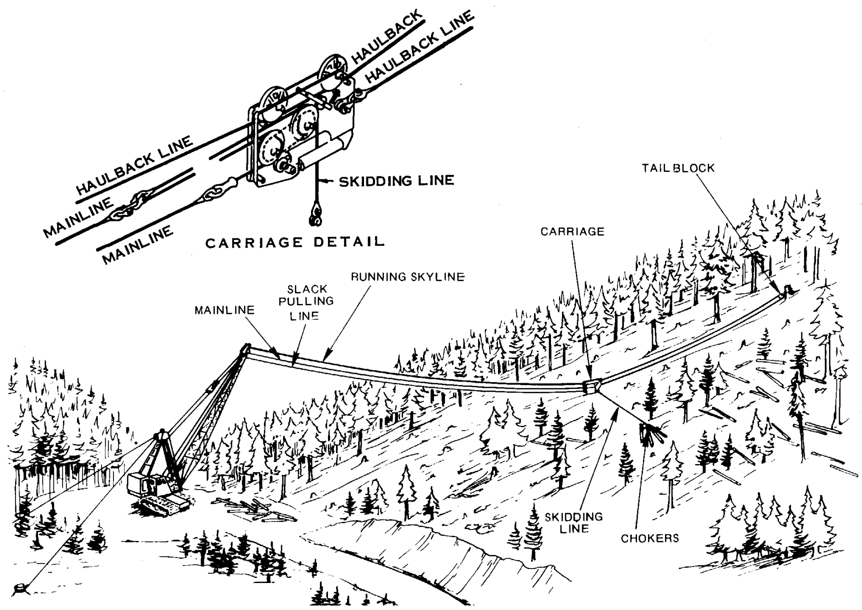
F4.8 Where topography and soil conditions permit (Figure 4.8), ground-based yarding methods provide the greatest flexibility for both the amount and distribution of retention.

F4.9 The wet climate, steep slopes, and silty to loamy surface soils that are susceptible to damage limit the areas in Clayoquot Sound that are appropriate for ground-based yarding methods.

Most of the cable yarding equipment currently used in Clayoquot Sound can be adapted to a variable-retention silvicultural system.

F4.10 Most of the cable yarding equipment currently used in Clayoquot Sound can be adapted to a variable-retention silvicultural system. For example, by replacing the log grapple with a slackpulling carriage with chokers, a grapple yarder becomes a yarding crane with lateral yarding capability (Figure 4.11). The mobility of yarding cranes makes them well suited to situations that require parallel corridors, such as along valley sides with uniform slopes. They can be used in both running skyline and live skyline configurations.

Figure 4.11 Retention with a yarding crane (swing yarder) equipped with a slackpulling carriage.[1]



[1]The slackpulling carriage provides increased lateral yarding capability, typically up to 30 m.

Lateral reach and partial to full suspension capabilities are often required.

F4.11 Lateral reach and partial to full suspension capabilities are often required for yarding in a variable-retention silvicultural system to maintain the required log control along the full length of the yarding corridor.

- Where retention is aggregated (e.g., in small patches, wedges, or strips), lateral reach may not be required, then highlead or grapple yarding can be used.
- Where retention is dispersed, lateral yarding capabilities are required; grapple yarding and highlead yarding are unsuitable. Yarding cranes with slackpulling carriages suit this situation.
- At high levels of retention, yarding corridors must be narrow and both line and log movement must be well controlled. With favourable topography, partial suspension (e.g., with a yarding crane) may be adequate. Where combinations of topography, long yarding distance, and high levels of retention preclude the use of yarding cranes, tower skylines or helicopters must be used.
- Parallel corridors are better suited to high retention levels than are radiating corridors which, because of corridor overlap, result in almost complete tree removal close to the landing (Figure 4.3).

- Where cross-slope yarding must occur, full log suspension is necessary to prevent damage to retained trees on the down side of yarding corridors. This requires the use of live or standing tower skylines.

The variable-retention silvicultural system will reduce the extent of grapple yarding in Clayoquot Sound.

F4.12 The variable-retention silvicultural system will reduce the extent of grapple yarding in Clayoquot Sound. Longer reach cable yarding methods (e.g., tower skyline) and helicopter yarding will increase as the length of roads on steep mid- to upper-slopes that are potentially unstable or sensitive to changes in drainage patterns (both surface and sub-surface) are minimized. Slope configurations will restrict the use of ridge roads and opportunities for uphill skyline yarding.

F4.13 High retention levels and/or slopes that are too steep to safely permit the precise bucking that helicopter yarding requires will constrain helicopter yarding. For high retention levels, removing trees in small patches (less than or equal to 0.3 ha) will permit helicopter yarding.

F4.14 Balloon yarding, which is characterized by poor control of the operating cables as the balloon moves, is not suited to a variable-retention silvicultural system.

F4.15 Yarding methods appropriate to a variable-retention silvicultural system (e.g., longer skyline spans, lateral reach capability) are more complex than past yarding methods in Clayoquot Sound.

F4.16 The variable-retention silvicultural system requires greater planning and more detailed layout of falling to meet retention objectives, yarding efficiency requirements, and worker safety.

Rigging skills have declined over the last decade.

F4.17 Rigging skills have declined over the last decade because grapple yarding does not require a high level of rigging skill, especially where mobile backspar machines are used. Retention cuts employing live or standing skylines, backspar trees, intermediate supports, or lateral yarding will require more advanced yarding and rigging skills.

F4.18 In general, falling and yarding efficiency will decrease as levels of retention increase. Findings from other areas with timber size and topography similar to Clayoquot Sound (e.g., Pacific Northwest Douglas-fir region) indicate a 1–41% decrease in production on areas that are partially cut or thinned (Daigle 1992). While falling and yarding costs generally increase with increasing levels of retention, there are also indications that where the extracted timber volume exceeds 350 m^3/ha, unit production costs ($\$/m^3$) are not significantly higher than those of clearcut operations (B.C. Ministry of Forests 1993e).

F4.19 In a variable-retention silvicultural system, the selection of leave trees and the falling and yarding of harvested trees profoundly affect faller safety and yarding productivity. Persons knowledgeable in the variable-retention silvicultural system, tree hazard assessment, and operational constraints in harvesting must select the trees in such situations.

F4.20 A past trend in harvesting operations has been to increase mechanization as a means of decreasing manpower requirements and increasing productivity. Harvesting methods appropriate to the variable-retention silvicultural system will counter this trend by requiring more labour. Although overall system productivity may be comparable, production rates per person-hour will decrease because of the larger crew.

Forest engineers, technicians, and forest workers will require greater knowledge and higher skill levels than have been required in the past. Labour requirements may double or triple.

F4.21 Because adoption of a variable-retention silvicultural system will require more planning, design, and engineering of harvesting operations (e.g., locating yarding corridors, ensuring adequate suspension), forest engineers, technicians, and forest workers will require greater knowledge and higher skill levels than have been required in Clayoquot Sound in the past. Information from various sources (e.g., B.C. Ministry of Forests 1993e) suggest that the labour requirement for engineering and field layout of harvesting operations may double or triple under a variable-retention silvicultural system.

4.4 Recommendations Regarding Harvesting Systems

The Panel's recommendations focus on harvest system planning, implementation, and worker training.

Harvesting systems are largely dictated by stand and site characteristics, in conjunction with management objectives as expressed in the Pre-harvest Silviculture Prescription. Panel recommendations, therefore, focus on harvest system planning, implementation, and worker training, rather than on specific criteria for selecting harvesting systems.

R4.1 Select a harvesting system that meets safety and other specified objectives (e.g., minimal ground disturbance) consistent with variable-retention silvicultural prescriptions.

R4.2 Plan and implement yarding to minimize soil disturbance, site degradation, and damage to retained trees. Restrict ground-based logging to hoe forwarding or similar low-impact yarding methods appropriate to the prevailing weather and soil conditions in Clayoquot Sound. Use partial or full suspension cable yarding and helicopter logging as required to minimize detrimental soil disturbance and damage to retained trees.

Undertake operational trials of harvesting with the variable-retention silvicultural system.

R4.3 Undertake operational trials of harvesting with the variable-retention silvicultural system at a range of levels and distributions of retention to establish design parameters and procedures for cutblock layout, falling, and yarding, particularly for skyline methods involving lateral yarding. Because this information is needed to support the recommended phase-in of a variable-retention silvicultural system, a cooperative effort (e.g., B.C. Ministry of Forests Engineering Branch, Forest Engineering Research Institute of Canada, and members of the forest industry) is warranted, including consultation with experienced operators in the Pacific Northwest.

Provide continuing education opportunities to encourage development of a skilled, motivated, and stable workforce.

R4.4 Develop education and training programs to provide forest engineers, technicians, and forest workers with the knowledge and skills required to plan and implement harvesting operations appropriate to a variable-retention silvicultural system in Clayoquot Sound. Provide continuing education opportunities to encourage development of a skilled, motivated, and stable workforce.

Training must address silvicultural objectives (e.g., habitat, biological diversity, regeneration) and operational constraints (e.g., harvesting system requirements, windfirmness, yarding patterns, falling patterns) at all levels, including:

- professional foresters who prescribe the level, type, and distribution of retention in the Pre-harvest Silviculture Prescription;
- forest engineers who formulate logging plans, and technicians who lay out retention cutting units; and
- fallers who make on-site decisions about safe and efficient falling, bucking, and yarding, and other forest workers involved in harvesting.

This education and training is urgent in view of the recommended phase-in schedule (Section 3.4.2, R3.21).

A university-level program of study in forest engineering is needed.

R4.5 A university-level program of study in forest engineering that would qualify its graduates for professional registration in both forestry (registered professional forester) and engineering (professional engineer) is needed to fulfil the greater demands for complex forest engineering and planning that the Panel's recommendations require.

R4.6 Government, forest companies, and labour, through discussion, must address issues of increased manpower requirements, reduced productivity (i.e., cubic metres per shift), and increased costs involved with the variable-retention silvicultural system.

5.0 Transportation Systems

Logs in Clayoquot Sound are transported by both roads and water.

Logs and other partly manufactured forest products (e.g., cedar shake blocks and cypress cants[90]) in Clayoquot Sound are transported by both roads and water. The road network is used for hauling logs, access by logging and silvicultural workers, movement of equipment (including heavy equipment), and access by recreational users and residents. Water transport is used to move most logs in Clayoquot Sound to processing facilities. After unloading the logs from logging trucks, the log handling system typically includes sorting and bundling logs in dryland sorts, watering log bundles, temporarily storing bundles in bag booms, and transporting via log barges. Water transport is also used extensively by residents and for recreational pursuits.

5.1 Road Transportation

Roads carrying low traffic volumes are often wider to serve both transportation and yarding.

The existing road system is the result of past requirements to accommodate off-highway trucks[91] and more recent requirements related to harvesting with grapple yarders. Roads often serve not only as transportation links but also as landings for grapple yarders. As a result, roads carrying low traffic volumes are often wider than 5 m, to serve both transportation and yarding functions.[92]

Photo 5.1

In Clayoquot Sound, road construction has tended to exceed guidelines for both running surface width and amount of productive forest area committed to permanent road.

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[90]Cants are partly manufactured logs that are roughly squared, usually for export. Cypress (yellow-cedar) cants may be manufactured in the woods using chainsaws, and are generally from lower grade logs that were not loaded out during earlier logging.

[91]Off-highway trucks are logging trucks of a size (width and / or weight) that exceeds legal highway specifications.

[92]In this report, references to road width refer to the width of the road running surface, unless otherwise noted. In other documents, the running surface may be referred to as “stabilized road width.” See Figure 5.1.

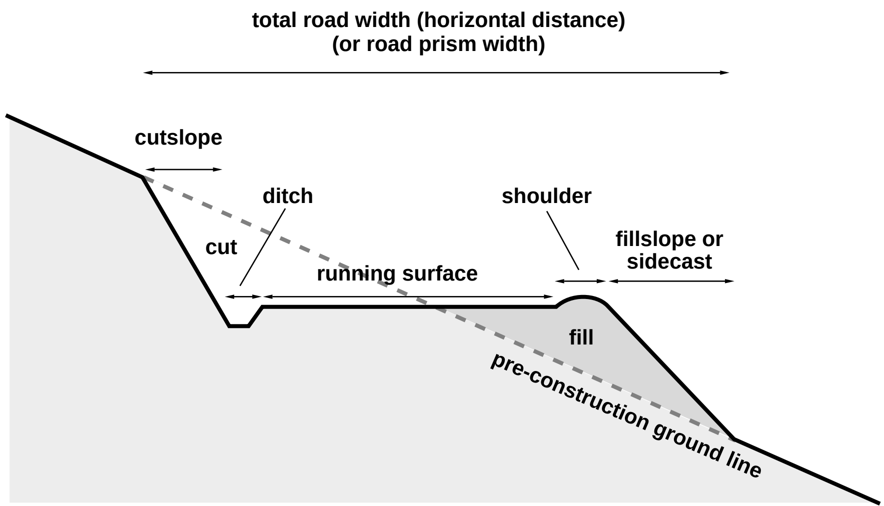
Determining the location of roads is complex.

Determining the location of roads is complex, and must consider many factors and objectives, including:

- operational and physical considerations:
  - existing road system;
  - transportation efficiency (including intended uses, road standard);
  - planned silvicultural and harvesting systems, and resulting layout;
  - engineering control points (physical, legal); and
  - topography.
- environmental considerations:
  - terrain, slope stability, and surface erosion hazard;
  - potential damage to growing sites (site degradation);
  - avoidance of riparian areas;
  - avoidance of special habitats (including habitats of rare, threatened, or endangered species) and ecologically sensitive sites (including karst[93]);
  - avoidance of heritage and cultural sites, and areas of special significance to First Nations;
  - potential visual impacts;
  - potential impact on recreational sites;
  - potential impact on reserves; and
  - rehabilitation potential.
- economic considerations:
  - road construction costs in relation to value of timber accessed as these differ among harvesting systems; and
  - operating and maintenance costs.

[93] Karst refers to the distinctive landforms, topography, and subsurface features, including caves, associated with limestone or other soluble bedrock.

Figure 5.1 **Cross-section of forest road.**



Road construction techniques changed significantly with the introduction of backhoes in the late 1970s.

Road construction techniques changed significantly with the introduction of backhoes (hydraulic excavators) in the late 1970s. Prior to that time, roads were built by bulldozers, so that the typical, fully benched roads[94] of steeper slopes involved sidecasting of waste excavated material. Most of the observed road-related landslides from older roads are associated with failures within or at the base of the sidecast material, and do not involve the actual road running surface. The Panel observed that roads constructed more recently by backhoes had fewer road-related failures. Better use and placement of excavated material, and better sorting of material (weathered soils and organics separated from unweathered materials and broken rock) all appear to have contributed to improved stability of the road prism.[95]

Most failures do not involve the actual road running surface.

During the last five years, a road deactivation program has been underway.

During the last five years, a road deactivation program has been underway on Vancouver Island. Currently the deactivation program appears to focus on restoring natural drainage patterns to the extent possible, and reducing failures in fill and sidecast materials.

[94]In a fully benched road the entire running surface is supported by a cut into the hillslope. In a partially benched road part of the running surface is supported by a cut into the hillslope and part is supported by fill material excavated from the cut (see Figure 5.1).

[95]Road prism refers to the geometric shape formed by the road from the top of the cut to the toe of the fillslope. The road prism width, the horizontal distance from the top of the cut to the toe of the fillslope, is several metres less than the clearing width, the width in which all trees are cut prior to road construction.

Photo 5.2

To create a road surface on steeper slopes, slopes were filled with sidecast material during construction (Figure 5.1). Most road-related landslides from older roads are associated with sidecast material.

5.1.1 Standards for Roads

Existing road standards have recently been collated in *Forest Road and Logging Trail Engineering Practices (Interim)* (July 1993). In addition, the *Clayoquot Sound Forest Practices Standards* require that:

- Road densities will be reduced from present practice. [No present or future density is specified.]
- Road layout will follow the overall access management plan. [That is, road permits would be issued only when an access development plan is in place.]
- Road width will be reduced to minimum requirements for off-highway hauling and equipment movement. In those instances where highway trucks are used, road widths may be reduced further. Road widths will be specified in approval documents. [This statement appears to recognize that grapple yarding has contributed to greater road widths in the past.] (B.C. Ministry of Forests 1993a:5)

Since 1991, efforts to reduce the amount of forest land converted to permanent access have increased.

Road widths in recent years average 5.4 m.

Since 1991, efforts to reduce the amount of forest land converted to permanent access (roads and landings) have been increased (B.C. Ministry of Forests 1991b, 1992c, 1992d). These guidelines were intended to limit permanent access to less than 7% of the productive forest area of a cutblock; and haul road running surface widths to 5 m. A recent review of haul roads reveals that the 5 m specification is not being met (Table 5.1). The review shows that road widths in recent years average 5.4 m. It also shows that total road width on steep slopes (i.e., greater than 55%) ranges from 21–24 m; 9–12 m of this total horizontal width is comprised of highly visible sidecast material, part of which is not capable of tree growth (Table 5.1).

Table 5.1 Average width of haul roads, by slope class.

		Weighted average width (m)					
Slope class (%)	Number of samples	Cutslope	Ditch	Running surface	Shoulder	Fillslope or sidecast	Total
< 25	118	0.8	3.4	5.2	1.4	4.7	**15.5**
26–55	176	1.9	2.7	5.4	1.8	7.0	**18.8**
56–65	27	3.9	1.7	5.7	0.7	8.8	**20.8**
> 65	16	4.8	1.0	5.8	0.9	11.8	**24.3**
All	**337**	**1.8**	**2.8**	**5.4**	**1.5**	**6.5**	**18.1**

Source: Adapted from Krag *et al.* (1993)

The November 18, 1992 letter from the regional manager, Vancouver Forest Region, requires licensees to evaluate terrain and stability conditions: where proposed cutblocks and roads are located *either* within terrain stability classes IV and V,[96] *or* Es1 and Es2 units;[97] in areas exhibiting natural instability, extensive gullying or slopes steeper than 60%; and in other specific areas designated by the district manager. Roads should not be approved on terrain with a moderate to high potential for road-induced landslides, unless such roads reach extensive areas of stable terrain *and* special road construction techniques are used to limit any potential road failure.

A recent, notable change is the requirement to apply erosion control by seeding all exposed soils associated with road construction.

The *Forest Practices Code of British Columbia Act* (July 1994) and proposed *British Columbia Forest Practices Code Standards with Revised Rules and Field Guide References* largely embody the provisions of the *Forest Road and Logging Trail Engineering Practices (Interim)* (July 1993). The most notable change is the requirement to apply erosion control by seeding all exposed soils associated with road construction (B.C. Ministry of Forests and B.C. Ministry of Environment, Lands and Parks 1994a:93).

In contrast to the interim practices, the proposed Forest Practices Code requires that "full bench cuts and end haul must be used on short-term roads built on areas identified as having terrain stability class IV or V slopes, unless other measures are designed by a professional engineer or professional geoscientist" (ibid.:87). This requirement follows from the more general requirement that "excavated material must not be sidecast on slopes identified as being stability class IV or V, unless the sidecasting has been prescribed by a professional engineer or a professional geoscientist" (ibid.:88).

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[96] A classification of terrain stability is described in *Coastal Terrain Stability Classification,* attached to the November 18, 1992 letter from the regional manager, Vancouver Forest Region (B.C. Ministry of Forests 1992b). (This attachment will be replaced in 1995 by a Forest Practices Code guidebook on mapping and assessing terrain stability. It is not anticipated that the five-class terrain stability classification will change.)

[97] "Es1" areas are "environmentally sensitive" areas of land mapped during forest inventory (1:20 000 scale) where the sensitivity of soils is high. Most (90% of the volume) of the timber growing on these sites is assumed to be unavailable and is not included in allowable cut calculations. "Es2" areas are also sensitive but the area may either be partly logged or logged under various constraints.

Terms describing the degree of slope stability in the proposed Forest Practices Code standards and regulations are ambiguous (but still undergoing revision), and include: "stability class IV or V slopes," "areas prone to mass wasting," "very unstable terrain," "potentially unstable terrain," and "unstable terrain." Panel recommendations are phrased in terms of stability classes, particularly stability classes IV and V.[98]

5.1.2 Findings Regarding Roads

Existing road standards encompass two potentially competing objectives.

F5.1 Existing road standards encompass two potentially competing objectives: to reduce impact on terrestrial and aquatic ecosystems, and to provide cost-effective log hauling. For example:

- Forest roads, logging trails, and drainage structures are located and designed to minimize the combined costs of construction, log hauling, maintenance, safety requirements, site degradation, remedial works, and deactivation (B.C. Ministry of Forests 1993f:1); and

- Forest road networks should be planned to optimize industrial efficiency and minimize environmental impact while providing for user safety. (B.C. Ministry of Forests and B.C. Ministry of Environment, Lands and Parks 1994a:79)

Because various road construction considerations can conflict, clear road location priorities are needed.

F5.2 Because various road construction considerations can conflict, clear road location priorities are needed.

F5.3 Some existing road standards are unclear or insufficient to ensure adequate protection of terrestrial and aquatic ecosystems. Improvements are required with regard to road construction in difficult terrain, road dimensions, area converted to roads, and erosion and sediment control. Existing standards for road drainage structures (ditches, culverts, and bridges), road maintenance, and road deactivation are adequate (with minor revisions) to maintain roads in a usable condition without excessive erosion. However, existing standards are inadequate to avoid changes in slope hydrology.

Even when roads are located, built, and maintained according to the standards, roads alter slope hydrology.

F5.4 Even when roads are located, built, and maintained according to the standards, roads alter slope hydrology by intercepting subsurface flows in road cuts, accumulating it in ditches, and conveying the water and any entrained sediment directly to the surface drainage network or to localized areas of slopes. This alteration short-circuits the natural routing of runoff and changes stream water regimes; it can also change water quality, and lead to decreased slope stability.

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[98] See footnote 96.

F5.5 Past road construction on steep slopes has commonly resulted in long fillslopes (e.g., Table 5.1)[99] that are highly visible, degrade growing sites, lead to fillslope and sidecast instability, and increase sediment production.

F5.6 Current standards do not require consistent application of erosion control measures to exposed soil materials along roads. Exposed soils associated with roads, landings, borrow areas,[100] and waste disposal sites commonly remain unvegetated and susceptible to erosion for extended periods.[101]

F5.7 For the last decade or so, road width (i.e., width of running surface or “stabilized road width”) has accommodated landing of logs along the road during grapple yarding and long snorkelling[102] as well as transportation functions. Resulting road widths commonly exceed 5 m.

Photo 5.3

The most convenient places for road construction are valley bottoms, which are also occupied by streams and rivers. The Panel recommends reserve areas on both sides of a stream to avoid negative impacts of roads (Figure 7.4).

[99]Fillslopes are slopes created by fill material that is excavated from adjacent cutslopes when building roads, or trucked in from elsewhere (see Figure 5.1).

[100]Borrow areas or borrow pits are areas of land from which materials such as sand and gravel are extracted for use elsewhere for road surfacing purposes.

[101]Adoption of proposed *British Columbia Forest Practices Code Standards with Revised Rules and Field Guide References* (Section 9.7.6) will remedy this failing.

[102]Long snorkelling is short yarding from roads using modified (extended booms) line loaders.

Standards allowing conversion of 7% of the forest land to permanent access are too rigid and too high.

F5.8 Current regional standards allow for up to 7% of the productive forest landbase to be converted to a non-productive condition for permanent access (i.e., roads and landings) on a cutblock-by-cutblock basis.[103] This standard is too rigid for cutblock-by-cutblock consideration. The overall road system pattern is determined as much by the pattern of topography and terrain within a watershed as by the road requirements of individual cutblocks. Individual cutblocks can reasonably have more or less road depending on topography and the harvesting systems used. Site degradation limits should be set over larger, more integrated units, allowing flexibility within individual cutting units.

Seven percent is too high a proportion for site degradation in the Clayoquot Sound area when using a mix of yarding methods, including skyline and helicopter yarding, which require considerably less road than highlead or grapple yarding (Table 4.4). It is also inconsistent with the *Clayoquot Sound Forest Practices Standards* (June 1993), which require reduced road density and width.

F5.9 The stumpage appraisal system does not encourage any reduction in extent of road construction because cost allowances are credited based on the length of constructed road.

5.1.3 Recommendations Regarding Roads

Recommendations seek to minimize impacts of roads on terrestrial and aquatic ecosystems while providing for safety of users.

The following recommendations seek to minimize impacts of roads on terrestrial and aquatic ecosystems while providing for safety of users. Road standards must establish a basic level of engineering practice (including location, design, construction, maintenance, and deactivation phases) that protects terrestrial and aquatic ecosystems. Operational decisions (e.g., hauling efficiency, road class, and associated costs) should not be embodied in standards.

Respect recommended priorities related to road location.

R5.1 Respect the following priorities in resolving conflicts related to road location:

- Where irreplaceable values or highly sensitive features are on or near a proposed road location, select another road location or do not build a road. Such features and values include special or rare habitats (including habitats known to be occupied by endangered, rare, and vulnerable species), heritage and cultural features, active floodplain areas and channels,[104] areas mapped as stability class V or Es1, and all but highly localized areas of marginally stable terrain.

[103] This is referred to as site degradation and includes the full width of disturbance no longer capable of tree growth (i.e., the non-productive portion of cutslopes, shoulders, and fill/sidecast slopes as well as the road running surfaces and ditch).

[104] See Section 7.4.1 for definition of active floodplain and Section 7.4.5 for discussion of roads in hydroriparian zones.

- Where damage to watershed integrity and ecosystem function is possible, construct roads only if: no alternative route is available; the road is required to access a substantial harvestable area; *and* mitigating measures (e.g., special construction, rehabilitation) are biologically and physically feasible. Seek professional advice from appropriate specialists approved by the B.C. Ministry of Forests (e.g., professional agronomists (soil scientists), professional biologists, professional engineers, professional geoscientists) whenever road construction is contemplated in areas including: mapped stability class IV terrain; highly erodible soils; mapped Es2 areas; localized areas of marginally stable terrain; or areas where significant impact on growing sites, riparian zones, or aquatic ecosystems can be anticipated.

- Where significant damage to visual or recreational values is possible, use the proposed location only where mitigating measures are feasible according to appropriate specialists.

R5.2 Improve on-the-ground performance in construction and maintenance of road drainage structures (ditches, culverts, bridges) to meet the demands of the wet climate. Reduce the impact of roads on hydrological regimes by constructing roads that allow the passage of shallow subsurface groundwater. Achievement of this recommendation will require research.

Require an overall road deactivation plan.

R5.3 Require an overall road deactivation plan that addresses and effectively integrates the needs for long-term access for stand tending, protection, and recreation. The plan should reflect the fact that roads are a long-term investment, often needed to facilitate future land management.

R5.4 For main or branch roads on slopes consistently greater than 55%, use full bench cuts and endhaul construction, or seek professional advice to ensure that slope stability is maintained and potentially affected resource values are not diminished. In rock cuts, use controlled blasting techniques and follow manufacturers' specifications to: avoid damage to standing timber, retain shot-rock on the right-of-way, maximize the utility of the rock for subgrade or rip-rap, minimize over-breakage, and prevent blast-triggered slides.

R5.5 Revegetate all disturbed areas associated with roads. Promptly apply erosion control, grass-legume (or equivalent) seed mixes to all denuded mineral soil surfaces (i.e., surfaces other than clean shot-rock or bedrock associated with road construction), including cutslopes, fillslopes, borrow pits, and waste disposal areas. Use indigenous, non-invasive species for revegetation wherever possible to avoid deleterious effects on non-forest communities (e.g., white clover, *Trifolium repens,* can invade saltmarsh communities and replace the native springbank clover, *Trifolium wormskjoldii*). Research is anticipated to increase the number of indigenous species available for rehabilitation.

R5.6 With the increased skyline yarding to central landings, and helicopter yarding that are expected to accompany the variable-retention silvicultural system (Section 4.3, F4.12), many roads will serve only transportation requirements (i.e., will not be used as a landing). Therefore, determine required road widths based on anticipated vehicles (i.e., vehicles that will use the road) and traffic volumes. Road widths should not exceed 4.25 m except as required on curves for sidetracking of trailer units and for turnouts. Wider or higher standard roads may be justified by special needs or safety, such as heavy industrial or recreational use, or regular use by local communities.

The maximum percentage of the harvestable area designated for permanent access should normally be less than 5%.

R5.7 Determine the percentage of the productive forest landbase to be converted to permanent access (roads and landings) on a watershed-specific basis during watershed-level planning. The maximum percentage of the *harvestable* area designated for permanent access should normally be less than 5%. All other temporary roads and access trails must be rehabilitated to a productive state.

5.2 Water Transportation

Most log sorting is now done on land.

British Columbia's coastal forest industry uses near-shore marine waters to transport logs from woodlands to mills. Historically, logs were dumped into water at the end of relatively short coastal road systems, water-sorted by species and grade, usually bundled into booms, and towed to a mill. Now, most sorting is done on land, with sorted bundles of logs dumped into the water for storage before transportation to manufacturing centres on log barges.

Photo 5.4

After sorting, logs are temporarily stored in large booms before being transported by barge to processing facilities.

Sheltered waters are used for dumping, limited water-sorting, and booming of logs. These three activities have several impacts on the foreshore and its resources:

Greatest bark accumulation occurs at the foot of skids where logs or log bundles enter the water.

- *Dumping:* Yarding of logs directly into the water with A-frames is seldom used today. At short-term dumping sites where logs are not sorted, logs may be pushed down skids either loose or in bundles, and bark may be lost in the process. These logs may then be moved to a main dump where they are removed from the water (dewatered), sorted on land, bundled, and replaced in the water. At all log dumping sites, greatest bark accumulation occurs at the foot of skids where logs or log bundles enter the water.

  Log bundling has reduced bark loss during dumping. Heli-logging has also reduced debris accumulation on the foreshore because logs are bucked and limbed in the woods. Dump sites for heli-logging must be deep enough to accommodate the plunge of dropped logs to avoid bottom damage and sediment production.

- *Water-sorting:* Bark loss and bottom churning occur if logs are sorted by dozer boats. These impacts are reduced if logs are sorted, graded, and bundled on land before being put into the water.

- *Boom storage:* In the past, booms were often held in estuaries where the influence of fresh water reduced damage by marine borers. Efforts are now made to locate log storage areas at sheltered, non-estuarine sites with deeper waters.

Estuarine ecosystems have especially high biological and cultural values.

Estuarine ecosystems have especially high biological and cultural values (see Section 2.2.5). They are important contributors to regional biological diversity, and because of their importance for fish, shellfish, and waterfowl, have traditionally been camping, fishing, or hunting sites. Several important traditional root vegetables were dug from estuarine saltmarshes by the Nuu-Chah-Nulth, including springbank clover, Pacific silverweed (*Potentilla anserina pacifica*), and missionbells (*Fritillaria camschatcensis*). Using estuarine waters for log dumping, water-sorting, and storage has damaged these environments. Bark deposition at dump sites, ocean floor compaction at shallow, tidal sites where booms are grounded, and accumulation of woody debris that escapes from booms during storms have all had negative effects.

During the last two decades, major log handling improvements have reduced the impacts of log dumping.

During the last two decades, major log handling improvements have reduced the impacts of log dumping on coastal waters, foreshore habitats, and near-shore resources. Because most logs are now sorted at dryland sorts, the input of bark and woody debris into the near-shore environment has decreased considerably. After being sorted on land, logs are usually bundled before dumping into the water, moved to temporary storage by dozer boats, and subsequently transported on barges. Log bundling and the use of barges has greatly reduced log loss during water transport.

Dryland sorts, which have replaced water-sorting, require the following features:

- proximity to logging operations and road systems;

- sufficient size to accommodate the required number of bunks[105] and to either permit truck access and turning on the dump or allow trucks to cross the dump and turn around off-site;
- protection for adjacent booming grounds from storm waves, because waves greater than 1 m make operating dozer boats and holding booms together difficult; and
- sufficient water depth that bundles do not hit bottom and break when put into the water.

5.2.1 Standards for Log Handling and Water Transportation

Protection of the environment during log sorting, water storage, and water transport is currently addressed in diverse guidelines, policies, and legislation.

Little explicit attention is paid to non-commercial species.

The *British Columbia Coastal Fisheries/Forestry Guidelines* protects Marine Sensitive Zones[106] through guidelines dealing with helicopter and balloon systems, A-frame and handlogging systems, and streamside areas. The *Fisheries Act* contains measures to prevent damage to fish and fish habitat. Federal Department of Fisheries and Oceans (DFO) policies, such as the "Policy for the Management of Fish Habitat" and the "No Net Loss Policy," prescribe measures to protect habitat, and require mitigative or compensatory measures in cases where damage occurs (e.g., with log dump construction and operation). Little explicit attention is paid to non-commercial species.

The format for site assessments is not standardized.

Current regulations require that applications for any proposed development with potential impact on foreshore, intertidal, or subtidal zones be submitted to BC Lands and the Coast Guard. BC Lands, as the lead agency in this process, refers such applications for review and comment to interested agencies and groups such as the DFO, First Nations, and upland landowners. The format for site assessments is not standardized, although DFO does have a system of classifying habitats according to fisheries value and sensitivity (Canada. Department of Fisheries and Oceans 1994). DFO may accept a proposal outright, accept it with compensation and / or a compensation bond, or reject it, depending upon the assessed value of the site to fisheries. The effectiveness of compensation projects is generally not known because of inadequate follow-up evaluation (i.e., cursory observation but not detailed data collection). The Coast Guard reviews the application only in relation to the *Navigable Waters Act*.

No special regulations apply to booms; the Coast Guard's primary concern is with safety of larger vessels (e.g., log barges).

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[105]Bunks are cradle-like structures in which logs of various species and grades are accumulated until the desired log bundle size—usually about 50 m^3—is attained.

[106]Marine Sensitive Zones include herring spawning areas, shellfish beds, marsh areas, juvenile salmonid rearing areas and adult salmon holding areas (B.C. Ministry of Forests, B.C. Ministry of Environment, Lands and Parks *et al.* 1993:184).

Roadbuilding standards, to the extent that they apply to construction adjacent to log dumping sites, are collected in *Forest Road and Logging Trail Engineering Practices (Interim)* (1993).

The *British Columbia Forest Practices Code Standards with Revised Rules and Field Guide References* (1994) require that aquatic (marine and freshwater) drop sites for helicopter and balloon logging be located beyond the littoral zone[107] (or beyond the 10 m depth contour). In addition "'A' frame and handlogging operations must not be conducted adjacent to or within marine-sensitive zones" (B.C. Ministry of Forests and B.C. Ministry of Environment, Lands and Parks 1994a:112).

5.2.2 Findings Regarding Water Transportation

Comprehensive standards for log dump development, operation, or maintenance have not been compiled.

F5.10 Comprehensive standards for log dump development, operation, or maintenance have not been compiled.

F5.11 Bottom accumulation of bark and woody debris is the most significant physical effect of log handling. Other problems include runoff of suspended material and leachates from dryland sorts, the release of leachates from logs and bark, bottom shading, and some escape of deleterious substances such as fuels, oils and anti-fouling compounds. Where logs are sorted or bundles are moved by dozer boats, scouring by propeller-wash may also occur. Compaction of bottom substrates by the grounding of logs or booms is a problem at shallow log dump and storage sites.

F5.12 Biological impacts of log handling include:

- crushing of organisms where booms ground in estuaries;
- poisoning of benthic organisms by toxic leachates;
- reduction of both species richness and productivity due to habitat alteration; and
- disturbance to spawning herring which may lead to abandonment of spawning sites.

[107] The littoral zone is, strictly speaking, the intertidal zone, and customarily, the zone between the upper limit of wave action (the back of the storm beach or cliff base), and the seaward limit of significant wave action on the sea bed (approximately the 10 m depth contour).

5.2.3 Recommendations Regarding Water Transportation

Water handling and transport standards must protect estuarine and marine environments, and their associated biota.

Water handling and transport standards must protect estuarine and marine environments, and their associated biota, by minimizing the impacts of log dumping, log sorting, booming, and transportation.

R5.8 Standards are required for dryland sort and log dump construction, operation and maintenance. Construct and operate dryland sorts to ensure that:

- the surface of the dryland sort slopes landward, rather than seaward; and
- surface runoff is intercepted by a ditch on the landward side of the dump. The ditch should direct runoff to a collecting basin from which solids are filtered and regularly removed.

R5.9 On all proposed log dump sites, undertake an ecological assessment that permits DFO to evaluate productivity and sensitivity of the system (including non-commercial species); a physical assessment to determine site exposure to waves and storms, anticipated wave velocities and direction, and near-shore terrain conditions; and an assessment of probable impacts (including noise) on heritage, scenic, wildlife, and recreational values.

R5.10 Minimize time logs are in the water, especially shallow water, by sorting on land and storing log bundles in deep water.

R5.11 Locate log dumps at sufficient distances from sensitive areas such as herring spawning sites, shellfish beds, estuaries, or eelgrass beds, to preclude physical disturbance or deposition of deleterious organic materials.

R5.12 Ensure log dump sites are deep enough to avoid problems with the propeller wash of dozer boats and grounding of booms or bundles.

R5.13 Restore sites that have been damaged by excessive accumulations of bark, woody material, or fine organic material.