A STUDY

OF

FIVE TIMBER HARVESTNG SYSTEMS USED FOR STREAMSIDE LOGGING

BY

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2

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Abstract

A survey of thirty-nine (39) industrial forest engineers was conducted to provide guidelines as to what harvesting system is best suited to specific stand and topographic variables when extracting streamside timber. The advantages and disadvantages of the operational characteristics of the standard highlead spar, mini spar, slackline, grapple yarder and rubber tire skidder are discussed both in terms of site disturbance and wood debris in British Columbia Coastal streams.

Productivity and cost data are analyzed for the standard highlead spar, grapple yarder and rubber tire skidder for three selected streamside conditions. The extra cost incurred by the forest sector to comply with stream protection measures requested by fisheries personnel for pre and post harvesting treatments is also presented.

Findings indicate that specific topographic and timber conditions, plus the limitations of each harvesting system dictate the selection of the system when logging adjacent to small British Columbia Coastal streams. The grapple yarder is shown to be the most cost effective and efficient system for streamside timber harvest and stream debris management.

The stump to dump productivities for the highlead spar, grapple yarder and rubber tire skidder are found to differ. For the three terrain conditions cited, the grapple yarder is shown to be most productive, while the rubber tire skidder is the least costly. Stream protection costs for fisheries concerns were found to be a substantial extra cost to the forest sector. Debris clean-up costs in particular, ranged from \$3.00 to \$15.00 per lineal metre of stream. The recommendations of the survey respondents and current literature all clearly demonstrate that each area to be harvested having fish values must be dealt with on a site specific basis.

TABLE OF CONTENTS

CHAPTER

LIST OF TABLES

TABLE

TABLE

LIST OF FIGURES

FIGURE

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CHAPTER I

INTRODUCTION

> The challenge is to maintain a mandate of multiple use and at least, be able to negotiate forest land alienation with a clear understanding of its impacts, both economic and social. Furthermore, economic analysis should help to strengthen the argument for the long-term benefits which flow from the intricate chain of inter-dependent resources and thereby reduce forest land alienation and conflicts (Jeanes, 1983).

Since the introduction of the British Columbia Forest Service, "Planning Guidelines for Coast Logging Operations" in 1972, there has been an increasing awareness of the need to maintain all forest resource values, specifically fish and forests. Improvement in understanding these two diverse resources is required by all agencies given the mandate to manage them.

Both the fish and forest sectors share a common base- the watershed. Forest harvesting may create situations whereby the fishery and/or fish habitat is affected. Some of the most recent examples of the user conflicts are evident at Riley Creek in the Queen Charlotte Islands (fish/forest) and Meares Island near Tofino (forest/water supply/tourism) which have both received prominent media coverage.

Current research demonstrates that timber harvesting activities may have harmful effects on fish and fish habitat (Gibbons and Salo, 1973; Hartman, 1982; Young,1984; Toews and Brownlee,1982; Lantz, 1971; Swanson, Lienkaemper and Sedell, 1976). Such findings suggest that wood debris created by the harvesting process has the most potential to alter fish habitat and water quality. To reduce these effects resource agencies entrusted with the mandate to protect the fish resource have imposed restrictions on timber falling and yarding operations adjacent to streams (Toews and Brownlee, 1982; Toews and Moore, 1982; Lantz, 1971; Young, 1984).

In areas where forest land is to be withdrawn from timber production to accommodate fish habitat, the value for timber can be assessed. For Coastal British Columbia, the Ministry of Forests (MOF) stumpage appraisal system takes into account three key components: existing market values, timber quality and the cost of extraction to determine the value of a tract of timber. The cost of timber harvesting adjacent to streams is, in turn, influenced by stream protection requirements and selection of the logging equipment.

Edie (1982) stated that there is a need for information that can support confident choices between land-use alternatives. Information that enables provision of specific constraints or techniques for mitigating impacts, or sometimes information that can identify circumstances under which particular activities may or may not occur. Some understanding of harvesting systems and the appraisal cost allowances associated with them should help resource managers make appropriate stream protection prescriptions when required.

Limited research has been done to describe the capabilities or the cost of harvesting systems utilized to extract timber adjacent to streams. Since each system has its own rigging and operational characteristics, each is adaptable to certain topographic conditions. In addition to the physical characteristics of the logging system, it may be possible to classify logging systems on their potential impact on streams and their usefulness for debris management. One can only discuss potential impacts as the actual impact on debris and water is likely to vary greatly from site to site (Froehlich, 1978).

The author has noted a general dissatisfaction with the resource information data base and current approaches being used in the regulation of timber harvesting adjacent to streams. Pearse (1982) also recognized that this lack of basic information stands in the way of effective planning. He recommended a comprehensive inventory of fish habitats in fresh water streams in British Columbia describing the biophysical characteristics of individual areas of fish habitat and also assessing their potential for producing fish. There appears to be a need for the selection of appropriate criteria to assess the full implications of alternative logging systems in such areas. There is an even stronger need to ensure resource agency personnel are consistent in both their approaches with and recommendations to the forest sector when stream protection requirements are being made. When a specific logging system is suggested, it must be practical, site specific, and cost effective.

This study provides a composite picture of the five main harvesting systems employed in the Vancouver Forest Region - the standard highlead spar, mini spar, slackline, grapple yarder and rubber tire skidder. The findings should prove useful to forest resource managers in planning more effective harvesting plans for streamside timber, both in terms of cost and stream protection.

Statement of the Problem

Timber harvesting restrictions and fish habitat managment prescriptions are becoming more complex in recent years as it is recognized that certain harvesting activities may have some harmful effects on fish and fish habitat. Fisheries personnel may dictate the method in which these activities may be conducted, specifically by imposing falling, yarding, and post-logging debris clean-up constraints. However, in the opinion of many field engineers, fishery officers make decisions with limited knowledge regarding forest harvesting methods, their costs, and additional costs incurred to achieve stream protection requirements.

Purpose of the Study

The purpose of this study is to consider the harvesting systems that are available for streamside logging and to recommend that method that is most efficient for particular topographic and stand conditions. Efficient within the context of this study implies the best alternative for achieving reasonable logging costs, required stream protection and acceptable debris management. With a better understanding of the appraisal system and existing harvesting systems, resource managers should be able to make sound decisions and encourage an adequate utilization of the forest resource while still maintaining the fishery resource at acceptable levels.

The specific objectives of the study were:

1. to identify the main resource agencies given the authority to regulate the forest sector.
2. to describe the British Columbia stumpage appraisal

2. system as it applies to the pricing of timber in Coastal cutting authorities.
3. to identify stumpage appraisal cost allowances for the stump to dump phases of the highlead spar, grapple yarder and rubber tire skidder.
4. to identify additional costs incurred by the forest sector for stream protection requirements and post-logging debris clean-up.
5. to identify forest stand and ground characteristics that may influence the selection of a specific logging system.

Limitations of the Study

1. The survey information was obtained through questionnaires and is therefore subject to the limitations of self-reported data.
2. Findings of the study are generalizable only to Coastal B.C. areas with similar characteristics to the three streamside conditions presented.
3. Appraisal cost allowances for the stump to dump phase was presented for only three of the five systems being discussed. The current Coastal Appraisal Manual only provides a means to assess the highlead spar, grapple yarder and rubber tire skidder.

Review of the Literature

Public forest lands are capable of a variety of uses that have value to society. Timber production is only one of these uses, fish production is another. Hartman and Holtby (1982, p.348) wrote "When one considers the impacts of a complex process such as forest harvesting on fish populations, it is necessary to recognize that there are many different activities associated with timber removal. These include road construction, tree cutting on hillsides, streamside cutting, yarding and post-logging treatment". Also, in a typical coastal stream there can be several species of fish, each with a series of different life stages and requirements, some of which can be altered by the logging process into a more favourable range or, alternatively, into a range of adverse effects (Hartman and Holtby, 1982).

Small streams in Coastal areas of British Columbia, respond quickly to rainfall. Virtually all water passes through the soil mantle on its way to streams instead of flowing over the soil surface. This lack of overland flow is perhaps the most important hydrologic characteristic of undisturbed forest land and one of the characteristics most easily altered by timber harvest activities (Fredriksen and Harr, 1979).

No doubt, the permanent impact that logging makes on the forest landscape is the development of a road system. As the road system has been repeatedly shown to be the source of most of the man-caused sediment reaching streams, it follows that any logging system which keeps the road mileage to a minimum should have the least impact on soil and water (Froehlich, 1978).

Long reach skylines (slackline) may require as little as 2% of the harvested area for roadways (Binkley,1976). Under favourable topographic conditions, highlead logging may require only 3 to 3.5 percent of the area for roads (Morrison, 1975; Swanson and Dyrness, 1975). However under normal conditions this figure is between 6.5 to 10 percent (Megahan and Kidd, 1972).

It is well recognized that forest harvesting practices can, and have, created water quality problems in forest streams, which can have harmful effects on fish and fish habitat. The major effects of timber harvesting on fish and water resources have been summarized by Gibbons and Salo (1973) to be: 1) introduction of sediments, 2) altered stream flow regimes, 3) introduction of logging debris, 4) degradation of rearing habitat through streambank erosion, 5) altered temperature regimes, and 6) altered in-stream energy sources.

It is noteworthy that in their summary of 193 articles relating to fish and logging practices, only seven have actual quantitative, documented evidence on the detrimental effects of logging on fish populations. Not one of the articles discussed the cost of stream protection, or attempted to put a monetary value on fish populations and fish habitat. Gibbons and Salo (1973) concluded that in the absence of precise information, biologists are inclined to recommend conservative regulations as a safety factor to protect the fish resource.

The yarding process of logging can expose mineral soil, compact the soil and create yarding trails which in turn may funnel overland water and sediment flow into stream channels. Toews and Brownlee (1981) note that sediment can fill the gravel interspaces, reducing the sub-gravel flow that is vital to the survival of developing eggs, and hindering alevin emergence from the gravel. Heavy sedimentation can also reduce aquatic insect populations and high suspended sediment levels can clog gills of fish causing respiratory distress or death by suffocation.

Soil disturbance and compaction vary among the logging systems that are available to a logging operator. According to Table 1, cable operations may cause much less soil damage than a tractor (skidding) operation.

Table 1-1

Disturbance and compaction of soil caused by three harvesting systems (adapted from Fredriksen and Harr,1979).

Harvest Method	Bare Soil (%)	Compacted (%)
Tractor(Skidding)	35.1	26.4
Highlead	14.8	9.1
Skyline(Slackline)	12.1	3.4

Clear cut logging,no matter what the logging system, can create increases in stream water temperatures. Fredriksen and Harr (1979) noted that elevated stream temperatures can be detrimental to populations of resident trout and anadromous fish. They discussed further, that although temperatures above 25°C may cause mortality, particularly for fish in juvenile and embryonic stages, reduced growth, vigor and resistance to disease are probably the main effects of high water temperature. Elevated water temperature can stress salmon and trout since, as the temperature rises, the amount of oxygen that the water can hold declines, and at the same time, the oxygen requirement for the respiration of fish increases. Because fish must migrate to cooler water to survive, the result of severe increases in temperatures of stream water is loss of habitat for juvenile fish.

In the same paper,Fredriksen and Harr (1979) noted an interesting result of stream debris and water temperature. They found that logging debris and under-story vegetation left after logging can provide sufficient shade to prevent an appreciable increase in temperature. In one case cited, water temperature of a stream increased 7°C after logging residue and peripheral shade were removed. In a nearby stream flowing through an unburned clear cut, residual vegetation and logging residue over the stream kept the water temperature increase to 2°C. After slashburning, water temperature increased 8°C in this stream.

A multi-disciplinary study of a small West Coast rain forest watershed and the effects of logging upon it was initiated in 1970 on the West Coast of Vancouver Island. The study, now referred to as the Carnation Creek Project, was designed to compare physical and biological conditions in the watershed prior to, during, and after application of various types of logging and post-logging treatments (Hartman,1983).

A recent symposium on the results from the Carnation Creek Project concluded that many of the research projects on the effects of logging on Carnation Creek were inconclusive (Hartman,1982). However, organic debris, both natural and logging, was identified as being one of the major influences in altering stream channel form and fluvial processes.

A striking feature of the small streams of the overmature West Coast forest is the number of trees, log chunks, branches, and root wads that accumulate naturally in the stream channel. This debris is deposited in the channel by natural processes and remains part of the stream for many years (Swanson, Lienkaemper and Sedell, 1976). Again, one must realize that not all debris inputs can be prevented. Forest harvesting activities, however, can accelerate input, size of debris and especially quantities of debris for a particular stream reach. This input can be substantial if there is poor layout, lack of deflection or if insufficient lift is given to the yarded logs. Large loads of debris may be deposited into the stream channel utilizing any logging system under the above conditions.

Clear cutting to the edge of the stream, streamside alder removal, and falling trees across the stream, and yarding them from the stream all contribute to a reduction in the volume and stability of large debris according to Toews and Moore (1982). The results of several treatments carried out on Carnation Creek were somewhat surprising. In a careful treatment, logging on both sides of the stream occurred with all merchantable trees felled and yarded away from the stream with care. In an intense treatment, all trees including nonmerchantable trees were felled along the streamside with approximately 25 leaning trees and snags felled into or across the stream and yarded out. Both treatments resulted in some reduced stability of large organic debris and introduction of small organic debris, and these contributed to some changes in the stream channel and

and increased streambank erosion (Toews and Moore, 1982). However, the degree of disturbance was not appreciably different between the two treatments.

Keller and Talley (1979) noted the total debris loading along a particular channel reach represents a relation between rates of debris entering and leaving the reach. Changes brought about by timber harvesting, particularly during the falling, bucking and yarding phases, can be divided into two categories - namely, the loss of tree cover (debris source) and the physical disturbance resulting from tree removal.

Froehlich (1973) found, under natural unlogged conditions, total stream debris loading could vary from 5.9 to 23.6 tonnes per 30.5 metres of stream channel. Logging, however, may significantly increase or decrease the debris balance of stream reaches. Froehlich (1975a) determined that as much as 4.5 to 9.1 tonnes of additional debris per 30.5 metres of stream channel resulted directly from logging in some Coastal Oregon streams. Kiss (1976) measured a total debris load after harvesting of 19.9 tonnes per 30.5 metres of stream channel in a second growth stand located at the University of B.C. Research Forest. He also measured 33.3 tonnes per 30.5 metres of stream channel found in a logged old growth stand near Tofino,B.C.

Froehlich (1975a) monitored the various phases of logging and identified the major source areas of debris to be:

1. debris from falling - direct input from breakage (tops, limbs and branches)
2. debris from yarding - direct input by yarding across streams (broken boles, stems, and lost pieces)
   - direct output by the removal of merchantable natural debris.
3. debris from downslope movement-gravity input of all debris sizes.
4. debris from downstream movement-flow input and output.

McGreer (1975) concluded that debris quantities increased during the falling phase, but that after yarding, debris volumes were lower than under natural conditions. Toews and Moore (1982) found debris is less stable, the debris volume is similar or lower, the number of pieces is greater and the average piece size is smaller following logging than in undisturbed reaches of Carnation Creek on the west coast of Vancouver Island.

The extraction of timber can have significant effects on stream debris loading. Many papers have been written on the sensitivity of a stream ecosystem to such disturbances. Lantz (1971), Narver (1972), Hall and Baker (1975) and Hartman (1981) have all summarized possible detrimental effects of harvesting operations on both channel morphology and fish and/or fish habitat. Toews and Brownlee (1981) have summarized negative impacts of forest harvesting activities on water quality and fish requirements. A draft Coastal Forestry/Fisheries Guidelines (1984) has also summarized potential impacts from falling and yarding activities in streamside areas.

It should be noted that not all the effects of introduced debris and harvesting are negative. Debris may help stabilize the channel banks and may affect the development of pools and resting places which are desireable components of fish habitat (Keller and Talley, 1979; Hall and Baker, 1975). Debris accummulations are utilized as cover by both young and adult fish. Upturned tree roots and areas under logs were preferred hiding and sheltering areas for overwintering coho salmon (Oncorhynchus kisutch) and older steelhead (Salmo gairdneri) (Bustard,1973). In addition, bacterial activity and food growth for fish is increased in many areas of natural debris accummulations (Cummins, 1975).

Young (1984) recognized both the positive and negative impacts of forest harvesting in respect to fish habitat. The draft manual has classified Coastal streams on a four class system based primarily on the presence of fish species groups and gradient. A Class I stream reach is considered to be of high value and a Class IV reach has no potential fish value. In the context of streamside timber extraction, all four classes have protection objectives including consideration of the following:

1. maintain sufficient stream channel integrity to prevent the degradation of downstream reaches through the accelerated transport of sediments or debris,
2. maintain water quality,
3. preserve the integrity of channels and banks by maintaining stable in stream organic debris and the root structures which provide bank cohesion, and
4. maintain the quality of streambed gravels.

Toews and Brownlee (1981) have also summarized stream protection objectives and proposed various restrictions on all phases of the logging operation. However, like many such guidelines, there is no attempt to recognize costs, quantify the value being protected, or address the practical realities of the logging process.

Summary

The review of the literature has identified several important aspects of the forest/fish relationship which occur in B.C. Coastal streams. Debris is a natural component of small streams. Forest harvesting activities, however, can accelerate input, size of debris and quantities of debris for a given stream reach. Natural and logging debris have been identified as being one of the major factors which may alter stream channel form and fluvial processes. Researchers have recognized both positive and negative impacts of forest harvesting in respect to fish habitat. It may be possible to classify and select logging systems on their potential for minimizing the negative impacts to stream habitat.

CHAPTER II

Methods

The overall study was conducted to provide guidelines as to what harvesting system is best suited to specific topographic variables (terrain, sideslope, yarding distance, log size, volume per hectare, stream gradient and deflection) where stream protection is required for fish values. The study was also to identify the cost of the individual harvesting methods and additional costs incurred for stream protection requirements.

The data were obtained utilizing two methods; 1) a questionnaire for the topographic variables and 2) an analysis of existing cost detail.

Questionnaire Description

The Harvesting System Questionnaire was developed by the author to determine the timber harvesting systems best suited to B.C. Coastal streamside harvesting. It was segregated into two major sections: one to evaluate specific variables which might effect the potential of each system, and the second to rate each system for harvesting three separate stream conditions.

The questionnaire was pre-tested for content and clarity with six (6) engineers in May,1983. Results indicated a fairly high degree of reliability of the responses, especially for the section on terrain and stand conditions. The Harvesting system Questionnaire was then distributed in July, 1983 to fifty (50) forest engineers employed by Coastal forest companies.

Questionnaire Sample Selection.

The Harvesting System Questionnaire was distributed to fifty (50) forest engineers employed by member companies of the Council of Forest Industries (COFI). This was done in order to relate the descriptive survey results to actual 1982 costs derived through the COFI Logging Cost Survey since many of the operations constituted the place of employment of the engineers being sampled. Participants completed the questionnaire and returned it to the author between the months of July and October 1983.

Harvesting Cost Data Description

The cost data are a summary of average 1982 phase logging costs as experienced by a selection of COFI members. The cost information was provided by twenty-two (22) Coastal operations participating in the Council's 1982 logging cost survey. The operations were selected by the Ministry of Forests (MOF), in conjunction with the Council, with the objective of acquiring a representative sample of the industry on the Coast.

Data Analysis

The cost estimates for the stump to dump phases of each logging system are derived through the use of a productivity system approach. The stand and ground conditions for each of the stream conditions presented were included into phase equations currently employed by the 1984 Ministry of Forests Coastal Appraisal Manual. The use of one specific cutting permit allows comparison of not only the logging system by phase, but also the differences that are created by stand and terrain conditions. The assumption that cost allowances represent experienced costs with only a small degree of variance had to be made. The results of the cost and productivity analysis are presented in Chapter VI.

The responses to the Harvesting System Questionnaire were not computerized, but rather grouped for each section of the questionnaire and analyzed separately. The findings from the Harvesting System Questionnaire are discussed in Chapter VIII.

CHAPTER III

Regulation of the Forest Sector

Introduction

"Protection measures for streamsides essentially focus on the questions of what harvesting methods should be applied, how much and what kind of vegetation should be left on the streamside, all within the context of what uses other than timber production are important" (Young, 1984, p.8).

Planning and administration of timber harvesting in British Columbia with respect to stream habitat management is generally the responsibility of one federal and two provincial agencies, namely Canada Fisheries, B.C. Ministry of Forests and the B.C.Fish and Wildlife Branch. The Federal Fisheries Act, Ministry of Forests Act and related regulations provide the principal direction for stream protection in the Province. The three agencies which are described in the following text are charged with the responsibility of ensuring the perpetuation and enhancement of their individual resources.

Forest Harvesting Regulatory Agencies

1. British Columbia Ministry of Forests

The mandate for forest management by the Ministry of Forests is expressed in a statement of objectives from Section 5 of the Ministry of Forests Act:

-to encourage the attainment of maximum productivity of the forest and range resources of the Province,

-to manage, protect and conserve the forest and range resources of the Crown, having regard to the immediate and long term economic and social benefits they may confer on the Province,

-to plan the use of the forests and range resources of the Crown, so that the production of timber and forage, the harvesting of timber, the grazing of livestock and the realization of fisheries, wildlife, water, outdoor recreation and other natural resource values are co-ordinated and integrated, in consultation and co-operation with other ministries and agencies of the Crown and with the Private sector,

-to encourage a vigorous, efficient and world competitive timber processing industry in the Province, and

-to assert the financial interest of the Crown and its forest and range resources in a systematic and equitable manner.

2. Canada Department of Fisheries and Oceans

In managing the salmon resource, Canada Fisheries has identified a broad set of management objectives as follows:

- to ensure the conservation, protection, orderly harvest and best use of the salmon resource to achieve optimum social and economic benefits for Canadians.
- to protect and preserve salmon habitat, the quality and productivity of which are jeopardized by conflicting water use, land use and waste disposal practices.
- to develop, improve and apply fish culture and other enhancement technology to increase the production of salmon to generate economic, social and environmental benefits (Toews and Brownlee, 1981).

3. British Columbia Fish and Wildlife Branch

The principles and goals for fisheries concerns are:

- to produce maximum economic, cultural, recreational and scientific benefits for present and future generations of B.C. by maintaining all native and introduced species of fish at optimum levels of distribution, abundance and health and protecting or enhancing essential fresh water habitat (Toews and Brownlee, 1981).

Legislation Regulating Forest Harvesting Practices

Federal Fisheries Act

It is important for forest land managers to recognize the fisheries mandates are backed by a strong piece of legislation, the Federal Fisheries Act.

Section 33 is most relevant to the forest industry as it deals with the injury to fishing grounds and pollution of waters. Subsection 2 says in part, "no person shall deposit or permit the deposit of a deleterious substance of any type in water frequented by fish or in any place under any conditions where such deleterious substances or any other deleterious substance may enter into any such water".

Subsection 2 and Section 31 (1) of the Fisheries Act are the key sections under which the primary environmental prosecutions occur (Environmental Law and Practice,1983). Section 31 (1) reads: "No person shall carry on work or undertaking that results in the harmful alteration, disruption or destruction of fish habitat". Section 33 (3) reads: "No person engaging in logging, lumbering, land clearing or other operations, shall put or knowingly permit to be put, any slash, stumps or other debris into any water frequented by fish or that flows into such water".

Toews and Brownlee (1981) noted that in September, 1977 final assent was given to Bill C-38 introduced to amend the Fisheries Act. These amendments relevant to the B.C. forest sector, both in terms of protection and enforcement included:

1) The definition of fish was expanded to include eggs, spawn, spat and juvenile stages of fish.
2) Fish habitat was defined as spawning grounds and nursery, rearing, food supply and migration areas on which fish depend directly or indirectly in order to carry out their life processes.
3) The basic prohibition against depositing a deleterious substance into fish bearing waters was retained, and amendments relating to protection of habitat were introduced.
4) Monetary fines for each infraction were to be levied for each day the infraction continued and/or the operation could be curtailed at the discretion of the Fisheries Officer.

Snow (1983) cites a court case in which the resultant decision has become the corner stone for the Crown's proof of deleteriousness. If a substance in any concentration in any waters could harm any fish, then it must be considered deleterious. This seems a handy test as most substances in sufficient quantity and in the right circumstances are harmful to most living creatures.

Snow (1983) also gives two examples where operators charged under the Fisheries Act may be able to get some relief:

1) where the defendant can demonstrate in evidence that there would be no likelihood that a particular deposit would harm the fish that frequent the waters in the area of that deposit, i.e. no link between the deposit and any fishery to be protected, there should be an acquittal.
2) that the Fisheries Act had no application to landlocked fish that were too small to ever be a fishery and were not part of the food chain for a fishery.

Ministry of Forests Act

The Ministry of Forests Act is of particular importance because it demands effective and consistent management of forest resources. It emphasizes the social and economic well being of British Columbians - not just the tasks of growing, protecting and selling wood. It insists on co-operative efforts with other agencies (Forest Range and Resource Analysis, 1980).

The Act stresses the need for consideration of all uses of forest land and provides for consultation with other ministries and agencies so that forest management decisions reflect the concerns of other users of forest land and watersheds.

Apsey (1984) warned foresters "that all resource values must be considered" and that while timber production will always be an important consideration, "it is no longer pre-eminent and must take its place in the overall scheme".

In addition to the mandate expressed in the Ministry of Forests Act, the Ministry of Forests includes standard stream protection clauses in every cutting authority approved by Ministry staff. Section 8.01 and Section 8.02, referred to as P.1 clauses, contained in all Coastal cutting permits, read as follows:

8.01 In respect of timber harvesting and related operations carried on under this Cutting Permit the licensee will not permit

(a) a lake, stream or spring that supplies water for any purpose, to be rendered unfit for that purpose, or

(b) trees, logs, logging debris or any polluting substance to be deposited into a lake, stream, or spring, unless authorized by a Forest Officer,, or

(c) logs to be skidded or equipment to be operated below the high-water mark of a lake or stream, unless authorized by a Forest Officer, or

(d) any obstruction, gravel or fill to be placed below the high-water mark of a lake or stream, unless authorized by a Forest Officer, or

(e) a landing to be located within 40 m of a lake or stream or in an area that is not designated for harvesting in this Cutting Permit, unless authorized by a Forest Officer, or

(f) slash to be burned closer to a lake or stream than the distance specified by a Forest Officer.

8.02 In respect of timber harvesting and related operations carried on under this Cutting Permit the Licensee will

(a) remove logging, milling and road-building debris deposited in and on the banks of lakes and streams,

(b) direct falling and yarding of timber away from lakes and streams and their banks,

(c) protect natural growth in and on the banks of lakes and streams from damage from logging and burning,

(d) build a bridge or install a culvert at every stream crossing, designed to accommodate the maximum flow of the stream and to permit unobstructed fish passage, and

(e) schedule the construction of stream crossings, as directed by a Forest Officer.

Fisheries personnel have the opportunity to add other protection measures during thereview of cutting permit applications. These are usually site specific and may contain certain restrictions before a particular harvesting proposal such as cross-stream yarding may take place. Many of the requested measures usually relate to falling, the method of yarding and post yarding debris removal as evidenced by the following examples:

1. Trees which would have to be felled into the creek are to be felled just prior to yarding. Where possible, directional falling with a timber tipping system should be used.
2. To prevent debris loading, trees falling into the creek are to be limbed after removal.
3. The yarding crew is to be advised to use extreme caution when setting turns and yarding to minimize or eliminate butt drag and to attempt maximum lift while yarding. If required, then smaller turns are to be taken to achieve maximum lift.
4. Yarding on that portion of the setting adjacent to the creek is to take place between June 1 and September 15 or during other periods of low flow as authorized in writing by the District Manager. Yarding is to be completed within the year of commencement.

5. A debris catchment facility (grizzly) must be installed and cleaned out regularly until such time as it can be removed once clean-up is completed to the satisfaction of a Forest Officer.
6. Debris introduced to streams, as well as any unstable natural debris shall be removed concurrent with the progress of yarding. Debris removal is to be done to machine capability. Debris is to be deposited in a location where it cannot find its way back into the stream.
7. Natural debris which is stable cannot be removed.

These so-called P clauses in Coastal cutting permits provide a workable means between the Fisheries Act and day to day administration of cutting permits. The clauses allow a Forest Officer to approve logging practices which <u>may</u> contravene a rigorous interpretation of Section 33 of the Fisheries Act following consultation with Fishery and Conservation Officers. The clauses constitute, in effect, an interpretation of the Fisheries Act and afford licensees a degree of protection from prosecution under the Act. Even so, licensees must comply with all contractual requirements protecting stream quality.

The Referral Process

In accordance with an approved Management and Working Plan, each licensee must prepare a Five Year Development Plan for each of its operating areas. The plan identifies all cut blocks proposed for harvest within the next five years. Usually the first two years of any particular plan are laid out in the field. The remaining years are generally paper projections based on air photos, preliminary ground investigations and forest inventory maps. The forest engineer responsible for a particular drainage attempts to identify potential conflict areas with other resource values.

Involvement by other agencies occurs once the Plan is submitted to the Ministry of Forests for review and approval. The Plan is then referred to other agencies for review and comments which must be returned to the Ministry of Forests within a specified time frame in some Forest Districts. Some licensees arrange for joint Five Year Plan meetings with representatives of all agencies, including the Ministry of Forests in an attempt to speed up the approval process.

Possible conflict areas are identified and discussed at this stage in relation to all resource values. High value or sensitive sites are then field inspected, and in most cases, harvesting techniques and stream protection requirements initially proposed. The Ministry of Forests District staff then send an approval of the Plan to the licensee. This approval is sometimes dubious, as it is in many cases, restricted to approval in principle and subject to further on site examination.

The referral process is hindered as it can take an excessive amount of time due to staff shortages of key agency personnel and thereby incur further costs to industry in delays. In addition, unlike the timber resource, stream inventories, fish presence and fish value data are not available for many Coastal areas currently under application for harvesting.

Summary

It is clear, that before any timber extraction can take place on Crown land in B.C., all the regulatory agencies must concur with the operators' proposal for harvesting a given area. The principle objectives of the three agencies with respect to stream and debris management are:

1. prevention of physical damage to the natural stream channel and adjacent vegetation during logging operations through tight limitations on machine activity and yarding in streams,
2. removal of introduced debris from streams following the yarding operations,

3. leaving debris of natural origin in place, unless it significantly interferes with fish passage, and
4. careful placement of roads and careful planning of operations in sensitive or unstable areas.

To meet these objectives and abide by restrictions on felling and yarding procedures, licensees must employ specific yarding systems and in the process may incur extra costs.

CHAPTER IV

VANCOUVER FOREST REGION STUMPAGE APPRAISAL

Introduction

Timber is a valuable commodity and when left in leave strips or alienated from logging to protect fish habitat, regulatory agencies must assure themselves that the values to be protected outweigh the timber values lost. This section briefly describes the pricing of timber for Coastal areas within the Vancouver Forest Region.

The pricing and assessment of timber values requires qualified personnel from the Ministry of Forests and Industry to secure a fair return for the Province's timber resource. Regulatory agencies with mandates to protect and enhance the Province's fishery resource must be made aware of timber values and the procedures utilized to price Crown timber. Many individuals have a misperception that any added cost of stream protection or clean-up incurred by a logging operator is reimbursed via the stumpage appraisal system. Resource managers having a base understanding of the appraisal process and how it works during low and high market conditions would be in a better position to negotiate alternative logging treatments for streams of varying fish values.

Timber appraisal refers to the procedures for determining the minimum acceptable price to the Crown for public timber harvested in British Columbia. It is designed to establish the net value of a tract of timber to be harvested by subtracting from the estimated value of the products that can be recovered from it, the costs necessary to realize these values, including a profit to the operator. The price of the timber is thus in the nature of a residual value i.e., the unearned increment or surplus of value over the necessary costs of utilizing the resource (Ministry of Forests Kamloops Appraisal Manual, 1978).

As approximately 95% of the forest land in British Columbia is owned by the Crown, stumpage represents the public equity in its forests. It is therefore the amount which the B.C. forest industry must pay to the government for timber. Stumpage payments represent approximately 10% of the total annual revenue to the Crown in a given year. It represents the majority of revenue from the provincial category called forest revenue.

Appraisals for Stumpage

The appraisal for stumpage is one of the functions of the forest valuation branch of the Ministry of Forests (MOF). The organization has been structured similarily in Victoria and the Forest Regions, in order to simplify administration and communication. Provincial policies are created and administered by the MOF located in Victoria. Each Region and associated Districts administer and perform the appraisal at the local level.

The forest land tenures upon which timber is appraised for stumpage are those Crown lands within Tree Farm Licences, Forest Licences and Timber Sales. Leasehold lands and Crown Granted Lands are normally reserved from stumpage. However, Licensees have the option of electing to pay stumpage instead of royalty on Timber Licences to take advantage of access road and silviculture funding programs.

With the exception of Timber Licences, the tenures do not actually grant the right to cut any timber. Actual harvesting is authorized by cutting permits for which timber dues are calculated through the stumpage appraisal system. Appraisals of timber are the responsibility of District MOF staff with significant input from licensees.

The unit of timber which is appraised is called a cutting permit. Appraisals are done on an annual basis - the first one at the initiation of the cutting permit and subsequent ones at the anniversary date of the permit. This procedure has evolved in an attempt to maintain current cost allowances and to revise any of the details which were originally submitted, should further knowledge of the area show necessity for revision - such as the re-location of roads, changes to falling boundaries, and updating of log size and log grades.

The forest system of appraisal provides the method for the determination of a reasonable value for an individual tract of timber by considering various details about the timber, the extraction processes, all costs related to the movement of logs to market, the value of logs and a margin for profit and risk. Cost estimates normally include all the necessary expenditures that would be incurred by a reasonably efficient operator to produce raw logs and to comply with the provisions of the cutting permit and the tenure being operated on.

Calculation of Stumpage

The basic calculation of stumpage is relatively simple and is known as the Rothery Method. Individual values for the three main components of selling price, profit and risk and operating cost can be of extreme importance in the determination of stumpage.

The Interior stumpage calculation is somewhat more complicated than the Coastal system, as it is based on end product (lumber) values and takes into consideration milling costs as well as logging costs. Other differences exist between the two systems, but the main thrust of this report concentrates on the Coastal log based procedure.

The appraisal formula applied individually to each timber species in a Coastal cutting permit is simply:

Stumpage = Selling Price of Logs - Operating Cost
- Profit and Risk Allowance.

The system is thus broken down into procedures for determining each of the three components of the above formula.

1. Selling Price - the MOF compiles log sales values by species and grade monthly. These values are for the Vancouver log market which represents approximately 14% of the Coastal log harvest. The individual selling price for each grade is then pro-rated by the percentage of that grade in the cutting permit (refer to Table 4-3). Grades are usually derived from historical scale of adjacent or similar timber.
2. Profit and Risk - also referred to as a profit ratio and represents a percentage return on the total cost of the operation. It is calculated by adding allowances for risk to a basic profit allowance of 10% for Coastal cutting permits. Other additional factors which are assessed and added to the basic allowance are:
   a) an allowance for market risk - the higher the log prices, the higher the risk.
   b) an allowance for defect and breakage - the more defective the timber, the higher the risk.
   c) an allowance for risk of logging chance - the more difficult the terrain, the higher the risk.

d) an allowance for investment risk - the more costly the road construction, the higher the risk.

The total profit ratio is usually in the range of 15-20%. The profit ratio would be much lower for an operation logging excellent Fir-Cedar stands near Vancouver, than for an operation logging rugged decadent, Hemlock-Balsam stands in the north coast area.

3. Operating Cost - represents the total costs required to process the logs from a given tract of timber to market. Appraisal manuals detailing the procedure for determining the operating cost have been developed by the MOF (with input from industry) for each of the eight appraisal regions within the Province.

Although each region has a few specific procedures peculiar to operations within their jurisdiction, the basic concepts are the same. Costs are developed for each logging phase and for overhead items. Table 4-1 indicates all phase costs recognized in a typical Coastal cutting permit.

The phase costs which are considered when a tract of timber is appraised have been projected with an indication of the cost allowances. Each one is assessed in variable detail to define the factors which affect it. For example, the allowance for yarding is based on a fixed shift production, which in turn is determined by the cutting permit slope, obstacle index and log size. Administration costs on the other hand, for operational and administrative overhead are a standard $7.93/m^3 for all cutting permits.

Table 4-1 presents a typical coastal cutting permit which has a calculated operating cost of $46.93/m^3 effective July 1, 1982. The phases can be separated into distinct categories for development costs (road, bridge and landing construction), stump to dump costs (falling and bucking, yarding, loading and hauling), and all other costs as defined in the table.

Minimum Stumpage Rate

The appraisal system can and does indicate very low and negative stumpage rates when market prices are low or where estimated operating costs are high. Minimum stumpage rates for the Vancouver Forest Region are 8% of the Average Market Value (AMV) of logs traded on the Vancouver Log Market.

Table 4-1

Sample Cutting Permit I Phase Costs

Logging Phases	Cost($/m^3)
Development Costs	
Road Construction	$ 4.46
Bridges	0.12
Landings	0.68
Sub-Total	$ 5.25
Stump to Dump Costs	
Falling & Bucking	$ 3.54
Yarding	6.77
Loading	3.85
Hauling	3.60
Sub-Total	$ 17.76
All Other Costs	
Road Maintenance	$ 1.82
Road Use Charges	0.05
Sorting & Booming	3.30
Scaling	0.19
Contractual Obligations	0.08
Camp & Cookhouse	3.68
Crew Transportation	3.54
Towing	1.13
Administration	7.93
Operational Engineering	0.97
Cruising	0.06
Remoteness	1.16
Sub-Total	23.91
Total Operating Cost	$ 46.93

Table 4-2

Cutting Permit I Data

Term: 1 year effective July 1, 1982

Area: 112.0 hectares

Volume:	Balsam	(BA)	= 22,000 m^3
	Cedar	(CE)	= 10,600 m^3
	Fir	(FI)	= 5,400 m^3
	Hemlock	(HE)	= 23,000 m^3
	Total Volume		= 61,000 m^3

The stumpage calculation employed in the Vancouver Forest Region for Coastal cutting permits is represented in Table 4-3. The example identifies how the selling price, profit and risk, and operating cost components of the appraisal system are utilized in determining stumpage rates for individual species contained in a given cutting permit. An example of a Coastal cutting permit is presented in Table 4-2.

Table 4-3

Stumpage Calculation for Cutting Permit I

		BA	CE	FI	HE
Market Risk	(%)	3	3	3	3
Defect & Breakage	(%)	0	2	0	0
Risk of Chance	(%)	3	3	3	3
Investment Risk	(%)	2	2	2	2
Basic Allowance	(%)	10	10	10	10
Total Allowance	(%)	18	20	18	18
Price/Grade A	($m/^{3})	-	-	148.50	-
B		-	-	106.15	-
C		52.44	-	56.87	-
D		56.79	109.25	120.13	61.90
F		-	104.04	-	-
H		47.64	84.72	50.36	49.62
I		38.01	73.25	45.01	38.52
J		27.72	60.98	31.90	28.35
K		-	86.38	-	-
L		-	71.43	-	-
M		-	53.56	-	-
X		13.24	22.49	16.91	16.20
Y		11.11	6.04	3.76	14.92
Percent Grade A		-	-	2	-
B		-	-	5	-
C		2	-	15	-
D		1	-	3	1
F		-	-	-	-
H		16	23	20	11
I		34	25	15	35
J		25	6	20	17
K		-	-	-	-
L		-	17	-	-
M		-	20	-	-
X		19	6	15	32
Y		3	3	5	4
Operating Cost	($/m^3)	46.93	46.93	46.93	46.93
Base A.M.V.	($/m^3)	33.20	70.30	48.10	30.50
Minimum %		8	8	8	8
Minimum Rate	($/m^3)	2.66	5.62	3.85	2.44
Pro-rated Selling Price	($/m^3)	31.94	65.84	46.31	30.16
Discount Value	($/m^3)	27.07	54.87	39.25	25.56
Indicated Stumpage	($/m3)	-19.86	7.94	-7.68	-21.37
Profit & Risk	($/m3)	4.87	10.97	7.06	4.60
Final Stumpage	($/m3)	2.66	7.94	3.85	2.44

Using the operating cost of $46.93 determined in Table 4-1 the stumpage rates for the sample permit are:

BA	$2.66
CE	7.94
FI	3.85
HE	2.44

All species with the exception of CE are at minimum rates. If 100% of the available 61,000 m^3 is harvested during the term of the permit, the stumpage payable to the Crown is calculated to be $219,595.

Should stream protection be required either through the installation of debris grizzlies, stream clean-up or end hauling by one of the regulatory agencies, additional costs would be incurred: a sum of $30,500 for a permit of this size not being excessive. This total would increase the operating cost for the permit by $0.50/$m^3$ to $47.43/$m^3$.

Table 4-4 shows the stumpage calculated for Cutting Permit I with the Operating Cost reflecting an additional cost of $30,500 for stream protection. Note, however, that the increase in operating cost is only reflected in a decreased stumpage payable for CE, as BA, FI and HE were already below the minimum rate. The stumpage payable with the increased cost of $30,500 for fish protection would now be $214,295.

Table 4-4

Stumpage Calculation for Cutting Permit I Recognizing Cost of Stream Protection

	Species			
	BA	CE	FI	HE
Operating Cost($/m^3)	47.43	47.43	47.43	47.43
Indicated Stumpage	-20.36	7.44	-8.18	-21.87
Final Stumpage	2.66	7.44	3.85	2.44

It is important to note that the difference in stumpage payable calculated for the operating cost of \$47.43/m^3 versus the initial value of \$46.93/m^3 is only \$5,300. Because only CE was on positive stumpage rates, the additional cost of \$30,500 incurred for stream protection was not fully recovered by the licensee. In fact, only the \$5,300 or 17.4% of the added cost of \$30,500 was accounted for, through the appraisal system.

The fact that the current appraisal system does not recognize any additional costs during low market conditions is an important consideration to logging operators. The added cost of stream protection and clean-up is discussed in greater detail in Chapter VII.

CHAPTER V

Timber Harvesting Systems Employed in the Vancouver Forest Region

Introduction

Logging is a specialized form of materials handling and transportation. The fact that the material in question is logs located on forested land only further defines the handling systems requirements. Environmental factors more specifically define the conditions under which logs must be transported (Studier and Binkley, 1974).

Clearcut logging is the general practice for timber harvesting Coastal areas of British Columbia. The practice involves the complete removal of the timber stand over a given area in a single cut. These clearcut areas can range in size from a relatively few hectares to a hundred hectares. In many Coastal areas, streams can either form a cut block boundary or may disect the cut block several times.

Resource managers must develop a background required to obtain a basic understanding of the logging systems currently employed in the Vancouver Forest Region. They must become acquainted with the actual operations of the logging systems and their general efficiencies under the various conditions found within the Region to appreciate their advantages and disadvantages in maintaining stream habitat.

Clearcuts may be yarded with any logging system, although log length cable yarders are considered to be the norm within the Vancouver Forest Region. There are a few areas within the Region where tree and log length ground skidding operations occur. Large quantities of slash (wood residue) frequently accumulate from clearcutting old growth timber stands as well as from stands characterized by a high degree of decay and windfall timber. The impact of clearcutting on stream habitat and water quality is associated primarily with (1) site exposure and soil disturbance, and 2) the presence of large quantities of forest residue (Montgomery, 1976).

The logging system used can have an influence not only on the extent of soil erosion, but also on the amount of debris concentrated in gullies and stream depressions. Four cable systems: the standard highlead spar, mini spar, grapple yarder and slackline, and one skidder system, the rubber tire skidder will now be discussed in context with their capabilities and limitations with regard to timber extraction and post logging stream debris clean-up. Some of the requirements and system descriptions have been adapted from "Cable and Logging Systems" by Studier and Binkley (1974). Streamside logging and post-logging debris clean-up capabilities have been derived from the author's personal knowledge and discussions with practicing forest engineers.

1. Standard Highlead Spar

The standard highlead spar (Figure 5-1) has been the most common yarding system utilized on Coastal British Columbia forested areas. The main reason for its use is its availability and that it can be used to log on almost any kind of ground, even under adverse terrain conditions. The system employs a mobile 27.5 metre tower, with mainline, haulback line and chokers.

The mainline yards in a turn of logs while the haulback line returns the rigging and empty chokers to the setting. The yarder requires clearcut settings and is usually used where yarding distances are between 200 to 300 metres. The system operates better on areas requiring uphill yarding as there is usually a lift on the yarded logs. Because the highlead spar is normally used in adverse terrain conditions where poor deflection and obstacles occur, there must be adequate tailhold stumps for the haulback line and guylines.

In terms of concurrent or post logging stream debris clean-up, the highlead spar is useful only for large broken boles or log chunks. Limbs, broken tree tops and smaller sizes of debris cannot be cleaned efficiently due to the inflexibility of the chokers. Nylon chokers have been tried in some operations with marginal success.

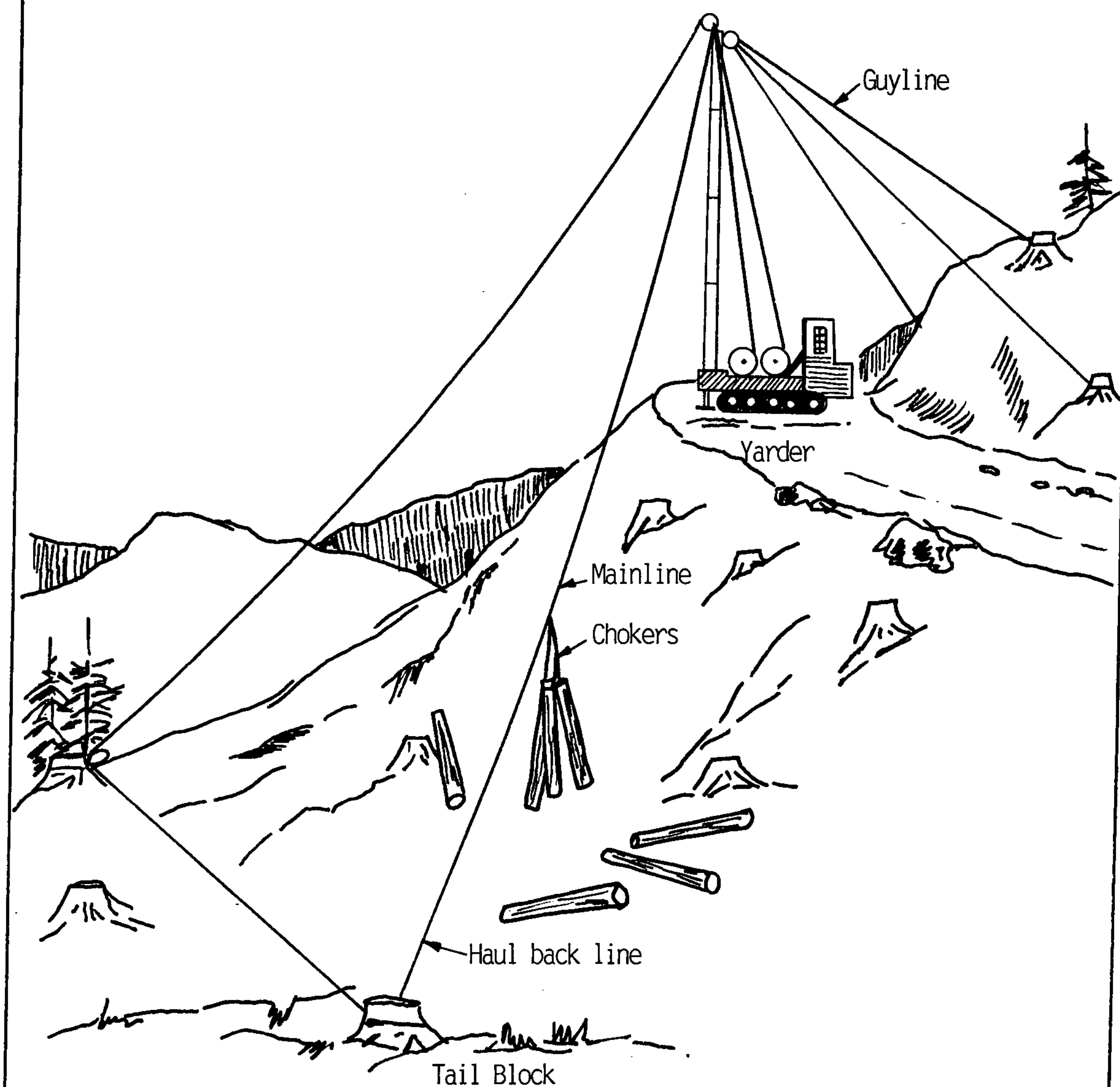


Figure 5-1 Standard Highlead Spar Yarder System

2. Mini Spar

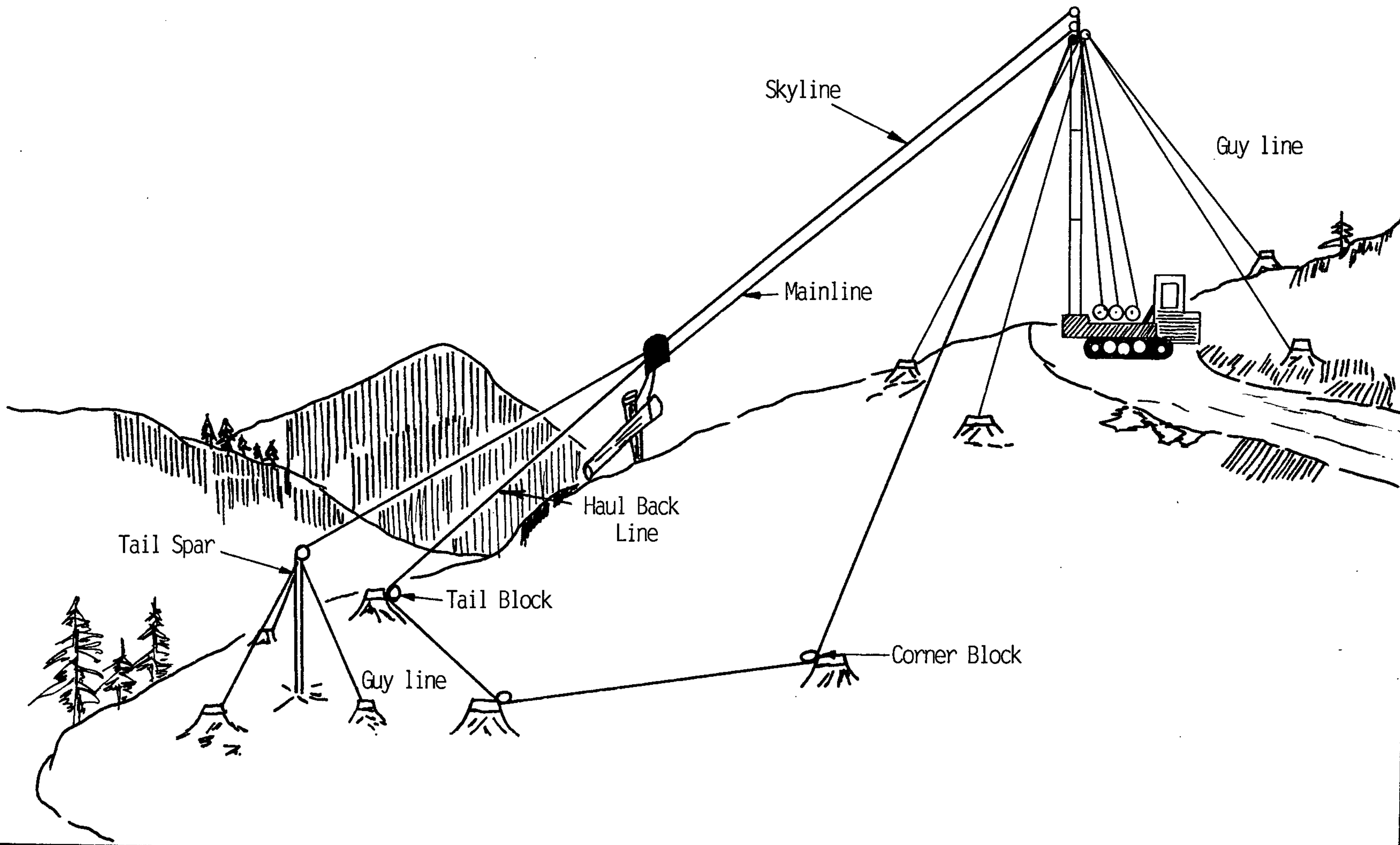
The mini spar operates on the same principles as the standard highlead spar. Because of the smaller machine size, its lift capabilities restrict its use to smaller log sizes. The lower 15 metre tower height also limits clearance for deflection and yarding distances to less than 150 metres. Again, the use of nylon chokers can allow for stream clearance of some small debris. The lower operating cost of the unit lends the machine to more intense post logging clean-up when compared to the other cable systems being discussed.

3. Slackline Yarder

The slackline (Figure 5-2) is similar to the standard spar, but is equipped with an extra line referred to as a skyline which a carriage rides on. The mainline and haulback line operate as in the standard spar. The main advantage with the slackline is the skyline can be raised or lowered by winding the skyline drum in or out, tightening and slackening the skyline as terrain conditions dictate.

The skyline set-up is designed to more effectively elevate or to fully suspend logs during the yarding phase. It is favoured in areas where logs are to be yarded across streams or cut blocks associated with deep gullies and canyons. The slackline requires long yarding distances, usually up to 500 metres. It may be used for both uphill and downhill yarding, but uphill yarding is preferred when operating adjacent to streams. Good deflection and adequate tailhold stumps are a must as full elevation of logs puts additional stress on all lines.

Figure 5-2 Slackline Yarder System



If a cut block is properly laid out for the slackline, the main advantage over a highlead operation in streamside harvesting is fewer hangups, less log breakage and less soil disturbance.

The slackline is not practical for concurrent logging and stream clean-up due to its high operating cost and large crew size. Because the system is designed to operate on very steep slopes, gravity movement of debris negates clean-up endeavours and endangers employees working in the stream reach.

4. Grapple Yarder

A grapple yarder (Figure 5-3) is similar to a heel boom loader, usually mounted on a tracked undercarriage. The system utilizes two mainlines, one haulback line and generally two guylines. The yarder is not tied to fixed landings, is very manoeuverable, but requires good to excellent deflection, as the operator has to have visual contact with the logs being yarded.

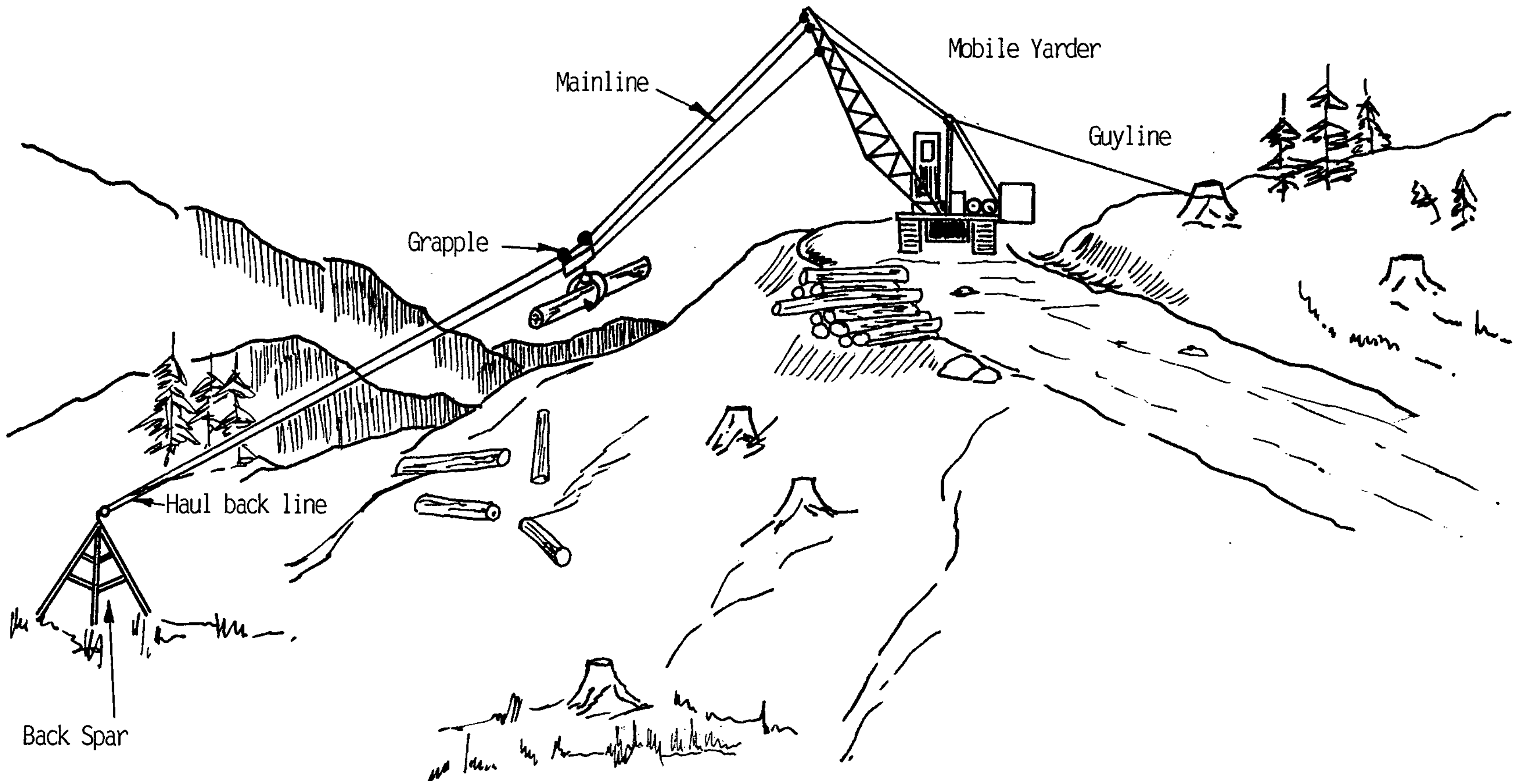
The grapple, riding on the haulback, is held open by pulling on one of the mainlines and closed by pulling on the other. The yarding distance can be between 200 to 300 metres with distances of less than 150 metres preferred. One advantage of the system is it need not be combined with a loading machine at all times. The logs can be windrowed along the roadside on flat to moderate sloped terrain and loaded out whenever it suits the operator.

Whenever ground conditions permit, a portable (mobile) back-spar usually mounted on an older crawler tractor is utilized to improve deflection and eliminate the need for changing fixed tailblocks. Depending on terrain, a skid trail may have to be constructed along the back of the setting to accommodate the back spar. Poorly constructed back spar roads may cause sediment problems adjacent to streams. The biggest advantage in stream-associated areas is the grapple yarder can log directly away from the stream for the full length of stream being harvested.

The grapple can be employed to assist in stream clean-up of medium to large size debris. It is not efficient for the removal of small debris such as broken branches and twigs unless they are in bunches.

Another variation of the grapple is a swing yarder which has the capability of both grapple and carriage logging. This machine in the carriage logging set up has the ability to assemble a turn before yarding (P.Oakley, personal communication, February 11, 1985). This feature may be especially advantageous in clean-up operations where several log chunks or debris piles may be assembled on either side of the yarding road. Then when enough material is assembled it may all be hooked and yarded away from the stream in one turn.

Figure 5-3 Grapple Yarder System



5. Rubber Tire Skidder

This system has maximum mobility requiring no tailhold stumps or rigging time. The skidder can be used for clear-cut or selective logging prescriptions. It is excellent for yarding small, isolated patches of timber on flat, dry or frozen ground.

The skidder may cause maximum soil disturbance, compaction of soils, increased runoff and siltation in stream situations. The skidder is not practical for debris clean-up, as the activity of the machine within the wetted perimeter of the stream can cause more disturbance to stream banks which outweigh any benefits accruing from debris removal. The system's inability to lift material is also a hinderance for clean-up operations.

Summary

Each timber harvesting system has its own rigging and operational characteristics. Each is adaptable to certain topographic conditions and is capable of prevention of physical damage to the natural stream channel and adjacent vegetation during the logging operation. The key consideration for any operator is to take a flexible approach in the application of logging systems at his disposal. One must appreciate that one particular harvesting system will not be the best approach for all stream circumstances. The operator and his crew having the choice of several harvesting systems must be willing to adjust their activity to varying site-by-site conditions.

CHAPTER VI

THE COST OF TIMBER HARVESTING

Introduction

Any unnecessary costs built into the harvesting of timber is actually a reduction in the timber resource value, which depending on market conditions will eventually be borne by either the Province or an individual operator. Therefore, when a recommendation is made by resource agencies to use a costly harvesting system, the decision must be made on a sound foundation of the systems capabilities and actual costs.

The removal of vegetation and the ensuing physical ground disturbance is generally associated with road construction and the "stump to dump" phases of the harvesting process. The machine costs for the standard highlead spar, grapple yarder, mini spar, slackline and rubber tire skidder are presented. Road construction costs are also discussed in general terms. The focus of this chapter is the "stump to dump cost"; falling and bucking, yarding, loading and hauling, of the standard spar, grapple yarder and rubber tire skidder.

Harvesting Cost Data Description

The cost data are a summary of average 1982 phase logging costs as experienced by a selection of Council of Forest Industry (COFI) members. The cost information was provided by twenty-two (22) Coastal operations participating in the Council's 1982 logging cost survey. The operations were selected by the Ministry of Forests, in conjunction with the Council, with the objective of acquiring a representative sample of the industry on the Coast.

The Ministry of Forests (MOF) requires input from the logging industry in order to collect a broad sample of all costs experienced in all phases of logging. The MOF compiles productivity and cost data from the annual Logging Cost survey to derive their Logging Equipment Hourly Cost Schedule (LEHCS). The reported rates are intended to demonstrate the industry's cost of operating company owned equipment over an entire year (Appendix II).

Regional Appraisal manuals are then updated to reflect the revised productivity and cost schedules. The manuals in turn provide estimates of logging costs for coastal appraisals for each phase of the logging operation. The estimates allow for a variety of site specific factors and are intended to reflect normal conditions for the area being appraised.

Table 6-1 identifies the hourly rate for each machine type derived from the 1982 LEHCS rates. The mini spar and slackline costs are based on a very limited sample of nine (9) and three (3) operations respectively. They are presented here to indicate the range of experienced costs for the five harvesting systems described in Chapter V.

Table 6-1

Logging Machine Hourly Costs

Machine Description	Number of Samples	Cost/Hour*
Grapple Yarder	50	$ 156.39
Highlead Spar	120	170.21
Heel Boom Loader	152	103.37
Slackline	3	173.58
Mini Spar	9	134.22
Rubber Tire Skidder	18	44.67
Front End Loader	48	56.19
Off Highway Truck	182	85.69
Falling & Bucking	22	44.02

* A range of values was not given to maintain the confidentiality of the participating companies. In any case, the values stated here are utilized for Coastal appraisals.

If a tract of timber on medium sloped terrain required no environmental considerations, two rubber tire skidders in combination with a front end loader ($89.34+$56.19 = $145.53/hr.) would be preferred over the slackline - heel boom loader ($173.58+$103.37=$276.95/hr.) in an economic comparison.

Road Construction

Road development is an integral component of any logging operation. On average, road construction costs derived from seventy-seven (77) Coastal operations constitute 9.7% and ensuing road maintenance, a further 2.4% of the total operating costs.

Of the twenty-two (22) operations included in the 1982 logging cost survey, the cost of road construction ranged from $32,000 to $153,000 per kilometre. The weighted average cost based on volume produced was $62,240 per kilometre.

Currently, there is limited data on the road requirements of each harvesting system. It was generally accepted in discussions with some of the questionnaire respondents that grapple yarding requires more road length for unit area developed when compared to a standard highlead spar. A comparison of volume developed for two (2) Coastal operations indicated that the grapple yarder layout required 11.6% more road for equivalent volumes developed. In this context developed volume refers to timber volume made accessible for harvest by a particular road system.

Sauder (1978) noted that the capability of the slackline system for yarding longer distances should create opportunities to reduce the costs and environmental effects of road development when it was compared to normal highlead yarding. However, there was no specific decrease in road density specified in the report.

For the purpose of the harvesting system cost comparison, the author decided to compare only the timber extraction phases of the logging operation; specifically the stump to dump unit costs. This decision was based on two reasons: (1) the extraction phase costs vary for the harvesting systems discussed, while administration, sorting, towing, etc. costs remain constant for a given operating area, and (2) for a cutting permit of the size used in the analysis, the road requirement of approximately 6 kilometres for the three systems being compared would not differ substantially.

However, should the decision be made to log a total Coastal division by a particular system the higher road length would be significant both in terms of cost and area disturbed. With many operating areas having one hundred kilometres or more of roads, an 11.6% difference in road length between the grapple and highlead spar equates to 11.6 kilometres. At the average cost of $62,240/km., the difference in road construction costs is calculated at approximately $722,000.

II. Logging Systems Recognized by The Vancouver Forest Region Appraisal System

The standard highlead spar, grapple yarder and ground skidding alternatives are the current logging systems recognized by the Vancouver Region appraisal system. Only the stump to dump phases (falling, bucking, yarding, loading, and hauling) are compared here as these phases of logging have the greatest impact on other resource values through vegetation removal and ground disturbance.

Cost estimates made for the stump to dump phases of logging are based on a productivity system approach. The system consists of methods of determining productivity, or the rate that harvesting can take place. Site and stand variables (e.g., slope and log size) that are specific to the area being harvested are included in separate equations for each logging system.

The falling and bucking and skidding phase equations are dependent on log size only. The yarding phase costs are related to log size and side slope of the timber tract being appraised. Loading productivity rates and cost estimates are a function of logs available at the landing, and hence are dependent on the productivity of the skidding or yarding method used. The hauling cost estimate is based on total cycle time.

The cost estimate for each phase of the actual logging operation is determined by dividing the hourly rate of the equipment being employed by the calculated hourly production.

The productivities presented are derived from equations in the 1982 Vancouver Forest Region Appraisal Manual. Hourly rates are based primarily on the 1982 Logging Equipment Hourly Cost Schedule.

In this analysis, the productivity and cost for each of the three systems can be compared directly. All values have been calculated for sample Cutting Permit II presented in Table 6-2. The use of one specific cutting permit allows comparison of not only the logging system by phase, but also the differences that are created by slope and terrain conditions.

The productivities and costs presented for each phase and machine type are those recognized under normal conditions. Any costs incurred for stream and habitat protection are additional costs which will be discussed in Chapter VII.

Table 6-2

<u>Sample Cutting Permit II</u>

Total merchantable area:	110.0 hectares
Total Volume:	71,500 m^3
Average log size:	1.4 m^3
Haul distance:	15.0 km
Estimated cycle time:	125 minutes
Load size:	69.0 m^3

Falling and Bucking

Under normal conditions, there is not much variance in falling for a particular system. The variation in productivity and resultant cost allowance is dependent on the timber size and slope and terrain conditions. The rougher the ground, the lower the productivity and the higher the cost allowance. Table 6-3 presents both the falling and bucking productivity and cost allowance for the three streamside conditions specified in the Harvesting System Questionnaire.

Table 6-3

Falling Productivity and Cost Allowance

Slope & Terrain	Productivty(m^3/hr.)	Cost Allowance($/$m^3$)
< 20% sideslope	12.82	$ 3.43
20-70% sideslope	11.68	3.77
>70% sideslope	10.68	4.12

Yarding

The productivity equations for all three yarding systems utilize log size to determine the base productivity. The highlead spar and grapple yarder productivities are further refined by using a combination of sideslope, obstacle index and terrain group ratings for the area being appraised.

Table 6-4 and Table 6-5 indicate the variation of productivity and cost allowance between the three systems.

In addition, it is evident from the tables that as the ground conditions become more severe, productivities decrease and cost allowance requirements increase for the individual systems.

Table 6-4

Yarding Productivity (m^3/hr.)

		Yarding System	
Slope	Highlead Spar	Grapple Yarder	Skidder
< 20%	30.70	33.69	20.28
20-70%	26.69	28.34	16.63
> 70%	21.89	25.54	N/A

Table 6-5

Yarding Cost Allowances ($/$m^3$)

		Yarding System	
Slope	Highlead Spar	Grapple Yarder	Skidder
< 20%	5.54	4.64	2.20
20-70%	6.38	5.52	2.70
> 70%	7.77	6.12	N/A

Loading

The loading phase cost for the highlead spar and grapple yarder systems is appraised utilizing a heel boom loader. All skidder loading productivities and cost allowances are based on a front end loader combination. As stated earlier the loading productivity is directly related to the yarding system being employed. Table 6-6 and

Table 6-7 identify loader productivity and cost allowance for each system.

Table 6-6

Loader Productivity (m^3/hr.)

	Yarding System		
Slope	Highlead Spar	Grapple Yarder	Skidder
< 20%	37.08	40.69	60.84
20-70%	32.24	34.22	49.90
> 70%	26.44	30.85	N/A

Table 6-7

Loading Cost Allowance ($/$m^3$)

	Yarding System		
Slope	Highled Spar	Grapple Yarder	Skidder
< 20%	3.36	3.14	0.92
20-70%	3.70	3.56	1.13
> 70%	4.18	3.81	N/A

Hauling

Log hauling cost allowances are based on truck size, a specified rate per hour and productivity per hour. These in turn are directly related to cycle time. Cycle time is the total time required for loading, round trip travel time, unavoidable delay and unloading of a logging truck. The cycle time is normally determined by taking into consideration all the factors that may affect it: distance, expected rate of speed, necessary delays, expected standard of roads, and their maintenance. In appraising an individual cutting permit, the cycle time will not vary significantly for the three logging systems being discussed. A cost allowance of $2.59/m^3 is used for all three systems.

Total Stump to Dump Costs

Table 6-8 combines the cost allowances for falling & bucking, yarding & loading and hauling for the three logging systems.

Table 6-8

Stump to Dump Cost Allowance ($/m^3)

	Yarding System		
Slope	Highlead Spar	Grapple Yarder	Skidder
< 20%	14.92	13.80	9.14
20-70%	16.44	15.44	10.19
> 70%	18.66	16.64	N/A

A sample of seventy-seven (77) Coastal cutting permits indicated that the stump to dump cost (excluding road construction and maintenance) represented 38% of the total operating cost. Road construction and road maintenance comprised a further 12.1%.

Table 6-9 presents the total operating cost calculated for the highlead spar, grapple yarder and ground skidder for the three slope and terrain conditions.

Table 6-9

Total Operating Cost ($\$/m^3$)

	Yarding System		
Slope	Highlead Spar	Grapple Yarder	Skidder
< 20%	39.26	36.31	24.05
20-70%	43.26	40.63	26.82
>70%	49.10	43.78	N/A

Summary

It is evident from the Tables presented in this chapter that significant differences in productivity and cost allowances exist in the comparisons of the highlead spar, grapple yarder and skidder logging systems. An operator having the three systems available to log a tract of timber with no stream protection or other management constraints would have a substantial advantage over an operator owning only a highlead spar.

To log a block of timber on moderately sloping terrain (20-70% sideslope), it would cost $\$43.26/m^3$ with the highlead system versus $\$26.82/m^3$ with the skidder system - a difference of $\$16.44/m^3$.

Again it is important to note that in many situations the operator has only one specific logging system available making such comparisons a moot point. Any recommendations to use a particular harvesting system must recognize the high capital investment required to obtain logging equipment.

All costs presented in this chapter for the three terrain conditions of flat to gently sloping ground ($<$20% sideslope), moderately sloping ground (20-70% sideslope), and steep to very steep slopes ($>$70%) were estimated for normal yarding conditions. Costs incurred for stream and habitat protection are in excess of the above costs. The extra costs of stream protection are discussed in the next chapter.

CHAPTER VII

THE COST OF STREAM PROTECTION TO THE FOREST SECTOR

Introduction

The major interaction between the fish and forest sectors occurs as a result of forest harvesting, particularly the timber extraction phases. All such activities pose a threat to fish and fish habitat, and it is through the need to modify these in order to fulfill stream protection requirements that the forest sector incurs its major cost of interaction at the fish-forest interface.

When harvesting of timber is associated with streams, logging costs will usually be increased to accommodate extra allowances for stream protection. Some of the measures which may involve extra costs include: (1) end hauling of excavated material in road construction, (2) uphill felling of trees, (3) stream clearance of logging debris, (4) special cable yarding - yarding systems for full suspension of logs, (5) restricted operations in and around streamside buffer strips, and (6) special road maintenance requirements to prevent excessive siltation from runoff and soil erosion.

The Costs of Regulation

To date, very few licensees have segregated the additional cost of stream protection in their accounting systems, and as a result, the available information is limited. A review of existing literature, however, does indicate that the stream protection costs are an added cost to the forest sector.

Ottens (1975) identified the percentage of damage-prevention cost to be 18.6% of total road construction costs for a road system requiring environmental and aesthetic constraints. The forest logging guidelines introduced in 1972 for Coastal harvesting resulted in about a 16% increase in logging costs (COFI, 1972).

Dykstra and Froehlich (1976) estimated that the direct cost of cable-assisted falling ranged from 1.68 to 2.06 times higher than conventional falling because of the additional labour and equipment required. McGreer (1975) indicated that cable-assisted falling costs were 2.36 times higher than conventional falling. He also noted that since this increase in falling cost was derived where the entire cutting units were cable-assist felled, the cost per unit volume for falling lesser amounts would be appreciably higher.

One of the respondents to the Harvesting Questionnaire also added falling and bucking costs from three cutting permits within a Coastal operation. Considerable directional felling by hydraulic tree jacking was required to keep debris from entering streams flowing through the cut blocks. The falling and bucking costs experienced for directional felling were approximately three times greater than for blocks where normal falling techniques could be performed. For the moderately sloping cost allowance determined from Table 6-3, three times the normal allowance of $\$3.77/m^3$ would result in $\$11.30/m^3$ for the falling and bucking allowance.

If one considers the sample Cutting Permit I described in Chapter IV, (Table 4-2) which contained 61,000 m^3, the extra falling cost impact is significant. It would be erroneous to infer the cost of $\$11.30/m^3$ would be borne by the total cutting permit volume. Even if only 10% of the volume required special falling techniques the difference of $\$7.53/m^3$ would result in a substantial extra cost of \$45,935 (10% x 61,000 m^3 x \$7.53), for the falling phase alone.

Post-logging debris clean-up can be a substantial extra cost to an operator. Froehlich (1975b) found hand cleaning debris from streams ranged from \$3.00 to \$15.00 per lineal metre of stream, depending on the amount of debris to be removed and the adjacent topography. One key note he emphasized was that machine cleaning results in a double cost: the amount required to operate the machinery and compensate the crew, and the amount of revenue forgone due to lost production. In units with stream clean-up, from 10 percent to 50 percent of the yarding crew's time may be spent in stream cleaning work.

Dykstra and Froehlich (1976) compiled estimates of stream-cleaning costs compared with estimates that resulted from the application of Forest Service appraisal allowances. They found (Table 7-1) that their estimates were approximately five times higher than the Forest Service allowance.

Table 7-1

Comparison of estimated stream cleaning costs and Forest Service Appraisal Allowances

Dollars per 30.5 metres of stream

	Estimated Cost	Appraisal Allowance
	$ 1,380	$ 186
	753	169
	135	111
	795	204
	1,628	204
	409	225
	262	178
	754	149
	1,477	179
	928	187
Mean	$852	$179

Marsh (1971) related that stream clearance activities along approximately 1,220 metres of Mill Creek in the Mill Creek Gorge area near Alsea, Oregon developed into a complex and expensive project. This cleaning operation involved the removal of log jams existing prior to logging and the removal of logging induced debris. The cost of debris removal ranged from $3.00 to $4.00 per metre of stream for hand cleaning and from $7.00 to $13.40 per metre of stream for machine assisted cleaning. Supplemental hand cleaning after December freshets ranged from \$0.40 to \$3.50 per metre of stream.

Sydneysmith (1978) estimated that fish-related concerns created additional costs for logging ranging from 2.6 to 4.6% of total logging costs. He also indicated that blow-down or recovery of leave strips increased the cost by another 7%, while post-harvest stream cleaning was another 1.0%.

The base operating cost of \$46.93/m^3 for the sample cutting permit presented in Table 4-1 would increase by \$4.69 to \$51.62/m^3 if a conservative increase of 10% was used for stream protection requirements, a substantial increment at the best of times.

Dorcey (1980) however reports forest industry and government costs to be very small for actual costs of environmental regulation. He also infers at least half and, in most cases substantially more than half of the net costs of compliance with fisheries protection regulation are borne by the general public as a result of stumpage appraisal allowances .

This inference bears truth during times of good lumber markets, but is very misleading for depressed markets under which the B.C. forest industry has been operating since 1982. Again, if the total operating cost of \$46.93 is utilized and the \$4.69 for stream protection costs is added to it, the total operating cost would become \$51.62/m^3. All species with the exception of CE are already on minimum rates. The stumpage calculation for CE utilizing the $51.62/m^3 operating cost would yield an indicated stumpage of $3.25/m^3. As the minimum rate for CE is $5.62/m^3, only $2.37/m^3 of the $4.69/m^3 stream protection cost can be recouped by the operator for only that species.

The total projected stream protection cost using a 10% factor would be (61,000 m^3 x 10%) x $4.69/m^3 = $28,610. However, only $2,460 or 8.6% of the $28,610 would be recoverable by the operator who must bear the remaining $26,150 as an operational cost.

The above example demonstrates that fish protection costs can be significant both in terms of lost stumpage revenue to the Province and increased operating cost to the operator. Working in the field of appraisals, the investigator has witnessed real costs experienced for several cutting permits. Those presented below are a selection of more recent examples:

1. Fisheries and Oceans personnel requested a cross-drainage ditch and settling pond prior to road construction approval - total cost $16,725.
2. Stream clean-up and construction and installation of two debris grizzlies to prevent downstream movement of debris - total cost $43,460.
3. Stream clean-up required concurrent with the yarding operation - total cost $32,600.

4. Due to steep sideslopes on glacial till, no side-casting was to be allowed during road construction. The excavated material had to be end hauled - total cost $50,200.
5. Debris clean-up on 325 metres of stream requested by fisheries personnel - total cost $55,570.

It is important to note the above stream protection costs are direct costs only. Lost production costs for crew and machinery required for the protection activities have not been included. Of the five examples presented, only one stream had fish present in the section being protected. Two sections surveyed prior to logging had no fish of commercial or sports value present.

Summary

As evidenced by the preceeding discussion, stream protection requirements may be a substantial added cost to normal costs of timber extraction. It is imperative when stream protection is requested by an agency that the cost of protection be weighed with the value being protected.

Edie (1982, p.381) speaking on behalf of the B.C.Fish and Wildlife Branch summed up the aspect of stream protection requirements and the cost of constraints: "Further it is fair to assume that the general trend of forestry operations moving into more difficult terrain to harvest poorer quality timber at greater cost and with more significant environmental constraints will continue through the 1980's. We can expect heightened resistance to any constraints that mean extra costs, and we can expect far more intense scrutiny of the bases for our recommendations, of their results, and of the cost effectiveness of our inventory and planning activities".

A stream system may be sensitive to modification, but if there is little demand for quality water, there is no justification for deferrment of adjacent timber or the expenditure of excessive dollars for protection. Conversely, where there is a high demand for quality fish habitat from a small sensitive watershed, the value of the fish habitat may well justify total protection from logging or the use of a special harvesting system which would minimize the impact on the area (ABCPF, 1981).

CHAPTER VIII

HARVESTING SYSTEM QUESTIONNAIRE RESULTS

Introduction

The questionnaire survey was conducted to obtain the opinions of experienced forest engineers regarding harvesting systems utilized for logging timber adjacent to streams. The engineers were asked to rate the efficiency of each harvesting system in terms of acceptable cost and physical capabilities.

Description of the Sample

Approximately 92% of the sample respondents were working in a B. C. Coastal environment at the time of the survey. Three respondents were working in an Interior setting, but had previous Coastal engineering and logging experience. Therefore, all the respondents' questionnaires were utilized in the data analysis and presentation.

Response Rate

Fifty Harvesting System Questionnaires were distributed. Thirty-nine of the questionnaires were completed and returned, giving a response rate of 78%.

Experience Level

The coastal experience level of the respondents ranged from 3 years to 35 years. The mean experience level was 12.8 years with 77% between 6 and 20 years. The experience distribution of the engineers is presented in Table 8-1.

Table 8-1

Experience of Respondents

Experience(Years)	Absolute Frequency	Relative Frequency(%)
0-5	6	15.4
6-10	11	28.2
11-15	10	25.6
16-20	9	23.1
20+	3	7.7
Total	39	100.0

Variables Affecting Coastal Stream Side Harvesting

The engineers were requested to identify the best suited harvesting system for logging timber adjacent to streams. They were to do this for seven terrain and stand conditions specified in the questionnaire: terrain, side-slope, yarding distance, log size, volume per hectare, stream gradient and deflection. In real life, each variable can affect the other and must be treated in combination to achieve the desired outcome for a given logging operation.

The variables were isolated in this exercise to determine which machine types were favoured by the participants. Some of the respondents indicated more than one machine type for a specific variable category noting more than one system could be suited to a given situation. As such, the number of responses in most cases is greater than the number of participants. The responses are presented in histogram form for each variable. Conclusions are those of the investigator drawn from the responses and comments of the engineers.

Terrain

Terrain classifications were presented as defined in the 1982 Vancouver Region Appraisal Manual as all the engineers had worked with and were familar with the definitions. The classifications considered were even, rolling, gullied and broken.

The skidder was favoured for even ground conditions. The standard highlead spar was indicated for use on rolling, gullied and broken terrain, but definitely preferred for gullied and broken ground. The grapple yarder on the other hand, was identified for even and rolling conditions, with preference for even ground. Very few respondents thought the grapple yarder could be efficiently used in gullied and broken areas (Figure 8-1).

There was no clear indication for the mini spar and slackline systems, although the mini spar was selected for rolling ground, and the slackline was preferred for gullied and broken ground.

Sideslope

The skidder was identified for use on sideslopes of 0-20%. The standard spar was preferred on slopes over 51%, while the slackline was identified for slopes over 71%. Conversely, the grapple yarder was chosen for slopes between 0-50%, as shown in Figure 8-2. Again, there was no definite conclusion to be drawn for the mini spar.

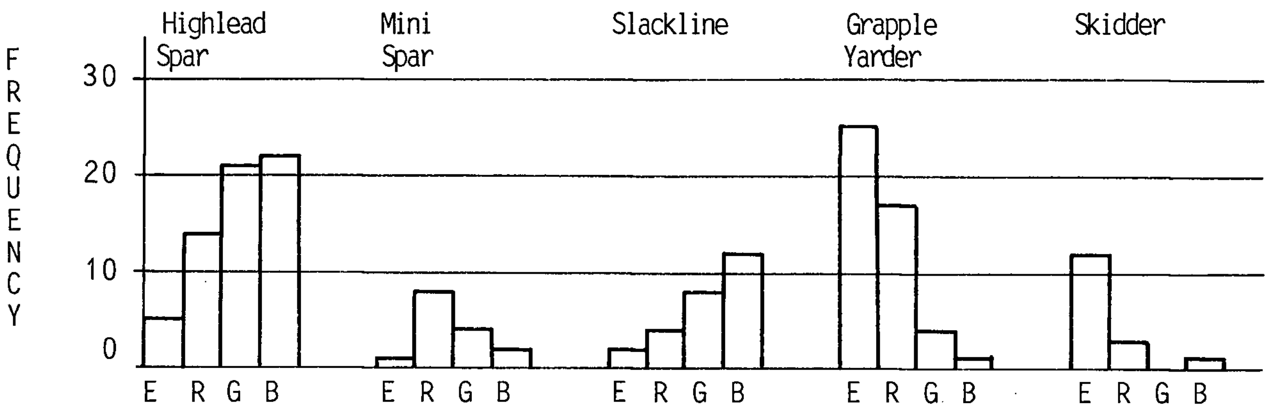
Yarding Distance

Yarding distances of up to 75 meters and up to 150 meters were preferred for the skidder and mini spar respectively, as can be seen in Figure 8-3. The grapple yarder was also identified for distances of less than 150 meters and the standard spar for 150 to 250 meters. The slackline was selected for distances of greater than 225 meters.

Log Size

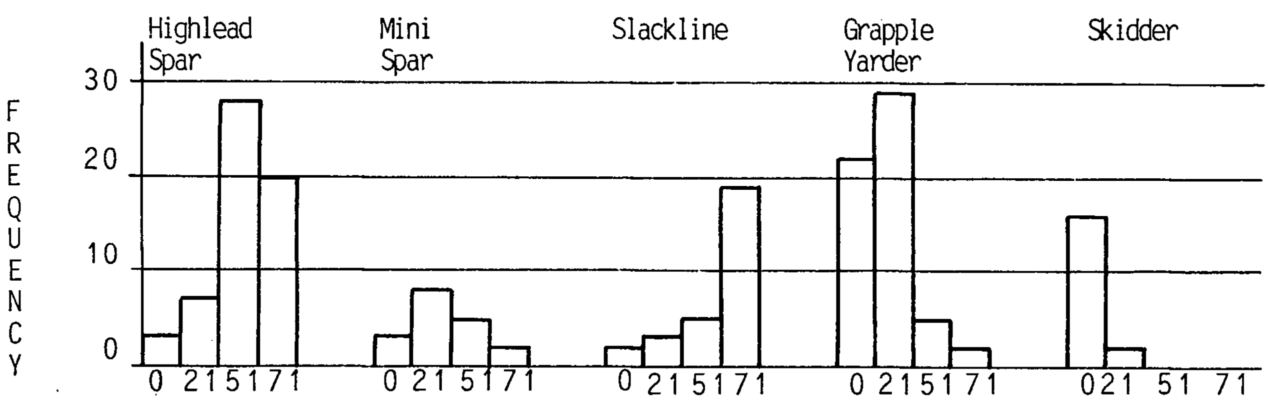
The slackline and standard spar were identified as best suited for the larger log sizes over 1.8 m^3, while the skidder and mini spar for log sizes less than 0.5 m^3 and 1.7 m^3 respectively. The grapple yarder was indicated for all log sizes, but weighted more so for 0.5 to 1.7 m^3 pieces (Figure 8-4).

Figure 8-1 Frequency of Responses for Best Yarding System for Selected Terrain.



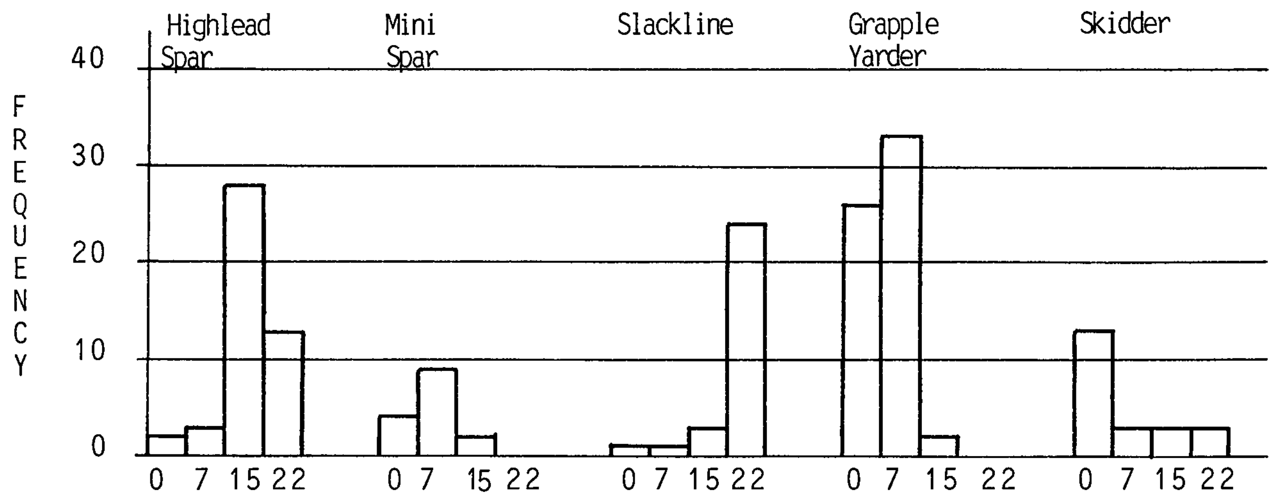
E = even
R = rolling
G = gullied
B = broken

Figure 8-2 Frequency of Responses for Best Yarding System for Selected Sideslopes.



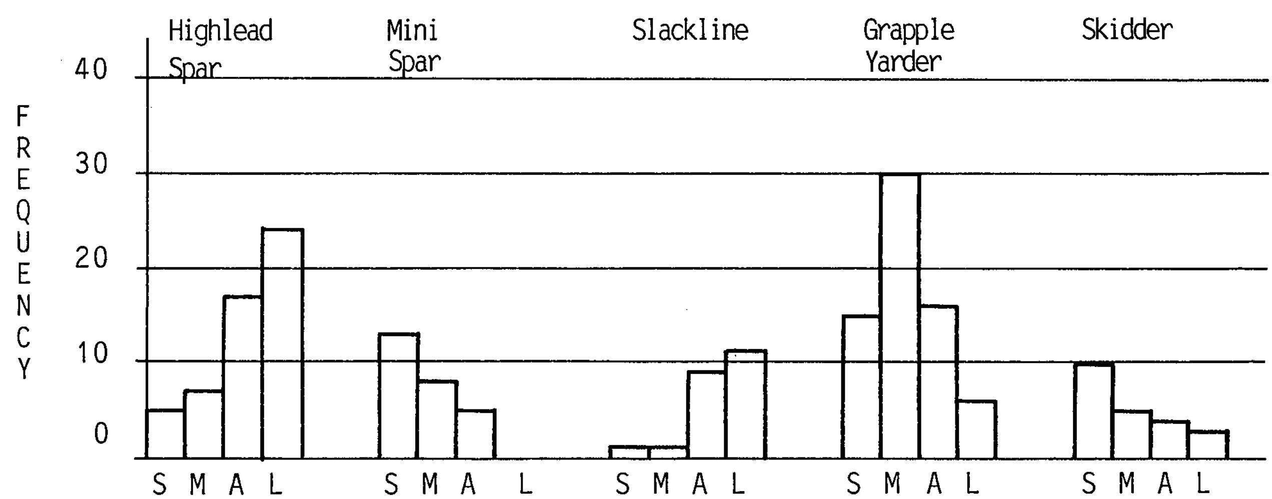
0 = 0-20%
21 = 21-50%
51 = 51-70%
71 = 71+%

Figure 8-3 Frequency of Responses for Best Yarding system for Selected Yarding Distances.



0 = 0 - 75 meters
7 = 75 -150
15 =150 -225
22 =225+

Figure 8-4 Frequency of Responses for Best Yarding system for Selected Log Sizes.



S = 0 - 0.5 cubic meters
M =0.5 - 1.7
A =1.8 - 2.5
L =2.5+

Volume Per Hectare

There were no clear conclusions to be drawn from responses for volume per hectare (Figure 8-5). The mini spar and skidder were thought to be best suited for lower volume stands (350-500 m^3), while the remaining three cable systems were suited for stands with greater than 500 m^3 per hectare.

Deflection

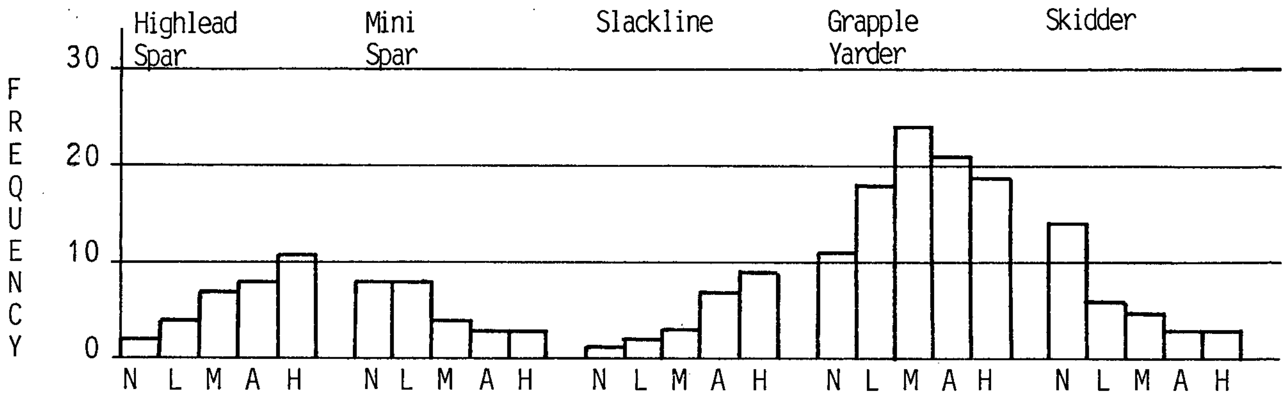
There were no conclusions to be drawn for the mini spar slackline, or rubber tire skidder with respect to deflection. However, it was definite that the grapple yarder was best suited to areas with excellent to good deflection. The standard spar was preferred for areas having average to poor deflection as shown in Figure 8-6.

Stream Gradient

The skidder was best suited to operate adjacent to streams having a gradient of less than 5%. The grapple yarder was identified for all four categories, but weighted to gradients of less than 25%. As can be seen in Figure 8-7, the standard yarder and slackline were best suited for stream gradient of greater than 16%.

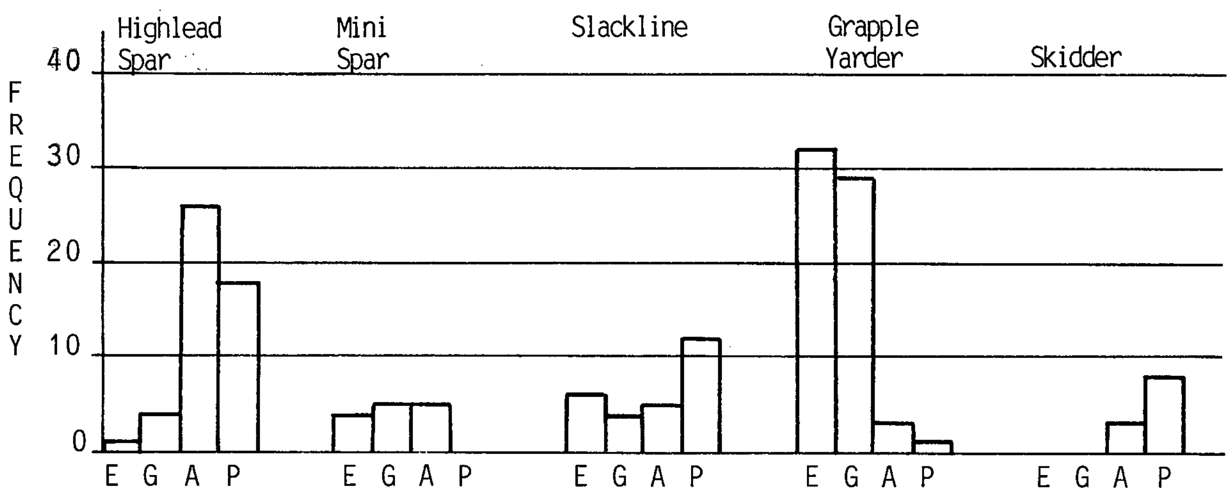
By reviewing all the individual variables and the best suited harvesting system for each, a composite of all the variables can be described for each system. The indicated trends are not definite and conclusive for the mini spar and slackline systems. This may be a result of the unfamiliarity of the participants with the systems as they are not prevalent in the region.

Figure 8-5 Frequency of Responses for Best Yarding System for Selected Volumes per Hectare.



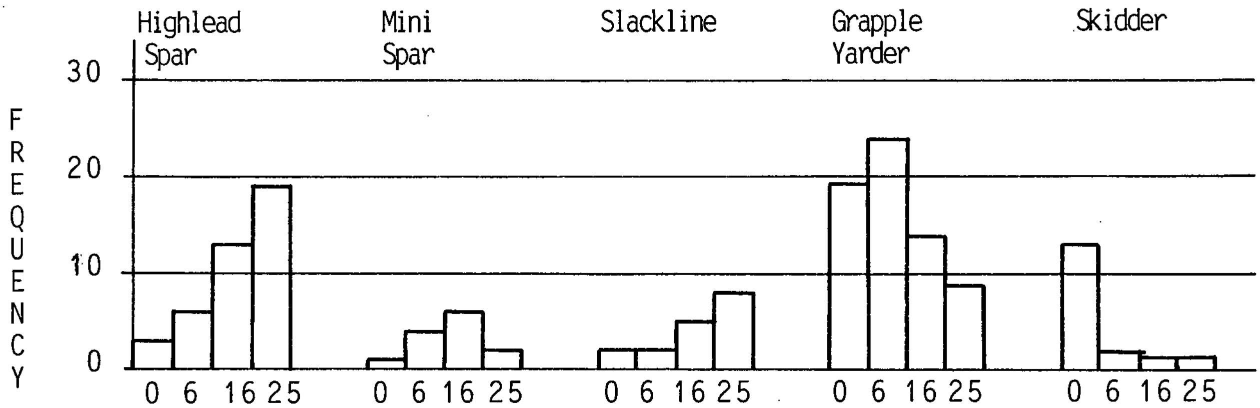
N = 0 - 350 cubic meters
L =351 - 500
M =501 - 650
A =651 - 800
H =800+

Figure 8-6 Frequency of Responses for Best Yarding system for Selected Deflections.



E = excellent
G = good
A = average
P = poor

Figure 8-7 Frequency of Responses for Best Yarding System for Selected Stream Gradients.



0 = 0 - 5%
6 = 6 -15%
16 = 16 -25%
25 = 25+%

Standard Highlead Spar

The highlead spar was recommended for stream gradients over 15%. This unit can be used for all sideslope conditions found on even to broken ground, but was recommended for sideslopes over 50% with gullied to broken terrain. Yarding distance should be between 150 to 225 metres and log sizes between 1.7 to 2.5 m^3. All cable systems operate more efficiently with adequate deflection, with the standard spar preferred for areas of average to poor deflection.

Mini Spar

The responses for this system were not very conclusive. However, one can generalize that it could be used adjacent to low gradient streams flowing through rolling terrain. It is preferred for lower volume, small log size stands and is most efficient when yarding distances are less than 150 metres. Deflection should be at least average for the system.

Slackline

The slackline was suggested for logging adjacent to or over streams having steep gradients. Steep sideslopes and long yarding distances over 225 metres are a feature of the system. High volume stands with large log sizes are a requirement due to the high operating cost. Adequate deflection is preferred but the slackline could be utilized in areas having average to poor deflection.

Grapple Yarder

The grapple yarder can be used on any stream gradient as long as the terrain is even to rolling and sideslopes are less than 70%. Yarding distances should be limited to under 150 metres. The system again requires high volume per hectare stands and log sizes less than 2.5 m^3.

Skidder

The skidder can be used adjacent to low gradient streams on even ground. The system is operable in low volume stands with smaller log sizes. Sideslopes preferred are less than 20% and yarding distances should be less than 75 metres. Deflection is not a requirement for the skidder system.

Cost and Effectiveness Rating of the Individual Harvesting Systems

The study sample of engineers was requested to rate each harvesting system for both cost and effectiveness for three major stream side conditions. If the general efficiency of a given system was considered not adaptable to certain topographic conditions (sideslope), the respondents were asked to indicate the system to be not applicable. This requirement is the reason why the total observations for each system does not sum up to the total number of participants in the study.

The cost rating result was deemed to be significant if over 65% of the respondents identified the low and medium categories for an individual harvesting system. Conversely, the effectiveness rating for timber extraction was considered significant if over 65% of the respondents rated a particular system in the medium and high category.

Field engineers identified the standard spar, mini spar and grapple yarder as viable alternatives both in terms of cost and timber extraction on flat to gently sloping terrain (Table 8-2; Table 8-3). The skidder was deemed to be effective only on areas with dry soil conditions and of very limited value in Coastal areas adjacent to streams.

1. Flat lying to gently sloping ground ($<$ 20% sideslope)

Table 8-2

Opinions Regarding the Cost Rating[1] of the Harvesting System

Harvesting System	Low	Medium	High
Standard Spar	5	21	9
Mini Spar	8	18	-
Slackline	4	2	16
Grapple Yarder	17	17	-
Skidder	16	7	6

[1] Cost Rating - was to be interpreted as extracting timber at the most efficient cost - lowest dollars per cubic meter.

Table 8-3

Opinions Regarding the Effectiveness Rating[1] of the Harvesting System.

Harvesting System	Low	Medium	High
Standard Spar	3	23	9
Mini Spar	2	16	8
Slackline	8	10	4
Grapple Yarder	1	6	27
Skidder	5	8	16

[1] Effectiveness Rating - was to be expressed in terms of timber extraction with minimal disturbance of the stream and streambank area.

Field engineers generally identified the standard spar, mini spar and grapple yarder as being the most cost efficient systems on moderately sloping terrain (Table 8-4). All four cable systems were thought to be effective in terms of timber extraction adjacent to streams (Table 8-5). However, the mini spar was noted to have limited use in most Coastal areas due to limitations on power and lift capacity in large log size stands. The high cost of the slackline system left the standard spar and grapple yarder as the two preferred systems for logging moderately sloped areas.

2. Moderately sloping terrain (20 - 70% sideslope).

Table 8-4

Opinions Regarding the Cost Rating of the Harvesting System

Harvesting System	Low	Medium	High
Standard Spar	5	21	8
Mini Spar	7	16	3
Slackline	2	10	16
Grapple Yarder	18	14	4
Skidder	4	3	9

Table 8-5

Opinions Regarding the Effectiveness Rating of the Harvesting System.

Harvesting System	Low	Medium	High
Standard Spar	1	20	14
Mini Spar	2	17	7
Slackline	3	14	11
Grapple Yarder	3	13	20
Skidder	11	5	-

The standard spar, grapple yarder and slackline were rated effective for logging steep to very steep slopes (Table 8-7). However, only the standard spar and grapple yarder were chosen as alternatives with respect to cost effectiveness (Table 8-6).

3. Steep to very steep slopes (>70% sideslope).

Table 8-6

Opinions Regarding the Cost Rating of the Harvesting System

Harvesting System	Low	Medium	High
Standard Spar	2	23	11
Mini Spar	8	7	10
Slackline	5	7	14
Grapple Yarder	8	10	11
Skidder	-	-	2

Table 8-7

Opinions Regarding the Effectiveness Rating of the Harvesting system

Harvesting System	Low	Medium	High
Standard Spar	5	19	11
Mini Spar	15	7	3
Slackline	2	12	12
Grapple Yarder	6	18	15
Skidder	3	-	-

It is evident, given the optimum topographic and timber conditions and the right logging crew, that each of the five logging systems can be effective in terms of timber removal adjacent to streams. The advantages and disadvantages of each harvesting system for streamside logging as perceived by the respondents are now discussed.

Advantages and Disadvantages of Each Harvesting System

A. Standard Spar

Advantages

The main advantage of the standard spar was its availability and that it could log on almost any kind of ground. The system can handle large timber, but is adaptable to all sizes. The spar is excellent for medium to long yarding and requires fewer roads than the other systems (except the slackline). The 27.5 metre tower can provide maximum deflection and lift of logs. Another key factor is that the operator does not require visual contact with the logs being yarded.

Disadvantages

Fixed landings, the requirement of firm tailholds and lack of mobility were identified as key disadvantages. In areas of poor deflection (convex topography: yarding one side of the stream), ground leading tends to leave scour patterns which intercept run-off and create erosion and sediment problems. Meandering streams can present landing problems if no cross-stream yarding is permitted. Because the landings are fixed, the standard spar cannot yard directly away from all sections of the stream. The system is not effective for clean-up of small sized debris.

B. Mini Spar

Advantages

Low equipment costs, the ease of set up (rigging), and mobility were identified as the main advantages. Smaller landing requirements and areas of short yarding ($<$ 150 metres) were also indicated. The system was thought to be excellent for small stands of timber and could assist in stream clean-up concurrent with the yarding process.

Disadvantages

The increased road density and the lower tower height of 15 metres, which limits deflection and subsequent lift capacity, were identified as major disadvantages. Unless tailholds were located across the stream, deflection and ground leading became a concern. The system is not effective for uphill yarding of large logs. Yarding distance in most cases is limited to 150 meters.

c. Slackline

Advantages

Its capacity for clear lifting of logs was deemed as the major advantage. Again, tailholds across the stream make the system more efficient and minimize scouring and soil disturbance. Longer yarding distances (and fewer roads) were also cited as being an advantage.

Disadvantages

The requirement of a large, experienced crew and difficulty of rigging were noted as disadvantages. Poor production and high costs in low volume stands were also noted. The system requires long yarding distance, large landings and concave slopes for good deflection to be effective. The slackline is ineffective for clean-up of medium to small wood debris.

D. Grapple Yarder

Advantages

The system's mobility and smaller crew were cited as the major advantages. The system is not tied to fixed landings, is very manoeuverable and can log directly away from streams for the full length of the stream. Fewer turns over the same ground decrease site disturbance. The addition of a mobile back spar (especially across the stream) makes the system very effective. The safety of crew in steep sideslopes (as no chokermen are required) is also an asset. The system is best suited for stream clean-up of most debris sizes, but the cost of the machine being non-productive has to be weighed in any clean-up operation.

Disadvantages

Good deflection is required in all cases as the machine operator requires visual contact with the logs being yarded. The system requires more roads than the standard spar, as it is not effective for long yarding. Sedimentation from poorly constructed back spar roads was also noted as a problem in areas adjacent to streams.

E. Skidder

Advantages

This system has maximum mobility and can function with a very small crew. It has low capital cost and requires no tailhold or rigging time. There is immediate operator control while getting very close to individual logs being yarded. The system was thought to be excellent for small, isolated patches of timber on flat, dry ground.

Disadvantages

The system can create a quagmire on wet or silty soils introducing large amounts of sediment into adjacent streams. The system causes maximum soil disturbance, compaction of soils, and increased runoff and siltation. If cross stream yarding is necessary, logs have to be dragged through the streams as there is no full lift of logs. Most respondents noted that skidders become ineffective when sideslopes are greater than 50%.

SUMMARY

As evidenced by the preceeding discussion each harvesting system has specific advantages and disadvantages when operating adjacent to streams. To be effective, all the cable systems require good delection to provide adequate lift of logs being yarded. Most respondents indicated the rubber tire skidder should not be used adjacent to streams having fish or fish habitat values. Some of the undesirable impacts of the harvesting process may be offset by utilizing a harvesting system that is considered compatible with streamside timber and terrain conditions.

Comments and Recommendations of the Respondents Regarding Harvesting Systems and their Relationship to Harvesting Streamside Timber.

It was gratifying that although Section D of the questionnaire (Additional comments pertaining to streamside harvesting) was optional, 65% of the respondents took time to write down their thoughts on the topic. Since many of the comments were similar in nature, the following is a consolidation of the information supplied.

1. Operators should make sure the Ministry of Forests and Fisheries personnel are well aware of any harvesting plans adjacent to or across coastal streams. It was emphasized that the absence of fish in the reach affected did not imply that notification to the agencies was not required.
2. Many current harvesting guidelines are based on academic/ theoretical decisions which have not been field tested adequately and which do not consider site-specific conditions. Several participants indicated they had experienced examples where the prescription recommended resulted in greater damage to the resource intended for protection (marginal leave strips windthrown on many West Coast Vancouver Island streams).

3. While the harvesting system capabilities and site specific topographic conditions influence the choice of equipment, it was emphasized that the willingness of the licensee and operator to protect streamside values was an important factor as well. It was suggested that the operator and crew attitude to environmental protection could make the best of plans go awry. People awareness and education in what was expected on a site specific basis was recommended several times.

4. It was emphasized that the falling phase is extremely important, as it can greatly reduce problems encountered in the ensuing yarding phase. If the timber is felled away from the stream or directly across the stream (tops and limbs intact), the yarding phase should generate minimal additional debris.

5. Roads (no matter which system is utilized) must be located to provide excellent deflection. This may be best obtained by selecting tailblocks and/or backspars on the opposite side of the streams. If poor deflection is experienced, ground leading can occur with all cable systems, creating site disturbance and subsequent sedimentation.

6. The availability of the harvesting system was a great concern for many respondents. If a given company has only steel spars, then that will be the harvesting method used.

7. Fisheries personnel usually have very little practical experience regarding harvesting. They very rarely consider site specific recommendations as to the method of logging suggested, based on terrain or stand conditions.

8. Another major problem with agency personnel is the lack of consistency during field inspections as to what is acceptable from the agency perspective. You can get the same individual dictating the removal of all debris in one instance and only fine debris in another on two similar streams.

9. It was emphasized that each stream, regardless of size, is different in some way or another from other streams. Where stream protection is required, a commitment from all parties involved must be reached for each individual site. Most engineers felt paper guidelines to cover an average site would not work.

10. The more varied the yarding system, the more options there are for dealing with streamside timber. However, in most divisions, only a standard high lead spar and/or a mobile grapple yarder are available. In these cases, the most valuable tool is good planning, full knowledge of the streamside management requirements and a commitment to doing a good job given proper layout and placement of roads and/or landings.

11. Splitting blocks along a stream and yarding away on both sides is often more damaging than cross-stream yarding, as deflection is reduced by placing tailblocks on stream edges. Also, if the cut blocks on either side are harvested in different years, the stream is disturbed twice. Concurrent yarding of the site utilizing cross-stream yarding allows for better deflection, less stream bank disturbance and more efficient fibre utilization.
12. Skidder yarding was thought <u>not</u> to be a practical alternative (especially on the West Coast of Vancouver Island), due to sediment problems it causes in streams.
13. Streamside logging prescriptions are often not compatible with the terrain or resource supposedly being protected. Extensive high cost and special falling and yarding techniques are required to protect a stream with no evidence of fish present.
14. Unfortunately, like so many environmental problems in the field of forestry, there is no single solution which adequately achieves its intended objectives when applied to all situations. Each area must be treated on its own merits (site conditions and systems available).

15. Resource agency personnel should have better inventories which classify the stream value in terms of fish presence and habitat potential. Many sites are only visited once the roads are constructed, making the harvesting options limited.
16. Resource agency personnel should have more information on the quantifiable effects of logging on fish and fish habitat. Too often restrictions on falling and yarding processes are made because "it <u>may</u> alter" the habitat.

CHAPTER IX

CONCLUSION, IMPLICATIONS AND RECOMMENDATIONS FOR FURTHER RESEARCH

Conclusion

The purpose of this study was to provide a descriptive overview of five alternative harvesting systems available to log streamside timber. It is intended to be used by resoure managers as a guide from which to evaluate the optimum or preferred timber harvesting system in terms of cost efficient logging and potential impact upon fish habitat. As harvesting restrictions and habitat prescriptions become more complex, resource managers and foresters must become more familiar with logging systems and how they may be employed to achieve maximum land and resource management benefits.

Results of the study revealed that significant productivity and cost differences exist between the highlead spar, grapple yarder and rubber tire skidder. The hourly costs were found to be \$170.21/m^3 for the highlead spar, \$156.39/m^3 for the grapple yarder and \$44.67/m^3 for the rubber tire skidder. The stump to dump cost allowances were calculated to be \$16.44/m^3 for the highlead spar, \$15.44/m^3 for the grapple yarder and \$10.19/m^3 for the skidder when operated on sideslopes between 20-70 percent.

Costs incurred for stream protection requirements were determined to be an extra cost to the forest sector, especially during depressed market conditions. Debris clean-up costs in particular, ranged from \$3.00 to \$15.00 per lineal metre of stream.

It is concluded that the grapple yarder can be the most cost effective and efficient system for streamside timber harvesting provided: deflection is good, logs are not too large, topography allows for windrowing and yarding distance is not greater than 150 metres.

It is important that the selection of the yarding system for a given cutblock associated with streams be based objectively on the following criteria:

1. Management constraints - recognition of other resource values and post-harvesting treatments.
2. Availability of the harvesting system to the operator.
3. Site specific factors - timber type, topography, proximity to stream areas.
4. Advantages and disadvantages of the systems being considered.
5. The cost of operating the system.

Implications of the Study

The reported findings of the study have several implications.

1. The study findings indicated the questionnaire participants had varied opinions regarding the five harvesting systems. However, opinions confirmed the capabilities of each system as identified in Chapter V.
2. Streamside timber should be identified as early as possible in the planning process. Past logging layout and road location may limit the streamside harvesting options.
3. Restrictions on falling and yarding activities should be flexible to allow for the selection of cost effective systems.
4. Agency personnel must be educated to understand the logging process and system options available to the forest sector.
5. Prescriptions must be based on the logging system available to the operator. If an operator only has a highlead yarder, that will be the system employed.
6. The study demonstrates that each area to be harvested having fish values must be dealt with on a site-specific basis.

Recommendations for Further Research

Based on the findings of this study, the following recommendations for further research are suggested:

1. The present inability to measure habitat values in a reasonably objective manner makes any economic analysis of fish-timber values unworkable. Researchers should attempt to develop a procedure for estimating fish and habitat values on a monetary basis. A strictly economic comparison could then be carried out on a site specific level as there is already a system available to price the timber resource.
2. The method of recognizing stream protection costs in British Columbia stumpage appraisals must be reviewed. When market conditions are depressed, the logging operator may have to incur the total cost of stream protection. Direct reimbursement from the agency requesting the protection measures should be considered.
3. Research on alternative logging systems should be carried out in stream areas to assess their capabilities in terms of cost and habitat disturbance levels.
4. The five harvesting systems discussed in this study were compared on descriptive data collected through questionnaires. Further research should be conducted on existing harvesting systems during the logging of streamside timber. The advantages of yarding away

4. from streams, or cross-stream yarding could be evaluated by machine type.
5. Alternative methods of reducing debris loading during the falling and yarding phases should be pursued. In a study by Powell (1977), breakage losses were lower for winter felled areas. In terms of volume, breakage in winter ranged from 1 to 10% of standing merchantable volume compared to 14 to 15% for summer fallings.
6. The forest sector harvests in a particular drainage for 5 to 10 years and is not back again for another 70 to 80 years for the next crop. Research should be conducted to determine if streams and fisheries tend to rehabilitate themselves over time. If so, the recovery rate of fish populations or fish habitat should be examined to determine what degree of disturbance would be acceptable for different value fish streams.

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GLOSSARY

Blowdown: a tree or stand of timber blown down by the wind; also referred to as windfall.

Buck: to cut felled trees into log length; to make any bucking cuts on logs.

Butt: the bottom of a tree; also the large end of a log.

Cable logging: a yarding system employing winches, blocks and cables.

Clearcutting: the complete removal of the timber stand over a given area in a single cut. Clearcuts can be yarded with any logging system, although cable systems are perhaps used more extensively on the B.C. Coast.

Costs: costs incurred providing access to and harvesting timber and delivering it to an approved marketing location in the form of logs.

Debris grizzly: a structure constructed from either metal or wood placed in a stream to collect and prevent the downstream movement of wood debris.

Deflection: technically, the amount of sag at the mid point below a straight line drawn between the two ends where the cable is anchored or supported. Simply, it is the clearance required between the ground profile and the cable utilized by various cable logging systems.

End hauling: the loading and removal of waste soil or rock material by truck (to a location some distance from the source) during subgrade construction of logging roads. In areas where stream protection or other environmental considerations are not required this excess material would normally be pushed over the embankment (sidecast).

Falling & bucking: the felling, bucking, measuring, topping and limbing of merchantable timber.

Gradient: the general slope, or rate of change in vertical elevation per unit of horizontal distance (of the water surface of a flowing stream).

Hauling: log transportation by truck from the woods landing to a dryland sort or other processing facility.

Highlead: a cable logging system in which running line lead blocks are placed at the top of the spar to provide lift to the logs during the yarding phase.

Landing: levelled area where trees or logs are yarded to for the purpose of loading onto logging trucks for further transport.

Loader: machine used for the loading of logs; either heel boom or front end loaders.

Road construction: the building of all extraction routes and drainage structures for the purpose of transporting forest products from the logging site.

Spar: the tree or mast on which rigging is hung for any one of the many highlead cable logging systems.

Stream: any watercourse which has a flow of water for all or part of the year and which has a defined channel showing signs of scouring or washing.

Stream cleanup: the process of removing wood debris from a stream area which has been affected by a particular logging activity. Cleanup can be either by hand or equipment assisted.

Streamside: the land, and the vegetation it supports, immediately in contact with the stream or sufficiently close to it to have a major influence on, or to be influenced by, its ecological character.

Stumpage: the value of standing timber.

Stumpage appraisal: the estimation of monetary worth of standing timber.

Turn: one or more logs that are yarded to the landing at one time.

Yarding: the process of pulling logs to a landing either by cable or skidder systems.

APPENDIX I

HARVESTING SYSTEM QUESTIONNAIRE

RATING OF THE FIVE MAIN HARVESTING SYSTEMS IN THE VANCOUVER FOREST REGION

A. Indicate the best suited harvesting system, for logging timber adjacent to streams under the various terrain and stand conditions specified below. (Please denote by a ✓ for each system).

	Harvesting System*				
	Standard Spar	Mini Spar	Slackline	Grapple Yarder	Skidder
1. Terrain:**					
even	____	____	____	____	____
rolling	____	____	____	____	____
gullied	____	____	____	____	____
broken	____	____	____	____	____
2. Side Slope:					
0 - 20%	____	____	____	____	____
21 - 50%	____	____	____	____	____
51 - 70%	____	____	____	____	____
71 + %	____	____	____	____	____
3. Yarding Distance:					
0 - 75m^3	____	____	____	____	____
75 - 150m^3	____	____	____	____	____
150 - 225m^3	____	____	____	____	____
225 + m^3	____	____	____	____	____
4. Log Size:					
< 0.5 m^3	____	____	____	____	____
0.5 - 1.7 m^3	____	____	____	____	____
1.8 - 2.5 m^3	____	____	____	____	____
2.5 + m^3	____	____	____	____	____
5. Volume/hectare:					
350 m^3	____	____	____	____	____
351 - 500 m^3	____	____	____	____	____
501 - 650 m^3	____	____	____	____	____
651 - 800 m^3	____	____	____	____	____
800 + m^3	____	____	____	____	____
6. Stream Gradient:					
0 - 5%	____	____	____	____	____
6 - 15%	____	____	____	____	____
16 - 25%	____	____	____	____	____
25 + %	____	____	____	____	____
7. Deflection:					
Excellent	____	____	____	____	____
Good	____	____	____	____	____
Average	____	____	____	____	____
Poor	____	____	____	____	____

* If a specific variable (e.g. yarding distance) is not applicable to a given logging system, please denote by N/A.

** Terrain classification is as per the existing Vancouver Appraisal Manual.

B. Please fill in rating and briefly note key points for <u>each</u> harvesting system you are familiar with for <u>each</u> of the three streamside conditions specified:

1. Flat lying to gently sloping ground (< 20% sideslope):

Harvesting System**	Advantages	Problems	Cost Rating*	Effectiveness Rating*
Standard Spar				
Mini Spar				
Slackline				
Grapple Yarder				
Skidder				

2. Moderately sloping terrain (20-70% sideslope):

Standard Spar				
Mini Spar				
Slackline				
Grapple Yarder				
Skidder				

Contd.../

B. Contd...

3. Steep to very steep slopes (> 70% sideslope):

Harvesting System**	Advantages	Problems	Cost Rating*	Effectiveness Rating*
Standard Spar				
Mini Spar				
Slackline				
Grapple Yarder				
Skidder				

* Rating for Cost and Effectiveness to be classed as High, Medium or Low.

** If general efficiency of system is not adaptable to certain topographic conditions, indicate by N/A.

C. The following information will be used only to describe the population being sampled.

1. Number of years of experience ________

2. Experience mainly. Coast ________ Interior ________

3. Have experience logging adjacent to streams. Yes _____ No _____

D. Additional comments pertaining to streamside harvesting.

APPENDIX II

LOGGING EQUIPMENT HOURLY COST SCHEDULE

PLATE 1

LOGGING EQUIPMENT HOURLY COST

SCHEDULES EFFECTIVE JULY 1, 1982

Type	Description	Rated Capacity(±)	Rate($/hr)
Bulldozer	Road Construction	90-105 kW	48.48
Bulldozer	Road Mtce. & Const.	120-150 kW	69.98
Bulldozer	Road Construction	175-230 kW	86.82
Backhoe	Road Construction	1.0 - 1.4 m^3	88.02
Rock Drill	Road Construction	17.0 -18.4 m^3/sec	83.69
Gravel Loader (F.E.L.)	Road Maintenance & Construction	3.0 - 3.5 m^3	54.32
Gravel Truck (c/w rock box)	Road Maintenance & Construction	11 - 12 m^3 (3.88 m^3/hr)	52.08
Grader (blades only)	Road Maintenance	100 - 135 kW	60.75
Grader (c/w hydraulic brushcutter)	Road Maintenance	100 - 135 kW	82.48
Hand Faller		-	29.46
Landing Bucker		-	23.47
Faller & Bucker		-	44.02
Backhoe	Feller Buncher	90 - 105 kW	84.91
Crawler Tractor	Tree Shear	90 - 105 kW	77.66
High Lead Spar	Log Yarding - Chokers	105 - 375 kW	170.21
Skyline Yarder	Log Yarding - Chokers	335 - 375 kW	173.58
Grapple Yarder	Log Yarding - Grapple	165 - 335 kW	156.39
R.T. Skidder	Log Skidding - Line	85 - 105 kW	44.67
R.T. Skidder	Log Skidding - Grapple	85 + kW	71.28
Crawler Tractor	Log Skidding - Line	90 - 105 kW	54.20
Soft Track Skidder	Log Skidding - Line	135 kW	78.13
Heel Boom Loader	Log Loading		103.37
Heel Boom Loader	Access Logging		103.37
Front End Loader	Log Loading	6 tonnes	56.19
Hwy Log Truck	Log hauling	260 - 290 kW	51.46
On/Off Hwy Truck	Log hauling(2.4-3.6m)*	260 - 290 kW	60.48
Off Hwy Truck	Log hauling(3.7-4.3m)*	300+ kW	85.69

* denotes bunk width

Rate includes basic machine operating cost plus operator, additional crew as required and accessories as noted.

APPENDIX III

BOTANICAL NAMES OF MAJOR TREE SPECIES

Botanical Names of Major Species (Hosie, 1969)

Coast

Abies amabilis (Dougl.) Forbes	Amabilis Fir
Abies grandis (Dougl.) Lindl.	Grand Fir
Abies lasiocarpa (Hook.) Nutt	Subalpine Fir
Chamaecyparis nootkatensis (D.Don) Spach	Yellow Cedar
Picea sitchensis (Bong.) Carr.	Sitka Spruce
Pseudotsuga menziesii (Mirb.) Franco	Douglas-fir
Thuja plicata Donn	Western Red Cedar
Tsuga heterophylla (Raf.) Sarg.	Western Hemlock
Tsuga mertensiana (Bong.) Carr.	Mountain Hemlock