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Development and Testing of a Field Treatment System for Logging Residues

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VANCOUVER CANADA

Environment Canada / Environnement Canada
Forestry Service / Service des Forêts

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CANADIAN FORESTRY SERVICE
PACIFIC FOREST RESEARCH CENTRE
VICTORIA CANADA

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ABSTRACT

Full utilization of the forest resource has long been the goal of resource planners. The aim of this project was to identify and test methods of reaching this goal.

Forest residues on two recently logged sites representing a range of residue concentration and type were inventoried and classified. Residues were collected into piles and were processed using two different types of mobile chippers. Samples of the processed material were analyzed to determine their physical and energy properties. A portion of the chipped material was transported to a hog fuel boiler for burning.

Each phase of the work was monitored to determine productivity, cost and fuel consumption. Results show the cost per tonne for each phase of the operation and the ratio of energy consumed to energy produced.

RÉSUMÉ

L'utilisation complète de la ressource forestière a été depuis longtemps le but visé par les planificateurs des ressources. Ce projet visait à identifier et expérimenter des méthodes pour atteindre un tel objectif.

Des résidus forestiers sur deux stations exploitées, représentant une gamme de concentrations et de types de résidus ont été inventoriés et classifiés. Les résidus ont été amassés en lots et traités à l'aide de deux types de déchiqueteuses mobiles. Des échantillons du matériel traité ont été analysés pour en déterminer les propriétés physiques et énergétiques. Une partie des copeaux furent transportés jusqu'à une chaudière à déchets de bois pour les brûler.

Chaque étape des travaux était surveillée de près afin de déterminer la productivité, les coûts et la consommation de combustible. Les résultats indiquent le coût par tonne pour chaque étape du travail et le rapport entre l'énergie consommée et l'énergie produite.

FOREWORD

ENFOR is the bilingual acronym for the Canadian Forestry Service's ENergy from the FORest (ENergie de la FORet) program of research and development aimed at securing the knowledge and technical competence to facilitate, in the medium to long term, a greatly increased contribution from forest biomass to our nation's primary energy production. This program is part of a much larger Federal Government initiative to promote the development and use of renewable energy as a means of reducing our dependence on petroleum and other non-renewable energy sources.

ENFOR projects are selected from among proposals submitted by private and public research organizations according to scientific and technical merit, in the light of program objectives and priorities. Regardless of proposal source, projects are carried out primarily by contract. For further information on the ENFOR program, contact . . .

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. . . or the director of the establishment issuing the report.

This project originated as an unsolicited proposal submitted by Forestal to the ENFOR Secretariate of the Canadian Forestry Service in December 1978. In February 1979, the project (P-36) was recommended for support under the ENFOR program during the fiscal year 1979-80. The conclusions of this report are the sole responsibility of the author, and may not correspond to the policies or views of the Government of Canada, its departments or agencies. Mention of brand names does **not** constitute an endorsement by the Government of Canada, its departments or agencies, in particular but not restricted to the Canadian Forestry Service.

Contract preparation was carried out in March 1979 and project work commenced in April 1979 with the selection of test sites, equipment, and subcontractors for the various phases of project work. Slash on test sites was inventoried and assembled into piles during May and June. Processing of the assembled material commenced in July but had to be postponed until late August due to an extended period of high fire hazard. Processing continued during September and all field work was completed by 1 October 1979. Data compilation and analysis were carried out during October and the draft report was completed in November 1979.

Forestal thanks Dr. Glenn Manning of the Pacific Forest Research Centre in Victoria, B.C. for his excellent cooperation and guidance in his capacity as Scientific Authority for the project.

Forestal also acknowledges the cooperation of Pacific Logging Company for providing a test site at their Sooke Logging Division. The assistance extended by Mr. Ray Pimlott (Division Manager) and Mr. Norm Barnett (Forestry Supervisor) at the Sooke Logging Division is very much appreciated. The assistance and cooperation of B.C.F.S. Ranger Syd Sykes and his assistant Harold Bell in granting permission to use a portion of the Cowichan Demonstration Forest as a test site is also gratefully acknowledged.

In addition, Forestal acknowledges the assistance of Mr. W. H. Trigg of Canada Customs, of Messrs. R. Leech and G. Elliot of Canada Manpower and Immigration, of Mr. R. Collard of the B. C. Motor Vehicle Branch and of Mr. M. Smith of B. C. Forest Products, Crofton Pulp Mill, on various phases of the project.

The use of trade names for various machines in the report does not imply any recommendation or endorsement by Forestal. The manufacturers should be contacted directly for current specifications.

A number of field measurements were made in imperial units of measure. These measurements were converted to S. I. units, using appropriate conversion factors. To provide a standard basis for comparison, all measurements presented in this report are in S. I. units.

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Reference: ENFOR Project No. P-36
DSS Contract No. 075B.KL017-9-1430
Forestal Project No. F941

Dear Dr. Manning,

Enclosed herewith is an original typescript of our final project report entitled: Development and Testing of a Field Treatment System for Logging Residues. Twenty-four bound copies of this report are being sent to you under separate cover. We hope that you will find the work undertaken during this study and described in this report satisfactory and in compliance with the requirements outlined in our contract.

Yours truly,

FORESTAL INTERNATIONAL LIMITED

K. J. Blakeney

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Enclosure

SUMMARY

1. Collection and processing of logging residues into a more concentrated form can be accomplished using land clearing equipment and mobile chippers. However, low productivity and relatively high costs make the commercial application of the methods developed and tested on this project uneconomical at the present time.
2. The cost of assembling residues at points accessible to mobile chippers ranged from \$6 per tonne on flat sites with light concentrations of second growth residues to \$9 per tonne for heavy concentrations of old-growth residues on moderate slopes.
3. Processing costs averaged \$70 per tonne. This included the cost of a mobile chipper and a crawler loader with a splitter or log fork attachment to assist the chipper.
4. Further development is required to overcome many problems associated with processing logging residues. These problems are associated with handling small diameter residues, damage to chipper knives by rocks and other foreign material, and a general under-utilization of equipment capacity.
5. Collection and processing recovery were affected by the size of residue material. The portion of original residue recovered in the form of processed material was substantially lower for small diameter material. This was particularly noticeable in material less than 8 centimetres in diameter.
6. Of the two mobile chippers tested, the Nicholson chipper showed the most promise. The average productivity of the Nicholson unit was double that of the Bartlett chipper. However, the 56-centimetre maximum size limitation would limit its use in old-growth residues, where a large portion of the residues is concentrated in the larger diameter pieces.
7. The Bartlett stump splitter can be used to reduce large stumps to smaller sized pieces prior to chipping. The splitting action releases most of the imbedded rocks and dirt from the root systems.
8. The Bartlett chipper, although capable of handling large diameter pieces, has a very limited productivity due to a number of design factors. The infeed system is slow and awkward. Major modifications would be required to overcome this problem and it is doubtful whether the chipping and chip outfeed mechanisms could accommodate any substantial increase in quantity of material. The modifications carried out on this project dealt with some of the limitations of this machine. However, much more work would be required to develop a commercial model.
9. If the methods developed and tested on this project were modified to achieve full utilization of all equipment through simultaneous collection and processing of residues, a combined collection and processing cost of \$60 per tonne could be achieved. Further modifications to overcome the problems of low productivity in processing small diameter material could reduce costs to about \$45 per tonne.
10. The average heating value of processed residues was 10 times that of fuels consumed in the collection and processing operations.
11. Substantial differences in heating value were obtained from samples of processed residues of varying moisture content and condition. Only slight differences in heating value were obtained from samples of different tree species and different tree components.
12. One tonne of logging residues has a potential heating value equivalent to about \$35 worth of oil at current prices. However, the market value of these residues is only 3 to \$5 per tonne due to a surplus supply of wood residues from sawmills and other wood processing plants.
13. Increases in the price of oil will likely force many industrial plants to convert to wood residues for their energy requirements. Increased consumption of wood residues is expected to put supplies of hog fuel in southwestern B. C. under severe pressure by the mid-1980s. This is expected to focus attention of industry on the use of logging residues as a source of additional fuel.
14. In preparation for the anticipated increase in demand for wood residues, research and development should be directed toward the following aspects of logging residue utilization:
    - Logging Residue Inventory
    - Source Areas
    - Materials Handling Systems
    - Processing and Product Technology
    - Marketing Procedures
    - Forest Policy and Wood Residue Utilization

1. INTRODUCTION

Recent developments in petroleum supply and price have focussed attention on alternative energy sources. Canada's forest resources offer a vast potential supply of renewable fuel. One of the prime objectives of the ENFOR program of the Canadian Forestry Service (C.F.S.) is to study the measurement, harvesting and transportation of total forest biomass in order to fully exploit this energy opportunity. In 1978, the Pacific Forest Research Centre commissioned a study by Paul H. Jones and Associates to examine the potential supply and economic feasibility of using logging residues for generation of electrical energy on Vancouver Island. This study concluded that by utilizing a combination of logging residues and red alder, electrical energy could be generated at a cost approaching that of coal (20 mills per kilowatt hour).

A key step in the development of a workable forest residue utilization technology is the collection and transportation of logging residues to a conversion plant. The aim of the present project was to develop and test a practical system for collecting and processing logging residues on typical west coast logging sites. Sites were chosen to reflect a range of logging residue accumulation and topographic conditions. Owing to budget limitations, equipment selected was limited to that currently available. Some modifications were carried out to adapt existing equipment to operating conditions encountered during the field testing phase of the project.

Field testing of the equipment and methods was carried out on Vancouver Island during the summer of 1979. Local contractors were used for most phases of the work. Forestal monitored all phases of the project in order to determine productivity and costs. Conclusions reached were based on data collected during the field trials and on general impressions gained from observing and working with the equipment on a day-to-day basis.

2. OBJECTIVES AND SCOPE

The major objectives of the project were:

- To identify suitable equipment, and to develop methods for collecting logging residues from forest sites, and for processing them into a more concentrated form which could be efficiently loaded, transported, unloaded and utilized at an energy conversion plant.
- To determine, through field testing, the technical and economic feasibility of implementing the derived methods on a commercial scale.
- To collect information on the composition, physical properties and heat value of the material produced in order to assess its suitability and value as an energy source for existing energy conversion plants.

Within the above broad objectives, the following specific objectives were to be met:

- To develop a system capable of handling a variety of material representing a complete range of species, piece size, concentration and condition of residues. Test sites selected for field trials were to be representative of post-harvesting conditions commonly found on B. C. coastal logging operations.
- To determine, by inventory methods, the quantity of forest residues on the test sites before and after collecting the material. This inventory also was to provide data on the species, size, source and condition of the residues.
- To collect as much of the loose forest residues as physically possible and assemble these residues at locations which would be accessible to transportable timber processing equipment. The material collected was to be as clean and free of non-organic material as possible.
- To test different types of equipment for processing the assembled forest residues and to monitor the productivity of the equipment over a sufficient period of time to be able to assess its efficiency and suitability for handling the material assembled.
- To carry out limited trials of transporting the material produced in order to assess loading and unloading methods and to obtain a measure of the volume produced over a unit of time. In conjunction with the transportation trials, weigh scales were to be used to determine weight-volume relationships of the material produced.

- To determine productivity and unit costs for each phase or function of the work performed.
- To determine the ratio of energy consumed during all phases of the work to the equivalent energy produced in the form of processed material.
- To carry out limited modifications on the selected equipment to make it more suitable for performing the required project tasks. To identify further modifications which, owing to time or budget limitations, could not be carried out during the project.
- To prepare a comprehensive technical report documenting the activities of the project and presenting the results in a form suitable for publication.

3. STUDY METHODS AND PROCEDURES

3.1 Selection and Demarkation of Test Sites

To ensure that a broad range of logging residue sizes, types and concentrations would be represented in the field trails, two test sites were selected (See key map, Fig. 1). Both sites were on areas that had been logged within the past year. The slash was in typical untreated post-logging condition.

One site was on Pacific Logging Company land about 20 miles north of Sooke, B. C. on the south coast of Vancouver Island. The other was on Crown land in the Cowichan Demonstration Forest, 8 miles west of Duncan, B. C. on the east coast of Vancouver Island. The sites will be referred to as the **Sooke** and **Cowichan** sites in this report. They were initially surveyed and slash concentrations and type were compared to the U. S. Forest Service publication: **Photo Series for Quantifying Forest Residues** (Maxwell and Ward 1976).

From this comparison, it was possible to make an approximate preliminary estimate of the quantity of logging slash present. This estimate was used, together with an estimate of processing equipment productivity, to determine the area of each test site required to provide sufficient slash material for 10 to 15 days of chipping trials.

The area required for the Sooke trials was only 2 hectares because of heavy residue concentrations. At the Cowichan test site, where residues were light, an area of 10 hectares was selected for chipping trials. This was subsequently reduced to about 8 hectares in order to exclude root rot plots under study by the Pacific Forest Research Centre's protection group. The test site boundaries were surveyed and delineated in the field, using a staff compass and chain. These boundaries were used as base lines for the inventory plot grid. All points were referenced to facilitate reestablishment at a later date.

The Sooke site logging residues were typical of over-mature (approximate stand age 250 - 300 years) Hemlock-Balsam[1] forests logged by highlead cable systems in coastal B. C. The slash concentration was very heavy, with many large broken logs, windfalls, snags and uprooted stumps. A high proportion of this material was rotten. The average slope at the test site was 15 to 25%. The area was scheduled for slash burning in the fall of 1979 and for planting in the spring of 1980.

Logging residues on the Cowichan site were typical of those found following wheeled skidder logging in young (approximate stand age: 60 years) second-growth Douglas-fir[1] forests. The slash concentration was relatively light and composed mainly of small saplings, tops and branches. The site was relatively flat, with a few small hummocks. No slash burning was planned due to the light concentration of slash on the area. The area was to be planted following destumping, to arrest the spread of the root rot. A brief summary of information on the location, size and original forest cover of the two test sites is tabulated in Table 1.

3.2 Inventory of Logging Residues

In early May, prior to the collection and assembly of the logging residues, an inventory was conducted using the planar intersect method as described in the **Handbook for Inventorying Downed Woody Material** (Brown 1974).

All downed and woody material on or near the ground with a diameter equal to or greater than 0.6 cm was tallied in size classes from 0.6 to 2.5 cm, from 2.6 to 7.6 cm, and then in 5-centimetre diameter classes from 7.7 to 53.3 cm, according to sound and

[1] See Appendix 1 for botanical names.

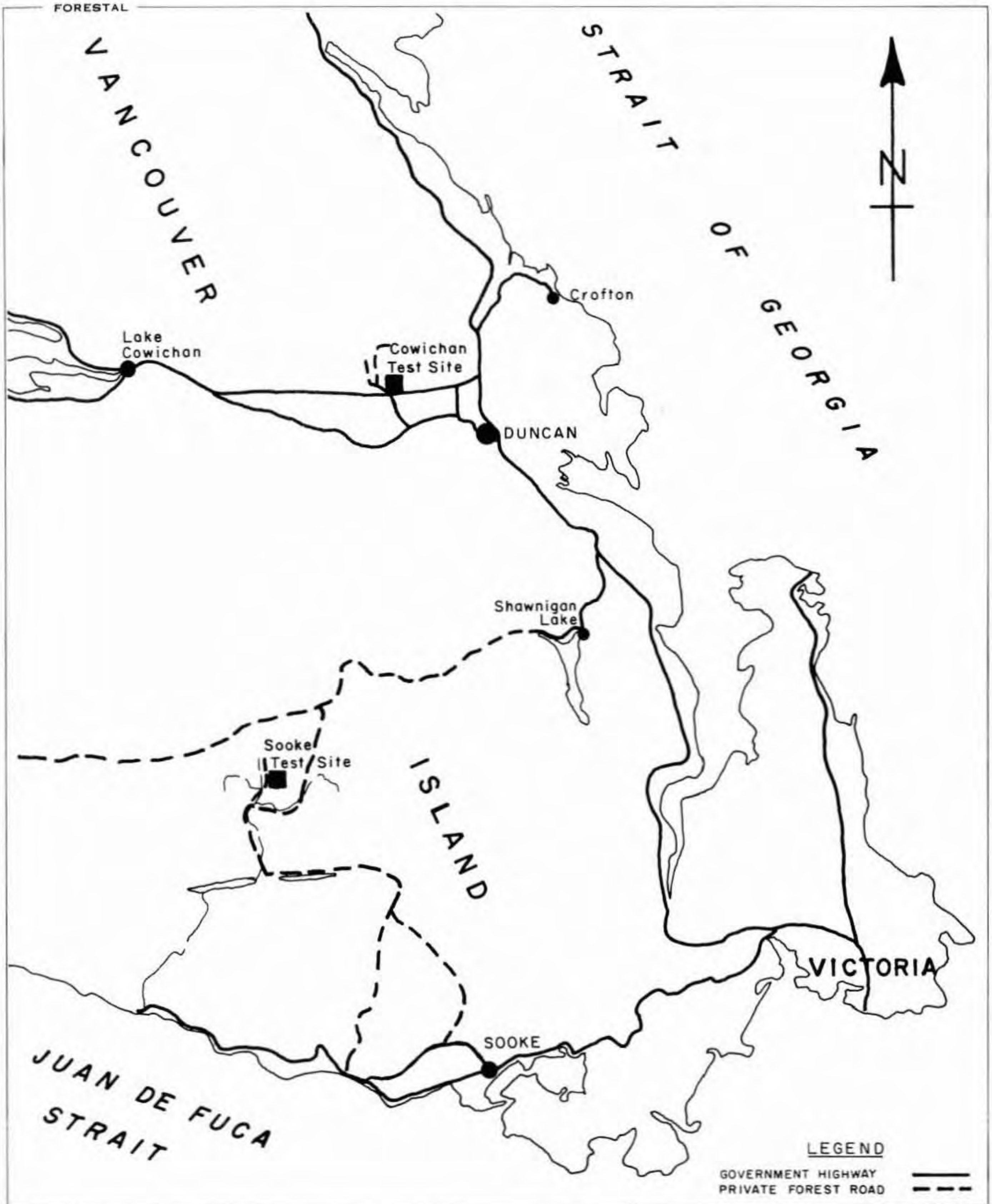


Figure 1 - Key Map of Test Site Locations
SCALE - 1:380,160

Table 1 - Basic Descriptive Information on Test Sites

	Sooke		Cowichan	
Location and Identification	Pacific Logging Company Sooke Logging Division Block No. 1271 Setting No. P78-3 Road No. J43-A		Cowichan Demonstration Forest Portion T. S. A. 10508 B. C. Highway No. 18	
Elevation	600 - 700 m		150 m	
Date of Logging	1978 - 1979		1979	
Total Area Logged	170 ha		28 ha	
Area of Test Site	2 ha		10 ha	
Original Stand Data Cruise Volume	I. U.[a] 400 m^3/ ha		I. U.[a] 110 m^3/ha C. U.[b] 270 m^3/ha	
Species Distribution[1]	Fir	8%	Fir	87%
	Cedar	12%	Cedar	1%
	Hemlock	45%	Deciduous	12%
	Balsam	34%		
	Cypress	1%		
	Total	100%	Total	100%
Stand Age	250 - 300 years		50 - 70 years	
Average Diameter (dbh)	75 - 100 cm		30 - 50 cm	

(a) I. U. - Intermediate Utilization Standard

(b) C. U. - Close Utilization Standard

[1] See Appendix 1 for botanical names

Table 2 - Inventory Plot Interval and Grid Line Spacing
(Metres)

Site	Plot Interval	Grid Line Spacing
Cowichan	30	50
Sooke	20	20

rotten categories. Material that was easily kicked apart or had obviously deteriorated was classified as rotten if the decayed material represented more than 50% of the piece. Land-firm roots and stumps were excluded from the inventory.

A uniform sampling grid was established on each site and plots were located at fixed intervals along the grid lines. Grid line spacing and plot interval are shown in Table 2.

A total of 50 plots were established on each site. Transect line directions were chosen randomly using the second hand on a watch and 5-second intervals to indicate one of 12 30° angles between 0° and 330°. Figures 2 and 3 show the inventory plot location plans for the Sooke and Cowichan test sites.

On both sides, transect lines of 1.83 metres were used to tally intersected residual material within the diameter range of 0.6 to 7.6 cm. On the Sooke site, a transect line of 9.15 metres was used to tally intersected residual material larger than 7.6 cm in diameter. The Cowichan site required a longer transect line (15.25 metres) to achieve the same precision level because of the lighter concentration of material larger than 7.6 cm in diameter.

At each plot, the species composition of the residual material was visually estimated. From these plot estimates, a weighted average species composition for each test site was calculated. This was used to determine the appropriate specific gravity for use in the calculation of tonnes/hectare.

Both sides were reinventoried after the residual material had been collected. On the Sooke site, the same grid and system of plots were used but of the original 50 plots, only 34 could be used. The remaining 16 plots were either in uncleared swampy areas or underneath the collected material. On the Cowichan site, a new uniform grid and plot system was used and 36 plots were established. The original grid system could not be used since many of the original plots fell in areas not cleared because of swampy ground conditions or because of the presence of study plots of the C.F.S root rot survey.

Figure 2 - Inventory Plot Location Plan - Sooke Site

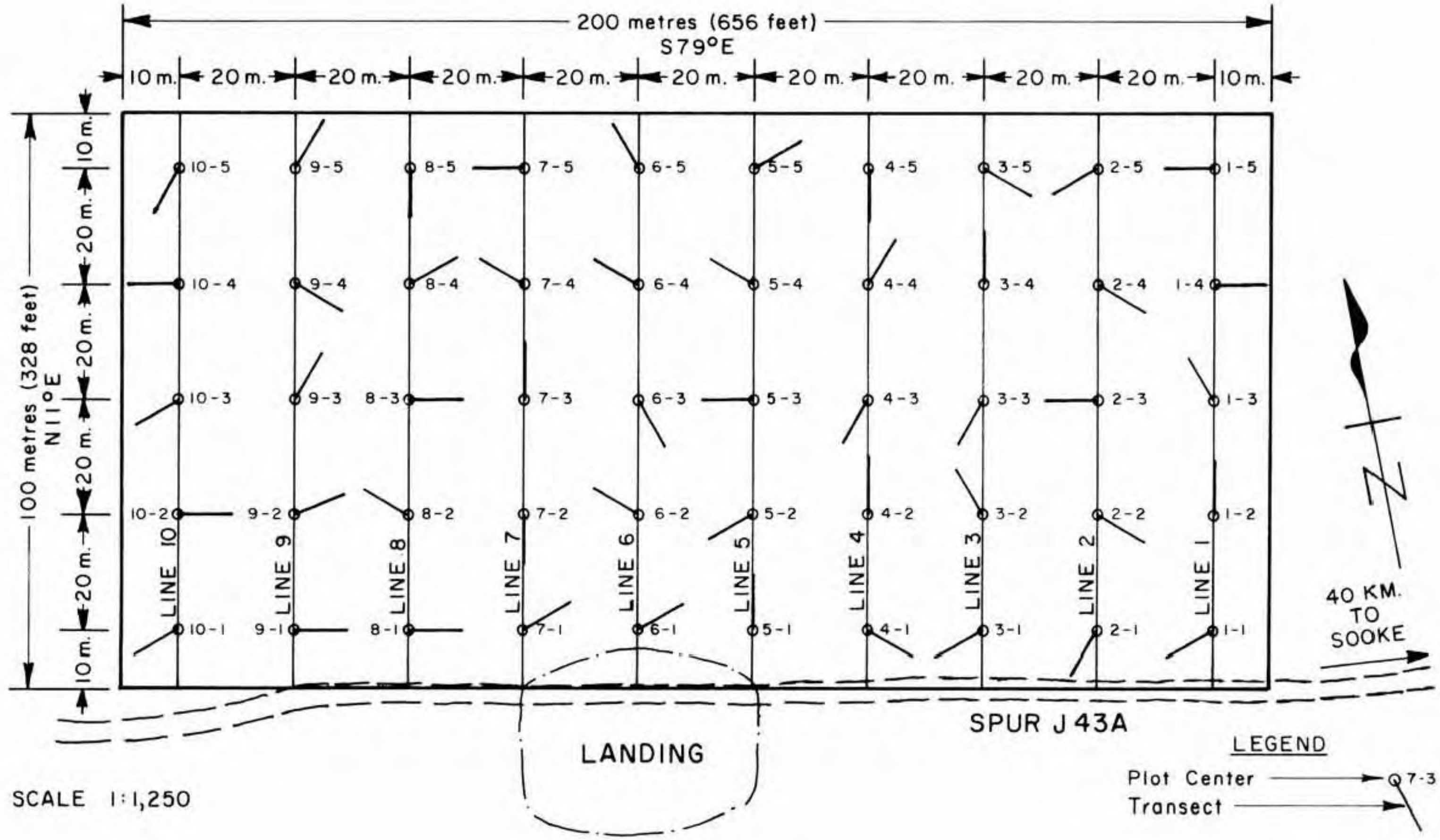
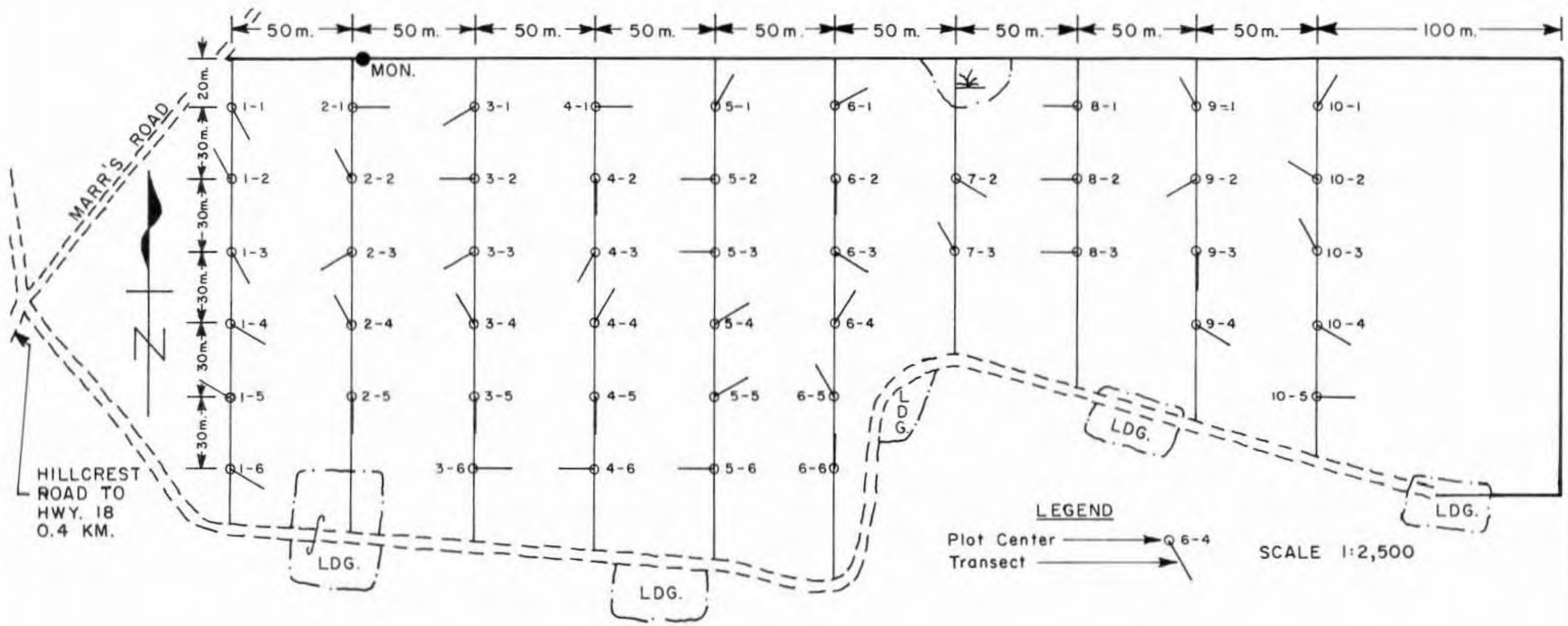


Figure 3 - Inventory Plot Location Plan - Cowichan Site



3.3 Collection and Assembly of Logging Residues

The main objectives in collecting logging residues from the project test sites were:

- To identify and test a method and equipment for collecting loose logging residues.
- To assess the suitability, productivity and cost of the method and equipment tested.
- To quantify the amount of material that can be practicably salvaged from recently logged-over sites.
- To assemble a representative sample of logging residues at a location where they could be processed using portable chipping equipment.

Various types of equipment were considered for use and the opinions of a number of persons experienced in land clearing were solicited. The residue material had to be moved distances of up to 100 metres. No uphill movement of material was required. The amount of dirt and rock collected with the residues was to be minimized in order to prevent excessive wear to chipper knives.

The final selection was based on equipment manoeuvrability and cost. Small crawler tractors (40-50 kw) with a low hourly operating cost and the ability to operate between stumps and on moderately steep slopes were selected. It was decided that a combination of brush raking and forwarding would be used. The equipment used consisted of two J.D. 450 crawler tractors, one with a brush rake attachment for collecting and piling the material over short distances, and the other with log loading forks which were used to carry the piled material to a roadside assembly point.

At the Sooke site, logging residues were collected from distances of up to 100 metres and piled in a 200 metre long windrow adjacent to the existing logging road. The piled material ranged in depth from 3 to 6 metres and extended up to 10 metres back from the edge of the road.

At the Cowichan site, where topography was relatively flat, it was decided to collect a portion of the material into a windrow along the existing logging road and to assemble the remainder in piles located throughout the site. Rough access roads were then constructed to these piles in order that processing equipment could travel to the assembled material. By using this method, the average distance over which material had to be moved was lessened. This helped to reduce collection costs and to reduce the quantity of dirt and rock collected along with the logging residues. Figures 4 and 5 show the Logging Residue Collection plans for the two test sites.

3.4 Processing of Logging Residue

A discussion of the equipment selection procedure, along with details and specifications of equipment used during the field trials, is included in Section 4 of this report.

At the Sooke site, a combination of equipment was used for processing. A self-loading drum chipper was used in conjunction with a hydraulic stump splitter to process the wide range of material sizes and types assembled along the logging road that traversed the test site.

The stump splitter, mounted on the front of a 80-kw crawler tractor, split large sized and odd shaped cull logs, stumps and roots into pieces that could be more easily fed into the chipper opening. The splitting operation was also done to remove encased rocks and dirt from stumps and roots.

The chipper was positioned at points along the pile of residues. Hydraulic stabilizer jacks were lowered into posiiton to reduce movement of the chipper during operation. Material was loaded into the chipper drum infeed hopper by a hydraulic grapple loader mounted on the rear of the chipper unit. This grapple loader was also used to sort and sift material to remove rocks and dirt prior to feeding into the chipper. To facilitate processing, a hydraulically operated lid was used to force material down onto the chipper drum. Material was fed vertically downward onto a rotating chipper drum with sets of knives mounted around its surface. The knives cut the material into chips and shreds which passed through the knife opening to the centre of the drum. Here, a large auger moved the chips along to one end of the drum where they fell onto a conveyer system which carried the processed material to a truck.

Figure 6 shows the operational layout of processing equipment at the Sooke site.

At the Cowichan site, logging residue piles were widely scattered throughout the test site and rough access roads were constructed to those piles not located along the main logging road. The mobile chipper (a Nicholson, 22-inch, V-drum chipper) was towed by a truck from one residue pile to another.

Residue material from the piles was fed by a log loader (mounted on the chipper unit) onto a horizontal infeed conveyor belt located at one end of the chipper unit. This belt, in conjunction with infeed rollers, moved the material into the V-drum chipper. Chipped material was blown out through a duct located at the opposite end of the chipper from the infeed belt. This duct was used to fill chip vans during transportation trials.

A small crawler loader with front-mounted log forks was used to carry material to the chipper, to assist in moving the chipper, and to clear roads and landings.

Figure 7 shows the operational layout of processing equipment at the Cowichan site. A more detailed description of processing equipment and

Figure 4 - Logging Residue Collection Plan - Sooke Site

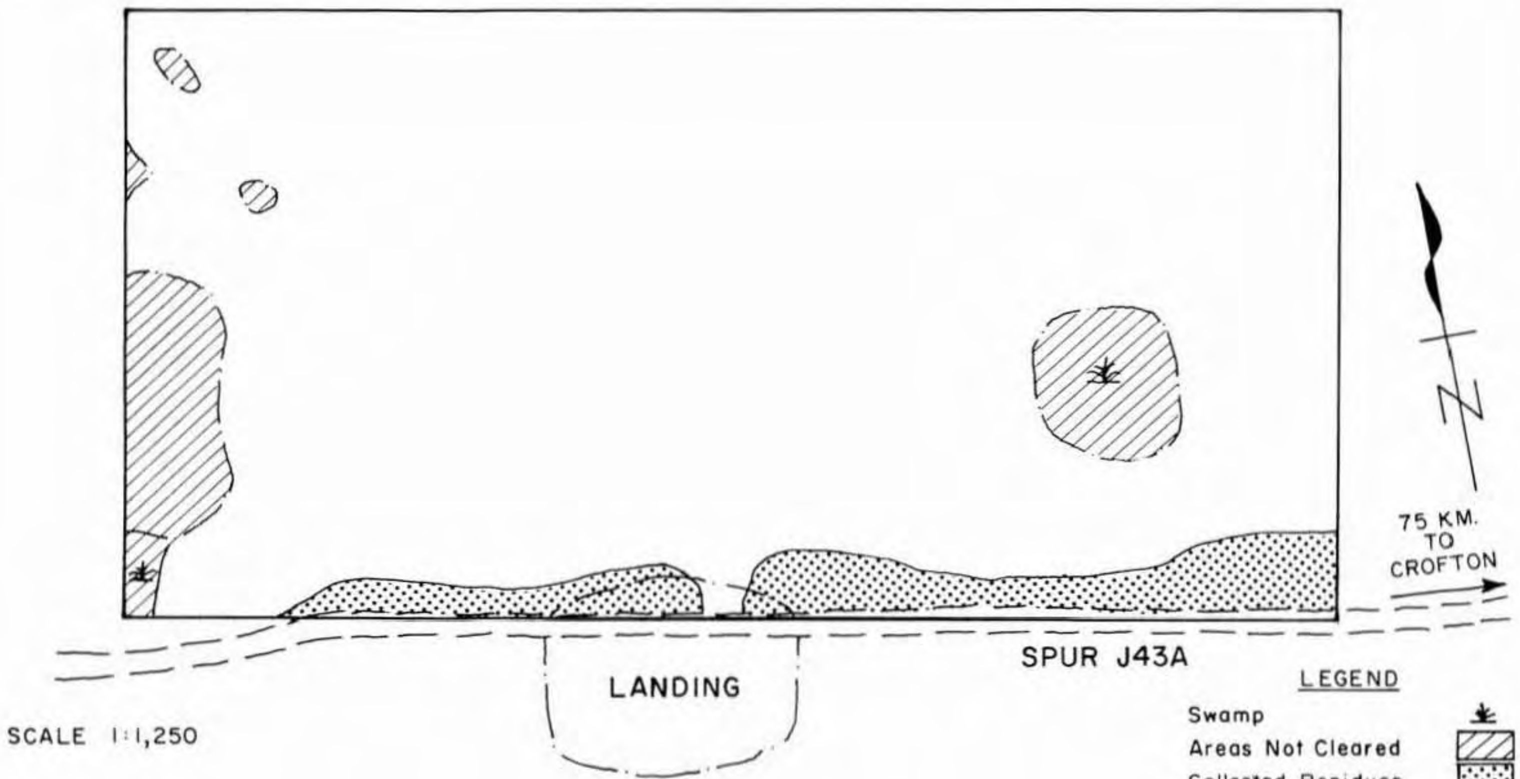


Figure 5 - Logging Residue Collection Plan - Cowichan Site

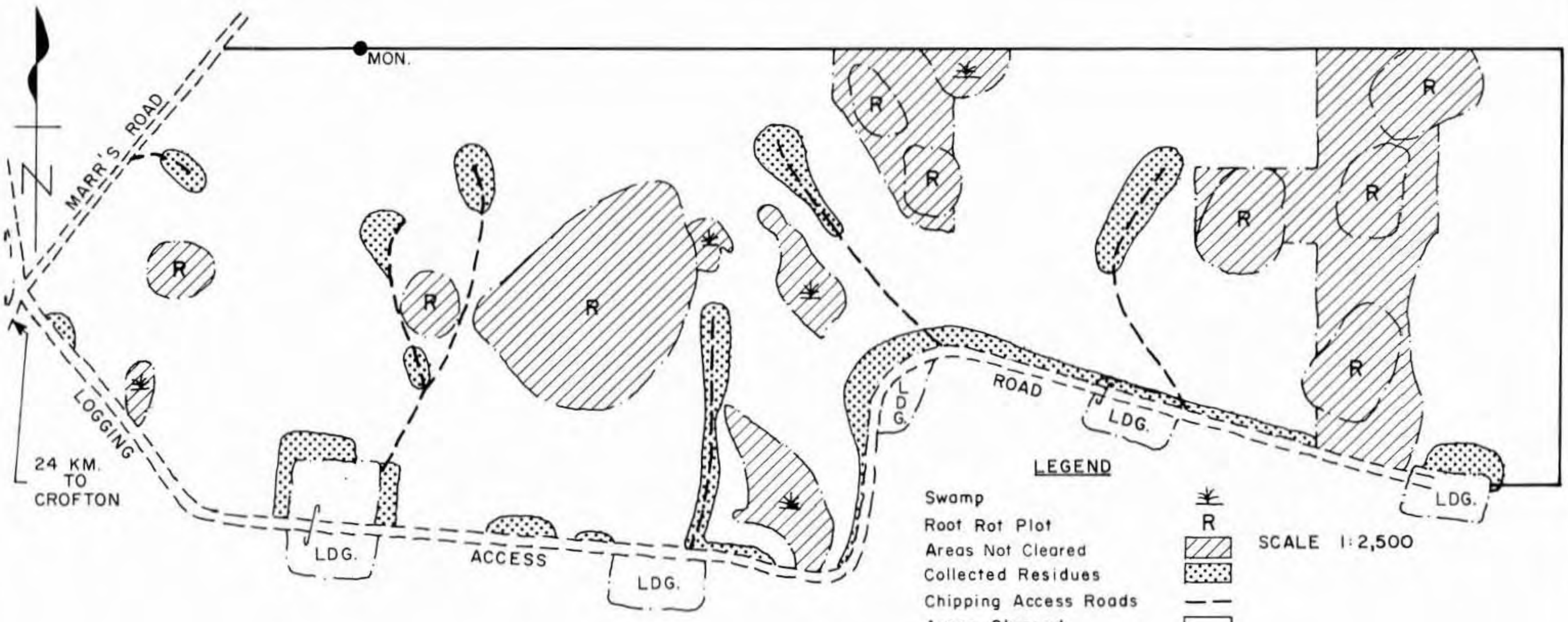
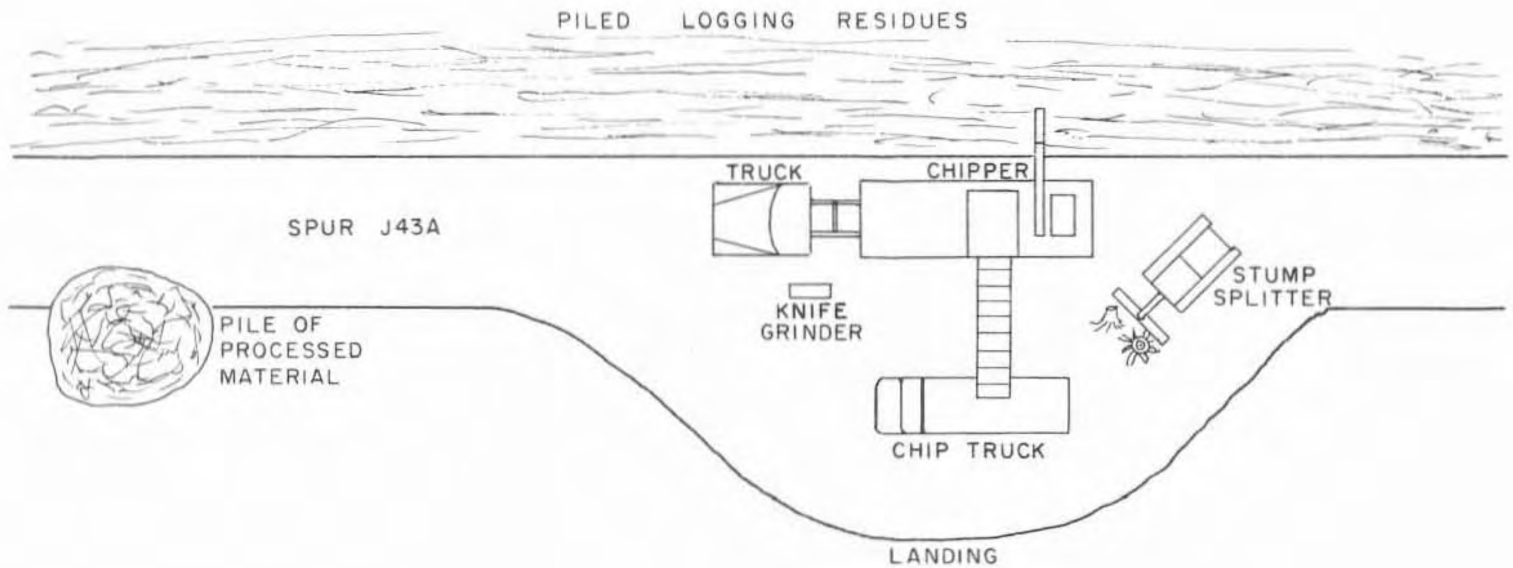


Figure 6 - Operational Layout of Processing Equipment - Sooke Site



methods used at both test sites is contained in Section 4.4 of this report. As assessment of the results of processing trials carried out at Sooke and Cowichan is included in Section 5.3.

3.5 Transportation and Disposal of Processed Material

To assess loading methods, productivity and weight-volume ratios of the processed material, transportation trials were carried out on a limited basis at both sites.

Due to truck availability and traffic density on the roads of the Sooke Logging Division, transportation trials were carried out on only 2 days at the Sooke site. During this period, a total of six loads were measured and transported. Loads were transported in a self-dumping truck with an approximate capacity of 20 cubic metres. Processed material was transported about 1 kilometre and dumped at a landing near the test site. Weighing was done with portable scales to determine individual wheel loads, which were then summed to give the total vehicle weight. The truck was weighed before and after loading to determine the net weight of processed material.

At the Cowichan site, transportation trials were carried out over a 3-day period using a 50-cubic-metre capacity chip van. A total of six loads were transported to Crofton pulp mill, where they were weighed and unloaded. Trucks were unloaded using a special "tipper" type dump which was installed at Crofton to unload hog fuel into an underground conveyor bin which feeds the hog fuel boiler.

At both sites, the volume of each load was measured and the loading time was carefully monitored to determine processing productivity in terms of volume produced per unit time. In addition, loads were weighed to determine the weight to volume ratio of the material produced. Fuel consumption and cycle time were recorded during the transportation trials.

3.6 Laboratory Analysis of Processed Material

Samples of the processed material were collected during field trials and submitted to Beak Consultants Limited (Beak) for analysis. Samples were selected to represent a typical range of types of material found on each test site. Two to 3 kilograms of a particular processed material type were collected from the chipper outfeed and placed in plastic bags in order to prevent moisture loss during transport to the laboratory. Bags were labelled in the field to identify source area and type of material. Table 3 shows the types of material sampled.

The field samples were prepared for testing at the laboratory and analyzed to determine a variety of physical properties as shown in Table 4.

In addition to the laboratory analysis of processed material carried out by Beak, a chip analysis was carried out on two samples of processed material from the Cowichan site by the chip testing department of B.C. Forest Products' Crofton pulp mill. This analysis shows the size distribution of the processed material. Samples of the material processed

Table 3 - List of Samples Submitted for Analysis

		Sample Description	
Source Location	**Species**	**Type**	**Condition**
Sooke Test Site	Cedar	Stemwood	Partially rotten
	Cedar	Stemwood	Sound
	Hem/Bal [a]	Stemwood	Partially rotten
	Hem/Bal	Stemwood	Rotten
	Hem/Bal	Branchwood	Sound
	Hem/Bal	Stemwood	Sound
	Hem/Bal	Stump/Roots	Rotten
	Hem/Bal	Stump/Roots	Sound
Cowichan Test Site	Alder	Stemwood	Green - Sound
	Alder	Stemwood	Air dry - Sound
	Fir	Stem/Roots	Sound
	Fir	Tops & Branches	Sound
	Fir	Stemwood	Partially rotten
	Fir	Stemwood	Rotten
	Cedar	Stemwood	Sound

(a) Hemlock and Balsam mixed. See Appendix 1 for botanical names.

Figure 7 - Operational Layout of Processing Equipment - Cowichan Site

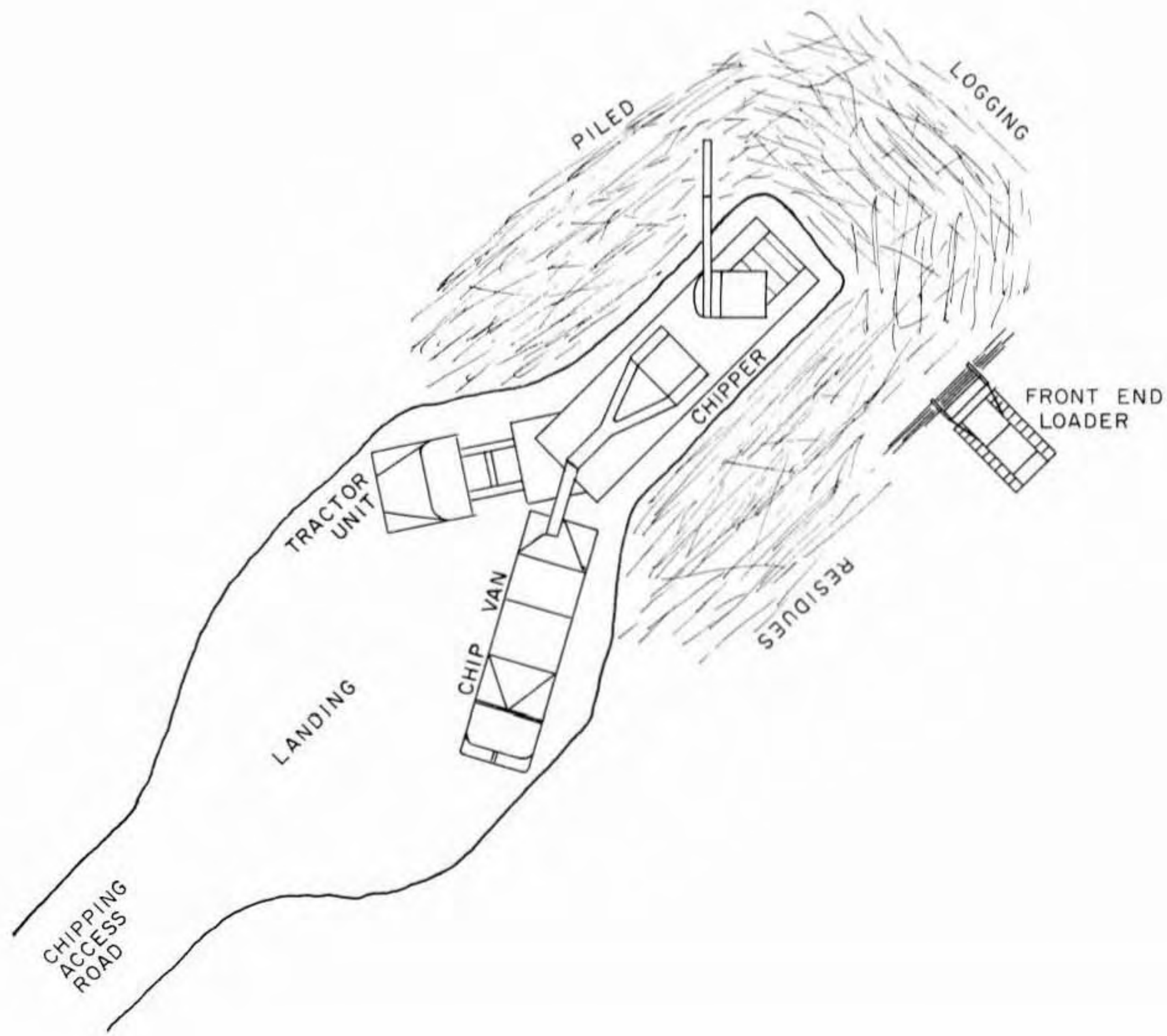


Table 4 - List of Properties Analyzed

Property	Basis	Units	Description
Moisture Content	wet[(a)]	%	weight of water as a percentage of total (wet) weight of sample
Ash Content	oven dried[(b)]	%	weight of non-combustible ash as a percentage of oven dried weight
Calorific Value	wet	BTU/lb	net heat released in burning a known quantity of the undried sample
Calorific Value	oven dried	BTU/lb	net heat released in burning a known quantity of the oven dried sample
Organic/Inorganic	wet	ratio	a ratio of the percentage of organic material to the percentage of inorganic material based on undried sample weight

(a) wet = sample in its original condition as collected in the field.
(b) oven dried = sample has been dried to eliminate all moisture.

at the Cowichan site were burned on the movable grate burner system of the Crofton hog fuel fired steam boiler. The results of these analyses are presented in section 5.5 of this report. A copy of Beak's laboratory analysis report is contained in Appendix 2.

4. EQUIPMENT UTILIZED

4.1 Inventory Equipment

Standard field surveying equipment was used in carrying out the inventory phase of the project. These equipment items and their use are described in the **Handbook for Inventorying Downed Woody Material** (Brown 1974).

4.2 Collection and Assembly Equipment

A John Deere JD450 crawler tractor with a 2-metre-wide brush collecting blade and hydraulic winch was used to push and skid forest residues into piles. A John Deere JD450 crawler loader with log loading forks (spaced 1.6 metres apart) and hydraulic winch was used to forward and skid material collected by the brush blade. The brush blade machine had standard land clearing tracks with 2-centimetre deep growsers which provided sufficient traction for operating on slopes encountered on the project test sites. The tractor with log forks was equipped with standard street pads (no growsers). The absence of growsers limited the effectiveness of this machine in negotiating the steeper slopes on the Sooke site. Figure 8 shows the John Deere JD450 crawler tractor with brush blade attachment.

4.3 Chipper Access Road Construction Equipment

A Caterpillar D8K was used to construct access roads to residue piles on the Cowichan site. This machine was used because it happened to be destumping root rot areas on the site at the time the access roads were required. The reason for using this machine was convenience rather than suitability. A smaller crawler tractor could have been used for this work with equal results.

4.4 Processing Equipment

a. Available Equipment Types

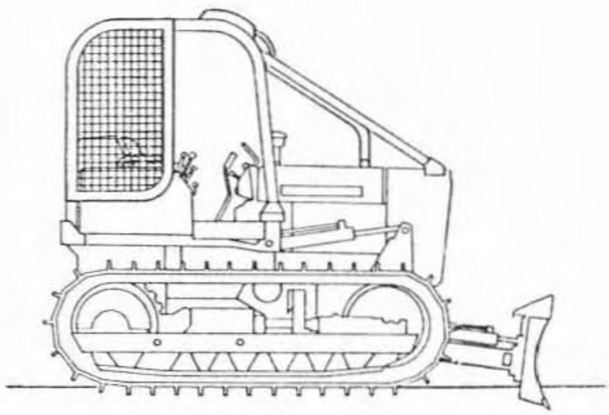
Logging residue is characteristically composed of pieces of varying size, shape and condition and does not lend itself to efficient materials handling methods. It is this variety of piece size and shape that makes it difficult to develop one type of equipment that will handle the complete range of piece types encountered.

Prior to selecting processing equipment for use on this project, the author reviewed available information on a number of equipment types and models. Robin T. Hamilton, in his publication, **SLASH . . . Equipment and Methods for Treatment and Utilization**, has identified and evaluated 50 different pieces of equipment that have the potential to reduce forest residues to a more homogeneous particle size and arrangement. This equipment generally falls into the following broad categories.

Slash Reduction Equipment

This equipment is generally designed to move over relatively flat ground and crush, chop, cut or flail the logging residue material into a ground

Figure 8 - John Deere JD450 with Brush Blade



SPECIFICATIONS

Overall Length	3.61 m.
Height	2.54m.
Weight	6455 kg.
Net Power at 2500 rpm	48.5 kW.

mulch. There is no processed material retrieval system. The ultimate purpose of this equipment is to dispose of or reduce slash to a non-objectionable form, rather than to produce a utilizable product that can be easily retrieved and transported.

Transportable Timber Processors

This equipment is generally designed to produce a utilizable end product and is equipped to retrieve the processed material and deposit it into a truck or van for transportation. Processors can be further classified according to the method used to break down the original material.

Chippers

Most of this equipment was originally designed to produce high-quality pulp chips from sound, debarked material in the form of whole trees or logs. Their main limitations for use in processing logging residues is the ineffectiveness of their cutting knives in slash material which is mixed with dirt and rocks and their inability to handle pieces larger than their design capacity.

Flails and Hammer Mills

This equipment uses blunt knives or flails that break, tear and crush, rather than cut or chip. These machines are generally not as sensitive to knife damage as the knife chipper. This category of equipment requires more power to operate than chippers.

All of the mobile flail machines available with retrieval systems have an infeed capacity which is too small to handle the large diameter pieces of slash.

Hammer mills designed to handle large diameter pieces require very powerful engines and consequently are too heavy, cumbersome and expensive for use in a portable slash processing system.

Splitters

This equipment is designed to split stumps and root masses or break up large logs. Often this equipment is required to split larger pieces of wood waste into smaller pieces so they can be fed into a chipper for further processing. In breaking up the root systems of stumps, dirt and rocks are removed, thus reducing the chance of knife damage during chipping.

Another source of information consulted during the equipment selection process was a compendium of mobile chipping equipment contained in the 1976 FAO publication **Wood Chips - Production, Handling and Transport.** This publication provides information on 44 different chippers manufactured in Europe and North America. For each chipper, the following data are shown:
- Manufacturer
- Chipper type (drum, "v" drum, disc, etc.)
- Weight
- Power requirements
- Maximum size of material handled
- Productivity
- Cost

b. Processing Equipment Selection

In selecting equipment for use on this project, all equipment in the two publications mentioned and some prototype models for which no published material was available were evaluated. The evaluation was based on the following criteria:
- Availability for use on the project.
- Capability of travelling over logging roads and working independently at remote sites.
- Suitability for processing the type of material at the two selected test sites.
- Capability of producing and retrieving material that can be easily transported and used as an energy source.

Slash reduction equipment was not considered suitable because of its inability to work on rough topography and the absence of a retrieval system for the processed material.

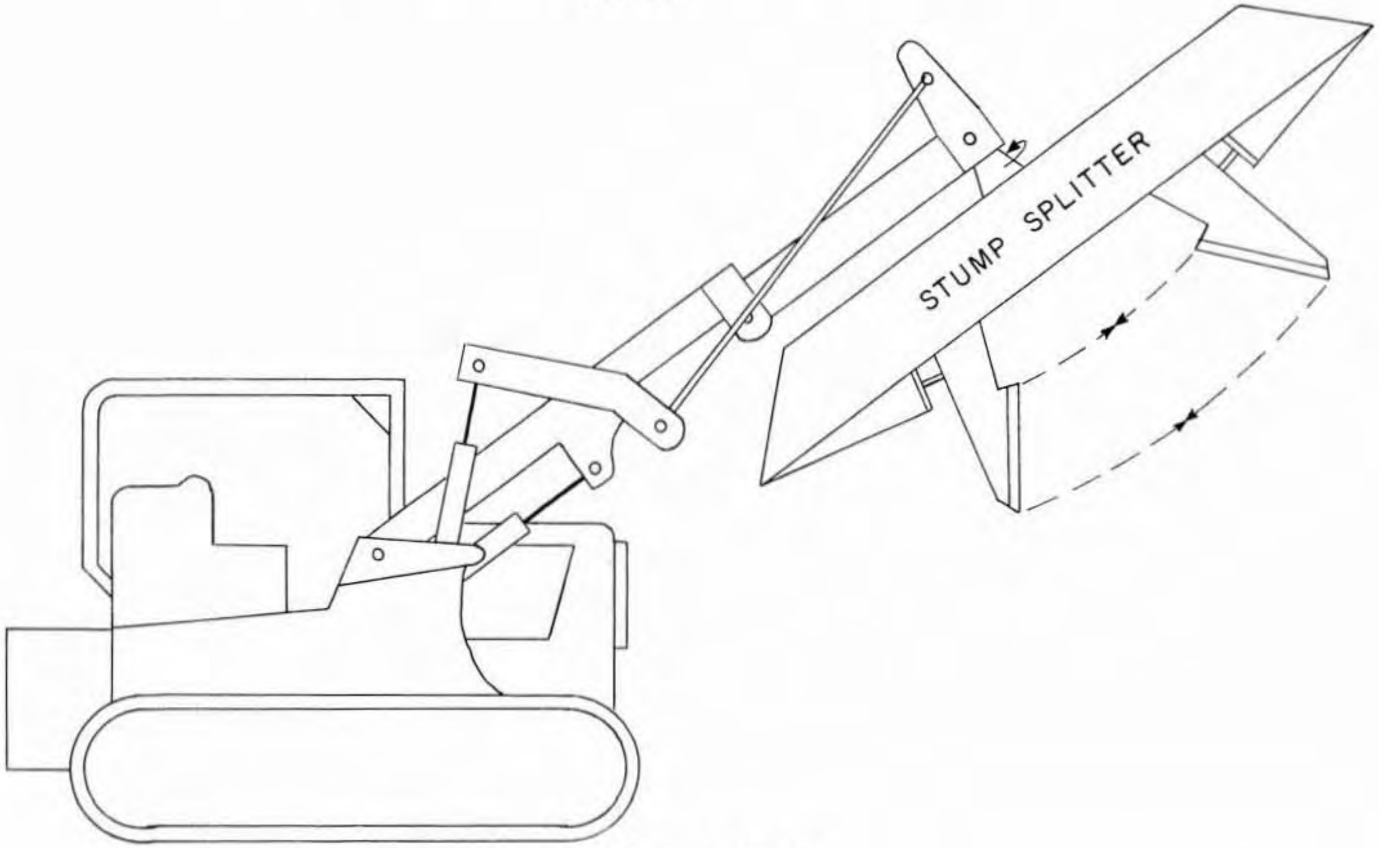
Of the transportable timber processors, the chippers seemed to hold more promise than the flail and hammer mill machines. One flail type machine, the Fling Demolisher, was well suited to processing logging residues. However, it was not capable of handling a large portion of the material on the test sites, due to a 30-centimetre maximum material size capability. Discussions with the manufacturer indicated that the size limitation could not be easily overcome. Several manufacturers of hammer mill equipment were contacted. They all indicated that a hammer mill with a capability of handling large material (50-75 centimetres) would require such a large horsepower motor and heavy drive train and support structure that it would be impractical to mount on a mobile carrier.

For the Sooke site, it was obvious from the inventory data that equipment capable of handling large diameter (up to 90 centimetres) material would be required. There are very few mobile chippers capable of handling material up to 50 centimetres in diameter. There is only one commercially available mobile chipper that can handle material up to 70 centimetres in diameter.

Originally it was planned to use a chipper with a 50-centimetre maximum size capacity in combination with a hydraulic splitter which could reduce the oversize material to smaller pieces that could be handled by the chipper. Several man-

Figure 9 - Bartlett Stump Splitter Mounted on a Crawler Loader

(Not to Scale)



SPECIFICATIONS

INTERNATIONAL HARVESTER 175A CRAWLER LOADER

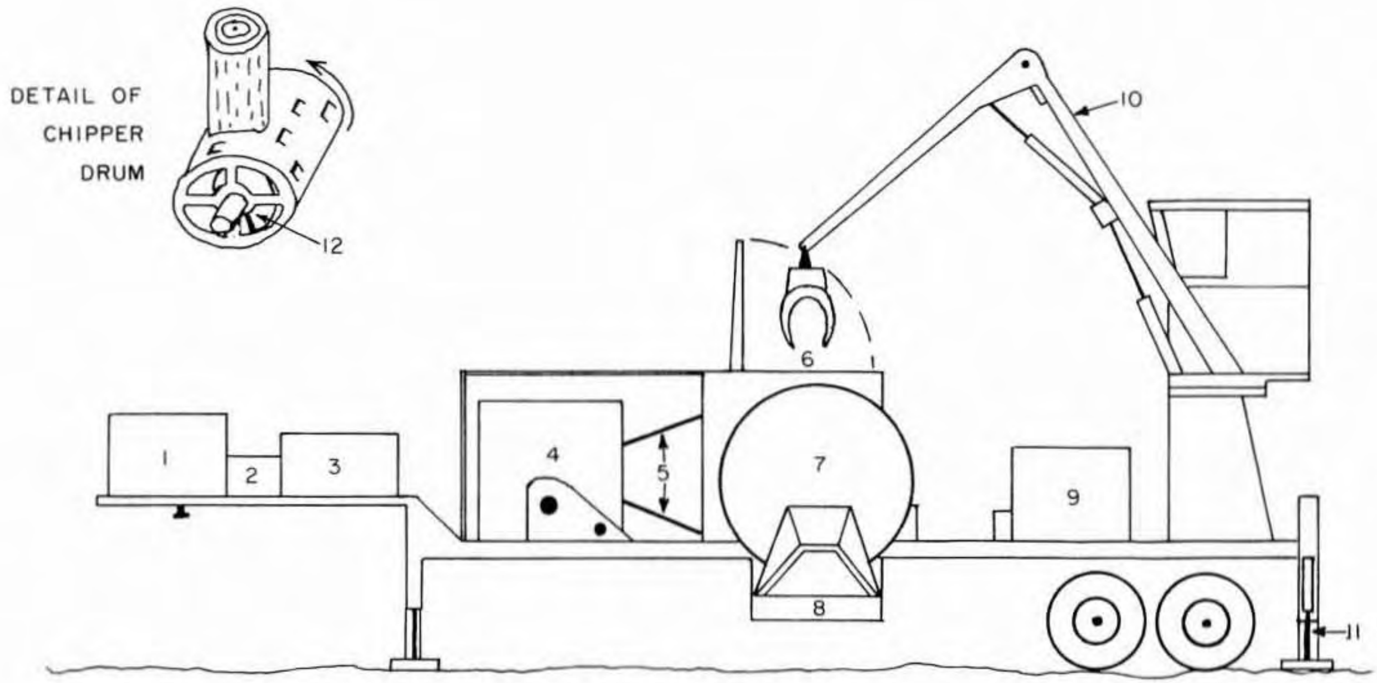
Length	3.0 m.
Width	2.2 m.
Weight	13,900 kg.
Flywheel Power at 2400 rpm	82 kW.

BARTLETT STUMP SPLITTER MODEL F60 - C6B

Weight	3068 kg.
Blade Length	61 cm.
Maximum Blade Opening	1.52 m.
Hydraulic Cylinders	2
Cylinder Closing Force	112,273 kg.

Figure 10 - Schematic Diagram of the Bartlett Chipper

(Not to scale)



LEGEND

1. Generator
2. Fuel & Water Tanks
3. Air Compressor
4. Chipper Drive Motor
5. V-Belts
6. Infeed Hopper with Hydraulic Door
7. Chipper Drum
8. Horizontal Outfeed Conveyor
9. Hydraulics Systems Motor
10. Hydraulic Log Grapple
11. Hydraulic Stablizer
12. Auger

ufacturers of splitting equipment were contacted. Mr. R. Bartlett, inventor and manufacturer of a unique type of stump splitter had also developed a working prototype of a top loading chipper capable of handling material up to 125 centimetres in diameter. Since no other available equipment could approach this capability, the decision was made to use this chipper for the Sooke tests. To assess this machine's capability for processing all residue types including stumps, the stump splitter was used in conjunction with the prototype chipper at Sooke. The chipper and stump splitter were obtained through the manufacturer in Vancouver, Washington, U.S.A.

As previously stated, the average size of material at Cowichan was considerably smaller than that at Sooke. Only 3% of the total quantity of residues at Cowichan was greater than 53 centimetres, compared to 36% at the Sooke site. A chipper with a 55-centimetre infeed opening was used for the Cowichan processing tests. A machine of this type was found to be available through a company in Seattle, Washington, U.S.A.

c. Processing Equipment Used at the Sooke Site

The stump splitter used at the Sooke site operates on the principle of a tree shear. The hydraulically powered splitter device is mounted on the front of a crawler loader and consists of two large cylinders that drive steel splitting blades through any woody material. The blades can be opened to accommodate up to 150-centimetre diameter pieces. The carriage can rotate 85 degrees to either side of centre so that only one approach by the crawler loader is necessary to pick up and split or cut stumps, roots or large rotten logs from a pile of residues. By breaking up the root systems of stumps, dirt and rocks are removed, thus reducing the chance of knife damage during chipping.

The hydraulic grapple loader on the chipper unit extracted oversized and odd-shaped logs, stumps and root masses from the residue piles and put them to one side of the road for splitting by the stump splitter unit. Figure 9 shows the Bartlett stump splitter mounted on a crawler loader.

The Bartlett chipper unit was positoned at points along the road and material was loaded from residue piles adjacent to the road into the chipper drum hopper by the hydraulic grapple loader mounted on the rear of the chipper unit. The chipper operates on a top loading principle, the material being fed vertically downward onto a rotating chipper drum. A hydraulically operated lid is used to force material onto the drum. The drum is mounted horizontally and is driven at about 200 revolutions per minute by a 450 kw diesel engine. There are 14 sets of knives mounted around the surface of the drum. These knives cut the material into chips and shreds which pass through the knife opening and enter into the drum. Inside the drum, a large rotating auger moves the chips along to one end of the drum, where they fall onto a horizontal conveyor. This conveyor moves the processed material laterally to an angled conveyor which carries the material upward to a height of about 4 metres, from where the chips drop into a truck or van.

A separate diesel motor drives the hydraulic pumps which operate the grapple log loader, conveyor systems, infeed hopper lid and stabilizer jacks. Figure 10 is a schematic diagram of the Bartlett Chipper, illustrating the location of various components of this equipment.

Several modifications were carried out on the Bartlett Chipper in order to adapt and improve the original equipment. The most important of these modifications was the installation of an electric generator, which served as a power source for a number of additional modifications designed to improve the chipper unit. A brief description of each modification and its purpose are listed in Table 5. The approximate location of these modifications is shown on a schematic diagram of the Bartlett Chipper in Figure 11.

d. Processing Equipment Used at Cowichan Site

At Cowichan, a John Deere JD450 crawler loader with log loading forks was used in conjunction with a Nicholson 22-inch Complete Tree Utilizer mobile chipper. The crawler loader was used to assist in feeding material to the chipper and in moving the chipper. This was the same loader used to forward and pile material during the collection phase of the project (see section 4.2 for description). A diagram of the John Deere JD450C with the log loader attachment is shown in Figure 12.

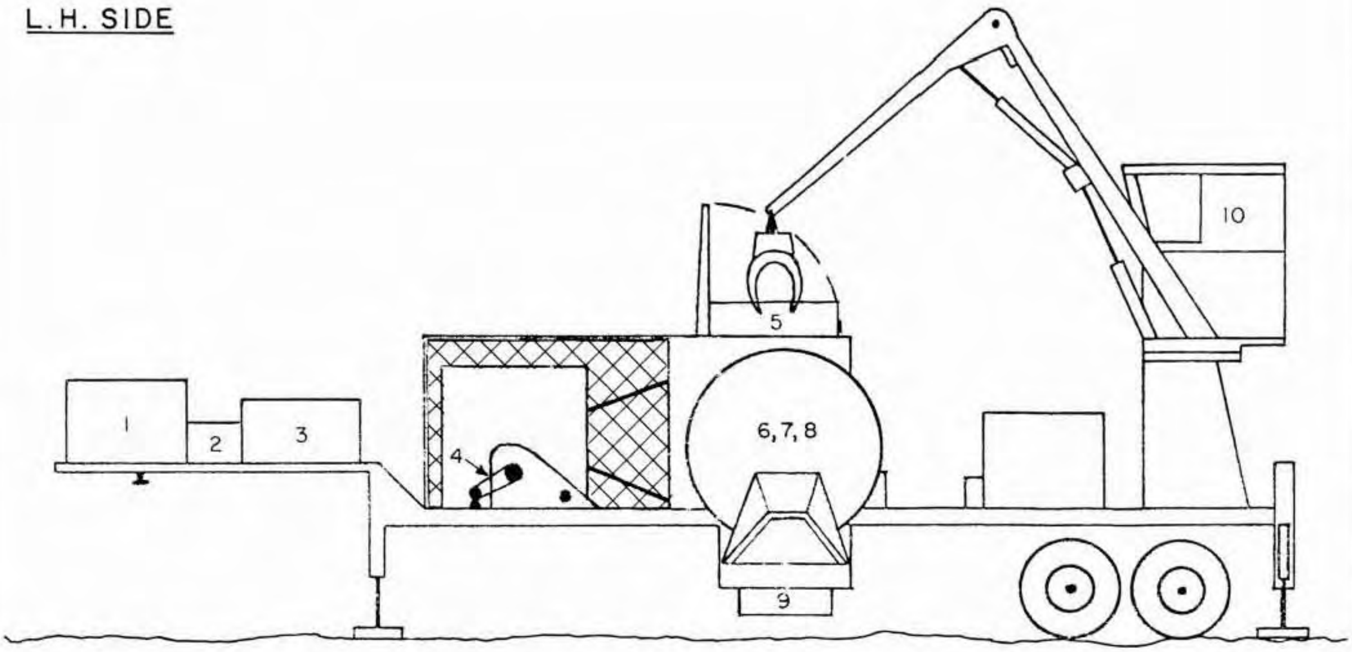
The Nicholson Complete Tree Utilizer (CTU) as shown in Figure 13, is designed to produce woodchips from whole trees, including bark, limbs and small branches. It can handle logs and trees up to 50-55 centimetres in diameter. The infeed opening on the chipper is 56 centimetres. The Complete Tree Utilizer is powered by a Cummins VT-1710-C635 turbo-charged diesel engine with a performance rating of 474 kw. This engine drives a V-drum chipper and a series of

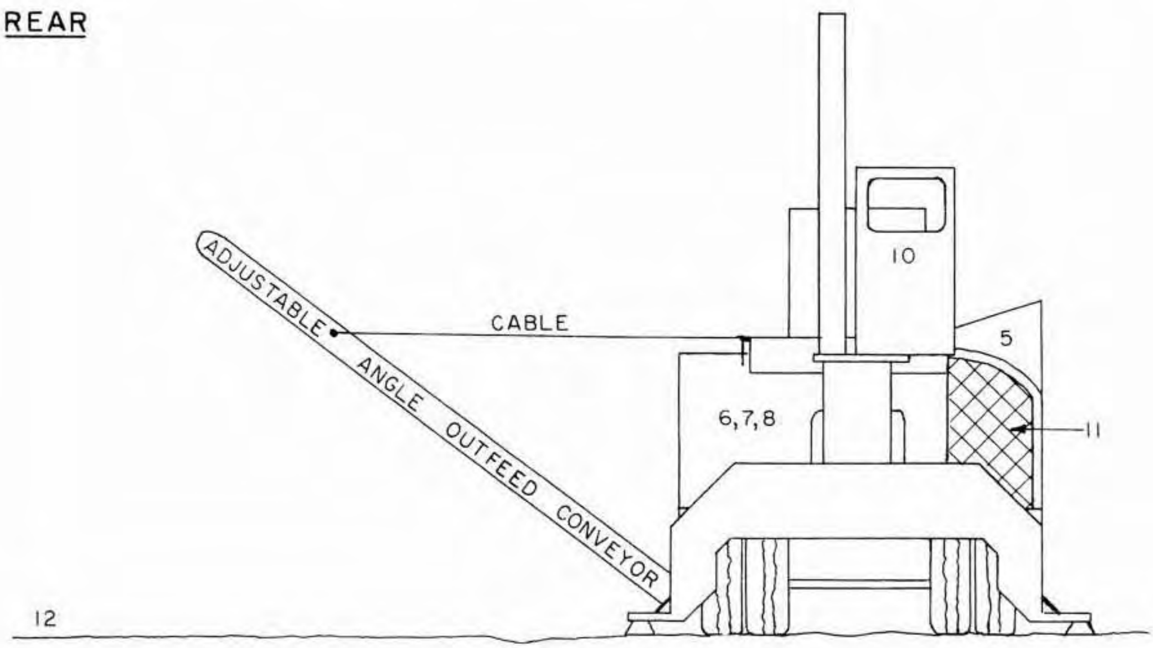
Table 5 - List of Modifications Carried Out on the Bartlett Chipper During the ENFOR Project

Description of Modification	Purpose of Modification
1. Installation of Generator and Electrical Outlets	An auxiliary electrical system was necessary to drive a variety of back-up equipment required to make the chipper more capable of operating independently at remote sites. This back-up equipment was required primarily for knife changes and maintenance.
2. Installation of Water Tank, Pump and Hoses.	Required for cooling chipper knives during grinding; for clean-up and for fire protection.
3. Installation of Air Compressor, Tank and Hoses.	Required for air-impact tools used during knife changes. Air was also used for daily cleaning of radiator screen and air filters and to remove dust and wood shavings from critical areas of the equipment.
4. Installation of an Auxiliary Electric Drum Drive Mechanism and Remote Controls.	Required to turn drum at low speed during inspections and knife changes. Drum was previously turned by hand during knife changes as chipper motor is turned off for safety reasons.
5. Fabrication and Installation of an Angled Chute on the Side of the Infeed Hopper.	Required to assist feeding long pieces of slash into chipper drum.
6. Installation and Subsequent Adjustment of Chip Breakers and Holders	To reduce the average piece size of processed material, a set of two chip breakers was installed at each knife. This was done to produce a size of chip which would comply with the piece size specifications of hogfuel boiler systems and to reduce the chance of blockage of the chipper outfeed. Several adjustments were made to these chip breakers during field trials in an attempt to identify their optimum position in relation to the chipper knives.
7. Modifications to Outfeed Auger Drive Mechanism.	The turning speed of the outfeed auger in relation to the drum speed was altered to reduce blockages.
8. Installation of Safety Guards and Inspection Plates.	A metal housing was fabricated and installed to enclose the drum drive mechanism. This was done to exclude foreign material and for safety reasons. Inspection plates were installed in this housing to enable lubrication and adjustment of key parts. An inspection plate was also installed in the chipper drum to assist in locating the position of drum blockages.
9. Fabrication and Installation of a Chip Spillage Prevention Guard.	This guard was required to reduce spillage of chips at the overlap of the horizontal and angled outfeed conveyors.
10. Installation of an Operator-Ground Crew Communications System.	This system was installed to overcome the effect of engine noise and thus enable the chipper operator to communicate with the ground crew without dismounting from the cab.
11. Modifications to Chipper Drum Drive Mechanism.	These modifications were carried out to increase chipper efficiency. Gear ratios were altered to make allowances for extra drag caused by the addition of chip breakers and to reduce drum blockage problems.
12. Fabrication of a Portable Knife Grinding Bench.	This equipment was required to enable on-site sharpening of knives and chip breakers.

The majority of these modifications were identified and carried out in Vancouver, Washington prior to commencement of field trials. Some minor modifications were done at the project site during the operational testing of the equipment. Comments on the effectiveness of the modifications are contained in Section 5 - Observations and Results. Suggestions for further refinements are contained in Section 6 - Conclusions and Recommendations.

Figure 11 - Modifications to the Bartlett Chipper

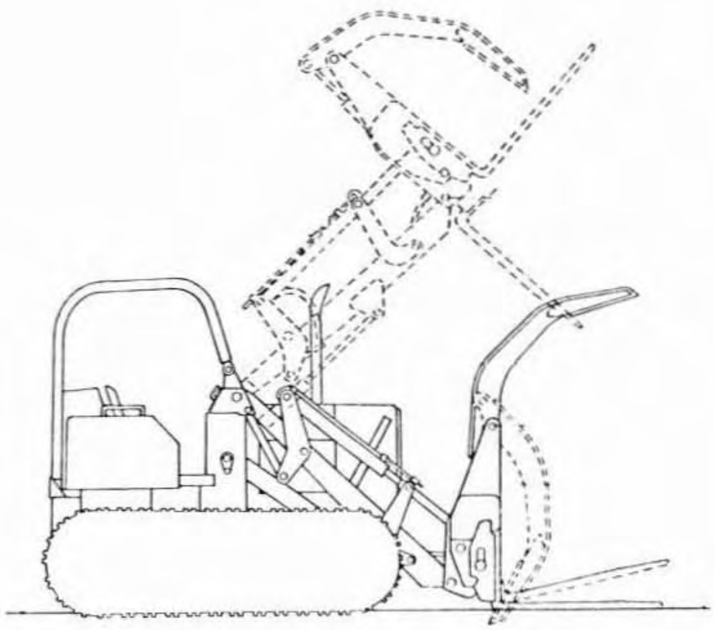




LEGEND

1. Generator & Electrical Outlets
2. Water Tank & Pump
3. Air Compress
4. Electrical Drum Drive for Knife Changes
5. Angled Infeed Chute
6. Chip Breakers (2 per knife) & Holders
7. Outfeed Auger Modifications
8. Safety Guards & Inspection Plates
9. Chip Spillage Prevention Guard
10. Operator - Groundcrew Communication System
11. Drum Drive Mechanism
12. Knife Grinding Equipment Bench (not shown)

Figure 12 - John Deere JD450 with Log Loader

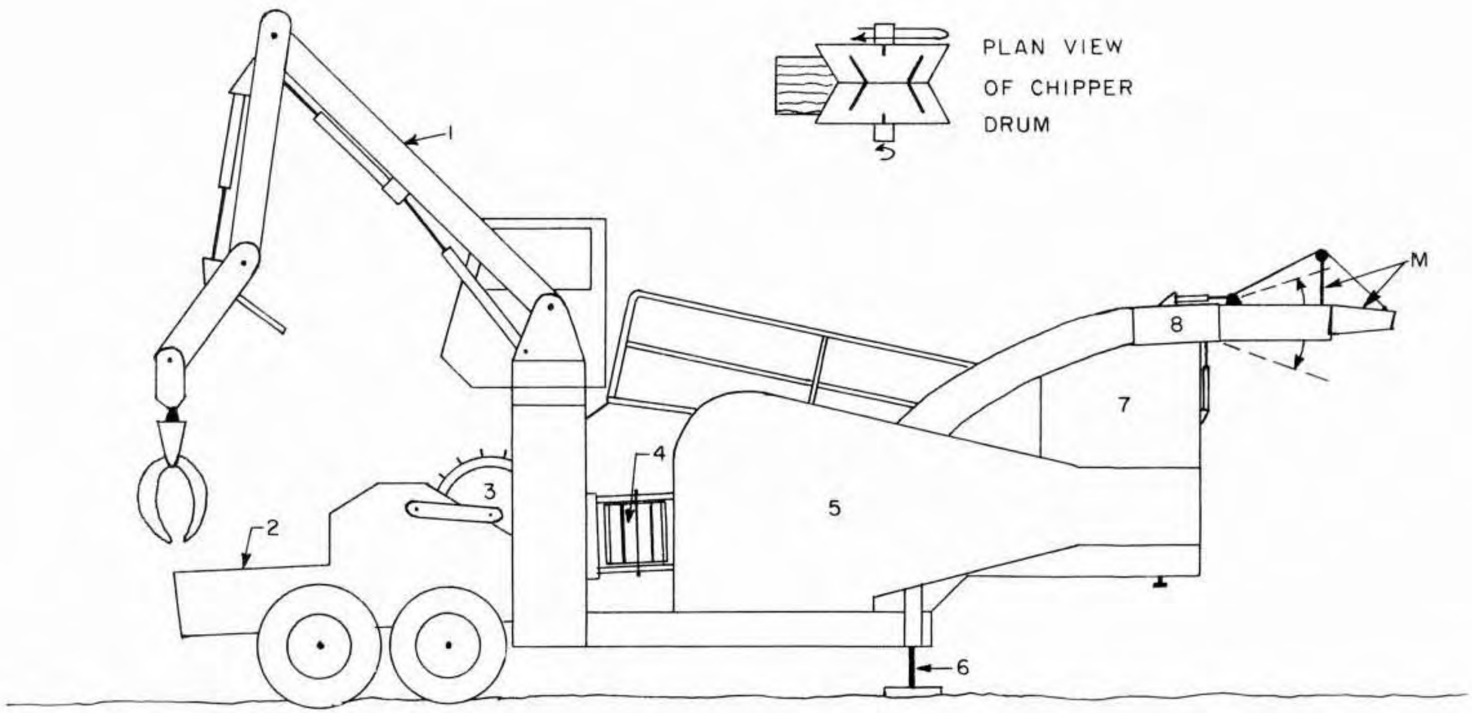


SPECIFICATIONS

Overall Length	4.71 m.
Height	2.43 m.
Weight	8913 kg.
Net Power at 2500 rpm	48.5 kW
Lifting Capacity	2908 kg.

Figure 13 - Schematic Diagram of the Nicholson Chipper

(Not to scale)



LEGEND

1. Hydraulic Log Grapple
2. Horizontal Infeed Conveyor
3. Horizontal Infeed Roller
4. Vertical Side Roller
5. Chipper Drum & Drive Belt Housing
6. Hydraulic Stabilizer
7. Engine
8. Outfeed Chute

M. MODIFICATION – Chip Deflector

hydraulic pumps which power the conveyor, horizontal crush roller, vertical side rollers, chip discharge spout, hydraulic jacks, chipper housing lift, and grapple log loader. The hydraulic system is designed to synchronize all feed works components and is controlled by engine speed. Maximum governed engine speed is 2100 RPM.

The infeed conveyor is equipped with a feed chain and bars which pull incoming wood toward the chipper drum. Maximum feed speed is 30 metres per minute. A horizontal crush roller and two vertical side rollers crush and align the incoming wood for optimum chipping.

The "V" drum chipper contains 3 sets (2 knives per set) of large main knives, each with a 30 centimetre wide cutting edge. These knives are mounted around the surface of the "V" shaped drum. Mounted at the outside edge of the "V" drum are three sets (2 knives per set) of small auxiliary knives. These small knives have an 8.5-centimetre-wide cutting edge and are spaced mid-way between the main knives (see inset, Fig. 13).

Attached to the sides of the drum are four large vanes that scoop and blow the chips into a discharge duct. The end of the discharge duct can be adjusted vertically and horizontally by hydraulic cylinders so that chip discharge can be aimed as required for loading chip vans or trailers. A chip deflector was fabricated and installed on the discharge duct during the field trials. This deflector diverted chip flow downward into the van and could be raised or lowered to direct chips into the front or rear portion of the van.

The total weight of the CTU is approximately 32 tonnes. Approximate travel dimensions are: 3 metres wide, 4 metres high and 11 metres long (16.5 metres, including tractor unit). When pulled by a standard (5th wheel type) tractor unit, the chipper constitutes a legal load and does not require pilot cars or special permits. Standard connections are provided for air brakes and clearance lights.

Fuel tank capacity is 1200 litres. The hydraulic tank contains approximately 1200 litres of hydraulic fluid. The basic electrical system uses two 12 volt batteries connected in a series to provide 24 volts. The hydraulic and air valves that control the feedworks are solenoid operated.

Controls for normal operation are located in the loader cab. A cab mounted tachometer allows the operator to adjust feeding to match engine speed for maximum production and smooth operation. Loader capacity is 3000 kilograms at full reach of about 7 metres.

4.5 Transportation Equipment

The selection of transportation equipment for use on the field trials was governed mainly by availability and convenience. The main aim in carrying out transportation trials was to assess the loading mechanisms of the processing equipment and to obtain some accurate information on the weight and volume produced over a unit of time.

At the Sooke site, a self-dumping gravel truck with a 9-cubic metre load capacity was modified by erection of plywood sides above the box to increase its load capacity to 20 cubic metres. Chips were loaded by positioning the truck under the outfeed conveyor of the Bartlett Chipper, as shown in Figure 14.

At the Cowichan site, a standard chip van was used for transporting the processed material. This van had a load capacity of approximately 50 cubic metres. The truck was loaded from the rear with the chipper discharge duct placed over the top of the van and the chip deflector diverting the chips into the truck box. A net was placed over the top of the van to prevent chip spillage during loading and transportation. The loading position of the Nicholson chipper and chip van is shown in Figure 15.

Sample loads were weighed at Sooke, using portable wheel scales, and at Cowichan, using the truck scale at the Crofton Pulp Mill.

5.0 OBSERVATIONS

5.1 Inventory Results

At both sites, the inventory included all logging residue material greater than 0.6 centimetres in diameter. The average quantity of logging residue on the Cowichan site was 54.96 tonnes per hectare. At the Sooke site, there were 184.69 tonnes of logging residue per hectare. A statistical analysis of these inventory results showed the precision of these estimates to be within the attainable levels of accuracy described in Brown (1974)[1]. To put these residue estimates in perspective, a comparison was made with Jones' (1979) estimates of the amount of sound and rotten logging residues on 42 Vancouver Island sites. The average quantity of residues on these sites ranged from a low of 40 tonnes per hectare to a high of 400 tonnes per hectare. The average for all sites surveyed was 160 tonnes per hectare.

On the Cowichan site, pieces ranged in diameter from 0.6 to 56 cm, on the Sooke site, from 0.6 to 86

[1] The standard errors of the estimates for the two test site inventories were −+19.3% at Cowichan and −+18.5% at Sooke, both at the 95% confidence level. These results are within the attainable limits of −+20% as described in Brown (1974).

Table 6 - Summary of Inventory Results: Quantity of Logging Residues by Diameter Class and Condition[a] (Before Collection)

	Sooke Site		Cowichan Site	
Diameter Class (cm)	**Tonnes per Hectare**	**Percent of Total**	**Tonnes per Hectare**	**Percent of Total**
0.6 - 2.5	4.82	2.6	5.63	10.2
2.6 - 7.6	25.44	13.8	18.02	32.8
7.7 - 27.9 (sound)	42.53	23.0	16.34	29.7
7.7 - 27.9 (rotten)	6.61	3.6	5.40	9.8
28.0 - 53.3 (sound)	18.40	10.0	5.63	10.3
28.0 - 53.3 (rotten)	20.15	10.9	2.15	3.9
53.3 + (sound)	13.70	7.4	0	0
53.3 + (rotten)	53.04	28.7	1.79	3.3
Total	184.69	100.0	54.96	100.0

(a) Logging residue inventory calculations are described in Appendix 2.

Table 7 - Summary of Inventory Results: Approximate Species Distribution of Logging Residues (a)

Sooke Site

Species	Percent
Hemlock	47.5
Balsam	32.0
Cedar	20.5
	100.0

Cowichan Site

Species	Percent
Douglas Fir	87.0
Alder (and other deciduous)	13.0
	100.0

(a) These figures are averages arrived at by estimating the percentage of species distribution by volume on each inventory plot.

Figure 14 - Loading Position of Bartlett Chipper and Chip Truck

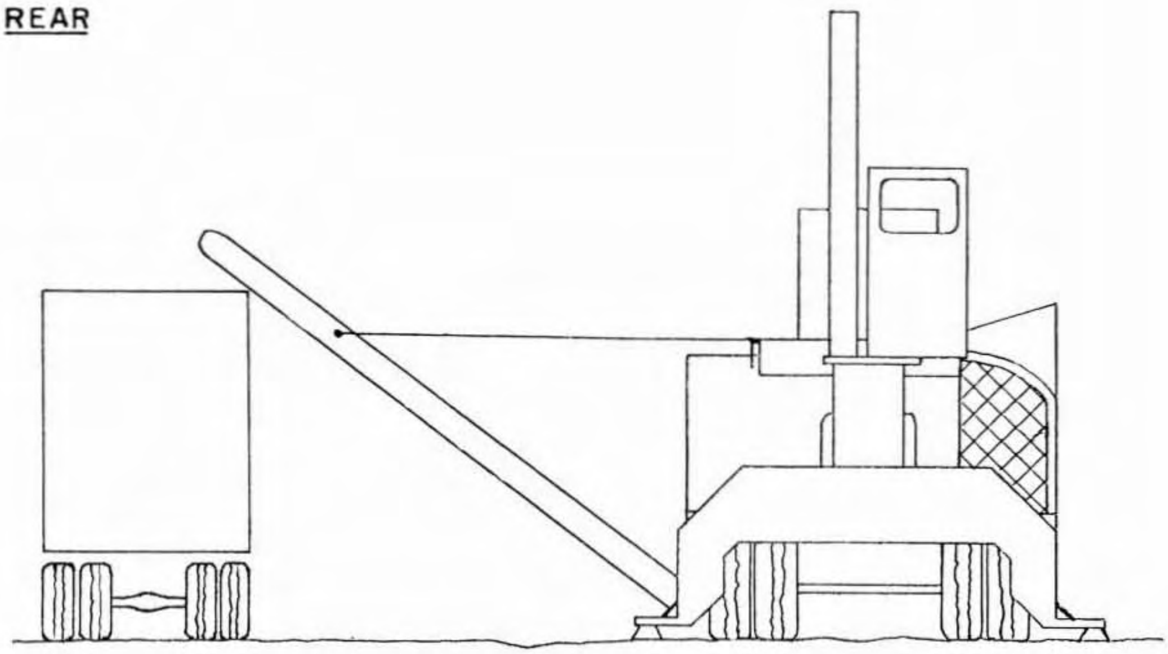
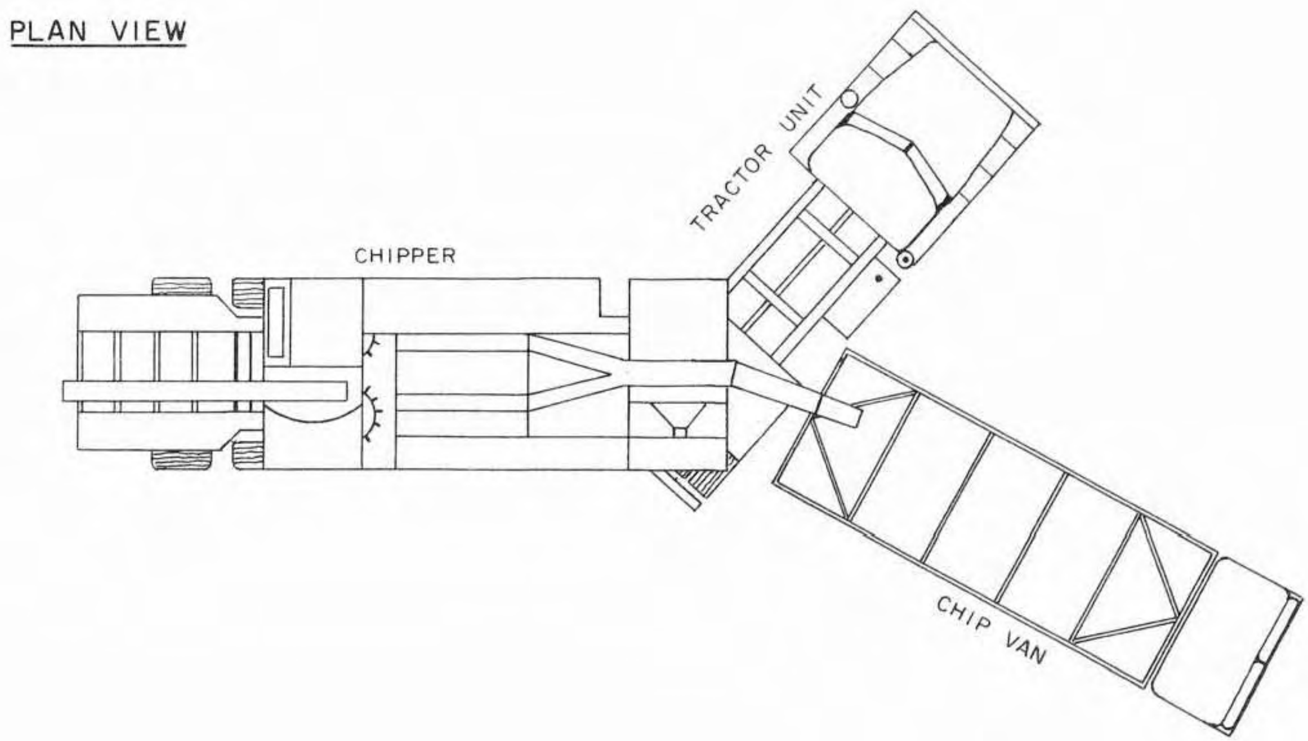


Figure 15 - Loading Position of Nicholson Chipper and Chip Van



cm. Pieces larger than 28 cm in diameter comprised 57% of the residue weight on the Sooke site and less than 18% on the Cowichan site. A detailed breakdown of residue quantities and their percentages by diameter classes is given in Table 6. A rough tabulation of the species distribution of residues on both sites is shown in Table 7.

In summary, the logging residue inventory showed a total of approximately 55 tonnes per hectare at the Cowichan site and approximately 185 tonnes per hectare at the Sooke site. The average piece diameter was about 50 centimetres at Sooke, whereas at Cowichan, the average piece diameter was about 20 centimetres.

Following collection of the logging residues into piles, a reinventory was carried out to determine the quantity remaining on the site. The results of this reinventory was described in Section 5.2 (c).

5.2 Collection and Assembly

a. Sooke Site

Collection of residue material from the Sooke site began in the latter part of May. The ground conditions at the time of clearing were not favorable, due to heavy rains prior to and during clearing operations. The crawler loader equipment with the log loading forks was stuck and unavailable for 3.4% of the total time. This lost time could have been avoided if the tractor had been equipped with growsers. The wet weather conditions also greatly increased the amount of soil and other inorganic material present in the collected material.

A large number of pieces were too big to handle with the brush blade or log forks. These pieces had to be skidded, using the winch line and chokers. Approximately 20% of the total machine time incurred was spent on skidding material to the roadside.

The total project area covered 2.02 hectares. Of this, residual material was collected from 1.90 hectares. The uncleared area of 0.12 hectares consisted of inaccessible swampy areas. A total of 102 machine-hours were spent in clearing the 1.90 hectares for a total collection cost of $2,995.

The average area cleared per machine-day was 0.15 hectares. The average cost was $9.10 per tonne collected at roadside.

b. Cowichan Site

The collection of logging residues began on the Cowichan site in early June under very favorable weather conditions. The site was dry at start-up and no rain occurred during the collection period. These conditions resulted in good equipment availability and productivity.

Dry conditions also helped to reduce the amount of dirt and other inorganic material present in the collected residues. On the Cowichan site, it was not necessary to use the winch line as the small material could be handled by the brush blade and log forks.

The total project area covered 10.48 hectares. Of this, residue material was collected from 8.1 hectares. The uncleared 2.38 hectares consisted of 0.38 hectares of inaccessible swampy areas and 2.0 hectares of root rot sample plots which were not disturbed.

A total of 87.5 machine-hours were spent clearing the 8.1 hectares for a total collection cost of $2,225.

The average area cleared per machine-day was 0.74 hectares. This varied with slope, collection distance and soil conditions. The average cost was $5.89 per tonne collected. Productivity and cost per collected tonne for both sites are summarized in Table 8.

Collection costs at the Sooke site were 50% higher than at the Cowichan site. Reasons for this difference were:

- Steep topography, high stumps and deep, wet soils limited equipment mobility at Sooke, thus reducing productivity and increasing costs.
- A number of large pieces were encountered at Sooke. These pieces had to be skidded to the road side, using the tractor winch. The extra time required to set and unhook chokers and to repair broken winch lines reduced productivity.
- At Sooke some additional material (mainly stumps not included in the original inventory)

Table 8 - Summary of Collection Productivity and Cost

Item	Average Daily Production Sooke	Average Daily Production Cowichan
Average area cleared per machine-day	0.15 hectare	0.74 hectare
Average quantity collected per machine-day	25.9 tonnes	34.5 tonnes
Cost per collected tonne	$9.10	$5.89

was collected inadvertently with the logging residue material. The time spent on this material could not be identified and was excluded from the cost calculations.

c. Reinventory

Both test sites were reinventoried following the collection of logging residues to assess the degree of recovery achieved. Total logging residue weight of all material greater than 0.6 cm in diameter remaining on the Cowichan site was 8.33 tonnes per hectare. The equivalent logging residue weight remaining on the Sooke site was 11.51 tonnes per hectare. The standard errors of these estimates were higher than those calculated for the original inventory. This was due to the high diversity in amount and distribution of downed material after clearing. An increase in sampling intensity to improve the precision of these estimates was not possible, due to the limited area of the test sites. Plots spacing had to be at least double the length of the transect lines in order to avoid overlaps in sampling.

On the Cowichan site, the amount of material remaining was less than at Sooke. This was because the smaller stumps and relatively flat topography at Cowichan resulted in increased equipment maneuverability, making it possible to retrieve more of the logging residue material.

At Sooke, the portion of original material collected was higher than at Cowichan. Based on the original inventory, 94% of the material was collected at Sooke; compared to 85% at Cowichan. This was due to the fact that the portion of material recovered was greater in large diameter material than in small material. This is illustrated in the summary of inventory results shown in Table 9.

The quantity of material actually collected may be slightly greater than indicated in Table 9, due to the fact that some land firm stumps and buried material not tallied in the original inventory were inadvertently collected along with the logging residues. On the other hand, some of the collected material was lost to wood cutters and salvage loggers during the time interval between collection and processing. It was not possible to determine the net effect of these additions and losses.

On the Cowichan site, where 8.1 hectares were cleared, the maximum attainable volume would have been 445 tonnes. The actual volume collected according to the reinventory was 378 tonnes. On the Sooke site, where 1.9 hectares were cleared, the maximum attainable volume would have been 351 tonnes. The actual volume collected according to the reinventory was 329 tonnes.

5.3 Processing

a. Sooke Site

Processing trials were carried out over a 12 day period at Sooke, using the Bartlett stump splitter and chipper. The system was able to handle the majority of piece sizes and types encountered, with the exception of small branch and top material which tended to pass through the chipper drum without being completely chipped. Portions of branches deposited onto the outfeed conveyor became tangled in the drive sprockets and chains, resulting in frequent blockage of the outfeed mechanism. This inability to chip small diameter material was one of the main limitations of the Bartlett chipper.

Table 9 - Summary of Inventory Results Before and After Collection

Diameter Class and Condition	**Quantity of Logging Residues by Diameter Class**							
	Cowichan Site				**Sooke Site**			
	Before Collection	**After Collection**	**Quantity Collected**		**Before Collection**	**After Collection**	**Quantity Collected**	
(cm)	(tonnes/ha)	(tonnes/ha)	(tonnes/ha)	(%)[1]	(tonnes/ha)	(tonnes/ha)	(tonnes/ha)	(%)[1]
0.6 - 2.5 (sound)	5.63	1.86	3.77	67	4.82	1.35	3.47	72
2.6 - 7.6 (sound)	18.02	4.04	13.98	78	25.44	5.07	20.37	80
over 7.6 (sound)	21.97	1.35	20.62	94	74.63	4.17	70.46	94
over 7.6 (rotten)	9.34	1.08	8.26	88	79.80	0.92	78.88	99
Total	54.96	8.33	46.63	85	184.69	11.51	173.18	94

[1] Percent of original material on the site before collection.

Another major factor limiting the effectiveness of the chipper was the lack of a self-feeding mechanism for long material. An infeed chute was fabricated and installed on the side of the hopper to support longer pieces during feeding. However, they frequently had to be pushed into the drum, using the grapple loader. This occupied a large portion of the operator's time. A self-feeding mechanism would enable the grapple to spend more time sorting and preparing material for feeding.

The installation of chip breakers in the chipper knives resulted in substantially reduced chip size (see photographs in Appendix 3). Some adjustments were required to achieve the optimum positioning of the chip breakers in relation to the main chipper knives. It was found that when the chip breaker cutting edges were mounted flush with the knife edges, material would not feed readily into the chipper drum. This situation was improved by recessing the chip breakers about a centimetre lower than the chipper knives so that the chipper knife made contact with the wood prior to the chip breaker. The knife then tended to pull the material into the drum, resulting in a faster feed rate.

The outfeed conveyor system performed reasonably well, although its position at the side of the chipper required an extra wide road width (9 metres) for loading a truck. A chip spillage problem on the outfeed system was overcome by installing a flap at the intersection of the two conveyors.

A number of rocks were accidentally fed into the chipper, causing excessive knife wear. This problem was reduced by making more use of the stump splitter and by using the chipper's log loader to shake and drop the material prior to feeding it into the chipper.

Productivity dropped substantially when the chipper knives became dull. Dull knives often resulted in long fibrous chips, which tended to foul the drum, auger and conveyor works. Best results were obtained by changing the chipper knives daily. Attempts to resharpen the knives while on the drum, using a portable disc grinder, proved ineffective. Excessive heat generated by this type of sharpening actually resulted in increased knife wear, due to loss of temper.

The addition of an electric generator, air compressor and water system proved very useful in speeding up the knife changing operation. The electric drum drive enabled the knife changing crew to position the drum quickly and accurately. Dull knives were replaced, using air impact tools. The knife grinding bench was used for on-site sharpening of knives and chip breakers. During grinding operations, knives were cooled with a fine water spray to prevent over-heating. The water system also proved useful for fire protection during cutting and welding operations and during periods of high fire hazard.

The stump splitter proved a useful tool for reducing stumps to small sized pieces and for removing dirt and rock entrapped in the root systems. However, it was not as effective as anticipated in cutting long bole sections into smaller lengths. This was mainly due to the fact that the guides were so worn that the splitter blades did not mesh correctly. Stumps and rotten windfalls were cut with little problem but sound stem sections were difficult to cut with the stump splitter. Eventually a chainsaw was used to cut long stems into shorter lengths.

Originally it was planned to exchange the stump splitter attachment periodically for a brush grapple attachment for carrying material to the chipper. However, this was not done because there was sufficient material within the reach of the chipper unit's grapple loader to keep the chipper supplied. From time to time the splitter unit was used to extract large material from the piles and simultaneously split and carry this material to the chipper.

The stump splitter could split material much faster than it could be processed by the chipper. As a result, the stump splitter unit was vastly underutilized. It was only productive 21% of the total time spent on processing trials.

Many mechanical problems were experienced with the Bartlett chipper, some of which were due to a general lack of planning and organization on the part of the operating crew. Others were due to the experimental nature of the equipment. The chipper was non-productive during almost half of the elapsed time, because of maintenance and repairs. The majority of this non-productive time was spent in rectifying a variety of problems in the hydraulic, electrical and drive train systems.

A complete breakdown of stump splitter and chipper machine time utilization is shown in Tables 10 and 11.

During the field trials, the quantity of processed material produced was measured. In 12 days of field trials, a total of 102 tonnes of processed material were produced. Total production was related to the productive machine time shown in Table 11. Average production per productive machine hour was 3.2 tonnes. Average daily production was 8.5 tonnes. If part days are excluded, including the first and last day when setup and demobilization were involved, the average daily production would be 10.76 tonnes. This ranged from a low of 4 tonnes per day to a high of 19

Table 10 - Sooke Processing Trials Machine Time Summary [a]

Bartlett Splitter

Time Element Classification	Function	Percent of Time Element Classification		Percent of Total Elapsed Time	
Productive Time	Splitting		17.8		3.7
	Forwarding		47.2		9.7
	Splitting/Forwarding (simultaneous)		15.0		3.1
	Sorting		0.4		0.1
	Road and Landing Maintenance		19.6		4.1
Subtotal		100	(17 hours)		20.7
Non-productive Time - Mechanical	Service and Warm-up		73.9		2.4
	Repairs		15.5		0.5
	Other		10.6		0.4
Subtotal		100	(3 hours)		3.3
Non-productive Time - Non-mechanical	Consultation		1.5		1.1
	Personal		0.1		0.1
	Lunch/Coffee		7.2		5.5
	Waiting (Enging Running)[b]		15.8		12.0
	Idle [c]		73.4		55.8
	Travel		2.0		1.5
Subtotal		100	(62 hours)		76.0
Total				100	(82 hours)

(a) Based on approximately 82 hours spent on the project site over a 12-day period.
(b) Waiting for another phase of the operation.
(c) Machine not required.

Table 11 - Sooke Processing Trials Machine Time Summary [a]

Bartlett Chipper

Time Element Classification	Function	Percent of Time Element Classification		Percent of Total Elapsed Time	
Productive Time	Chipping		93.0		34.8
	Sorting		0.6		0.3
	Other		6.4		2.4
Subtotal		100	(32 hours)		37.5
Non-productive Time - Mechanical	Service and Warm-up		24.3		11.1
	Repairs		42.5		19.3
	Jams (drum or conveyor)		9.7		4.4
	Knife Changes [b]		23.5		10.7
Subtotal		100	(39 hours)		45.5
Non-productive Time - Non-mechanical	Consultation		4.3		0.8
	Personal		2.4		0.4
	Lunch/Coffee		31.3		5.3
	Waiting		16.6		2.8
	Travel and Setup		40.7		6.9
	Miscellaneous		4.7		0.8
Subtotal		100	(15 hours)		17.0
Total				100	(86 hours)

(a) Based on approximately 86 hours spent on the project site over a 12-day period.
(b) Includes sharpening knives in place on drum.

tonnes per day.

Average unit costs for the processing operation were calculated, using the actual contract rate (per operating hour) and the number of operating hours incurred. Operating hours include productive machine time plus a portion of the non-productive machine time. Repairs, maintenance, knife changes and personal breaks are not included in operating time. A summary of cost and production for the Sooke processing operation is shown in Table 12.

The above table indicates a unit processing cost of $70.10 per tonne. These costs do not include the cost of modifications to equipment, transportation of equipment to and from the project site, and accommodation provided for the operators and crew. The contractor's hourly rate did not include fuel. This item was provided at extra cost and is shown as a separate item in the table.

The aforementioned costs are based on operating hours only. The very high non-productive time associated with the Sooke processing trials is not reflected in these costs. If the equipment has been leased or rented on a full-time basis and labor hired to operate this equipment, the unit costs of processing would have been much higher.

b. Cowichan Site

Processing trials at the Cowichan Site were carried out over a period of 13 days. Material was processed using a Nicholson (22-inch) mobile chipper. A small crawler loader (J.D. 450) assisted the chipper by forwarding material which was outside the reach capacity of the chipper's log loader. The crawler loader operator acted as ground man for the chipper, carrying out such functions as:

- cutting off roots and oversized stems with a chainsaw
- assisting during knife changes
- freeing jammed material in the infeed and outfeed works
- assisting during chipper moves.

Additional equipment used during the processing trial included a crawler tractor to build access roads to residue piles located away from the existing logging road and a 50-cubic-metre chip van to haul processed material during transportation trials. The system operated very well, particularly considering that the operating crew had no previous experience in this type of work.

The crawler loader proved very useful for carrying material to the chipper. This substantially reduced the number of chipper moves required. The crawler loader also assisted during chipper moves on rough terrain and kept the roads and landings around the chipper free of debris.

The Nicholson Chipper performed well, with virtually no mechanical breakdowns except for broken hydraulic lines on the grapple loader. The system was able to handle the majority of piece sizes and types encountered. Several large, oversized pieces were split, using the log loader forks of the J.D. 450. Root systems were bucked off with a chain saw. This was done to eliminate rocks which were often imbedded in the roots. Loose rocks, mixed in with the piled material, were removed by lifting and shaking the material with the J.D. 450 and then lifting and dropping with the hydraulic grapple prior to feeding onto the chipper infeed conveyor. In spite of these precautions, the occasional rock did get into the conveyor. When this happened, the operator reversed the conveyor to reject the rock from the system. Several small rocks and one choker went through the chipper during the trials, causing excessive damage to the chipper knives. However, it was possible to resharpen the knives and continue to use them. One knife was broken and could not be reused.

Table 12 - Sooke Processing Trials: Summary of Production and Costs

Item	Hourly Rate	Operating Hours	Cost Incurred	Production (Tonnes)	Unit Cost ($/Tonnes)	Portion of Total (%)
Bartlett Splitter with Operator	$ 50	42	$2,100	102	$20.59	29.4
Bartlett Chipper with Operator and Ground Crew	$100	46	$4,600	102	$45.10	64.3
Cost of Fuel			$ 450		$ 4.41	6.3
Total			$7,150		$70.10	100.0

Table 13 - Cowichan Processing Trials
Machine Time Summary[a]
J.D. 450 Log Loader

Time Element Classification	Function	Percent of Time Element Classification		Percent of Total Elapsed Time	
Productive Time	Forwarding		70.7		22.0
	Sorting		3.1		0.9
	Reject Material Removal		4.4		1.4
	Road and Landing Maintenance		15.3		4.7
	Assisting Chipper Move		5.9		1.8
	Splitting Oversized Logs		0.6		0.2
Subtotal		100	(33 hrs.)		31.0
Non-productive Time - Mechanical	Service and Warm-up		30.6		1.0
	Repairs		68.9		2.3
	Other		0.5		0.0
Subtotal		100	(4 hrs.)		3.3
Non-productive Time - Non-mechanical	Consultation		1.0		0.7
	Personal		0.1		0.0
	Lunch/Coffee		18.7		12.3
	Travel		2.3		1.5
	Waiting[b]		15.8		10.4
	Idle[c]		62.1		40.8
Subtotal		100	(70 hrs.)		65.7
Total				100	(107 hrs.)

[a] Based on approximately 107 hours spent on the project site over a 13-day period.
[b] Waiting for another phase of the operation.
[c] Machine not required: operator working as groundman.

Table 14 - Cowichan Processing Trials
Machine Time Summary[a]
Nicholson Chipper

Time Element Classification	Function	Percent of Time Element Classification		Percent of Total Elapsed Time	
Productive Time	Chipping		26.9		12.0
	Sorting and Feeding		73.1		32.6
Subtotal		100	(48 hrs.)		44.6
Non-productive Time - Mechanical	Service and Warm-up		21.7		4.9
	Repairs		18.3		4.1
	Jams		30.2		6.7
	Knife Change		29.8		6.7
Subtotal		100	(24 hrs.)		22.4
Non-productive Time - Non-mechanical	Consultation		12.8		4.2
	Personal		0.8		0.3
	Lunch/Coffee		31.3		10.3
	Waiting		19.8		6.6
	Travel		28.9		9.5
	Setup		4.2		1.4
	Knife Inspections		2.2		0.7
Subtotal		100	(36 hrs.)		33.0
Total				100	(108 hrs.)

[a] Based on approximately 108 hours spent on the project site over a 13-day period.

As with the Bartlett Chipper, small branches and tops were difficult to process. A steady feeding of small pieces generally resulted in a blocked infeed roll, due to broken pieces jamming between the roll and the chipper drum. The infeed rolls rejected a considerable amount of this short, broken material, which collected in piles at the side of the machine. The infeed roll blockage problem was eventually overcome by alternating the type of material being fed onto the infeed conveyor. From time to time, large pieces (windfalls or large saplings) were fed in to clear out the small chunks which tended to collect in the space between the infeed roll and the chipper drum.

During the field trials, the operator found that when engine speed dropped below 1500 RPM, there was insufficient blowing power to carry chips up through the discharge spout. This often occurred when chipping large windfalls and when chipper knives were excessively dull. The result of this loss of blowing power was a blockage of chips in the discharge duct when the operator continued to feed material into the chipper. It was found that by stopping the infeed works and allowing engine RPM to recover, the blockage problem could be avoided. A blocked outfeed duct required from 1 to 2 hours to clear.

Due to the fact that the crawler loader was not required full-time and the operator worked part of the time as a groundman, the loader was engaged only in productive functions about one-third of the time. The remainder of the time it was idle or waiting while the operator performed other duties.

The Nicholson Chipper was productively engaged for about half the available time on the project. The remainder of the time was spent on a variety of maintenance and repair items and moving between logging residue piles. Only 4% of the total time was spent on repairing mechanical breakdowns. Knife maintenance and clearing of jammed infeed or outfeed works each accounted for about 7% of the total time. A complete breakdown of chipper and crawler loader time utilization is shown in Tables 13 and 14.

The machine time summary for the Nicholson chipper shows that it was productive for about half the total elapsed time on the project. Only 27% of this productive time was spent on chipping. This percentage was derived by measuring and recording the total time during which chips were actually flowing from the outfeed duct. The remainder of the productive time was composed of sorting, loading and feeding functions.

Attempts were made to measure quantities of processed material produced in relation to chipping time. The Nicholson chipper outfeed blower spread the processed material over a wide area, making accurate measurement of the quantity produced very difficult. Chip piles were measured on selected sites where topography resulted in a more concentrated accumulation of chips. In addition to these measurements, an accurate measure of quantities produced were obtained during the loading of six chip vans over a 3-day period. A calculation of quantities produced over unit time, using both pile measurements and chip van measurements, indicates an average production of 76.5 cubic metres per chipping hour[1]. Chip vans were weighed to determine the average density of this processed material. The average density, based on weighing vans at Crofton, was 228.3 kilograms per cubic metre (14% greater than the density of material processed by the Bartlett chipper, mainly due to compaction caused by the blower). Based on this density, the average productivity was 17.5 tonnes per chipping hour[1] (4.7 tonnes per productive machine hour).

The total quantity processed during the 13 days of field trials was 994.5 cubic metres of 227 tonnes. Average daily production was about 17.5 tonnes, ranging from a low of 12 tonnes per day to a high of 26 tonnes per day.

Average unit costs for the processing operations were calculated by using the rental rates for the equipment used and the actual operating costs incurred for labor, fuel and other items. A summary of cost and production for the Cowichan processing operation is shown in Table 15.

Table 15 indicates a total collection and processing cost of about $70 per tonne. Costs of modifications to equipment, transportation of equipment to and from the project site and costs associated with setting up the project are not included in these costs.

c. Summary of Processing Efficiency

Following processing trials, unprocessed material remaining in chipper landings was examined to determine the type and quantity of this material. The material remaining was composed of:

At Sooke site - Small diameter branches and tops
- Short broken pieces of all diameters

At Cowichan site - Small diameter branches and tops
- Short broken pieces of all diameters
- Large and misshapen pieces over 55 cm in diameter

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[1] Chipping hour refers to the time function "Chipping" in the Machine Time Summary.

Table 15 - Cowichan Processing Trials: Summary of Production and Cost

Item	Daily Rate	Operating Days	Cost Incurred	Production (Tonnes)	Unit Cost ($/Tonne)	Portion of Total (%)
Chipping						
Nicholson Chipper						
Rental	$530[a]	13	$ 6,890			
Operator	125	13	1,625			
Knife Maintenance	—	—	710			
Fuel and Lubricants	—	—	709			
Maintenance and Repairs			243			
Subtotal			$10,177	227[c]	$44.83	64
Kenworth Truck (for moving chipper)						
Rental	$ 60	13	$ 780	227	3.44	5
Other Equipment						
Chain Saw	$ 25	13	325			
Pick-up/fuel tank	$ 25	13	325			
Subtotal			$ 650	227	2.86	4
Subtotal - Chipping			$11,607	227	$51.13	73
Forwarding						
J.D. 450 Loader						
Rental	$200	13	$ 2,600			
Operator[b]	80	13	1,040			
Subtotal - Forwarding			$ 3,640	227	$16.04	23
Access Roads						
Cat D8 Tractor						
Rental	$600	1	$ 600	227	$ 2.64	4
Total			$15,847	227	$69.81	100

(a) Based on monthly lease rate of $9,920 (U.S.) ($11,656 Can.) and a standard 22-day working month.

(b) Loader operator worked about 40% of his time as groundman for chipper.

(c) Of the 227 tonnes produced, only 210 tonnes were processed from material collected during the project. The remaining 17 tonnes were processed from material that had been collected during logging operations and left in landings.

Table 16 - Estimated Portion of Collected Material That Could be Processed Efficiently

Diameter Class (centimetres)	Portion of Collected Material Processed	
	Sooke Site	Cowichan Site
	%	%
0.6 - 2.5	20	20
2.6 - 7.6	70	70
7.7 - 27.9	80	80
28.0 - 53.3	90	90
53.3 +	95	50
Weighted Average (a)	85	70

(a) Weighted by quantity of residue material in each diameter class.

Table 17 - Collection and Processing Efficiency Factors

Diameter-Class (cm)	Sooke Site Collection Efficiency Factor	Sooke Site Processing Efficiency Factor	Sooke Site Combined Recovery Factor	Cowichan Site Collection Efficiency Factor	Cowichan Site Processing Efficiency Factor	Cowichan Site Combined Recovery Factor
0.6 - 2.5	0.72	0.20	0.14	0.67	0.20	0.13
2.6 - 7.6	0.80	0.70	0.56	0.78	0.70	0.55
7.7 - 27.9	0.97	0.80	0.78	0.91	0.80	0.73
28.0 - 53.3	0.97	0.90	0.87	0.91	0.90	0.82
53.3 +	0.97	0.95	0.92	0.91	0.50	0.46
Weighted Average	0.94	0.85	0.80	0.85	0.70	0.60

- Stumps and root systems containing imbedded rocks

As with the collection phase, the portion of the available material that could not be handled increased as the piece size decreased. In general, the Bartlett chipper was more capable of handling short pieces than the Nicholson chipper. Neither machine could efficiently handle large quantities of branch material. Many branches simply went through the chipper and came out in their original form. Estimates of the portion of material that could be handled efficiently by the processing systems, are presented in Table 16. These estimates are based on observations made during processing trials and on examination of unprocessed residues.

The remainder of the collected material could not be processed efficiently, due to the inability of the system to handle certain types of material. The extra feeding time and non-productive time, due to blockages incurred in processing this material, were out of proportion to the amount of material produced. Although the Nicholson chipper used at the Cowichan site could not handle material greater than 55 centimetres, a portion of this material (50%) could be processed by being split into small pieces using the crawler loader forks, and fed into the chipper.

d. Recovery Factors

A combined recovery factor was developed to relate the original quantity of logging residues on the test sites to the quantity of processed material that could be expected to be recovered. The basic equation used is shown below.

As the collection and processing efficiency factors varied with the size of material, this equation would be applied separately to the quantity of material in each diameter class.

Table 17 lists factors for predicting the quantity of processed material that could be produced from a known quantity of logging residues. These factors were combined to give a weighted average recovery factor based on the quantities of material measured during the trials at Sooke and Cowichan.

In cleanly logged typical second growth Douglas-fir stands on flat sites, one can expect to salvage and process about 60% of the total amount of loose forest residues, using the methods described in this report. In decadent old-growth Hemlock, Balsam and Cedar stands on moderate slopes, one can expect to salvage and process about 80% of the total amount of loose forest residues using the methods described in this report.

To check these factors against actual operating experience, a rationalization of source material versus processed material for the Cowichan processing trials was made, using the factors in Table 17.

Example of Combined Recovery Factor applied to the Cowichan Site:

Forest residue loading according to inventory (Before Collection) 55 tonnes/ha

Area from which residues were collected 8.1 ha

$$\text{Processed Material (tonnes)} = \text{Logging Residues as Inventoried (tonnes)} \times \text{Collection Efficiency Factor} \times \text{Processing Efficiency Factor}$$

Deductions for residues not processed[1]	1.0 ha
Net area from which processed residues were collected	7.1 ha
Total material available for collection and processing	390 tonnes
estimated Processed Material recovery according to Factors in Table 17	234 tonnes
Actual Processed material produced from material collected	210 tonnes
Difference (Estimated minus Actual)	24 tonnes

Using the conversion factors from Table 17 to predict the quantity of processed residues that would be obtained from the Cowichan site resulted in a 24 tonne (10%) overestimate when compared to the quantity of processed material actually produced from collected material. This error in estimate is primarily due to collected residues that were cut from the piles by fuel wood cutters over the time period between collection and processing. An additional source of error could be in the processing efficiency factors, which were based on estimates rather than measurements.

A rationalization of the quantity of processed material in relation to the quantity of logging residues collected was not possible at the Sooke site. This was due to the fact that only a small portion of the total material collected was actually processed. It was not possible to relate the residues processed to the area from which they were collected.

5.4 Transportation

a. Sooke Site

During the transportation trials carried out at Sooke, the angled conveyor outfeed system of the Bartlett chipper was used to load trucks parked alongside the chipper. A road width of about 9 metres was required. This limited the use of the truck-loading system to landings and road junctions where sufficient road width was available.

The outfeed end of the conveyor can be raised to a maximum height of about 4 metres. To achieve an even load distribution during the filling operation, the end of the conveyor should be placed over the mid-point of the van. This limits the system to loading trucks with a maximum side height of about 3.5 metres.

During 2 days of transportation trials, six loads of processed material were transported over a distance of 1 kilometre to a dumping point, using a modified gravel truck. By the addition of plywood sides extending above the standard 9-cubic-metre box, the load capacity was increased to about 20 cubic metres. The average load carried during the transport trials was 18.5 cubic metres. Weights taken during the transport trials indicated an average payload of 3.7 tonnes. The average density of the processed material was calculated to be 200 kilograms per cubic metre.

As the transportation distance was very short (1 km) and the truck was not designed for hauling logging residue material, costs incurred during the Sooke transportation trials were not representative of costs under operational conditions.

Some difficulty was experienced in dumping the processed material. This was due to the "stringy" nature of the chipped material, which tended to cling together and resist the tendency to slide easily from the truck box. However, it was possible to dump the loads by using the momentum of the truck travelling in reverse combined with a sudden application of the brakes.

b. Cowichan Site

During the 3 days of transportation trials at Cowichan, a total of six chip van loads of processed material were transported to Crofton Pulp Mill. The average round trip time per load was 3.6 hours, of which 2.3 hours was loading time and 0.8 hours was round trip travel time for the 24 kilometre distance between the processing site and the mill. The remainder of the time was divided between positioning the van under the chipper and dumping and weighing at Crofton.

Vans loaded during the transportation trials averaged a net payload weight of 8.9 tonnes. A total of 53 tonnes of chips were transported during the 3-day period.

Chip vans were loaded by positioning the van behind the chipper and placing the outfeed duct over the back of the van. The force of the blower resulted in an initial concentration of chips toward the front of the van, followed by a spillage of chips when the front portion of the van was full. Attempts were made to overcome this problem by placing a net over the top of the van to prevent spillage and by attaching a deflector to the end of the outfeed duct to deflect chips into the centre and rear of the van. These measures were only partially successful. Spillage was reduced to an acceptable level but the van continued to be unevenly loaded, resulting in under-utilization of the available capacity. The van, which had a nominal capacity of 50 cubic metres, could only be filled to about 80% of capacity due to uneven load dis-

[1] Includes residue piles burned in an accidental fire that occurred during the processing trials.

tribution. Because the van was rented on a short-term basis, it was not possible to carry out any major modifications. However, it appeared that an opening cut in the back of the van to accommodate the chipper outfeed duct would have been useful. A closed topped van with an opening across the top of the rear door for the chip outfeed duct would have been the ideal vehicle for use with the Nicholson chipper.

The in-line loading system of the Nicholson chipper enables loading to be carried out on virtually any road with a width of 3 to 4 metres. If the truck which pulls the chipper is to be left under the chipper's fifth-wheel during loading, it must be "cocked" to an angle to permit the van to back under the outfeed duct. This requires an additional road width of 2 to 3 metres. An alternative to "cocking" the truck would be to use a detachable outfeed duct extension to blow chips over the chipper-truck and into the van. A 3-to-5 metre long extension would be required, depending on the type of truck being used. According to the manufacturer, there would be sufficient blower force to prevent blockages in this extension duct. However, this was not attempted during the field trials. Experience gained during the trials indicates that the extension duct should be horizontal or downward sloping to minimize the possiblity of blockages.

During the field trials, the chipper either blew chips onto the site or remained idle during the time when the van was travelling to and from Crofton. Obviously this would not be practical under operational conditions, where the objective would be to operate continuously and recover all of the processed material. In this case, a second van or trailer would be required to complete the system. One unit would be travelling while the other was being loaded, resulting in maximum utilization of all equipment.

Processed material was unloaded on the hog fuel dump at the Croft Pulp Mill. Some difficulty was experienced in dumping. The dump had to be raised and lowered several times before the material finally slid out through the hinged back door. This difficulty was due to compaction of the processed material by the blower outfeed system of the Nicholson chipper.

5.5 Laboratory Analyses

As previously mentioned, representative samples of the processed material were analyzed to determine their physical and energy properties. The original **Report of Analysis** from Beak Consultants Limited is presented in Appendix 3. A summary of the results is shown in Table 18.

Moisture content of the material analyzed from the Sooke site was higher than that of the Cowichan site. This was due to a higher proportion of rotten material and a larger average piece size on the Sooke site. Moisture retention in large, rotten pieces is greater than in small, sound pieces. It should be noted that 43% of the material processed at Sooke was rotten, compared to only 17% at Cowichan. Furthermore, 57% of the material processed at Sooke was greater than 28 centimetres in diameter, compared to only 17% at Cowichan.

The higher moisture content resulted in significantly lower calorific values for the material processed at the Sooke site.

Another reason for the lower calorific value of the Sooke material could be the presence of a higher proportion of non-combustible inorganic material. This is indicated in the higher ash content of the Sooke material. The higher inorganic content resulted from quantities of dirt collected with the residues during the collection phase. Dirt tended to adhere to the residue material in greater quantities when the material was wet. At Cowichan the material was generally drier, as were weather conditions at the time of collection. From the results of the laboratory analysis of processed material samples, it is possible to make several general conclusions. These conclusions are somewhat tentative, due to the limited number of samples collected. Tables 19 through 22 illustrate the relationship of calorific value to a number of factors.

There is significant loss in calorific value as wood deteriorates. Table 19 shows the average calorific value of air dry samples in varying degrees of deterioration.

Moisture content has a large effect on calorific value of the processed material. Table 20 shows the range of calorific values that were obtained for samples of sound and rotten wood of varying moisture contents.

There appeared to be little variation in calorific value between samples of different tree species. For air dried samples of sound material with similar moisture content, the range of calorific values obtained is shown in Table 21. The range of calorific values for oven dried samples also showed little variation among species. The range for all species sampled was 20,400 to 20,700 KJ/kg for oven dried wood.

There appeared to be little variation in calorific value between samples taken from different components of the tree. Table 22 shows the range of calorific values obtained for air dried samples of sound material with similar moisture content.

The ratio of organic to inorganic material was higher in sound wood than in rotten wood. This is

Table 18 - Summary of Laboratory Analysis Results

		Sooke Site	Cowichan Site
Moisture Content		**%**	**%**
(% of total weight)	Average [a]	60.9	56.5
	Low	53.7	39.4
	High	71.0	69.2
Ash Content		**%**	**%**
(% of oven dried weight)	Average [a]	0.8	0.6
	Low	0.3	0.5
	High	2.0	0.8
Organic/Inorganic Ratio		**Ratio**	**Ratio**
(% organic) based % inorganic on air dried sample weight	Average [a]	0.639	0.798
	Low	0.369	0.428
	High	0.833	1.495
Calorific Value - Air Dry		**KJ/kg [b]**	**KJ/kg**
(net heat released in burning air dried sample)	Average [a]	7,000	8,100
	Low	3,000	4,600
	High	9,500	12,300
Calorific Value - Oven Dry		**KJ/kg**	**KJ/kg**
(net heat released in burning oven dried sample)	Average [a]	17,200	19,500
	Low	10,400	16,200
	High	20,700	20,900

(a) Numerical Average of samples collected.
(b) Kilojoules per kilogram.

Table 19 - Relationship of Calorific Value to Condition of Wood

Condition of Sample	Average Calorific Value KJ/kg
Rotten Wood	4,000
Partially Rotten Wood	5,800
Sound Wood	9,000

Table 20 - Relationship of Calorific Value to Moisture Content

Sound Wood		Rotten Wood	
Moisture Content %	**Calorific Value KJ/kg**	**Moisture Content %**	**Calorific Value KJ/kg**
0 [a]	20,500	0 [a]	14,700
39	12,350	65	5,800
55	9,000	68	4,100
59	8,300	71	3,000

(a) Oven dry

Table 21 - Relationship of Calorific Value to Tree Species At Approximately 55% Moisture Content

Species	Average Calorific Value KJ/kg
Hemlock - Balsam	9,050
Fir	8,800
Cedar	8,900
Alder [(a)]	9,050

(a) Calorific value for Alder at 55% Moisture Content was extrapolated from laboratory analysis data.

Table 22 - Relationship of Calorific Value to Tree Component

Portion of Tree	Moisture Content %	Calorific Value KJ/kg
Stem Wood (Cedar)	56.2	9,050
Stem Wood (Hem-Bal)	55.1	
Branch Wood (Hem-Bal)	54.5	8,925
Branch Wood (Fir)	53.9	
Stump and Roots (Fir)	54.8	8,850
Stump and Roots (Hem-Bal)	53.7	

again due to a high moisture content in the rotten wood.

Ash content was higher in rotten material than in sound material. This was due to dirt that adhered to the wetter rotten wood during the collection phase and to a higher proportion of non-combustibles in the rotten wood.

Samples of the processed material from the Nicholson chipper were analyzed at Crofton Pulp Mill to determine the distribution of chip sizes. Virtually all the material sampled was well within the acceptable size limits for the Crofton pulp mill hog fuel boiler (0 to 200 millimetres). This boiler uses a moving grate burner to produce process steam for the pulp and paper mill. Indications were that the Cowichan site material was compatible with the burner feed mechanism and burned well, with little or no residue.

Although no formal size distribution analysis was carried out on the processed material from the Bartlett chipper, the average chip size was considerably larger than at Cowichan. However, as with the Nicholson chipper, most of the chips were within the acceptable size limits for the hog fuel burner.

Chips from the Nicholson and Bartlett chippers varied considerably in size, depending on the condition of the chipper knives. Generally, as the knife edges became dull, the chip size increased. When knives were sharp, the chip size from the Nicholson machine was uniform, the majority of chips (60 to 70% by weight) falling in the 10-to-50-millimetre size range. Dull knives frequently produced large "card" chips up to 200 millimetres in length. The approximate piece size distribution of the processed material from the Nicholson chipper with sharp knives, is shown in Table 23.

The Bartlett chipper produced a much more variable size of chip. Prior to the installation of chip breakers, piece size frequently ranged up to 200 millimetres. The number of large pieces was substantially reduced through the use of chip breakers. With sharp knives and chip breakers installed, the distribution of chip size was as shown in Table 24. Photographs of the processed material from both types of chipper are included in Appendix 3.

The density of the material produced was determined from weights and volume measurements carried out during the transportation trials. The average density of the material produced by the Bartlett chipper was 200 kilograms per cubic metre. The average density of the material produced by the Nicholson chipper was 228 kilograms per cubic metre. The higher density of the Nicholson material was due to compaction caused by the blower and to smaller chip size.

Table 23 - Nicholson Chipper - Approximate Chip Size Distribution

Size Class (Millimetres)	Proportional Distribution
0 - 5	20%
5 - 10	15%
10 - 30	50%
30 +	15%

Table 24 - Bartlett Chipper - Approximate Chip Size Distribution

Size Class (Millimetres)	Proportional Distribution
0 - 50	30%
50 - 100	50%
100 - 150	15%
150 +	5%

Table 25 - Energy Consumed by Operational Phase

Operational Phase	Sooke Site (MJ/Tonne)[b]	Cowichan Site (MJ/Tonne)
Residue Collection	74	54
Residue Processing	782	759
Subtotal - Collection and Processing	856	813
Transportation of Processed Material [a]	296	99
Total (Collection Processing and Transport)	1,152	912

[a] Estimated energy consumption, based on transportation of material from both sites to the hog fuel boiler at Crofton using a chip van with a 10 tonne payload. Sooke Site to Crofton 75 km; Cowichan site to Crofton 25 km.

[b] Megajoules per tonne.

5.6 Energy Consumed versus Energy Produced

During the course of the field tests, records were kept of fuel consumed by all equipment used in collecting, processing and transporting the material produced. These fuel consumption data were converted to equivalent energy consumption, using the appropriate energy value for the fuel used. The energy consumed in each phase of the project was related to the quantity of logging residue handled in that particular phase. The energy consumed per tonne of material produced is summarized for both test sites in Table 25.

Representative samples of the material produced were analyzed to determine the potential energy value available. As expected, the results of this analysis indicated a significant difference in energy potential between rotten and sound wood, as well as between woods of varying moisture content. Energy values were applied to the proportion of material produced in each category to determine the weighted average energy value per tonne. The unit energy value per tonne of material produced at the Sooke and Cowichan sites is summarized in Table 26.

The energy value of fuels consumed in collecting, processing and transporting the logging residues from both sites was compared with the energy potential of the material produced during the tests. The unit value of energy output to energy input for both sites is summarized in Table 27.

Table 26 - Energy Value Potentially Available from Material Produced

Material Type		Sooke Site			Cowichan Site		
Species	Condition	Average Moisture Content (%)	Proportional Distribution (%)	Average[a] Energy Value (MJ/ Tonne)	Average Moisture Content (%)	Proportional Distribution (%)	Average[a] Energy Value (MJ/ Tonne)
Conifer	Rotten	70	11.4	3,840	69	4.4	4,750
Conifer	Partially Rotten	64	34.1	5,630	65	13.3	5,930
Conifer	Sound	55	54.5	9,300	55	69.3	8,700
Deciduous[b]	Sound	—	—	—	39	13.0	12,350
Weighted Average		60	100.0	7,425	55	100.0	8,630

(a) Based on laboratory analysis of representative samples collected and tested in air dry condition.

(b) Primarily Alder.

Table 27 - Summary of Unit Values of Energy Consumed Versus Energy Produced (Megajoules/Tonne)

Operational Phase	Sooke Site In[a]	Sooke Site Out[b]	Sooke Site Ratio (Out/In)	Cowichan Site In[a]	Cowichan Site Out[b]	Cowichan Site Ratio (Out/In)
Residue Collection	74	7,425	100.3	54	8,630	159.8
Residue Processing	782		9.5	759		11.4
Collection and Processing	856	7,425	8.7	813	8,630	10.6

(a) In = Energy Value of Fuel Consumed

(b) Out = Weighted Average Potential Energy Value of Processed Residues.

The reasons for the consistently higher energy output to input ratio for the Cowichan site are:

- Material on the Cowichan site had a substantially higher average energy potential than that on the Sooke Site. This is primarily due to lower moisture content of the Cowichan material.
- Residues at Cowichan consisted of smaller, lighter material than those at Sooke. In addition, the collection of material on the Cowichan site was carried out on relatively flat, dry ground, requiring less energy consumption to collect the logging residues than on the steeper Sooke site. The Cowichan site also had lower stumps and lighter debris concentration, which resulted in higher productivity in the collection operation.
- At Cowichan, the relatively flat topography enabled the construction of access roads to logging residue assembly points located throughout the site. Thus, the average distance over which material was transported to these assembly points was less than at the Sooke site. This resulted in less energy consumption per tonne collected.
- Organization and operating efficiency of the contractor at Cowichan was superior to that of the contractor who carried out the Sooke tests.
- Average processing productivity at the Cowichan site was 17.5 tonnes per day, compared to 8 to 10 tonnes per day at Sooke.

6. CONCLUSIONS AND RECOMMENDATIONS

6.1 Assessment of Methods Used

a. Inventory

A quick, approximate estimate of the quantity of residues present on the site was obtained through the use of the U.S.D.A Photo Series for Quantifying Forest Residues (Maxwell and Ward, 1976).

The line-intersect method of sampling downed, woody material (Brown, 1974) gave a good estimate of the quantity of residue by size, species and condition. The method is simple, fast and easy to apply. It enables advance estimates to be prepared for planning of residue collection and processing operations.

The line-intersect sampling inventory carried out on ENFOR project test sites showed an average residue quantity of 185 tonnes per hectare at Sooke and 55 tonnes per hectare at Cowichan.

b. Collection

The use of small crawler tractors to collect logging residues into piles prior to processing resulted in a good percentage recovery with a minimum of ground disturbance. The material collected by this method was relatively free of dirt.

At Sooke, gound conditions were moderately steep and chipper access was confined to the existing logging road. All residue material was collected into a windrow along the existing logging road. Average collection distance was 50 metres. At Cowichan, where topographic conditions permitted the construction of chipper access roads into the area, the average collection distance was reduced by collecting residues into a number of piles scattered throughout the test area.

An inventory carried out following residue collection showed that the percentage recovery varied with piece size. The average recovery of material included in the original inventory ranged from 70% in 0.6-2.5-centimetre diameter material to 80% in 2.6 to 7.6-centimetre diameter material to 94% in material greater than 7.6 centimetres in diameter. The overall average recovery was 85% at Cowichan and 94% at Sooke.

Costs of collection ranged from $5.89 per tonne at Cowichan, where the topography was relatively flat and piece size was small, to $9.10 per tonne at Sooke, where the ground was moderately steep and many large pieces were encountered.

c. Processing

It is difficult to compare the two chippers owing to the completely different nature of the logging residue material on the two test sites. In terms of their ability to process all of the available material the Bartlett chipper was able to handle 85% of the material, compared to 70% for the Nicholson chipper. In terms of productivity, the Nicholson chipper produced an average of 17.5 tonnes per day, compared to the Bartlett chipper's average of 8.5 tonnes per day. Based on productive machine hours, the productivity for the Nicholson chipper was 4.7 tonnes per productive machine hour, compared to 3.2 tonnes per productive machine hour for the Bartlett chipper.

Costs for the Sooke operation averaged about $48 per tonne for chipping and $22 per tonne for splitting and forwarding, for a total processing cost of $70 per tonne. At Cowichan, chipping costs, including construction of access roads, averaged $54 per tonne and forwarding costs were $16 per tonne, for a total processing cost of $70 per tonne.

The trials at Sooke proved the usefulness of the stump splitter to cut large stumps into smaller size pieces and to release dirt and rocks in the root systems. However, the value of the stump splitter for cutting large logs and saplings into shorter lengths was very limited. In most cases, a chain saw would have performed this function more effectively at a much lower cost. If stumps are not to be recovered in logging residue harvesting operations, no stump splitter will be required.

The Bartlett chipper proved to be capable of handling all sizes of material, but its productivity suffered due to frequent and time consuming breakdowns. Obviously many refinements are required before this machine can be considered as an operational, rather than a prototype, model. Chipper modifications carried out on this project dealt with a number of the original limitations of the machine, but there are many more problems to be overcome. The infeed mechanism should undergo major modifications to enable material to be fed independently without the constant attention of the operator. The outfeed mechanism should also be changed to overcome blockage problems associated with branch material and to enable loading of vans positioned end to end with the chipper rather than alongside. The side loading feature of the present machine limits its use to very wide, flat areas, which are not frequently found on forest operating sites.

On both sites, experience showed that a small crawler loader equipped with a brush grapple or log forks should be used to assist the chipper. The loader proved very useful for forwarding, sorting

Table 28 - Summary of Production Costs

Item	Production Costs Sooke Site ($/tonne)	Cowichan Site ($/tonne)
Residue Collection	9.10	5.89
Residue Processing	70.10	69.81
Total	79.20	75.70

and bunching material for the chipper. Without this equipment, the chipper grapple would have difficulty in assembling sufficient residue material to fully utilize the chipper's productive capacity.

6.2 Summary of Production Costs and Revenues

a. Costs

The costs of collecting and processing forest residues, based on information gathered during field trials at Sooke and Cowichan, are summarized in Table 28.

Collection and processing costs are based on actual costs incurred on the project, excluding those costs associated with project mobilization and demobilization. As the sites were chosen to be representative of moderate slope logged-over areas on Vancouver Island, similar costs could be expected under similar operating conditions, using the methods described.

Transportation costs were estimated, based on field experience and on the following assumptions:

- Processed material from both sites would be transported to B.C. Forest Products' Crofton Pulp Mill in 10 tonne capacity trailers.
- A spare trailer would be used to eliminate the need for the truck and driver to wait during the loading phase.
- One-way distance to Crofton from: Cowichan site - 25 km; from Sooke site - 75 km.

Based on the above assumptions, the cost of processed material transportation is estimated to be $13.26/tonne from the Sooke site and $5.63/tonne from the Cowichan site.

b. Revenues

To determine the possible revenues from the sale of processed logging residues, the current hog fuel selling price was examined. The current selling/purchase price of hog fuel utilized on Vancouver Island is little or nothing. The purchaser generally acquires hog fuel for the cost of delivery. Hog fuel used for the production of steam and power is costing the user $2.50 to $6.75 per unit, delivered to conversion plants on the South Coast of B.C. Net income to the selling mill ranges between a loss of $2 per unit to a profit of $2 per unit, depending on proximity to the conversion plant (Appelby 1978). These low revenues to the producer reflect a surplus of mill residues and represent an attractive alternative to disposal costs which currently range from $2 to $7 per unit.

Crofton Pulp and Paper Division pays $3 per unit (about $2.75 per tonne) for hog fuel delivery to their boiler facility. This hog fuel comes from sawmills located within about a 50 kilometre radius and is produced as a waste product of sawmilling operations. The difference between present forest residue production and delivery costs ($80-$90 per tonne) and the delivered value of this material ($2.75/tonne) is such that it would not be economically feasible to use logging residues as an energy source at this time. This situation may change if the present hog fuel surplus diminishes and comes into balance with usage. This has been predicted for the south coast region of B.C. by the early 1980s (B.C. Wood-Waste Energy Coordinating Committee 1978), when present and planned construction of wood fired boilers at several pulp mills on the south coast is completed.

c. Value of Processed Material in Terms of Alternative Fuels

One measure of the value of wood residues as a fuel source is in terms of the equivalent value of fuel oil. A rough comparison was made to determine the quantity and value of fuel oil which would provide an amount of potential energy equivalent to one tonne of forest residues. The basic assumptions of this comparison are listed below.

- One tonne of sound, processed forest residue with a 55% moisture content would have a potential energy value of 9,000 megajoules.
- One litre of #2 fuel oil would have an approximate energy value of 40 megajoules (Hensel 1978).

- Therefore, one tonne of sound processed forest residues would have a potential energy value equivalent to about 225 litres of fuel oil.
- Bulk price of #2 fuel oil in Vancouver, B.C., January 1980, was 15.4 cents per litre.
- Therefore, in terms of equivalent potential energy value, wood residue has a present value of about $35 per tonne.

This comparison does not take into consideration the following factors:

- Burning Efficiency
  Oil fired boilers commonly achieve net boiler efficiencies of 80 to 85%, while wood fired boilers commonly have net boiler efficiencies in the range of 65 to 75% depending on the moisture content of the fuel (Curtis 1978).
- Capital Cost of Boilers
  Because of the bulky nature and high moisture content of wood fuels, steam plants using wood fuels cost considerably more than plants using oil. Costs of wood fuel boilers are two to four times more than oil fired boilers (B.H. Levelton and Associates 1975).
- Operating Cost
  The cost of operating wood fired boilers is higher than oil fired boilers, due to the extra personnel required to maintain and operate the feeding and ash recovery mechanisms.

In summary, wood residues have an apparent present value of $35 per tonne in terms of potential energy. However, due to the high cost of building and operating wood fired boilers and a low net boiler efficiency, this value in terms of equivalent net energy produced in comparison with oil would be considerably lower.

Present surplus hog fuel supplies from existing wood using conversion plants have resulted in a market price of about $3 per tonne. This barely covers production and transportation costs but is acceptable to the producers, who look upon this revenue as an offset to their disposal costs. While this situation exists there is little hope for an economically viable system for utilizing logging residues as a source of energy.

Based on a calorific value of 9000 MJ/tonne for processed forest residues and a calorific value of 40 MJ/litre for oil, a graph (see Fig. 16) was constructed relating the monetary value of residues to oil price. Line A on the graph shows the relationship between residue value per tonne and oil price per litre over a range of oil prices. Onto this graph was superimposed the relationship of residue production and delivery costs to oil cost based on fuel consumption information collected during field trials. This second relationship is illustrated by Line B on Figure 16.

The point at which delivered processed material cost is equal to the monetary value of the material produced is at a point where oil costs are $0.40 per litre. This means that until oil costs reach a point in excess of $0.40 per litre, it will not be economically feasible to utilize logging residues as replacement fuel for oil. Actually, due to the higher cost of building and operating wood fired boilers and their lower combustion efficiency, the cost of oil would have to be considerably higher than $0.40 per litre before logging residues could be economically salvaged and utilized to replace fuel oil.

Line C on Figure 16 illustrates the same relationship between delivered cost and equivalent value of logging residues for a modified operational processing system. This system is discussed in section 6.4 and cost estimates are illustrated in Table 30. Line C shows that if delivered cost can be reduced to $50 to $55 per tonne, the point of equal cost and value will be at an oil cost of $0.24 per litre.

6.3 Future Research and Development Requirements

a. Logging Residue Inventory

To identify and evaluate potential source areas where the utilization of logging residues may be feasible, more information is required on the nature, volume and location of logging residues. A system is required to predict the quantity and type of residues that can be expected to remain following logging. This system should take into consideration the nature of the forest, topography and method of logging to be used.

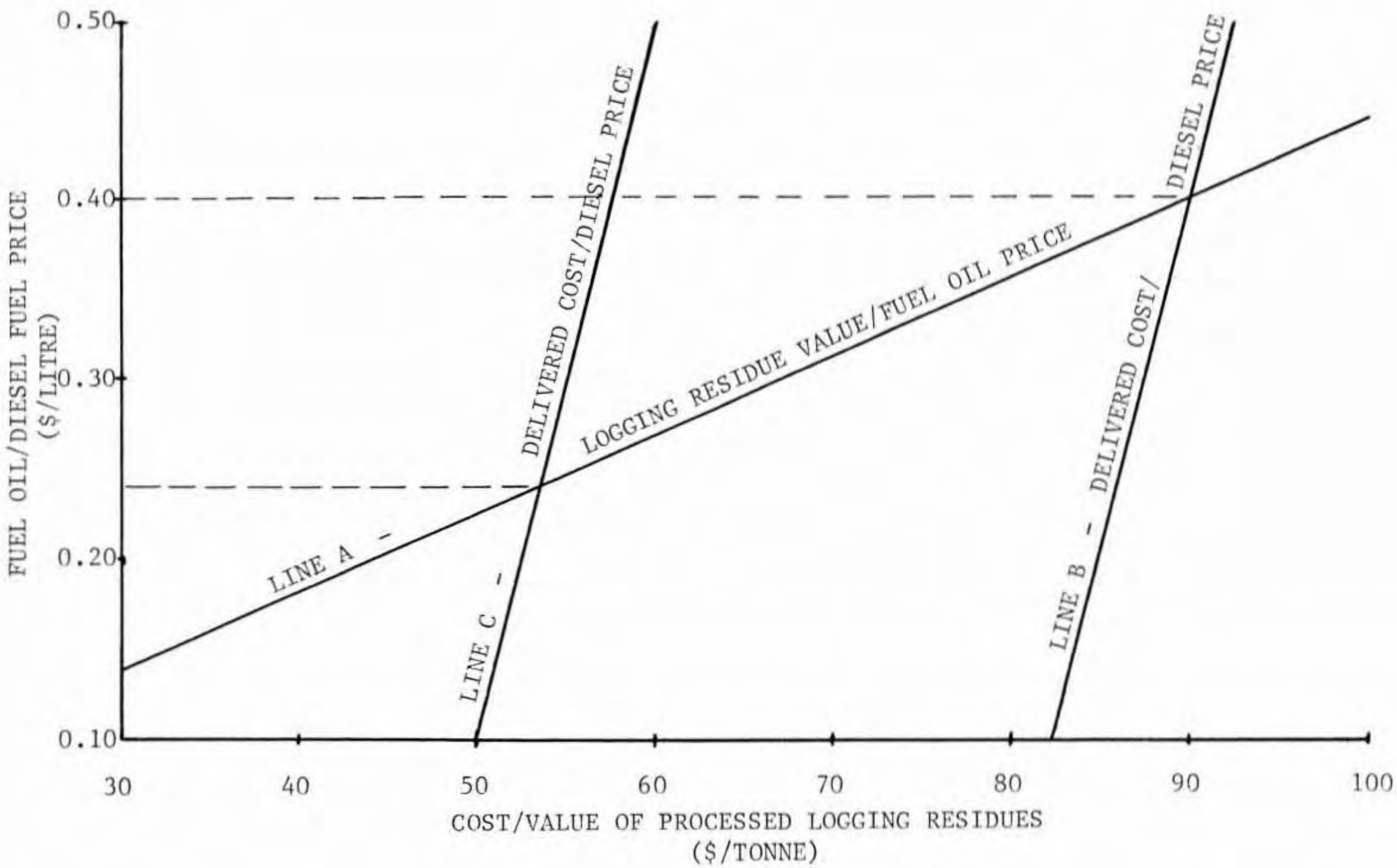
b. Source Areas

Studies such as that carried out by Paul H. Jones and Associates (1979) to assess the volume, location and availability of wood biomass from the forest areas of Vancouver Island should be done for other geographic areas. Comparative studies of logging residue availability and cost with power and process steam requirements should be done on a regional basis. This would enable the indentification of areas where logging residues could be used to satisfy specific local energy requirements.

c. Materials Handling Systems

More efficient methods of harvesting and transporting logging residues should be investigated. In particular, research efforts should be directed toward the development of harvesting methods for steeper slopes and a one-pass system to retrieve logging residues and merchantable logs in a single, joint operation. This research should include the development of systems for separating

Figure 16 - Relationship of Delivered Cost and Equivalent Value of Logging Residues to Changes in Diesel and Fuel Oil Prices.



LINE A. VALUE OF LOGGING RESIDUES IN TERMS OF EQUIVALENT VALUE OF FUEL OIL

LINE B. AVERAGE DELIVERED LOGGING RESIDUE COST - PROJECT TEST SITES TO CROFTON PULPMILL

LINE C. ESTIMATED DELIVERED LOGGING RESIDUE COST - MODIFIED OPERATIONAL PROCESSING SYSTEM and handling of these two types of material on steep forest sites under the limitations imposed by the narrow roads.

On flatter sites, a self-propelled chipper could be used to process logging residues piled at points distributed throughout the logged-over area. This system would eliminate the need for chipper access roads, as well as reduce residue collection costs by shortening the distance over which residues must be carried to a concentrating point. A self-propelled chipper would have the advantage of improved manoeuverability and lower system cost than a chipper that depends on a separate truck for its mobility.

The system of feeding residue material into the chipper requires refinement. A major limitation of existing equipment is the slow, cumbersome feeding of small branch and top material, using the hydraulic log grapple. This equipment was designed to handle large diameter, long length pieces. Because of the time involved to handle the many small volume pieces, the grapple cannot supply a sufficient quantity of material to fully utilize chipper capacity. This results in a very low system productivity.

A system of bulk loading piled slash into the chipper is required in order to more fully utilize the productive capacity of the chipper. A sloped vibrating screen placed ahead of the chipper infeed mechanism would remove most rocks and dirt from the residue material while ensuring a steady feed of large quantities of material to the chipper. Another possibility for improving productivity would be to compress the branch and top material into bales prior to chipping. The capacity of the chipper could be more fully utilized in chipping bales and there would be no protruding pieces to cause infeed blockages.

Processed material loading and transportation methods and equipment could also be improved. The optimum transportation system may involve the use of trucks with detachable, interchangeable chip containers. These box type containers could be off-loaded and left with the chipper for loading. The truck could pick up loaded chip containers and return to the conversion plant, thus eliminating unproductive truck waiting time. Single chip containers could be hauled on small manoeuverable trucks on the forest road portion of the route and then transferred to tandem trailers capable of hauling several containers on the highway portion of the route.

Chip containers or other forms of load carrier should be designed to be compatible with the particular chip discharge system of the chipper and with the unloading system to be employed at the conversion plant.

For off-road chipping systems, a forwarder vehicle would be required to move loaded chip containers to road-side. Possibly a combined residue collection and container forwarder vehicle could be developed.

d. Processing and Product Technology

From experience gained during the field trials, it is clear that further development work is required on processing equipment in order to overcome problems associated with:

- Chipping of small diameter and short length material.
- Sensitivity of knives to damage and excessive wear caused by rocks and dirt.
- Productive time losses due to knife changing and maintenance.
- Productive time losses due to blockages of infeed and outfeed mechanisms.

Further research and development is required to determine the optimum shape and size of fuel chip. Present equipment, such as that employed on project field trials, was not designed to produce a specific product for a particular energy conversion process. Different types of burning systems (fluidized bed, moving grate, suspension, etc.) would likely require fuel chips of varying size and shape. Similarly, if the processed forest residues are to be pelletized, the fuel chips produced should be compatible with the pelletizing equipment to be used.

Further research to determine the optimum practical moisture content of fuel chips is also required. Perhaps the use of pre-driers or bailing equipment to squeeze moisture out of the chips would be justified in order to achieve higher combustion efficiencies.

Further information is required on the burning characteristics of decayed wood. Since a large portion of logging residue material is not presently utilized, due to decay, more information on this subject is required. Perhaps through the addition of other substances during the combustion process the burning characteristics of rotten wood could be enhanced.

e. Marketing Procedures

Forest residue utilization technology will begin to evolve when the value of wood residues in comparison with other competing fuels becomes sufficiently high to cover the cost of collecting, processing and transporting this material to an energy conversion facility. In preparation for this point of value-cost equilibrium, studies should be undertaken to determine methods of marketing processed forest residue material to both domestic and industrial users. The direction of materials handling and product technology will, to a large extent, be governed by the markets where the processed material will be utilized.

f. Forest Policy and Wood Residue Utilization

As more energy users convert from traditional fossil fuels to wood residues it is probable that mill residue supplies may not be sufficient to meet demand. At that time, the focus of attention may shift to logging residues as a supplement to mill residues. In order that the removal and use of logging residues from crown land be regulated and allocated to the optimum end use, new forest policy regarding wood residues must be prepared. This may involve new legislation covering salvage rights, stumpage payments and a policy of fuel chip direction and allocation similar to that now in effect for pulp chips.

6.4 Concept for Commercial Application

Production costs could be reduced by altering certain organizational aspects of the systems developed and tested on this project. The system tested used a two-phase concept for collection and processing. By carrying out both operations simultaneously, the amount of equipment required could be reduced.

One chipper could work together with one to two small crawler tractors as a production unit. The land clearing machines would be used to collect sufficient material for the chipper, assist the chipper during moves, position chip containers and carry out road and landing maintenance as required. A landingman with a power saw would be required to buck over-sized pieces and roots suspected of containing rocks. He would also assist the chipper operator in clearing blockages and changing knives.

Transportation could be handled by chip containers (10 tonne capacity), which could be dropped off in the landing and picked up by a truck when full. It is estimated that three to four of these containers would be required, depending on the distance from the operating area to the energy conversion plant. As the truck would likely not be required on a full-time basis, the use of contract trucks on an "as required" basis is recommended. Containers could be loaded onto the truck, using the crawler tractor or a winch system mounted on the truck.

Larger capacity trucks or truck-trailer units capable of handling two or more 10 tonne chip containers would result in a lower transportation cost. However, the use of larger trucks would likely be impractical because of lack of space in landings, low standard roads and traffic congestion in active logging areas.

Equipment and labor requirements and estimated costs for the system outlined above are listed in Table 29. The cost of collection and processing is estimated to be \$57.50 per tonne. Transportation costs would vary with distance and would range from 7 to \$12 per tonne for a total delivery cost of 65 to \$70 per tonne.

A key factor in improving system costs is to speed up the handling of small diameter, short-length residue material. Studies carried out in Sweden (Danielsson 1977) investigated the use of bundling devices for compressing and tying residues prior to chipping. Field trials showed a marked increase in production through more complete utilization of the chipper infeed mechanism and reduce infeed blockages. By increasing the volume of material fed into the chipper per unit of time, daily production was increased by up to five times over that when feeding loose material. A production increase of this magnitude would reduce collection and processing system costs from the estimated \$57.50 per tonne as shown in Table 29 to about \$30 per tonne.

More realistically, it is likely that prebaling of small residues would double chipper output, thus reducing the processing portion of the system cost by about 50%. However, the additional cost of prebaling must also be considered. It is estimated that the total collection and processing cost, using a prebaling concept would be \$42.50 per tonne, as shown in Table 30. Total delivered cost using this system would be 50 to \$55 per tonne.

The previous discussion indicates that prebaling of residues in order to increase processing productivity would result in a reduction of about \$15 per tonne in the total delivered cost of processed residues.

The author investigated the cost of collecting residue material along with merchantable logs in one operation. Residue collection costs for single pass yarding were estimated by Jones (1979) to be 10 to \$12 per tonne, based on highlead yarding of residues in conjunction with primary logging. This cost reflects the steep, rough terrain typical of highlead yarding sites on Vancouver Island. On flat or gently sloping land, wholetree skidding to recover residues along with merchantable logs is expected to cost 8 to \$10 per tonne.

Possibly costs could be reduced by collecting and processing only the larger diameter logging residues. These larger pieces would result in higher system productivity and thus lower costs. However, the larger diameter logging residues would likely be those with the least energy value, due to a higher proportion of rotten wood. It is also possible that many of these larger pieces could be transported along with merchantable sawlogs and processed in a mill waste-wood chipper more economically than by field chipping.

Table 29 - Cost Estimates for an Operational Forest Residue Collection, Processing and Transportation System

Collection and Processing	
Equipment	
1 Crawler Tractor (50 kw) with Brush Blade	
1 Nicholson Complete Tree Utilizer	
1 Power Saw	
Estimated Owning and Operating Cost:	$ 750 /day
Labor	
1 Chipper Operator	
1 Crawler Tractor Operator	
1 Power Saw Operator/Landing Man	$ 400 /day
Total Equipment and Labor	$1,150 /day
Estimated Collection and Processing Productivity	20 tonnes/day
Collection and Processing - System Cost	$57.50 /tonne
Transportation	
Equipment and Labor	
1 Contract Truck (with operator)	$ 200 /day
3 Chip Containers (10 tonne capacity)	$ 75 /day
Total Equipment and Labor	$ 275 /day
Transportation Cost 0- 50 km	$ 7 /tonne
50-100 km	$ 9 /tonne
100-150 km	$ 12 /tonne
Total Delivered Cost (rounded)	$65-70 /tonne

Table 30 - Cost Estimates for an Operational Forest Residue Collection, Prebaling, Processing and Transportation System

Collection, Prebaling and Processing	
Equipment	
2 Crawler Tractors (50 kw) with Brush Blades	
1 Prebaler	
1 Nicholson Complete Tree Utilizer	
Estimated Owning and Operating Cost:	$1,250 /day
Labor	
2 Crawler Tractor Operators	
1 Chipper Operator	
1 Landing Man (to operate Prebaler and Power Saw)	
Estimated Labor Cost	$ 550 /day
Total Equipment and Labor	$1,800 /day
Estimated System Productivity	40-45 tonnes/day
Estimated System Cost	$42.50 /tonne
Transportation (as in Table 29)	$ 7-12 /tonne
Total Delivered Cost	$50-55 /tonne

In spite of possible cost reductions through modifications in the residue processing system, the collection and utilization of logging residues would not be commercially feasible at the present time, due to the large unfavorable difference between revenue and cost. Revenues will continue to be low for some time, owing to a surplus of wood residues available from wood processing plants. Mill residues are presently treated as waste products and therefore carry no share of the logging and transport costs incurred in delivering them to the mill. The value of these mill residues is presently considered to be only the cost of processing (in most cases hogging) and transportation, which currently varies from 2.50 to $5.00 per unit (approximately 2.30 to $4.60 per green tonne).

In summary, it would appear that although field processing of forest residues is technically feasible, the commercial application of methods developed and tested on this project would not be economically feasible at this time. This may change as more cost efficient methods of retrieving and processing logging residues are developed, as the surplus of mill residues comes into balance with demand and as the price of alternative fuels increases.

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APPENDIX 1 - TERMINOLOGY AND CONVERSION FACTORS

TERMINOLOGY

Logging Residues - For the purposes of this study logging residues refers to all loose woody material remaining on the ground following logging operations. This material is commonly called slash.

Processed Material - This refers to the material produced by the chipping equipment used on the project. Sometimes referred to as fuel chips to distinguish from pulp chips or hog fuel.

Hog Fuel - Refers to mill wood waste processed by hogging equipment which tears, crushes or breaks wood rather than cutting.

Residue Loading - The term loading in conjunction with logging residues refers to the quantity of residue per unit area of logged over land. In this report, the unit of measure for logging residue loading is tonnes per hectare.

Chip Breaker - A knife set into the main chipper knife holding mechanism to further split the chip into smaller pieces.

Tonne - All logging residue measurements in this report are based on air dried metric tonnes.

BOTANICAL NAMES OF SPECIES REFERRED TO IN REPORT

Common Name	Botanical Name
Alder	Alnus rubra (Bong.)
Balsam	Abies amabilis (Dougl.) Forbes
Cedar	Thuja plicata (Donn)
Fir	Pseudotsuga menziesii (Mirb.) Franco
Hemlock	Tsuga heterophylla (Raf.) Sarg.

Conversion Factors

The following table lists the factors used to convert imperial units to metric units.

Measure	Multiply Imperial Unit	By Conversion Factor	To Obtain Metric Unit
Length	inches	2.54	centimetres
	feet	0.3048	metres
	miles	1.609	kilometres
Area	acres	0.405	hectares
Volume (solid)	cubic feet	0.0283	cubic metres
	units (200 ft^3)	5.663	cubic metres
Volume (liquid)	gallons	4.546	litres
Weight	pounds	0.4536	kilograms
	tonnes	0.907	tonnes
Energy	horsepower	0.7457	kw (kilowatts)
	BTU	1.0544	KJ (kilojoules)

APPENDIX 2 - LOGGING RESIDUE INVENTORY

Calculations of Weight per Hectare From Inventory Data

The basic formula used to obtain weight per hectare as derived by James K. Brown in his **Handbook for Inventory Downed Woody Material** is as follows.

a) Inventory for material in the 0.6 - 2.5 and 2.6 - 7.6 cm diameter classes.
tonnes/hectares = 11.64 (n) (D^2) (s) (a) (c) / NL 2.2417

b) for material 7.6 + cm in diameter:
tonnes/hectare = 11.64 (d^2) (s) (a) (c) /

NL 2.2417

Where:

n	= Number of pieces
D	= Average diameter for the appropriate diameter class
d	= Diameter of residue at point of intersection in inches
s	= Specific gravity
a	x= Factor for correcting orientation bias of residual material
c	= Slope correction
N	x= Number of plots
L	x= Length of transect line in feet
11.64	= A derived constant
2.2417	= Conversion factor for tons/acre to tonnes/hectare

APPENDIX 3 -

PROCESSED MATERIAL -

ANALYSES AND ILLUSTRATIONS

1. Report of Analysis - Sooke Site
2. Report of Analysis - Cowichan Site
3. Illustrations

Beak Consultants Limited

Laboratory/3851 Shell Road
Richmond/British Columbia
Canada/V6X 2W2
Telephone (604) 273-1601
Telex 04-508736

REPORT OF ANALYSIS

Client: Forestal International Limited
1550 Alberni Street
Vancouver, B.C.
V6G 1A5

Attention: J. Blakeney

Project: K4404/38

Date received: 19 July 1979

Number of samples: 6/8

Sooke Site

Sample reference	4368	4369	4370	4371	4372	4373
Moisture Content, %	64.8	53.7	55.1	54.5	56.2	63.7
Ash Content (oven Dried), %	0.67	0.87	0.31	0.46	0.44	0.72
Calorific Value (Wet), BTU/lb	2430	4015	4105	3900	3970	2410
Calorific Value (Oven Dried), BTU/lb	6730	8885	8920	8790	8845	6810
Organic/Inorganic Ratio, Wet Basis	0.527	0.833	0.805	0.820	0.766	0.552

Ref: 4368 - Sooke Cedar Slab Partially Rotten - 14/7/79
4369 - Sooke Stump and Root Wood Sound - 16/7/79
4370 - Sooke HemBal Stemwood Sound
4371 - Sooke Branchwood Mixed Species
4372 - Sooke Cedar Stemwood Sound
4373 - Sooke HemBal Stemwood Partially Rotten - 14/7/79

All results expressed as mg/l except
pH (units), coliform (organisms/100 ml), color (units)
conductivity (umhos/cm), salinity (‰), turbidity (NTU)

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Beak Consultants Limited

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Canada/V6X 2W2
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Telex 04-508736

REPORT OF ANALYSIS

Client Forestal International Limited

Project: K4404/38

Date received: 19 July 1979

Number of samples: 2/8

Sample reference	4374	4375				
Moisture Content, %	68.4	71.0				
Ash Content (Oven Dired), %	0.94	2.03				
Calorific Value (Wet), BTU/lb	1750	1280				
Calorific Value (Oven Dried), BTU/lb	5415	4510				
Organic/Inorganic Ratio, Wet Basis	0.442	0.369				

Ref: 4374 - Sooke Stump and Root Wood Rotten
4375 - Sooke Rotten Old Windfall Stemwood

All results expressed as mg/l except
pH (units), coliform (organisms/100 ml), color (units)
conductivity (umhos/cm), salinity (°/₀₀), turbidity (NTU)

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REPORT OF ANALYSIS

Client: Forestal International Limited
1550 Alberni Street
Vancouver, B.C.
V6G 1A5

Attention: J. Blakeney

Project: K4404/38

Date received: 1 October 1979

Number of samples: 6/7

Cowichan Site

Sample reference	4455	4456	4457	4458	4459	4460
Moisture Content, %	58.7	39.4	55.1	69.2	54.8	64.5
Ash Content (Oven Dried), %	0.71	0.68	0.52	0.84	0.47	0.65
Calorific Value (Wet), BTU/lb	3580	5320	3830	2040	3600	2550
Calorific Value (Oven Dried), BTU/lb	8940	9020	8870	7030	8550	7490
Organic/Inorganic Ratio, Wet Basis	0.683	1.495	0.798	0.428	0.809	0.535

Ref: 4455 - Green Alder - Stem and Top
4456 - Dry Alder - Stem
4457 - Cedar Windfall - Sound
4458 - Rotten (Punky) Fir Windfall
4459 - Fir Saplings with Root Wad
4460 - Partially Rotten Fir

All results expressed as mg/l except
pH (units), coliform (organisms/100 ml), color (units)
conductivity (umhos/cm), salinity (‰), turbidity (NTU)

[signature]

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REPORT OF ANALYSIS

Client Forestal International Limited

Project: K4404/38

Date received: 1 October 1979

Number of samples: 1/7

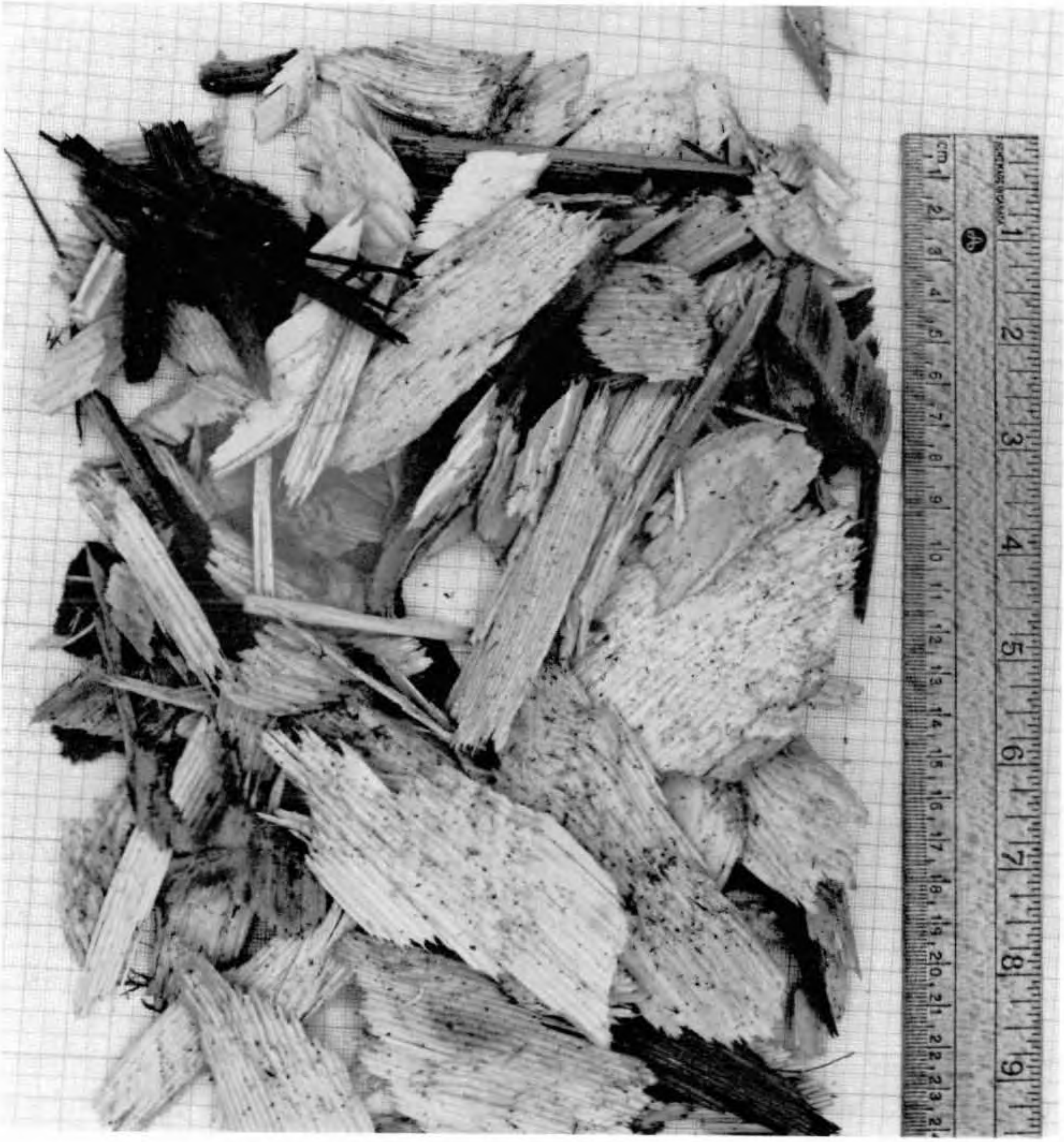
Sample reference	4461					
Moisture Content, %	53.9					
Ash Content (Oven Dried), %	0.49					
Calorific Value (Wet), BTU/lb	3780					
Calorific Value (Oven Dried), BTU/lb	8780					
Organic/Inorganic Ratio, Wet Basis	0.839					

Ref: 4461 - Fir Tops and Branches

All results expressed as mg/l except
pH (units), coliform (organisms/100 ml), color (units)
conductivity (umhos/cm), salinity (‰), turbidity (NTU)

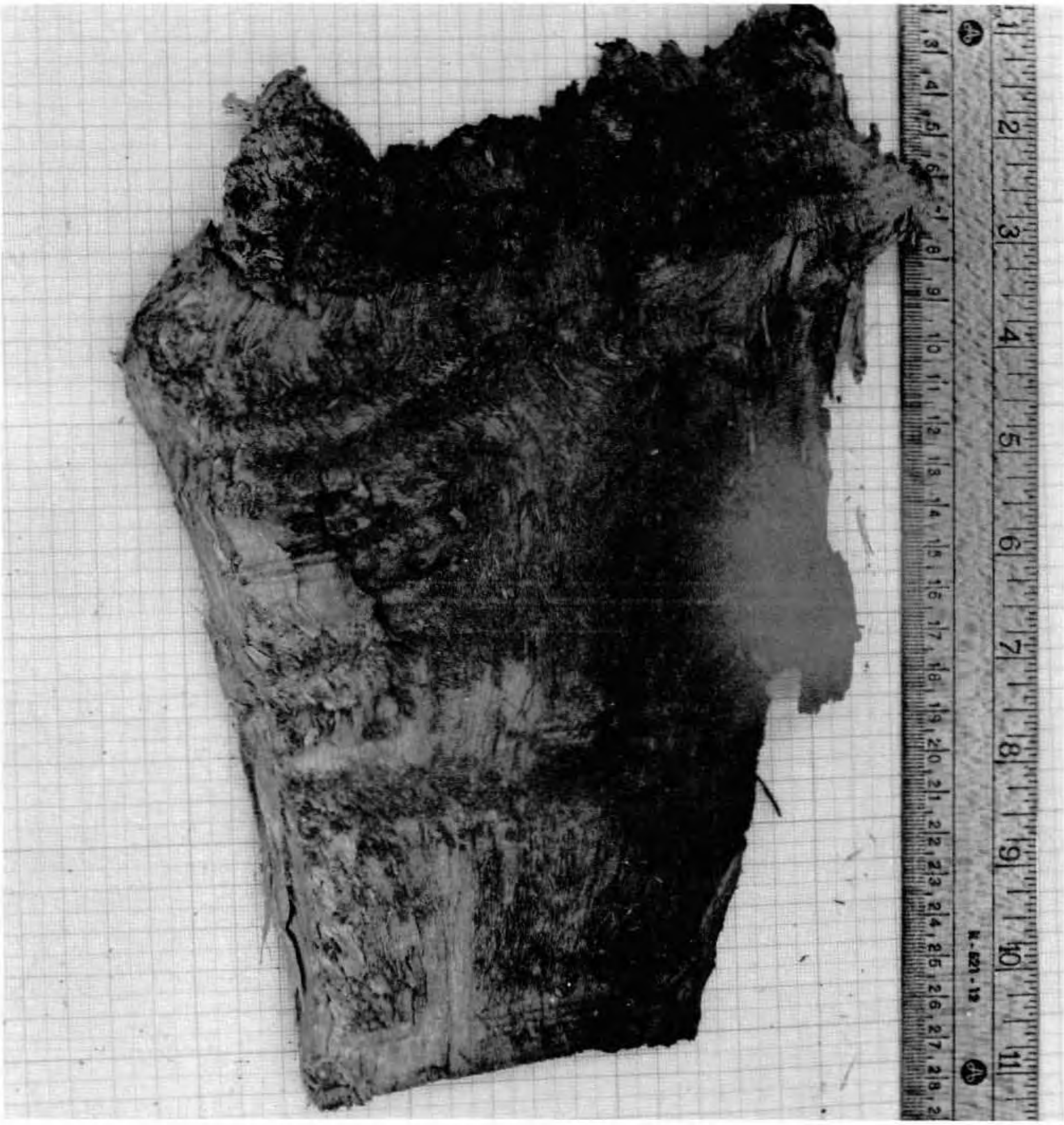
J. A. Crerar

Typical Processed Material from Bartlett Chipper
Prior to Installation of Chip Breakers

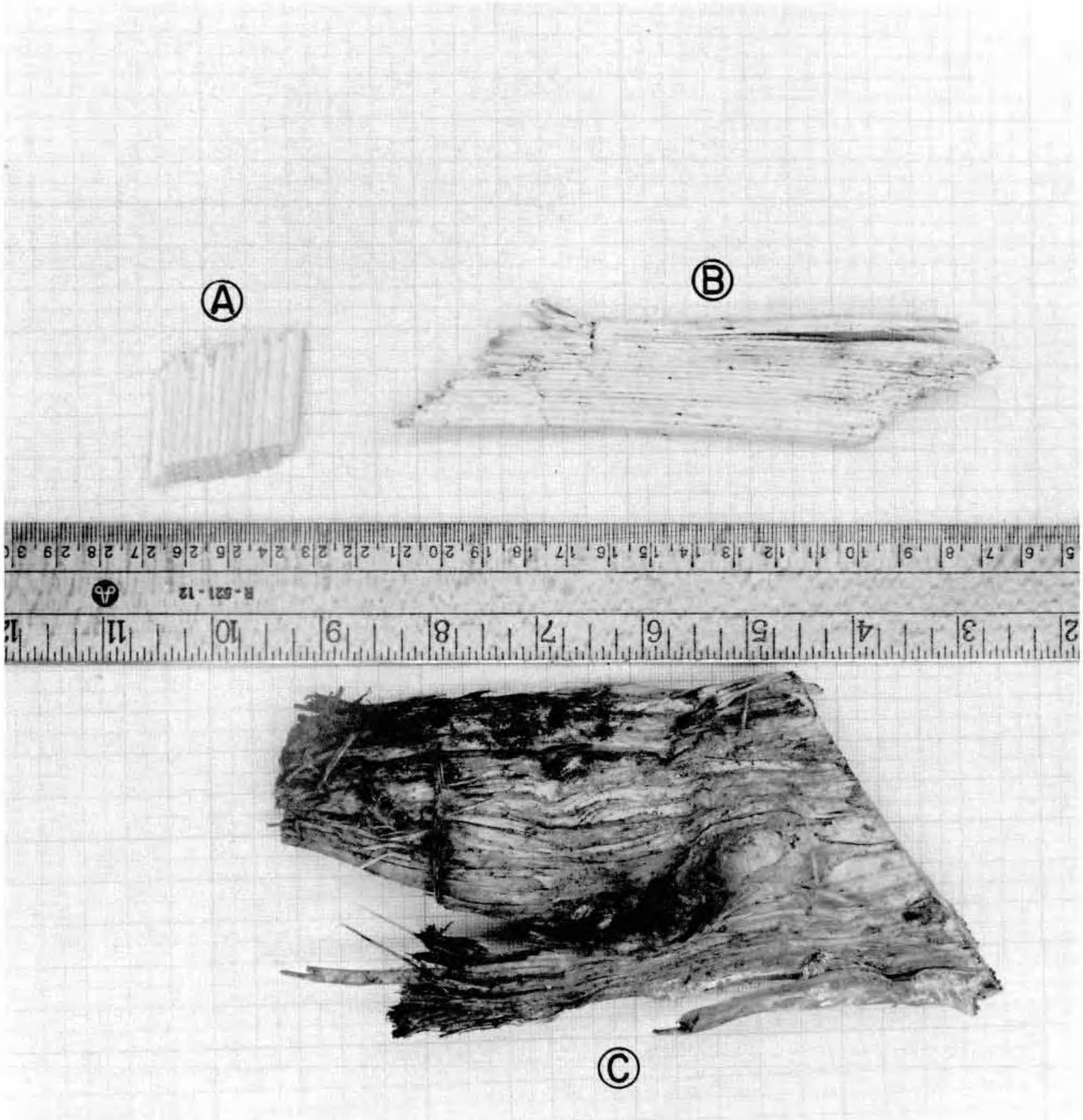


Typical Processed Material from Bartlett Chipper
After Installation of Chip Breakers

Typical Processed Material from Nicholson Chipper with Sharp Knives

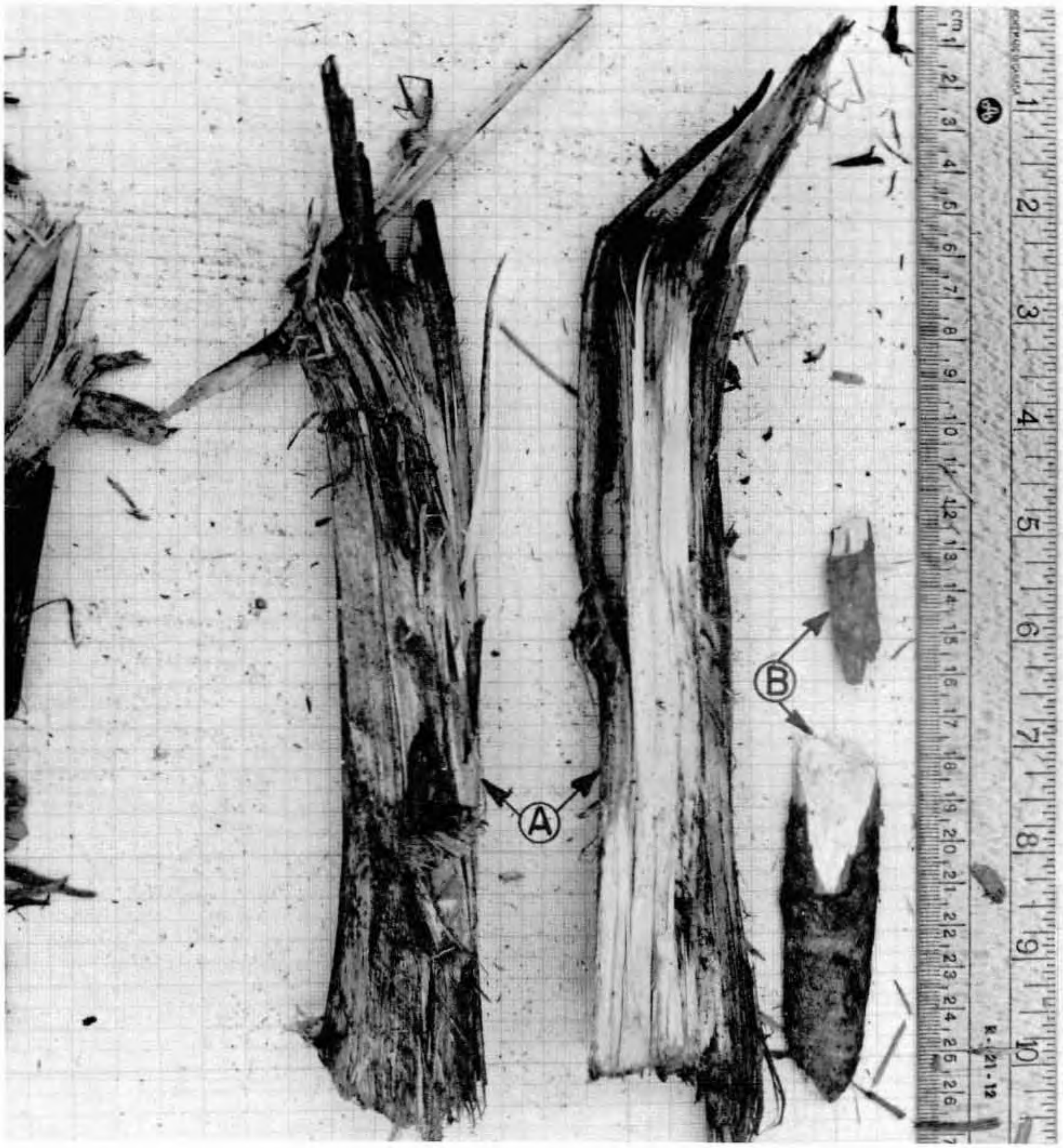


Large "Card" Chip from Nicholson Chipper with Dull Knives



Comparison of Chip Sizes:

a. Nicholson Chipper
b. Bartlett Chipper (Chip Breakers)
c. Bartlett Chipper (No Chip Breakers)



Typical Chips from Branch Material

a. Bartlett Chipper
b. Nicholson Chipper

Canadian Forestry Service
Pacific Forest Research Centre
506 West Burnside Road
Victoria, B.C. V8Z 1M5
BC-X-212, September, 1980