SOIL DAMAGE ASSOCIATED WITH PRODUCTION THINNING

G. MURPHY

Forest Research Institute, New Zealand Forest Service,
Private Bag, Rotorua, New Zealand

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ABSTRACT

Soil damage caused by five types of ground extraction machines used in thinning of young stands of Douglas fir (**Pseudotsuga menziesii** (Mirb.) Franco) in America during winter and spring was visually assessed. Total area impacted ranged from 11 to 30%, the amount being affected by machine type, thinning intensity, planning and location of skid tracks, and bunching system employed. The severity of damage was related to machine type, soil conditions, and number of loaded passes. Previous studies indicate that loss in the potential growth of final-crop trees (with resulting increased costs and decreased returns) may result from damage levels similar to those observed. Research to determine growth losses of radiata pine (**Pinus radiata** D. Don) due to soil damage is recommended.

INTRODUCTION

Production (or extraction) thinning can be a means of improving stand condition and value while obtaining an intermediate yield before clearfelling. Thinning is often delayed to obtain a reasonable piece size to ensure that returns from the operation exceed costs. Production thinnings may therefore require rotation extensions and so incur considerable opportunity costs (Fenton 1970). It is not as easy to evaluate the other costs that can be incurred, e.g., nutrient removal (Webber 1977), residual stand damage, and soil damage. This paper deals with soil damage, mainly on flat country.

Damage from extraction-thinning machinery can be classified as:

- Compression of the soil due to machinery weight – this leads to increased bulk density and mechanical impedance to root growth, and to reduced aeration, infiltration, and mycorrhizal growth;
- Deformation of soil structure due to track or wheel skidding – this further reduces infiltration and leads to puddling of the topsoil;
- Removal of topsoil, leading to reduced nutrient availability.

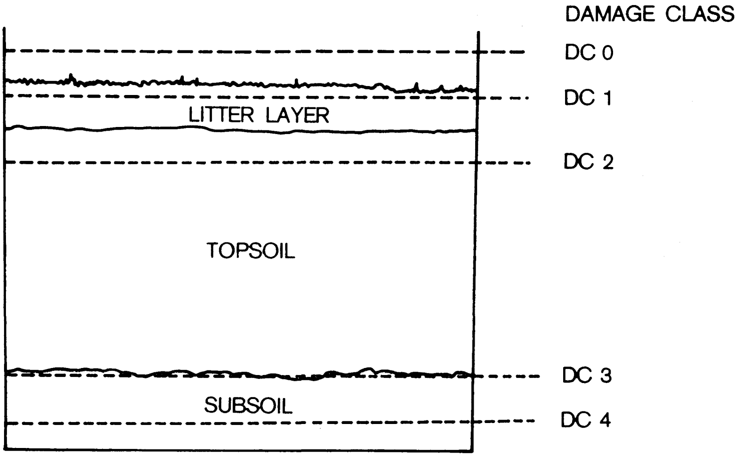
In mid-1980 the author studied soil damage caused by five ground-extraction machines thinning 30- to 50-year-old naturally regenerated stands of Douglas fir in the Willamette region of Oregon, United States. The objectives were to determine the extent of area impacted and the severity of the damage, and to identify factors affecting extent and severity. The logging techniques employed and soil types encountered were similar to those found in conifer plantations in some parts of Australia and New Zealand, so the results of this study should be applicable to such areas.

EXTRACTION THINNING OF DOUGLAS FIR STANDS IN OREGON

The extent of area impacted was measured in two ways. The first method involved surveying the boundaries of the area logged and the location of all soil damage within that area. Measuring tools used were a Suunto hand-held compass, a Suunto hand-held clinometer, and a 50-m plastic tape. The logged areas were then mapped and the amount of the area impacted was calculated.

Where surveying was too complicated or time-consuming the second method was used. Line transects on a 50-m north/south and east/west grid pattern were run through the logged area. The only measurement tool used was a Topofil string gauge. The amount of area impacted was calculated by summing the lengths of line crossing soil damage areas and expressing it as a percentage of total transect line length.

Quantifying the severity of soil damage can be very time-consuming and requires skilled technicians if soil physical properties are to be measured in detail. However, assessment on a purely visual basis, although much cruder, can be carried out quickly by relatively inexperienced personnel and still yield useful results. The latter approach was adopted for this study. Site damage was visually assessed using the five classes detailed in Fig. 1. This classification system recognises that for most machinery types,



DAMAGE CLASS	DC 0	MACHINES HAVE NOT TRAVELLED OVER THE AREA
	DC 1	MACHINES HAVE TRAVELLED OVER THE AREA BUT DID NOT BREAK THROUGH THE LITTER LAYER
	DC 2	MACHINE HAS BROKEN THROUGH THE LITTER LAYER AND IS STARTING TO COMPACT THE TOPSOIL
	DC 3	MOST OF THE TOPSOIL IS PUDDLED AND THE SUBSOIL IS BEING COMPACTED
	DC 4	SUBSOIL IS BEING PUDDLED AND COMPACTED

FIG. 1—Visual classification of soil damage.

as damage increases, the components of soil destruction occur together. Thus significant soil damage is unlikely where the litter layer is undisturbed (DC 1). Similarly, when the subsoil is exposed (DC 3+) significant damage in the form of topsoil removal, root damage, and compaction is likely to have occurred.

The ground-extraction machines* and the season in which they were used are listed in Table 1. Study area descriptions and thinning techniques are summarised in Table 2. It will be noted that all machines were used in winter or spring when soils are wet and most likely to incur more severe damage (Moehring & Rawls 1970). The severity of damage as recorded in these studies is thus likely to be higher than would be found after summer logging.

Area Impacted

Total area with soil damage (DC>0) ranged from 11.7% to 29.1% of the areas logged (Table 3). Although some of the relevant factors cannot be completely separated from one another it seems that:

(1) Preplanning and marking the location of skidtracks can almost halve the total area impacted. The area logged by the Fiat Allis F8 did not have the skid tracks located and marked before felling, and the total area impacted was between 25% and 30%. In similar areas where the skid tracks were planned, only 12–20% of the area was impacted (Table 3). The greater area impacted in the unplanned area was a result of the much higher density of tracks (950 m/ha *v.* about 400 m/ha in planned areas) which have an almost random pattern. This pattern was caused by the machine operator trying to take the tractor to every stump. Figure 2 exemplifies the differences in the layout of planned and unplanned skid tracks respectively.

(2) For similar areas, the proportion of the area impacted decreased as thinning intensity increased. For example, about 22% of one area was impacted where thinning intensity was 200–300 stems/ha. On an area where thinning intensity was 450–550 stems/ha, only 14% of the area was impacted. The differences are again related to track density – 560 m/ha and 465 m/ha respectively. More laterals have to be visited to build a load when thinning intensity decreases, and to speed up the stropping process the operator tries to get his machine closer to the logs.

(3) Prebunching trees prior to extraction may lead to a 15–30% reduction in area impacted. (A small radio-controlled skid-mounted winch was used in this study for prebunching; it caused no noticeable soil damage.) When trees are prebunched to the skid track the operator does not take the machine down the laterals to get closer to the logs. On a prebunched site logged by a Clark 666, 12% of the area was impacted while 14–16% of similar areas, not prebunched, was impacted.

(4) In Location 2, logged by the FMC 100, 23% of the area was impacted. However, part of the damage had been caused when the area had been clearfelled at the

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* Trade names have been used in this paper for clarity and to simplify the author's task. The machines studied and named are representative of many similar machines. Neither criticism nor endorsement of any particular machine is implied.

TABLE 1—Machine characteristics

	Fiat Allis F8	Clark 666	Bombardier Muskeg	Timbermaster TM70	FMC 100 (prototype)*
Horsepower (kW)	66	84	68	98	88
Width (cm)	254	252	224	234	213
Length (cm)	427	532	558	500	610
Weight (kg)	8132	7731	4831	5357	8626
Ground pressure (kPa)	41	82	15	26	42
Max. speed (km/hr)	9.0	27.0	20.6	14.4	22.4
No. of tracks or tyres	2	4	2	4	2
Track or wheel type	Steel track	Rubber tyre	Rubber belt with steel crosslinks	Nylon belt with replaceable grousers	Steel track
Steering	Clutches and brakes	Articulated	Controlled differential	Articulated	Controlled differential
Suspension	Oscillating track frames	Fixed	Wheels mounted in tandem	Heavy duty walking beam	Torsion bar
Season used	Winter 1978	Spring 1978	Spring 1979	Winter 1979–80	Spring 1980

* The FMC 100 was a prototype at the time of study. A production model (FT-180) with similar features is now on the market.

TABLE 2—Area descriptions and thinning techniques

Machine	Location	Soil type*	Slopes	Skid track location	Extraction direction	Thinning intensity (stems/ha)	Tree size (m^3)
Fiat Allis F8	1	Peavine - fine	Up to 20°	Unplanned	Uphill and downhill	—	0.34
Clark 666†	1	McCully - friable with c. 10% rock	Up to 10°	Preplanned and marked	Downhill	—	0.28
Bombardier Muskeg	1	Peavine - fine-textured, small surface rocks, dry	Up to 10°	Preplanned and marked	Uphill and downhill	—	0.26
Timbermaster TM70	1	McCully - friable with c. 10% rock	Up to 15°	Preplanned and marked	Downhill	450–550	0.18
Timbermaster TM70	2	Peavine - fine-textured	Up to 15°	Preplanned and marked	Downhill	450–550	0.18
FMC 100	1	Peavine - fine-textured	Up to 20°	Preplanned and marked	Uphill and downhill	—	—
FMC 100	2	Blitzen - 20–40% rock	Up to 15°	Preplanned and marked	Downhill	200–300	0.70
FMC 100	3	Peavine - fine-textured, very wet	Up to 10°	Preplanned and marked	Uphill and downhill	200–300	0.37

* Described in more detail in unpublished report by S. H. Duncan and E. C. Steinbrenner, Weyerhaeuser Co.

† For the Clark 666 operation only, trees were prebunched with a Nordfor Flying Saucer winch. For other operations trees were not prebunched.

TABLE 3—Soil damage assessment*

Machine	Location	Measurement technique	Trail density (m/ha)	Area impacted (%)				
				DC 1	DC 2	DC 3	DC 4	Total
Fiat Allis F8	1	Line transect	N.A.	7.9	7.9	4.5	4.7	25.0
Fiat Allis F8	1	Survey of 50-m radius circular plot	950	6.5	9.6	7.1	5.9	29.1
Clark 666	1	Survey	220	1.8	4.0	1.2	4.8	11.8
Bombardier Muskeg	1	Survey	320	3.8	6.9	1.0	0.0	11.7
Timbermaster TM70	1	Survey	415	9.8	3.7	0.2	0.0	13.7
Timbermaster TM70	2	Survey	465	10.9	3.0	0.1	0.3	14.3
FMC 100	1	Survey	395	5.6	7.4	1.5	1.6	16.1
FMC 100	2	Survey	560	8.5	9.3	1.7	3.7	23.2
FMC 100†	2	Survey	395	8.0	6.6	0.3	0.0	14.9
FMC 100	3	Line transect	N.A.	7.0	3.2	2.8	8.6	21.4

N.A. Not assessed

* Landings not included

† Old skid tracks excluded

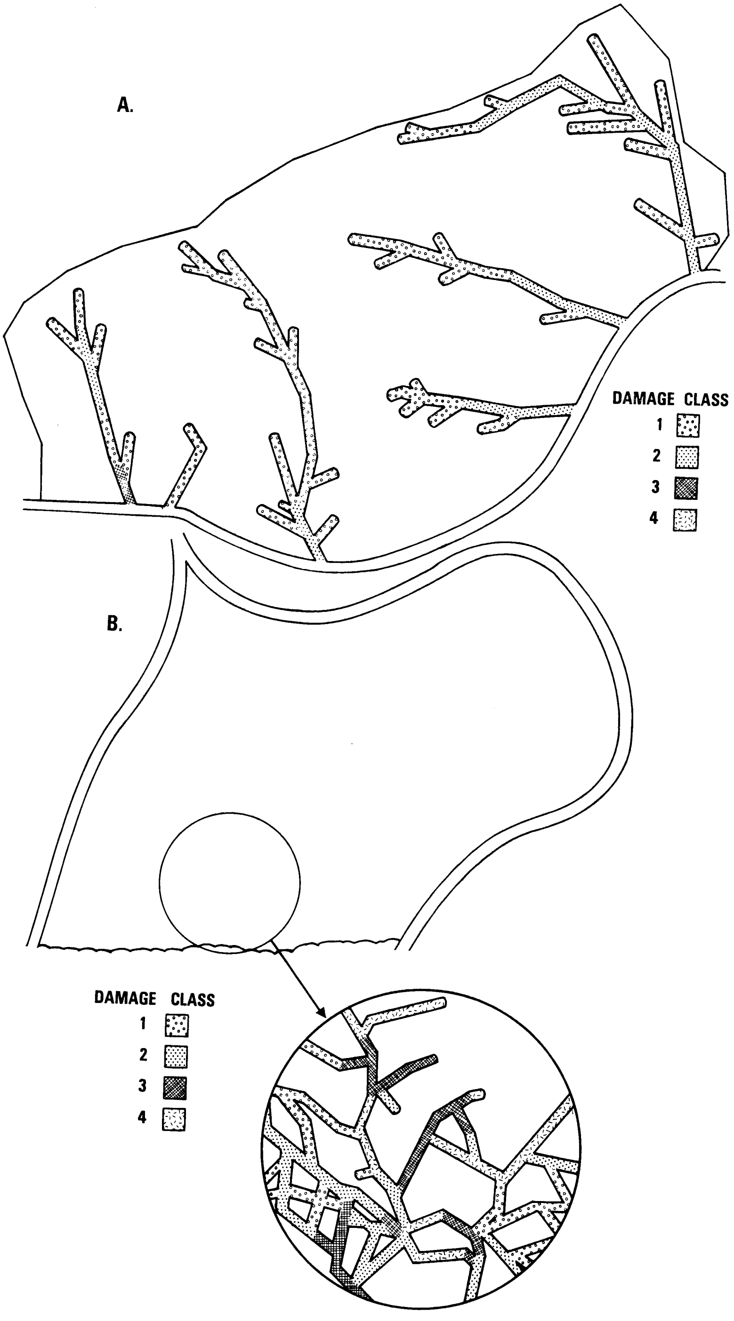

FIG. 2A—Area with skid track locations planned (logged by Timbermaster TM70 in winter 1979–80).

FIG. 2B—Area with skid track locations unplanned (logged by Fiat Allis F8 in winter 1978).

end of the previous rotation*. When damage on old skid tracks was subtracted, the total area impacted fell to 15%. Using old skid tracks for extraction during thinning would reduce the amount of new damage but this may not always be possible as optimum locations for thinning skid tracks may not coincide with those for clearfelling.

Damage Severity

Of just as much importance as area impacted is the severity of damage. Table 3 shows that there is wide variation in the distribution of area impacted among the damage classes. Several factors were examined to see if some of this variation could be accounted for.

As expected, the type of machine being used affected the severity of damage (Table 4). The rubber-tyred skidder with its high ground pressure and fast speeds had the greatest potential for causing Class 3 and 4 damage. The Timbermaster TM70, although it exerted slightly higher ground pressures than the Bombardier Muskeg, had the lowest potential for causing Class 3 and 4 damage. This was probably because the Timbermaster had articulated steering while the Bombardier had controlled differential steering.

TABLE 4—Effect of machine type on damage severity

Machine type	Percentage of damaged area in Damage Classes 3 and 4
Clark 666	51
Fiat Allis F8	40
FMC 100	20
Bombardier Muskeg	9
Timbermaster TM70	2

For areas logged by the Clark, Bombardier, FMC, and Timbermaster the number of loaded passes over each section of the trail was estimated (from stump counts) and recorded as the tracks were surveyed. Because of the almost random pattern of tracks in the area logged by the Fiat Allis it was impossible to estimate the number of passes for this machine. Figure 3 depicts the effect of number of loaded passes and machine type on the severity of soil damage as indicated by analysis of the data.

As the number of loaded passes increased so too did the severity of damage. Although this trend was evident for the four machines the number of passes required to get to a specific damage level differed markedly. For example, the Timbermaster TM70 could haul about three times the number of loads over the same piece of ground as the Clark 666 before soil damage was classed as 4.

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* Some skid tracks for clearfelling were still evident after 30 years and were characterised by the occasional presence of suppressed trees or, more commonly, the complete absence of trees.

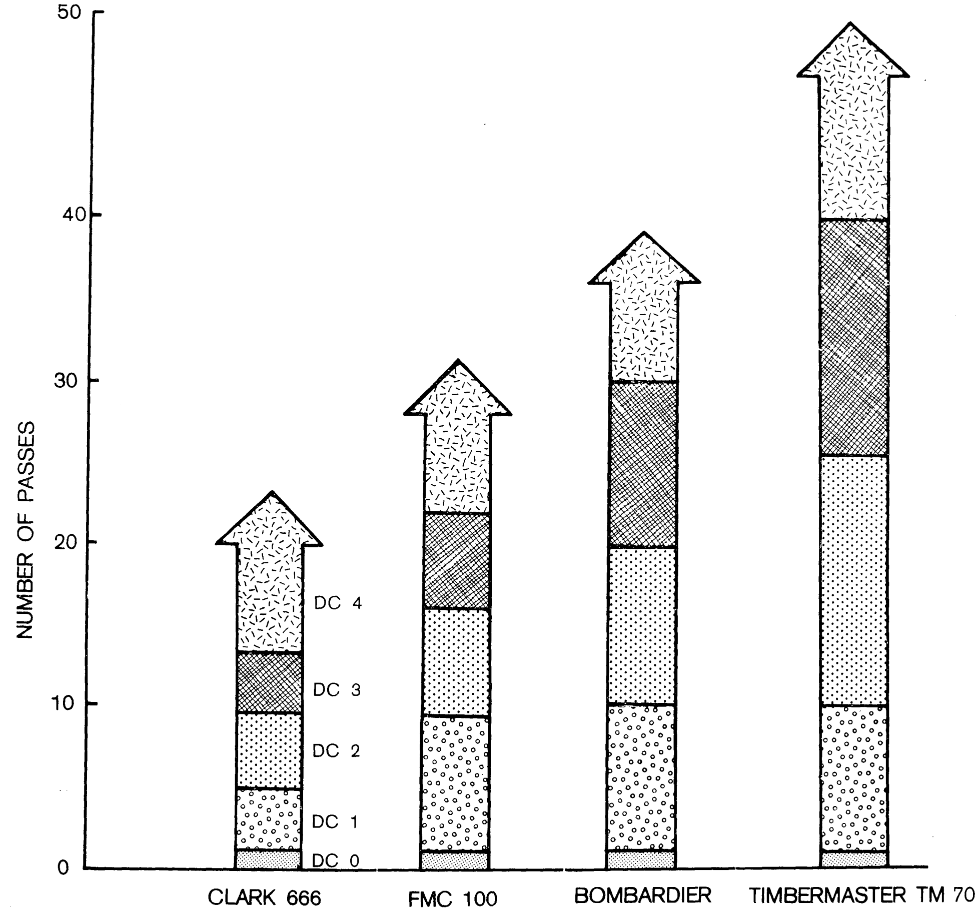

FIG. 3—Effect of number of passes on soil damage.

Slope was tested to see if it affected damage severity. Favourable and adverse slopes ranged from –20° to +22° and over this range there was no significant effect on damage severity. Data were limited, however, over +14° and common sense indicates that damage severity will increase with slope.

The condition of the soil itself has an effect on damage severity. For example, the FMC 100 was used to log two areas on Peavine soils. In one area with very wet soils over half the damage was in Classes 3 and 4; the other area had drier soils and only one-fifth of the damage was in these classes. Other work on soil damage from logging indicates similar findings, i.e., damage on drier soils will generally be less than on wet soils (Moehring & Rawls 1970; King & Haines 1979). For example, King & Haines (1979) could detect no compaction on a soil with only 13% water content in a plantation thinned with a TH-105 Thinner Harvester despite the harvester exerting ground pressures of over 120 kPa.

DISCUSSION

If soil damage caused by harvesting was a short-term effect there would be little cause for concern. There is evidence, however, that soil damage, especially the severe types, can last for decades. Skid tracks were still evident in a naturally regenerated Douglas fir stand in Oregon over 30 years after clearfelling of the previous crop. Froehlich (1979) recorded that soil compaction from logging equipment was readily measurable 16 years after thinning of a ponderosa pine (*Pinus ponderosa* Laws.) stand in Oregon. At a workshop in Australia on "Compaction of Forest Soils" examples were given of skid tracks being evident 50 years after logging and soil compaction increasing, in some places, from one rotation to the next.

Before a new crop is planted establishment techniques such as ploughing or deep-ripping may partially rectify damage occurring during clearfelling. It is unlikely, however, that soil damage caused by production thinning can be rectified without seriously disturbing the root systems of the residual tree crop. Once inflicted it is there for the rest of the rotation.

There is also much evidence available that soil damage will reduce tree growth, but the magnitude of the reduction varies considerably with species, original soil conditions, original stand conditions, stocking, and the severity of damage. Growth of 26-year-old loblolly pine (*Pinus taeda* L.) trees in the United States was 55% less on compacted areas than on adjacent sites (Perry 1964), and trees in a 40-year-old loblolly pine stand showed a 43% growth loss when soil around them was heavily compacted (Moehring & Rawls 1970). Froehlich (1979) reported growth losses of 14% for residual Douglas fir trees where trees were moderately impacted (11–40% of root zone affected by a 10% or greater increase in soil density) and 30% where they were heavily impacted (>40% of their root zone affected by a 10% or greater increase in soil density). Moderately impacted western hemlock (*Tsuga heterophylla* (Raf.) Sarg.) residual trees had a 14% reduction in growth (Froehlich 1979). Froehlich also found that growth of residual ponderosa pine was affected by soil damage – "Moderately impacted trees showed a 6% reduction in growth rate and heavily impacted trees showed a 12% reduction over a 16-year period".

Of more interest to New Zealand foresters and to many Australian ones is the effect of soil damage on growth of radiata pine. Reduced growth of planted seedlings on heavily damaged skid tracks and landings was noted on pumice soils at Kaingaroa State Forest in New Zealand in the late 1960s. Deep ripping and fertiliser application were recommended to overcome this problem (Ballard 1978). Growth of trees planted on these sites, however, does not compare favourably with that of trees on adjacent unimpacted sites.

In South Australia the reduction in productivity of second-rotation radiata pine stands on sandy soils has been around 20% (G. D. Brown, C. M. Kerruish, T. Talsma, unpubl. data). Sands *et al.* (1979) suggested that although it has been shown by Woods (1976) that fertiliser can partially correct the problem "there is [also] a non-nutritional component to the effect" – i.e., soil compaction. Sands & Bowen (1978) found that the growth of radiata pine sown in pots packed with sand decreased as density of the medium increased. A reduction of almost 50% in root and shoot dry weight was recorded for a sand bulk density of 1.60 g/cm^3 as compared with 1.35 g/cm^3. These pot studies, although indicative, may not relate exactly to field conditions (Sands & Bowen 1978) especially for trees which have a root system established before soil damage occurs.

Bowen (1964), Moir & Bachelard (1964), and Will (1966), in studies on a range of soil types, have all reported that the greater part of the root system of radiata pine is distributed in the top 30–40 cm of the soil. It may also extend outwards for several times the crown diameter (G. M. Will pers. comm.). It is in these upper soil levels that compaction, soil displacement, and root damage are most likely to occur during production thinning (Froehlich 1972). The impact of these problems may be reduced because of the root grafting of radiata pine which is common in plantations (Will 1966). However, the ability of radiata pine under stress to draw resources via root grafts from less stressed parts of a stand is unknown.

Further research to quantify the effect of soil damage on radiata pine growth under field conditions needs to be carried out.

CONCLUSIONS

The methods of logging studied in Oregon do not differ greatly from those used in New Zealand and Australia, therefore it is reasonable to expect similar levels of damage in these countries. When arranging harvesting operations, logging planners can take into account all the factors which have been identified in this study as affecting soil damage – logging season, machine type, skid track density and location, logging system.

Each solution the logging planner adopts has a production cost and a readily identified potential soil disturbance level. Research is needed now to quantify the costs of soil disturbance so that the option with least total cost can be selected for each area.

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