Table 12. Plant species present on cutting unit 3

Species	Number of Quadrats occupied	Frequency %
1. Groundsel - Senecio vulgaris L.	344	17.70
2. Salal - Gaultheria shallon Pursh.	219	11.26
3. Vine maple - Acer circinatum Pursh.	70	3.60
4. Grasses and rushes slender hairy-grass - Deschampsia elongata (Hook.) Munro. common wood-rush - Luzula campestris (L.) DC.	43	2.21
5. Harebell - Campanula petiolata A. DC.	39	2.01
6. Sword fern - Polystichum munitum (Kaulf.) Presl.	27	1.39
7. Blackberry -Rubus macropetalus C. & S.	18	.93
8. Hemlock - Tsuga heterophylla (Rafn.) Sarg.	12	.62
9. Bracken fern - Pteridium aquilinum (L.) Kuhn. var. pubescens Underw.	9	.46
10. Bedstraw - Galium aparine L.	8	.41
11. Thimbleberry - Rubus parviflorous Nutt.	7	.36
12. Oregon grape - Berberis aquifolium Pursh.	5	.26

Table 12 Con't. Plant species present on cutting unit 3

Species	Number of quadrats occupied	Frequency %
13. Lupine - Lupinus sp. L.	4	.21
14. Douglas-fir - Pseudotsuga menziesii (Mirb.) Franco.	4	.21
15. Elderberry - Sambucus melanocarpa Gray.	3	.15
16. California lettuce - Claytonia sibirica L.	3	.15

Total 6 x 6 inch quadrats observed - 1,944
Total occupied - 745
Total plant frequency - 38.32%

Plants present but not occurring in grids sampled

1. Thistle - Cirsium edule Nutt.
2. Fireweed - Epilobium adenocaulon Hausskn.
3. Three-leaved cool-wort - Tiarella trifoliata L.

ing favored the establishment of groundsel. Although blackberry, Rubus macropetalus C. & S., ranked only seventh in importance on unit 3, Isaac termed it, "The most important perennial invader on new burns". However, since it is a rapidly spreading species, the frequency of blackberry may be expected to increase in the future. Grasses and rushes, Deschampsia elongata (Hook.) Munro. and Luzula campestris (L.) DC., (ranked fourth), harebell, Campanula petiolata A. DC., (ranked fifth), and bracken fern, Pteridium equilinum (L.) Kuhn. var. pubescens Underw., (ranked ninth) are other invading species which may be expected to increase in importance until they are crowded out by the encrouching brush.

Salal and vine maple, Acer circinatum Pursh., are the most evident species held over from the forest understory on unit 3. Salal, along with Oregon grape, Berberis aquifolium Pursh., are the universal holdovers from the standing forest and they often remain through the brush succession to form part of the ground cover in the new forest. The moderate abundance of vine maple is of considerable significance as it may increase in density sufficiently to retard the growth of forest reproduction. Sword fern, Polystichum munitum (Kaulf.) Presl., has remained comparatively abundant, however, Isaac has found that although this species persists after logging, it then gradually declines.

Only 16 forest tree seedlings were included in the samplings, thus suggesting that the natural reforestation of the area is proceeding at a slow rate. Twelve of these seedlings were

western hemlock, Tsuga heterophylla (Rafn.) Sarg., however, a higher percentage of Douglas-fir, Pseudotsuga menziesii (Mirb.) Franco., stocking is the desired end result.

The results of vegetation sampling on unit 4 present quite a different picture from those obtained on unit 3. Since the vegetation on this clear cut was only in its first growing season following slash burning, the four principle species were all those which had been carried over from the original forest understory. Oregon grape was the most numerous species, occupying 5.06 per cent of all the quadrats. Salal was also abundant, followed by vine maple and sword fern in the order of their frequency. It may be expected that in the future Oregon grape and salal will maintain their position without increasing, sword fern density will diminish, and the vine maple will slowly increase in importance. Table 13 contains a complete list of the plant species found on unit 4 and their frequency percentages.

Perhaps the most striking difference between the vegetation on units 3 and 4 is the difference in its density. Cutting unit 4 appeared almost devoid of vegetative growth and possessed a total plant frequency of only 11.27 per cent. Unit 3, on the other hand, had a plant frequency more than three times as high, mainly due to invasion by annual weeds. Isaac (27, p. 720) found that the percentage of vegetative cover usually increases rapidly for the first three years, after which it slowly declines.

Cutting unit 10 was sampled 1 month after burning and as would

be expected very few plants were present. Only six species of plants were noted within the enlarged circular plots, and all were located in unburned or undisturbed areas. Most of the holdover species present on this clear cut were also prominent on the other two cutting units. Thistle, Cirsium edule Nutt., was considerably more abundant on unit 10 and was the only species present which can be considered as an invader. Since logging of the area ceased in the spring of 1955, the thistle undoubtedly seeded in during the interval between logging and burning. Table 14 contains the list of species present on unit 10.

Table 13. Plant species present on cutting unit 4

Species	Number of Quadrats occupied	Frequency %
1. Oregon grape - Berberis aquifolium Pursh.	93	5.06
2. Salal - Gaultheria shallon Pursh.	51	2.77
3. Vine maple - Acer circinatum Pursh.	32	1.74
4. Sword fern - Polystichum munitum (Kaulf.) Presl.	26	1.42
5. Harebell - Campanula petiolata A. DC.	7	.38
6. Douglas-fir (planted) - Pseudotsuga menziesii (Mirb.) Franco.	6	.33
7. Grass - probably Deschampsia sp. (Hook.) Munro.	4	.22
8. Wild cherry - Prunus emarginata Dougl.	4	.22
9. Blackberry - Rubus macropetalus C. & S.	3	.16
10. Pink trefoil - Lotus stipularis Greene var. sublaber Ottl.	2	.11
11. Dagger-leaved rush - Juncus ensifolius Wiks. (probably)	1	.05

Total 6 x 6 inch quadrats observed - 1,836
Total occupied - 207
Total plant frequency - 11.27%

Table 14. Plant species present on cutting unit 10

Species	Number of circular Plots occupied (5 ft. radius)
1. Oregon grape - Berberis aquifolium Pursh.	13
2. Thistle - Cirsium edule Nutt.	10
3. Salal - Gaultheria shallon Pursh.	8
4. Vine maple - Acer circinatum Pursh.	7
5. Grass - Deschampsia elongata (Hook.) Munro.	3
6. Blackberry - Rubus macropetalus C. & S.	1

Total No. of plots - 54
No. occupied - 21

SUMMARY AND CONCLUSIONS

The point observation data collected on the three cutting units indicated a considerable variation in soil condition from one clear cut to another. It was found, for example, that the percentage of the soil surface area in the severely burned condition ranged from 1.3 per cent on cutting unit 3 to 16.1 per cent on unit 10. The mean soil condition values for the three units were as follows: 44.7% lightly burned, 8.0% severely burned, 30.1% disturbed but unburned, and 17.2% undisturbed. These soil condition values may be considered fairly representative of broadcast burned clear cuts in this area.

It is significant to note that a surprisingly large area of the average clear cut is not subjected to the effects of fire. The mean percentage of the soil surface which is untouched by fire is 47.3 or almost one-half, and 17.2 per cent of the total soil surface has been left in a completely undisturbed condition. Unfortunately some workers have failed to mention that the results of their work on the effects of slash burning on the soil are applicable to severely burned soils only, or to less than one-tenth of the total area. Perhaps if the emphasis were placed on the effects of slash burning on the entire clear cut rather than on one small segment, the detrimental effects of burning would no longer appear to overbalance the beneficial effects.

Mechanical analysis of the 180 soil samples revealed that

severe burning appreciably altered the amounts of the various sizes of mechanical separates within the top two inches of soil. The data for the other soil conditions revealed no consistent differences in soil texture. The treatment means for the three cutting units show that there is 6.3 per cent less clay in the soil which has undergone severe burning than in the control soil collected under the adjacent timber. In other words, when the severely burned soil is compared to the timber soil it is seen that it contains only 84.3 per cent as much clay. The Melbourne clay soil on unit 4 and the Olympic clay on unit 10 both exhibited a reduction in silt content and an increase in the amount of sand along with the drop in per cent clay when subjected to severe burning. In the case of cutting unit 3, however, severe burning had the opposite effect on the particle size distribution of Blachly loam. Although the clay percentage was also lowered in this soil, there was a slight drop in the amount of sand and a noticeable increase in the silt content.

There seems to be only one feasible explanation for this obvious shift in soil texture occurring at high temperatures. In the case of units 4 and 10, the increase in sand accompanied by the loss of silt and clay suggests the possibility of the fusion of fine particles. At extremely high temperatures it would be reasonable to assume that the resultant aggregates would be very stable as the result of complete dehydration of the particles. This is exactly what was found, for during the course of the study it was noted that these aggregates were almost completely

resistant to dispersion and consequently they were considered as primary particles. The sandier soil of unit 3 was affected differently by severe burning than were the clay soils of the other two clear cuts. It is probable that the aggregates resulting from clay fusion on this unit were smaller and silt-sized. Evidence for this is the lower clay percentages and the increase in the silt content of severely burned samples.

The results of the moisture equivalent determinations indicate that the ability of the soil to retain moisture is appreciably lessened by exposure to intense heat. Whereas the surface two inches of soil in the standing timber possessed a mean moisture equivalent value of 40.5 percent, severely burned samples had a mean value of only 35.3 per cent. Surprisingly, light, superficial burning had no consistent effect on moisture equivalent values in this study. However, the treatment mean for the disturbed, unburned samples is 38.4 per cent, or 2.1 per cent below the timber treatment mean. This difference is sufficiently large to be considered significant at the 5 per cent level of probability.

The lower moisture equivalent values for severely burned soils may be attributed to loss of organic matter and their coarser texture. The slightly lower values in the case of the disturbed, unburned soils may be due to structural breakdown as a result of compaction.

It was found that the percentage of total soil aggregation was also at a lower level in severely burned soils. The results of

aggregate analysis demonstrated that severely burned samples contained an average of 41.8 per cent aggregates from 5 to .1 millimeter in diameter, while the samples from the surrounding timber had a mean per cent aggregation of 52.7. None of the other treatment means deviated appreciably from that of the timber.

The lower degree of aggregation in the severely burned soils may be due to several factors. First of all, the removal of the colloidal organic matter involved in particle cementation may have caused aggregate disintegration. Secondly, the cementation of finer particles into virtual primary particles larger than .1 millimeter also undoubtedly reduced the per cent aggregation values because of the procedure followed in the determination. This procedure consisted of subtracting the weight of the primary particles remaining after dispersion from the original weight of aggregates plus particles. Therefore, the weight of any aggregates formed as a result of the intense heat and which were so stable as to be resistant to dispersion would also be subtracted, thus lowering the calculated percentage of aggregation.

Organic matter determinations showed that once again the only treatment to have significant detrimental effects was severe burning. The mean value for per cent organic matter in timber soil samples was 10.8 per cent, as opposed to only 4.2 per cent in the severely burned soils. No other treatment mean departed more than .4 per cent from the value found for the surface two inches of soil in adjacent timber stands.

Middleton's erosion ratio was determined for 36 soil samples from cutting unit 10. The timber, lightly burned, and severely burned soil conditions were represented by 12 samples each. The mean erosion ratio values found for these soils were as follows: timber, 3.01; lightly burned, 4.19; and severely burned, 9.97. Since Middleton places the limit for non-erodable soils at 10, the preceeding values indicate that burning does not increase the erodability of the soil to a dangerous extent, at least insofar as it is assessed by this somewhat empirical method.

Field observations and the results of laboratory determinations indicated that there are several effects of logging and slash burning which would tend to increase the erosion potential of the soil. Although not exposed to the effects of fire, skid trails in disturbed, unburned areas may be the source of excessive runoff and accompanying erosion because of their compacted condition. Lightly burned areas, even though occupied by soils with essentially unaltered physical properties, may also be more susceptible to erosion due to the destruction of protective ground vegetation and forest litter.

This study has shown the severely burned soils to be the most adversely affected and consequently the most susceptible to erosion. Since soil aggregation is one of the most important factors in controlling soil erodability, the decrease in aggregation found for severely burned soils indicates a significant increase in erosion potential. Furthermore, it is probable that

future aggregate formation will proceed very slowly due to the coarser texture of the soil and loss of colloidal organic matter. The complete absence of litter on the surface of the severely burned soils leaves the soil exposed to the puddling action of rain which ultimately results in appreciably slower infiltration rates.

There are, however, several factors which tend to minimize the danger of soil erosion in severely burned areas. First of all, a stabilizing surface crust was observed on the majority of severely burned soils. Secondly, severely burned soils never occupy large areas but are found in small, scattered spots throughout the clear cut. Furthermore, severely burned soil conditions were very seldom found on the steeper slopes which would be more easily eroded, as slash tended to accumulate on the more gentle slopes.

Outside of some mechanical soil compaction caused by logging, the main threat to soil stability on the cutting units studied may be attributed to slash burning. However, as was previously stated, soil conditions in lightly burned areas are not affected appreciably and there is no serious increase in erodability in these areas. Tarrant (57) has found essentially the same thing in his study of the effects of slash burning on the percolation rate of the soil. He reports that light burning had no lasting effect on soil permeability. He did, however, find that severe burning increased soil bulk density which, in turn, reduced rates of water percolation. Therefore, it is apparent that severe burning not

only causes the soil to be less resistant to removal by runoff, as was demonstrated in the present study, but it also results in a soil with a lowered capacity for water absorption and hence a tendancy for the initiation of runoff during heavy rains.

The amount of severely burned soil present following broadcast slash burning is, in this area, largely dependent upon two factors: (1) the amount of slash to be burned and its distribution, and (2) the moisture status of the slash, litter, and soil at the time of burning. If, for example, the quantity of slash is well distributed over the entire area, the danger of exposing the soil to extremely high temperatures in localized areas is lessened considerably. Furthermore, the level of wood utilization has a profound influence on the extent of the severely burned soil condition. It is to be expected that in the future it will be economically feasible to remove many of the logs which at present are rejected. Since many of the severely burned areas were noted to result from the burning of cull logs, this increased utilization will tend to decrease the occurrence of the severely burned soil condition. A recent improvement in the technique of slash disposal which has already proved its worth is the practice of burning slash soon after a fall rain. It has been found that burning the slash when the litter and soil are still moist results in far less damage to the soil. The severely burned areas are limited to the soil immediately beneath large accumulations of slash, and even here the effects of the fire penetrate the soil

to only a limited depth.

The results of the vegetation sampling carried out on the three cutting units illustrate the yearly increase in vegetative cover which invariably occurs for at least the first three years. The vegetation on unit 4, which was in its first full season of growth, had a total frequency of only 11.3 per cent and was mainly composed of species held over from the forest understory. The most important species on this unit were: Oregon grape, Berberis aquifolium Pursh., and salal, Gaultheria shallon Pursh. Unit 3, on the other hand, supported vegetation in its second full season of growth and had a total plant frequency of 38.3 per cent. This large increase in frequency over unit 4 can be attributed to the presence of large numbers of a variety of invading species, of which the principal one was groundsel, Senecio vulgaris L. Unit 10 was sampled one month after burning and consequently the vegetation was limited to unburned areas and a small number of dominantly holdover species. Thistle, Cirsium edule Nutt., was the only species present on the unit which could be classified as an invading species.

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