Soil Quality Monitoring on the Tongass National Forest

The Tongass' Interpretation of the Region 10 Soil Quality Standards.

Part 2: Summarizing 4 years of data collection

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Introduction and Background

The Region 10 Soil Quality Standards (SQS) were written in 1992 and have guided soil quality monitoring efforts for 18 years on the Tongass National Forest. The standards received minor revision in 2006. The Region 10 standards define detrimental displacement and detrimental surface erosion as areas at least 100 square feet in size. (It should be noted under detrimental soil displacement that mixing of surface soils and organic humus or removal of small areas by scalping for planting purposes *are not* considered detrimental.) The Region 10 SQS did not define minimum size criteria for the remaining detrimental soil conditions including puddling, burned, compaction, altered wetness, mass movement, and lack of ground cover.

Landwehr (1993a) recognized the need to define minimum size criteria for all detrimental soil conditions to facilitate field monitoring of the Regional Soil Quality Standards. The 1992 Regional Soil Quality Standards referenced Howes et. al. (1983) for methods when designing soil monitoring projects. Howes. et. al. used 1 foot as a minimum measurement unit in their examples. Landwehr (1993a) suggested using 1 foot as a minimum measurement unit for the detrimental soil conditions with no defined minimum size requirement in the Region 10 Standards. In this report Landwehr's 1993 minimum size criteria is referred to as the Tongass interpretation of the Region 10 Soil Quality Standards.

To date, the Tongass National Forest has collected over 50 miles of soil disturbance transect data, typically within 1 to 2 years following timber harvest. Prior to 2011 all of the soil disturbance monitoring occurred in stands which received their first vegetation treatment. (Some of these stands can be described as old-growth and some were even-aged wind throw regenerated stands.) Even with the very small minimum size criteria for detrimental soil conditions used by Landwehr (1993a) all stands met Regional Soil Quality Standards. The logging systems typically employed prior to 2011 were a variety of cable systems, helicopter, and shovel yarding (restricted to slopes less than 30 percent gradient). Typically detrimental soil conditions averaged about 3 percent for partial suspension achieved with cable systems and shovel systems and 2 percent for full suspension achieved with helicopter or cable systems (Landwehr and Nowacki 1999).

Areal extent standards for the Alaska Region:
Detrimental Compaction, Displacement, Puddling, Mass Movement, Erosion, and Severely Burned. Leave a minimum of 85 percent of an area in a condition of acceptable productivity potential for trees and other managed vegetation following land management activities. Specified (system) roads which include cut, fill, road bed, landings and log transfer facilities are excluded from the activity area, but side cast and other waste materials are not excluded. FSM R-10 2500-2006-1

Pre-harvest areas of exposed mineral soils are very low due to the presence of thick duff layers covering almost 100 percent of the forest floor, rocks, and downed trees. In natural conditions exposed mineral soil is rarely expressed outside of wind-thrown areas, landslide tracks, and stream-banks. Because of these

conditions the Tongass has collected very little soil disturbance data prior to harvest. Even on extremely steep, cliffy terrain, rock or mineral soil exposed is typically less than 2 percent of a stand prior to timber harvest (Landwehr 1993b).

The Region 10 Soil Quality Standards and Landwehr's interpretation of them suggests that minimizing soil disturbance is best for maintaining soil productivity.

Since 1995 research has suggested that many soil disturbances may not be detrimental to soil productivity, and in some cases soil disturbances may be beneficial to soil productivity (Bormann et. al. 1995, Kramer 2000, Banner et. al. 2005). Soil disturbance may prevent paludification (accumulation of thick layers of organic matter that effectively reduce soil drainage class) on some sites and prevent formation of cemented layers in the soil profile. The Region 10 Soil Quality Standards do not mention beneficial soil disturbance and monitoring efforts to date have not attempted to identify sites where soil disturbance may be beneficial to site productivity.

Anecdotal evidence collected during soil investigations in older young-growth stands suggests that many of the small soil disturbances (less than 25 square feet in size) documented as detrimental soil conditions may not be evident after 10 or more years, and even mid-size (25 to 100 square feet in size) soil disturbances are not evident nor do they appear to be affecting canopy closure or stand growth. If small soil disturbances are not evident 10 years after creation we must ask: Are those small disturbances detrimental to soil productivity which is measured by desired vegetation growth at the site scale and the stand scale and over a time scale of several decades?

At this time the Tongass National Forest is beginning to identify our first commercial timber sales in young-growth or previously harvested stands. There is a need to understand the amount of soil disturbance incurred during past harvest activities, the duration of that soil disturbance on the landscape, and the effects of the disturbance on desired plant growth.

The Region 10 Soil Quality Standards require managers to leave 85 percent of an area in a condition of acceptable productivity potential for trees and other managed vegetation following land management activities. In other words the standards require that no more than 15 percent of an activity area be in a detrimental soil condition.

The National Forest Management Act (NFMA) of 1976 mandates that all National Forest System lands be managed under the principles of multiple use and sustained yield without permanent impairment of the productivity of the land. Forest Service Manual direction requires that management maintain or improve soil productivity. NFMA also required continuous monitoring and assessment in the field of each management system so that it will not produce substantial and permanent impairment of the productivity of the land.

Following NFMA each region of the National Forest System developed guidelines for soil quality monitoring and defined acceptable levels of change in soil properties. The Alaska Region first adopted soil quality standards in 1992 through a Forest Service Manual Supplement. The supplement received minor edits in 2006.

Continued application of Landwehr's 1993a interpretation of minimum size limits for detrimental soil conditions may unnecessarily restrict harvest opportunities in older young-growth stands because the cumulative total of detrimental soil conditions may be more than 15 percent of a stand that was previously harvested with less regard for soil resources than is considered appropriate today. Continued efforts to minimize soil disturbance on some sites may lead to a reduction in soil productivity through paludification processes (Banner et; al 2005). Currently the Tongass soil disturbance protocols document soil disturbances as small as one square foot as potentially detrimental to soil productivity.

The soil scientists on the Tongass believe it is time to test the Tongass' interpretation of the Region 10 Soil Quality Standards. In broad terms the Tongass needs to know how soil disturbance affects desired vegetation growth. Under what ecological conditions does soil disturbance effect desired plant growth? What is the minimum size, severity, and areal extent of soil disturbance that is detrimental to desired plant growth at the site scale? At the stand scale? How long does the effect of soil disturbance on desired plant growth last? These are very broad questions and difficult to answer. The more immediate needs can be summarized in simpler questions. What are the current soil and vegetation conditions in previously harvested stands that are being considered for commercial thinning or other vegetation treatments that require ground disturbance? What is the minimum size and severity of soil disturbances that persist after 10 years of recovery? After 50 years of recovery? To answer these questions the ecological site conditions need to be considered. Different soils respond differently to soil disturbance.

This report is the second in a four year effort monitoring soil quality in young-growth stands on the Tongass National Forest. The field work started in 2007 and continued in 2009 to 2011. Results from the first year's work were reported by Landwehr (2008). The results of the first report will be summarized in this report.

Purpose and Need

There is need to understand the minimum size, severity, and ecological conditions of soil disturbances and their impact on desired vegetation growth at the site scale. There is a need to be able to predict the size and severity of soil disturbances from proposed activities that will affect soil productivity into the future.

To adequately estimate cumulative effects there is a need to understand the existing condition of soils in young-growth stands proposed for vegetation treatments that have the potential to create ground disturbance. Do detrimental soil conditions still exist from the original harvest? What are the common traits, ecological conditions, size, and severity of the soil disturbances that are affecting desired vegetation growth?

Objectives

The first objective is to understand the minimum size, severity and ecological conditions of physical soil disturbances still evident in harvest units after 10 years of tree growth and litter fall.

The second objective is to determine the common traits (minimum size, severity, and soil conditions) of a soil disturbance that negatively affects the desired plant growth at the site scale after 50 years of recovery. Meeting this objective will also help us understand the existing soil conditions in young-growth stands that that may be ready for commercial thinning. When aggregated to the stand scale do these detrimental soil conditions violate the Region 10 areal extent standard for soil quality?

The outcome of this monitoring may result in a reasoned change to the Tongass' (Landwehr 1993a) interpretation of the minimum size criteria for detrimental soil conditions

Soil Productivity

Soil productivity is defined in the Region 10 Soil Quality Standards as the soil component of long-term site productivity and is the inherent capacity of a soil to support the growth of specified plants, plant communities, or a sequence of plant communities. Soil productivity may be expressed in terms of volume or weight/unit area/year, percent plant cover, or other measures of biomass accumulation. (FSM R-10 Supplement 2500-2006-1)

Goals and Objectives

The Tongass Land Management Plan (2008) defines the goals and objectives for the soil resource. The two goals are: 1) to maintain soil productivity forest-wide and minimize soil erosion resulting from land-disturbing activities and; 2) Minimize sediment transported to streams from land-disturbing activities.

Desired Future Conditions

The Tongass Forest plan identifies Desired Future Conditions based on Land-Use Designations. For most development LUDs allowed activities involve soil disturbance that may affect soil productivity and not completely meet the goals and objectives for the soil resource. The tradeoffs between lost soil productivity and road or recreation site development cannot be clearly weighed unless the affects of the activity on soil productivity are known.

Methods

Part1 Re-monitoring 15 year-old stands

To determine the fate of small soil disturbances after 10 years of recovery, randomly located transects were completed in portions of timber harvest units where relatively high levels of soil disturbance were documented shortly after harvest more than 10 years ago. The Tongass NF had this information stored in spreadsheets and summary reports, complete with transect maps for each harvest unit monitored. The detailed methods for this part of the monitoring can be found in Landwehr (2008).

Part 2 Monitoring in 50 year-old stands

To document detrimental soil conditions in older-young-growth stands and identifying traits common to soil disturbances affecting plant growth over the long-term, soil disturbance transects were completed in stands that were more than 50 years old. In the

50 year-old stands randomly located transects were used to document soil conditions and the extent of the identifiable skid trail network. Visual observations of tree height differences associated with soil conditions were noted and if possible photographed. Soil duff thickness measurements were taken along transects based on the protocol update documented by Landwehr 2009. Duff thickness measurements in young-growth stands were compared to duff thickness measured using the same methods in adjacent unharvested stands.

Duff thickness monitoring was prompted by observations that duff was thinner in the 50 year old young-growth than in the unharvested stands on Kosciusko Island. Under the Kosciusko Timber Sales EIS the young-growth stands are proposed for commercial thinning and the unharvested stands are proposed for their first timber harvest. Duff thickness was also identified as a measureable soil quality indicator by Deluca and Archer (2009).

What is an Unharvested Stand?
Unharvested stands can have old-growth characteristics, but may be even-aged or two aged wind generated stands. All of the unharvested stands measured for this report are likely in excess of 200 years old, although tree age was not determined. Unharvested stands are those stands that have not received any vegetation treatments.

Soil compaction studies using core samples were also conducted in one of the young-growth stands. Paired core samples on and off skid trails were collected at two depth classes. The depth classes were 7.62 to 15.24 centimeters (3 to 6 inches) and 15.24 to 22.86 centimeters (6 to 9 inches). These depth classes were chosen because compaction present in the rooting zone should be identifiable at these depths (Corns 1987, Sturos and others 1995, Johnson and other 1991, Standish and others 1988, Seixas and McDonald 1997). Analysis of the core samples included oven drying at 105 degrees C for 48 hours, sieving and weighing the fine earth and coarse fragments separately, calculating the volume of the coarse fragments via displacement in water and reporting fine earth bulk density in grams/cc.

Stand selection (Part 2)
Stands harvested more than 50 years old were chosen because this age class represents many of the oldest young-growth stands on the forest and the group of stands more than 50 years old is large enough to provide the desired sample size. Age 60 to 80 is generally required before stands on productive soil are ready for a commercial thinning which commonly involves some level of ground-disturbance. Currently few harvested stands on the Tongass are older than age 60. To be selected for sampling the stands had to meet the age requirement and be immediately adjacent to a comparable unharvested stand.

Comparable unharvested stands had to be on the same soil type and bedrock type and have the same aspect and general slope as the young-growth stand to be measured. A range of site productivity was desired, but most of the 50 year-old harvested stands on the Tongass are on very productive sites. Reasonable access was also considered in stand selection. If many high productivity stands were selected on the same rock and soil type the selection was narrowed to the ones with relatively easy access. Conversely because few low productivity stands were available, all low productivity stands were included in

stand selection regardless of access difficulties. This site selection process greatly reduced the potential unit pool from hundreds of stands down to approximately 20 stands.

To further understand the role of severe soil disturbances on site productivity, stands with severe soil disturbances documented by photographs during or shortly after harvest were investigated and photographs retaken. All of these stands were more than 10 years-old. These stands included a 15 year-old tractor and A-framed logged stand on productive soils on Cap Island, a 20 year-old stand where shovel yarding and a rubber tired skidder were used on a dense slash trail, and a 20 year-old shovel yard stand where ruts were created on wet soils over till.

We attempted to replicate soil disturbance transects completed shortly after timber harvest in two stands at Yakutat where Billings et. al (1970) identified soil productivity concerns due to harvest related soil disturbance. Soil disturbance and productivity relationships in these two stands at Yakutat were also the subject of a research paper by Harris et.al.1976.

Duff thickness and soil conditions were measured using randomly located transects in a 40 year-old alder dominated stand near Luck Lake on Prince of Wales Island. This stand was selected, because soil disturbance was the primary hypothesis behind alder dominance of this stand and there was a chance to compare soils under alder versus soils under conifer young-growth in the same stand.

Soil disturbance and woody debris accumulation was documented using randomly located transects in four 15 year-old stands where aerial reconnaissance indicated that woody debris accumulation on shovel trails was retarding conifer growth.

In 2010 and 2011 soil disturbance monitoring also included documentation of skid trails and soil conditions in recent commercial thinned 50 + year-old young-growth stands and a wildlife gap creation with mechanized equipment project in a 40 year-old stand. The soil disturbance studies in the commercial thin stands included bulk density sampling for soil compaction. The findings from the commercial thinning studies and the mechanical gap creation are documented in two separate monitoring reports (Landwehr and Silkworth 2011a and 2011b). The findings from these reports will not be summarized here.

Results and Discussion

Part 1 Re-monitoring 15 year-old stands

The results from *Part 1* of this monitoring were documented in a separate report (Landwehr 2008). The results are summarized here.

In the summer of 2007 soil disturbance transects were completed in seven harvest units where relatively high levels of soil disturbance was documented in the early 1990s. The units were harvested between 1990 and 1993. Table 1 displays the dates of the original transects, the mean soil disturbance, the dates of the re-monitoring and the mean soil disturbance.

The data does not indicate a consistent reduction in soil disturbance over time. In particular data from Unit 533-108 indicate more soil disturbance in 2007 than in 1991 (Table 1). This increase in soil disturbance is due to the inclusion of several small snow avalanche areas in the harvest unit and a severe snow winter which during the spring snow melt caused soil erosion in and adjacent to the snow avalanche areas. In all other units the amount of soil disturbance observed in 2007 is less than that observed in the same areas prior to 1993 (Table 1).

Table 1. Soil disturbance values for original soil disturbance monitoring and the re-monitoring for seven harvest units.

Unit number	Date monitored	Mean soil disturbance*	Date monitored	Mean soil Disturbance**
577-110	August 1990	9%	June 2007	1%
577-103	August 1990	8%	June 2007	1%
533-108	August 1991	8.7%	June 2007	11%
620-117	May 1991	15%	October 2007	0%
594-103	Sept. 1993	9.9%	August 2007	1%
620-123	October 1993	12.0%	October 2007	0%
620-124	October 1993	10.0%	October 2007	5%

* Mean values are for all mineral soil or rock exposed. Prior to 1993 soil disturbance values include very small disturbances down to about 6 inches in size.
**Minimum size of soil disturbance measured at 1 foot and meeting criteria for Lack of Ground Cover.

Based on the unit narratives and individual transect values, and the author's personal experience in conducting the monitoring both pre-1993 and again in 2007, a substantial amount of vegetation and duff layer recovery has occurred and is occurring in the disturbed areas. Many small areas of soil disturbance are no longer visually evident after 15 years of recovery. The 2007 monitoring can be summarized in several key points.

Key Points from the 2007 work *(Part 1)*

Where detrimental soil conditions still exist 15 years after timber harvest the soil in these areas consists of cobbly and/or dense subsoil material or bedrock and the site is in a landscape position where the exposed soil does not receive fine soil material or organic matter from adjacent areas. Heavy rainfall, wildlife traffic, snow avalanching and/or snowmelt continue to disturb or erode the site, preventing natural recovery.

A grass stand was established on the small landslides in deep till on the lower slopes in unit 577-110 shortly after the slide occurred. The grass stand was able to trap fine sediments and seeds of woody plants and provide a seedbed for woody plant establishment.

Conversely, on disturbed organic soils or richer mineral soils, grass seeding may retard growth of woody plants through grass stand dominance of the site. In one forested

wetland area of unit 577-103 timber was sparse prior to timber harvest and soil disturbance. Grass seeding of shovel ruts in organic soils in this area has resulted in grass dominating the site. Where grass seeding did not occur on disturbed organic soils in nearby unit 577-110 natural woody vegetation is beginning to occupy the site.

The 2007 monitoring indicates that many small soil disturbances, less than about 25 square feet in size are not identifiable after 15 years of recovery and likely not detrimental to woody plant growth even on relatively poor soils. The Tongass' interpretation of the minimum size requirements for detrimental puddling, lack of ground cover, burned areas, altered wetness, and compaction could be changed from 1 square foot to 25 square feet with very little risk of missing any detrimental soil conditions.

For more detail regarding results and discussion of Part 1 of this monitoring please refer to Landwehr 2008.

Part 2 Monitoring in 50 year-old stands
Portions of 27 young-growth stands were investigated between 2009 and 2011. As mentioned in the methods section these stands either were selected for their age and comparable and adjacent unharvested stands (15 stands), or photo documentation of severe soil disturbance (5 stands), or observation of dense slash mats affecting growth of the desired vegetation (7 stands). Results for Part 2 will be organized by these three emphasis areas of this monitoring.

<u>Existing soil conditions in seven 50-year-old young-growth stands, Tractor Logged</u>
Tractor logging was used to harvest 7 of the 15 stands monitored. Tractor skid trails still evident after 50 years occupy an average of 15 percent of the stand. As a result of soil displacement we estimate that 7 percent of the tractor logged stands are in a detrimental soil condition. Detrimental soil conditions were typically soil displacements 10 to 16 feet wide and tens of feet long. The displaced areas support either no woody growth on the skid trail or shorter trees on the skid trail when compared to adjacent undisturbed areas.

Tractor skid trails in highly productive soils in 50-year-old young-growth stands on the Kosiusko Project Area support little or no woody vegetation, however the trees growing in the nutrient-rich topsoil berm adjacent to the trails were some of the largest trees in the stand. By age 50 canopy closure is nearly complete over the skid trails. Although the skid trails are 12 feet wide and hundreds of feet long, some trails are no longer evident on current air photos. It is likely that tree regeneration and growth was delayed on the displaced soils on the skid trails and that trees growing on the nutrient rich berm of soil grew rapidly and provided shade to vegetation growing on the skid trails. By age 50 the shade is nearly complete and very little woody vegetation is growing on the skid trails (Figure 1). After 50 years of recovery detrimental soil conditions on the limestone soils typically were limited to severe soil displacements on either tractor skid trails or heavily used yarding corridors between spar trees and yarders. These detrimental soil conditions were almost always more than 10 feet wide and tens of feet long.

Table 2. Average amount of skid trails and detrimental soil conditions in fifteen 50-year old young-growth stands.

Stand Name	Stand Age in 2010	Yarding system	Amount of skid trail, (percent of stand)	Amount of detrimental soil conditions (percent of stand)	notes
Kosciusko #1c (Sarkar soils)	54	Hi-Lead Portion	2%	2%	Temp roads need to be added. Identifiable yarding corridors are displaced.
Kosciusko #1t	54	Tractor portion	11	11%	All identifiable skid trails are displacements. Temp Roads need to be added.
Kosciusko #2 (Sarkar soils)	54	Cable with spar trees to road	<1% cable skid trail identifiable	0%	Few spar trees in this stand and no temp roads.
Spit point (Sarkar soils)	50	A-frame cable to beach	2%	1%	Buried profiles in both OG and YG. Two eroded spots in YG.
Mud Bay (Tolstoi soils	85	Tractor to beach	7%	7%	Displaced skid trails to water (major corridors). Support alders.
Maybeso (Karta soils)	51	Hi-lead to road	0%	0%	Clean harvest, Soils mostly shallow to dense till or bedrock. No evident corridors or trails.
Coffman Cove A-frame (Tolstoi soils)	45?	A-frame to beach	2%	1%	Not all corridors detrimental. Less than 1% are linear displacements in wet soils.
Coffman Cove tractor (Tolstoi soils)	53	Tractor to beach	18%	6%	Secondary trails are mixed and not detrimental. Primary trails are displacements
Ocean boulevard Tuxekan Soils	41	Tractor to road	18%	6%	Skid trails covered in alder. Comparable is on different aspect and slope
Ocean boulevard Tuxekan soils	41	Cable Hi-lead to road	8%	2%	Primary skid trails deep and rutted, mostly supporting alder. Comparable is on different aspect and slope.
Vank Island (SWPD Blaquirre)	60	Tractor to beach	7%	5%	Secondary trails not considered detrimental. Primary trails eroded to bedrock or Cr.
Thomas Bay (Fanshaw soils)	52	Tractor to road	38%	11%	Secondary trails not detrimental, displaced trails are affecting plant growth in the trails.
Flicker/Alder Sarkar-McGilvery Soils	76	A-Frame cable yarded to beach	2%	1%	Displaced soil on lower corridor. Upper corridor not detrimental
Winter Harbor, Ulloa-Sarkar Soils	65	Tractor logged to beach	1%	1%	Transects rarely hit identifiable tractor trails, side trails not detrimental or winch used.
Deweyville Ulloa-Sarkar soils	64	A-frame and High-lead to beach	1%	1%	Main corridor clearly identifiable and displaced to bedrock, but transects did not cross it.

These observations suggest that productive soils may tolerate larger soil disturbances before a change in productivity is obvious. On the nutrient rich limestone soils where soil erosion is not a concern our observations suggests that a minimum size for detrimental soil conditions is likely 100 square feet or greater. More definitive monitoring and research is necessary to truly define detrimental soil conditions based on site characteristics.

Table 2 displays the amount of skid trail and detrimental soil conditions in the fifteen 50-year old young-growth stands monitored for detrimental soil conditions, skid trails and duff thickness, based on site observations.

At Thomas Bay tractor logging on extremely gravelly outwash soils also resulted in displacement of nutrient rich topsoil on primary skid trails and landings. Primary skid trails are those skid trails that connect one part of the stand to another and have received numerous equipment passes. On primary skid trails displacement of the nutrient rich surface layers was common and in severe cases canopy closure had not yet been achieved on some trails even 52 years after harvest (Figure 2).

Secondary skid trails are those skid trails used to access one part of the harvest area and the number of equipment passes is limited to the number needed to access one small part of the stand. Soil mixing was common on secondary skid trails at Thomas Bay. Soil mixing on secondary skid trails may have retarded regeneration enough on these soils that woody vegetation became established only to grow at reduced rates compared to trees growing on adjacent, relatively undisturbed soils. Mixing may have resulted in some of the surface organic matter being leached to deeper soil horizons outside the reach of plant roots. The duff and upper nutrient rich soil horizons contain the vast majority of the nutrient capital in these gravelly outwash soils. Future timber harvest on these soils should minimize soil disturbance. Tree measurements will be needed to determine if the secondary skid trails at Thomas Bay are detrimental soil conditions.

The gravelly outwash at Thomas Bay is a very productive soil, yet not as productive as the limestone soils on Kosciusko Island. The Thomas Bay site is also on the mainland and likely receives more snow and colder temperatures than Kosciusko Island. The density of skid trails that are still evident on the ground is also much higher at Thomas Bay than at Kosciusko.

Secondary skid trails were not easily identifiable on the limestone soils on Kosciusko Island so they either did not exist or the lighter level of disturbance did not inhibit plant growth. At Thomas Bay secondary skid trails were relatively easy to identify by soil characteristics (mixing of duff and upper mineral soil horizons) and the higher density of smaller diameter trees than the adjacent stand.

Adjacent cable logging on Kosciusko Island may have eliminated the need for secondary skid trails or the higher nutrient capital in the limestone soil at depth allowed rapid recovery of these trails and the trails are no longer evident today. These observations indicate that the limestone soil has the ability to tolerate a moderate level of soil

disturbance and still be able to rapidly grow trees when compared to the gravelly outwash soils at Thomas Bay. At Thomas Bay even moderate soil disturbance (mixing of duff and upper nutrient rich horizons) appears to be affecting plant growth. For the soils at Thomas Bay our observations suggest that a detrimental soil condition may be defined by mineral soil exposure or even mixing of upper horizons over areas as small as 100 square

Figure 1. Tractor skid trail in 54 year old young-growth on Kosciusko Island. Canopy closure is almost complete and the trails are difficult to identify on recent air photos of the stand.

Figure 2. Tractor skid trail and landing in 52 year old young-growth at Thomas Bay. Canopy closure is not achieved at age 52.

feet. Most of the skid trails documented at Thomas Bay were at least 10 feet wide. Tree age, height and diameter measurements could help determine if the soil disturbance delayed regeneration or if the soil disturbance reduced site productivity over several decades. LiDAR may be another tool to use to correlate tree heights to soil disturbance over extensive areas.

It is apparent that an alder seed source was not present at the time of logging at either Thomas Bay or Kosciusko Island and historic air photos give no evidence of alder at the time of logging. During our monitoring a few young alder trees were identified along the road system at both Thomas Bay and Kosciusko Island. The few, young alders indicate a relatively recent colonization of alder in these areas. If alder had been present at the time of logging, it is likely that many of the heavily disturbed skid trails would have been colonized by alder and these stands would have looked much different. Our monitoring of tractor logged stands in other areas where alder was present at the time of logging (Vank Island and Ocean Boulevard) indicates a large amount of alder on the skid trails (Figure 3).

Figure 3. Alders occupying a tractor skid trail in a 60 year old stand on Vank Island.

Research has shown that soil compaction can remain in the soil for many years (Corns 1987). To determine if detrimental soil compaction was still present, ten bulk density samples were taken from 54 year-old skid trails on Kosciusko Island. The limestone soils on Kosciusko Island were selected for bulk density sampling because the clay content in the limestone soils is slightly higher than in other soils on the forest and the coarse fragment content is much less. Limestone soils should be more susceptible to compaction than other soils on the forest. The samples on the skid trail did not show a significant

increase in bulk density over adjacent undisturbed soil at the 7.62 to 15.24 centimeter depth but a significant increase in bulk density was observed for samples from the skid trail at the 15.24 to 22.86 centimeter depth. The increase was not a 15 percent increase required to classify the skid trails as detrimentally compacted and the analysis shows that the skid trail samples may have come from lower soil horizons which typically have a higher bulk density than upper horizons. The samples do not indicate detrimental compaction on the skid trails. Other bulk density sampling on the forest (Landwehr and Silkworth 2011a, Foss and Landwehr 2006, Alexander 1990) support the statement that most Tongass soils are not susceptible to soil compaction from equipment under normal forestry practices.

Most of the tractor logging in the seven stands investigated occurred on well drained soils. On Vank Island the soils in the tractor logged stand are dominantly somewhat poorly drained. The soils formed in 30 inches of loess over bedrock. On Vank Island the primary tractor trails displaced soil down to bedrock or Cr material and the trails went straight down the slope to saltwater. Soil erosion post-harvest must have been a concern because several of the trails (which look like drainage ditches) were "blocked" by berms of soil presumably to prevent erosion. The berms have created small ponds in the skid trails (Figure 4). An alder seed source was present at the time of harvest on Vank Island based on pre-harvest air photos. Large portions of the young-growth stand are dominated by red alder today.

Figure 4. Primary tractor skid trail with erosion control berm and pond on Vank Island.

Detrimental soil conditions in the Vank Island young-growth stand consisted of the primary skid trails where soil was displaced down to bedrock. Secondary skid trails were sometimes evident by paired ruts in parts of the stand. In the Vank Island stand interpretations of detrimental soil conditions based on desired vegetation growth were difficult due to the lower drainage class, nutrient rich loess soils and widespread alder.

On moderately productive soils (well drained soils derived from till with mixed mineralogy) primary skid trails consisted of lineal soil displacements 10 to 14 feet wide. Desired vegetation on these trails was either absent, delayed or growing more slowly than adjacent undisturbed sites. Secondary skid trails consisted of soils with mixed upper soil horizons. On these sites the impacts to desired vegetation growth was less obvious and ranged from no impact to delayed growth compared to adjacent undisturbed areas. The secondary skid trails supported desired vegetation but the vegetation was either delayed or growing more slowly than adjacent undisturbed sites.

Existing soil conditions in eight 50-year-old young-growth stands, Cable Logged
After 50 years of recovery identifiable cable corridors occupied an average of two percent of the eight stands monitored. Typically the yarding corridors still evident after 50 years were the ones carrying high volumes of logs between a spar tree and landing or saltwater. Detrimental soil conditions on these corridors are estimated to occupy on average one percent of these stands. Four of the eight stands were A-frame logged to saltwater. The remaining four stands were cable logged to a road.

In seven of the eight stands yarding corridors occupied less than two percent of the stand. In the Ocean Boulevard stand cable yarding corridors occupy 8 percent of the stand and detrimental soil conditions comprised two percent of the stand. The soils in the Ocean Boulevard stand are well drained and alluvial in origin. The soils naturally support large spruce with well developed understories of salmonberry and devil's club with lesser amounts of vaccinium. Soil disturbance on alluvial soils typically results in intense brush competition. Yarding corridors are still evident at Ocean Boulevard due to intense brush competition post harvest and the brush persists after 50 years of recovery.

Soil displacements and soil erosion were the only detrimental soil conditions noted along cable yarding corridors. Ponding of water sometimes occurred in large soil displacements on level ground where dense till soils were exposed. Most corridors in the 50 year-old stands were no longer actively eroding, but there was evidence that soil erosion had occurred in many steep slope corridors following timber harvest. Soil displacement was especially noticeable along the main corridor in the Deweyville stand, but the main corridor to the spar tree was the only identifiable yarding corridor in the stand (Figure 5 right).

On very productive sites vegetation adjacent to yarding corridors is almost large enough at age 50 to achieve canopy closure over the displaced yarding corridor (Figure 5 left). Other corridors were alder covered, or had ephemeral streams flowing in them. During project reconnaissance for the Kosciusko timber sale, one yarding corridor on level ground had displaced enough mineral soil that a small permanent pond had formed. On

other corridors between spar trees and landings or saltwater the soils had been displaced and eroded down to underlying bedrock. In all cases the detrimental soil conditions on the yarding corridors were at least ten feet wide and tens of feet long.

In the displaced areas the desired vegetation (conifers) is either absent or not as vigorous (trees not as tall) as in adjacent, undisturbed or lightly disturbed areas. Tree height measurements and tree age determinations could help identify if the trees on the disturbed sites regenerated slowly or if the soil productivity of the soil was impaired to the extent that tree growth is slower than in adjacent undisturbed areas due to soil conditions.

Some of the soil disturbances caused by cable yarding occurred on steep slopes. The minimum size criteria for detrimental soil conditions also need to consider the site's susceptibility to mass movement. Very small soil disturbances on landslide prone terrain can contribute to the occurrence of landslides (Landwehr 1998).

Where an alder seed source was present the displaced soil areas were often dominated by alder. In young-growth areas where an alder seed source was absent at the time of harvest the displaced areas are dominated by mosses on gentle slopes. On steeper slopes where the displaced site subsequently eroded, salmonberry, ferns, elderberry and devil's club were more common. Scrubby red cedar sometimes dominated areas where soil displacement exposed limestone bedrock.

Figure 5. Left: An A-frame yarding corridor in the Flicker Creek stand. Soils are shallow to limestone bedrock. Right: An A-frame yarding corridor in the Deweyville stand. Dense till underlies the yarding corridor at this site.

Duff thickness measurements

Duff thickness was measured in portions of 15 young-growth stands and portions of 13 adjacent unharvested stands. The results are displayed in Table 3.

Table 3. Average duff thicknesses from 50 year-old young-growth stands and adjacent unharvested stands on similar soils.

Stand Name	**Mineralogy or substrate**	**Average duff thickness OG (cm)**	**Average duff thickness YG (cm)**	**Statistically different at 90% confidence**
Kosciusko #1c Cable logged (Sarkar soils)	Hecata limestone (Sab)	24	14	Yes
Kosciusko #1t Tractor Logged (Sarkar Soils)	Hecata Limestone (Sab)	24 Same as above	13~~0~~	Yes
Kosciusko #2 (Sarkar soils)	Hecata Limestone (Sab)	20	17	Yes
Spit point (Sarkar soils)	Mixed weathered till over (Pm) Crinoidal marble	22	14	Yes
Mud Bay (Tolstoi soils	Weathered till over (KJgs) metasedimentary rocks, phylittes	15	13	No
Maybeso (Karta soils)	Mixed, dense till over (SOt) volcanic turbidites, argillite and chert	12	15	No
Coffman Cove A-frame (Tolstoi soils)	Weathered till over (SOt) volcanic turbidites, argillite and chert	17	22	No
Coffman Cove tractor (Tolstoi soils)	Weathered till over (SOt) volcanic turbidites, argillite and chert	17	18	No
Ocean boulevard tractor logged (Tuxekan soils?	Unharvested site is kupreanof-Tuxekan and Mitkof Soils, bedrock is Gabbro (Kgb)	21	10	Yes*
Ocean boulevard Cable logged (Tuxekan soils with Yakobi inclusions)	Unharvested site is Kupreanof-Tuxekan and Mitkof Soils, bedrock type is Gabbro (Kgb)	21 Same as above	15	Yes*
Vank Island (SWPD Blaquirre)	Loess over (KJgv) volcanic breccias	10	8	No
Thomas Bay (Fanshaw soils)	Glacial outwash, gravelly, mixed	15	12	No
Flicker/Alder A-Frame Cable logged, Sarkar-McGilvery Soils	Heceta Limestone (Sab and Drl) Check rock type	22	16	Yes
Winter Harbor, tractor logged	Heceta Limestone (Sab and Drl)	23	19	Yes*
Deweyville A-frame Ulloa-Sarkar soils	Heceta Limestone (Sab and Dsl)	21	19	No**

*the stands are not comparable due to differences in landscape position and drainage class.

**If two outliers are removed from the young-growth analysis they are different.

Duff thickness on soils in unharvested stands over limestone is significantly thicker than duff thickness on limestone soils in harvested stands or on soils with mixed mineralogy that are either harvested or unharvested. There is no significant difference in duff thickness between harvested and unharvested stands on soils with mixed mineralogy or on harvested limestone stands. There are a couple of potential reasons for this phenomenon. 1) The limestone soils measured in this monitoring were some of the most productive soils on the forest with 50-year site indices consistently over 100 feet. The more productive sites likely produce more litter fall and hence thicker duff layers. 2) There is a difference in pre-harvest plant association between stands, caused by periodic catastrophic blow down combined with rapid conifer growth rates in the absence of an alder seed source.

Many of the even-aged unharvested stands on limestone are dominated by a conifer overstory and moss understory. The successional pathway of these stands is interrupted by periodic stand replacing windthrow events. Under these conditions conifers grow rapidly into stem exclusion phases and the understory is dominated by mosses and remains so until the next stand replacing windthrow event.

Stands that are not interrupted by catastrophic blowdown experience gap-phase dynamics and more old-growth conditions. The gap-phase stands develop a blueberry and herbaceous understory. The litter from blueberry and herbaceous understory plants decomposes much more quickly than mosses or conifer overstory litter and thus would lead to thinner duff layers. In stands with a well developed understory the understory litter can be 25 percent of the litterfall in the stand (Hilli et. al. 2008). More work on duff composition, chemistry, and the effect of differing successional pathways on duff thickness would be necessary to verify the reason for thicker duff in unharvested stands underlain by limestone.

The duff thickness in 50 year-old young-growth (harvested) stands on limestone is significantly thinner than the duff in unharvested stands over limestone. It is possible that the thinner duff layers measured in 50 year-old young-growth is an effect of timber harvest. Limestone soils are well drained and soil temperature may increase following timber harvest. As soils warm microbial rates increase dramatically. It is possible that as microbial rates increased more organic matter was consumed, thus reducing the thickness of the duff layer. This is not necessarily a negative effect from a soil productivity standpoint and may result in more available nutrients at least over the short term.

It is also possible that the duff layer in harvested stands on limestone was compacted either by equipment traffic or heavy snow accumulations in the stands shortly after harvest. More work on duff density would be necessary to determine if this was the cause of reduced duff thickness.

Vank Island soils generally had thinner duff layers than other soils and this is likely due to the high amounts of deciduous litter in both the harvested and unharvested stands. In the harvested stands red alder was a strong component. In the unharvested stands blueberry and rusty menziezii were prevalent. Alder was also present on Vank Island

prior to timber harvest. The conifer canopy in the unharvested stand on Vank Island had a low level of canopy closure due in part to individual tree windthrow, allowing more sunlight to hit the forest floor and a strong understory component has been able to persist. The deciduous leaf litter decomposes much more rapidly than the conifer litter and this is a possible explanation for thinner duff horizons in the Vank Island stands measured. Earthworms are rare in Tongass soils, but Vank Island soils had more earthworms over extensive areas than other soils sampled in this monitoring. Earthworms can rapidly incorporate organic material from duff layers into mineral soils.

Sites with documentation of severe soil disturbance

This monitoring also investigated five sites with documentation of severe soil disturbance. The five sites are Cap Island, Luck Lake alder dominated stand, Yakutat Timber Sale, Tawah Timber Sale, and the Canyon Spur shovel trail.

Figure 6. Summary of photo documentation of soil disturbance at Cap Island, 1991 to 2009.

The Cap Island A-frame timber harvest occurred on a complex of highly productive mineral soils and moderately productive well drained organic soils that are typically less than 50 centimeters thick over limestone bedrock. On lower slopes near the bottom of the spar tree corridor a thin layer of dense till underlies the soils. The yarding operation was first reviewed by the author in 1991 and photographs were taken of the yarder, spar tree,

yarding corridor, and landing at the spar tree. Tractor yarding was used on the lower slopes near saltwater. Yarding operations ceased in 1994 and the site was revisited in 2009 after 15 years of recovery. Photos were taken near the original photo points and soil disturbance transects were completed. Duff thickness averaged 12 centimeters in the stand. Tractor skid trails averaged 7 percent of the stand. Most of the stand was cable logged. About 2.1 percent of the stand had soil displacements in excess of 100 square feet and 1.8 percent of the stand had "lack of ground cover" which in this stand were small soil displacements exposing bedrock or mineral soil.

Figure 6 displays comparison photos from 1991 and 2009. The background photo is from 2005. The yarding corridor between the spar tree and saltwater, the tractor skid trails in the north end of the stand, and the Hi-lead yarding corridors south of the spar tree landing are evident on the 2005 background photo. In 1991 the soils in lower part of the main yarding corridor between the spar tree and saltwater had been displaced to a depth of 1 to 2 meters and bedrock was exposed. In 2009 the area has exposed bedrock and woody debris left from the yarding. In the Hi-lead areas the stand is dense conifer young-growth. In the tractor logged areas there is height difference for the conifers growing on tractor trails where soils had been displaced and the adjacent relatively undisturbed soils. Regeneration is sparse and growth delayed on the heavily disturbed areas near saltwater where the tractor skid trails and spar tree yarding corridor converge.

The Cap Island stand represents a broad range of soil disturbance severity and vegetation response in one stand. Severely disturbed areas support ferns and sparse conifer vegetation. Areas with thin duff layers over mineral soil support conifers mixed with salmonberry. Where the duff is thicker, soils support hemlock and red cedar. Hemlock and red and yellow cedar typically occupy well drained organic soils over limestone. Disturbed mineral soils over limestone typically regenerate with spruce and hemlock, but in this stand spruce was not as extensive as we have seen in other stands on similar soils.

The upper left hand photo in Figure 6 is somewhat surprising. The photo shows a non-vegetated mineral soil that was severely disturbed just downslope of the spar tree. It is surprising that no vegetation is occupying this relatively rich, well drained mineral soil. The soil looks like a very recent disturbance and not a disturbance that has had 15 years of recovery. Lack of an alder seed source is a partial explanation, but not a full explanation as to why this soil is not supporting some vegetation.

The Luck Lake alder-dominated stand was logged in 1969 with a downhill Hi-lead cable yarding system (Figure 7). Soil quality monitoring, including duff thickness measurement was conducted in 2009 after 40 years of recovery. Only one detrimental soil condition, a recent landslide was identified along the soil disturbance transects. Duff thickness averaged 11 centimeters across the stand. There is not a significant difference between the duff thickness under the alders versus the duff thickness under the conifers at 90 percent confidence.

Soils under the alders at Luck Lake more commonly had abbreviated soil profiles with A horizons overlying Bh and BC horizons in 8 of 23 (35%) profiles. E horizons were only

present in 3 of 23 soil profiles (13%) under alders. Under conifers only one of 39 profiles (<1%) had an A horizon and 19 of 39 profiles (49%) had intact E horizons. The A horizons identified are likely indicative of mixing of O, E and Bh horizons during yarding. In the Luck Lake stand an alder seed source was present at the time of harvest and the alders are strong indicators of disturbed mineral soil in this stand.

Aerial photos taken in 1971 shortly after timber harvest do not suggest high amounts of soil disturbance. Hi-lead yarding corridors are visible, but exposed mineral soil and erosion is not evident (Figure 7). Soil disturbance in this stand was enough to cause mixing of the upper mineral soil horizons and duff layers but not enough to cause soil erosion or soil displacements. The mixing of upper mineral soil horizons is not considered a detrimental soil condition and may be beneficial to site productivity.

Red alder is generally not the desired vegetation in a Timber Production land-use designation. There is currently no market for red alder. The mixing of the upper soil horizons was enough to create conditions conducive to alder occupation of the site, and alders continue to dominate much of the site today, 40 years after harvest (Figure 7).

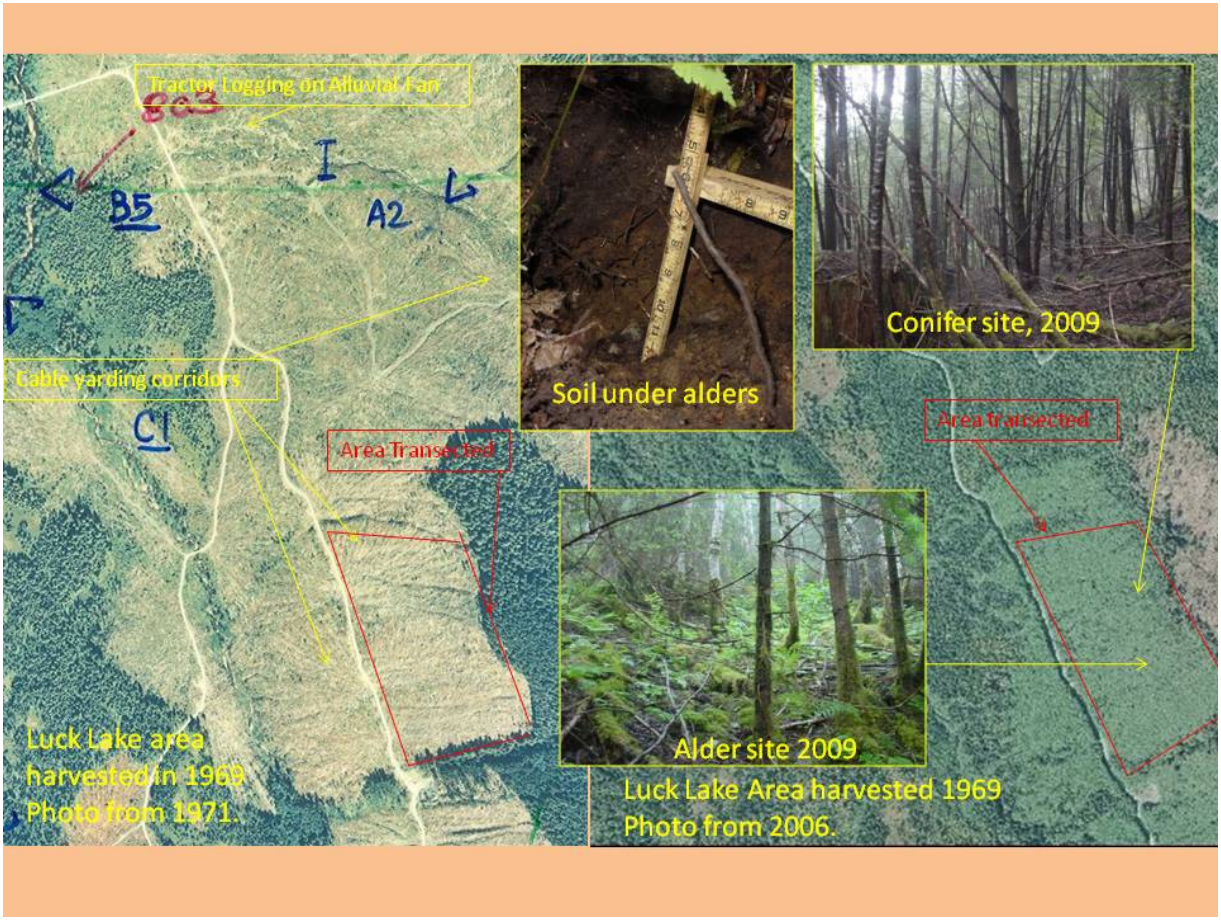

Figure 7. Year 1971 and 2006 air photos of an alder dominated stand near Luck Lake.

Tractor logging on coarse textured glacial outwash soils in the Yakutat 1 Timber Sale caused widespread and severe disturbance documented in a single 2,000 foot long

transect by Rich Billings in 1970. Soil disturbance and regeneration within this stand was also investigated by Harris et. al. in 1976.

In 1970 Billings found 28 percent bare mineral soil, nine percent road, 38 percent mixed mineral soil and duff and 25 percent undisturbed soil on his transect. In 2011 the first 1550 feet of Billings' transect was repeated and similar soil disturbance levels were documented. In 2011 thirty-two percent of the transect was identifiable as skid trail and 24 percent of soil pits showed mixing or displacement Table 4). The stand was 44 years old in 2011. Canopy closure has not been achieved over the severely disturbed skid trails and landings. Some skid trails are evident on the 2008 air photo (Figure 8). The duff thickness averaged 4.6 centimeters in the 31 soil pits along the transect. This thin duff layer is partly a legacy of harvest related soil disturbance documented by Billings in 1970.

A mix of vegetation occurs in the disturbed areas in the Yakutat Timber Sale. Mosses and salmonberry occur in the severely disturbed sites while willow, elderberry, and short conifers with some cottonwood and alder grow on moderately disturbed sites. Interpretation of the site is difficult because frost pockets occur in the stand and not all sites were fully occupied by conifers prior to harvest (Harris 1976). The physical soil conditions are similar to the Thomas Bay stand discussed earlier. To encourage conifer regeneration and growth soil disturbance should be minimized on these soils. Harris noted that severe soil disturbance will affect site productivity.

The Tawah Timber Sale was logged in the winter of 1972 and 1973. A. S. Harris investigated soil disturbance and tree stocking on the Tawah Timber Sale in 1976. He found bare mineral soil occupied 36 percent of soils in the stand. Another 5 percent of the stand was haul road and 21 percent of the soils had the duff and mineral soil mixed. In 2011 fifteen-hundred feet of transect was completed in the vicinity of Harris et.al.'s 1976 work.

Table 4. Comparison of 1976 and 2011 Monitoring of stands at Yakutat

1976 Monitoring	Percent of the stand	2011 Monitoring	Percent of the stand
Yakutat			
Bare mineral soil	28	Skid trail	32*
Road	9*		
Mixed duff and mineral	38	Mixed duff and mineral	24
Undisturbed	25	Recovered	44
Tawah Timber Sale			
Bare mineral soil	36	Skid trail	19*
Road	5*		
Mixed duff and mineral	21	Mixed duff and mineral	24
Undisturbed	38	Recovered	57

* Roads were not included in the 2011 monitoring.

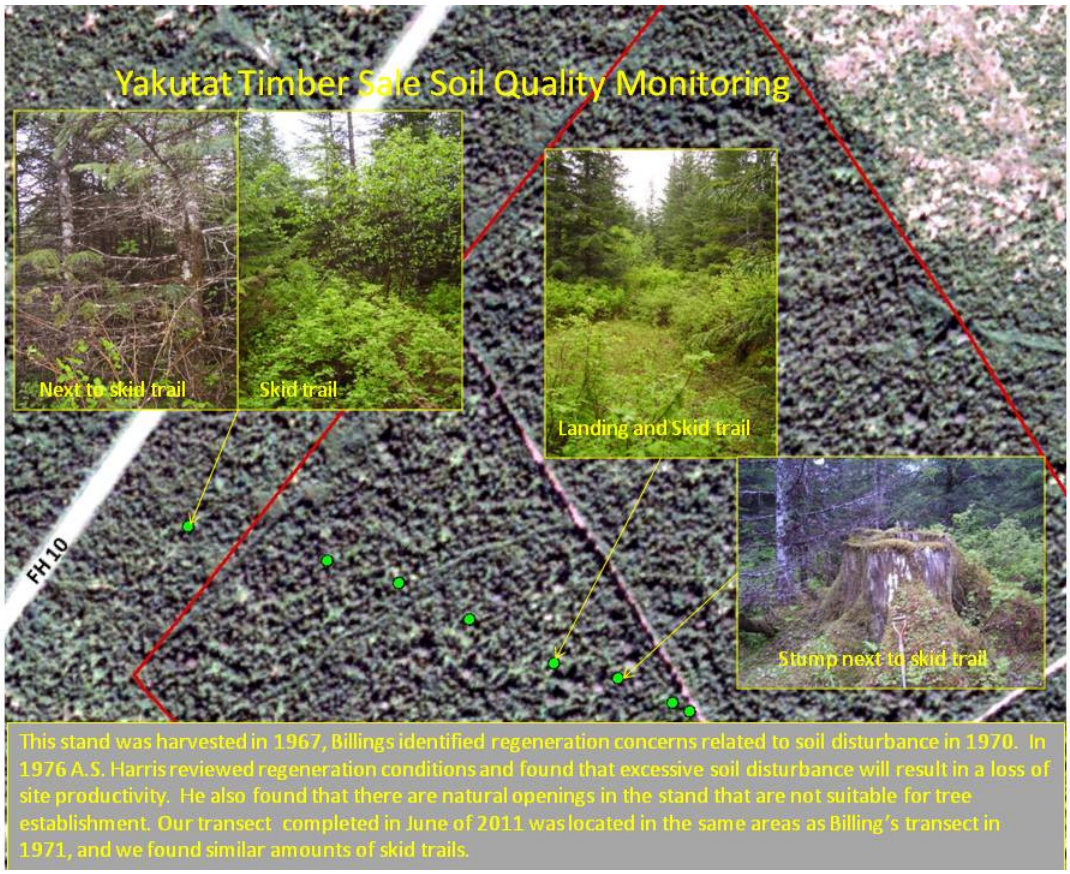

Figure 8. Sampling of vegetation conditions in the Yakutat Timber sale along a transect similar to Billings' 1970 transect.

The Tawah Timber Sale is located on a beach ridge and inter-ridge wetland. The beach ridge soils are well drained sands. The inter-ridge wetlands are peats and silt loams and are poorly drained. Nineteen percent of the 2011 transect crossed identifiable skid trails. The stand was recently pre-commercially thinned and the ground covered with much slash so that identifying skid trails was somewhat difficult on the beach ridge portion of the stand. Mixing of soil horizons was noted in 24 percent of the 34 soil pits in this stand (Table 4). Duff thickness averaged 9 centimeters. Winter logging protected many of the soils, especially the wetland soils in this stand.

Conifers dominated the well drained beach ridge soil but canopy closure has not yet occurred in parts of the stand. On the wetland soils skid trails and landings are open grassy or sedgy areas and it is unclear how much of the wetland portion of the stand was forested prior to logging. It was obvious some of these areas were landings created for the timber sale as evidenced by stumps piled adjacent to the landing. Harris et. al. (1976) had recommended planting the Tawah Timber Sale as soon as possible due to low stocking numbers. There is no documentation that planting was ever completed. Frost may also play a role in the lack of conifer regeneration in the wetland areas of this sale.

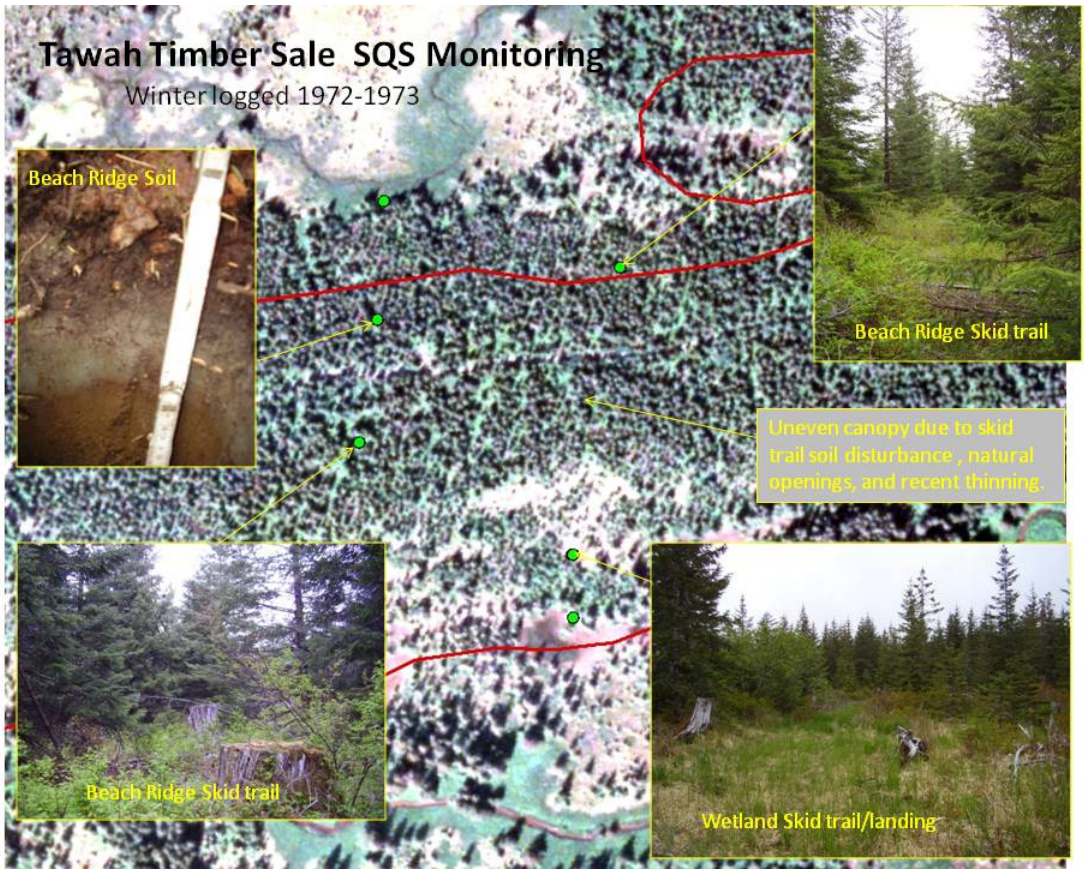

Figure 9. Sample of soil and vegetation conditions on the Tawah Timber Sale.

The 2008 air photo (Figure 9) shows a very open canopy and sand road in the center of the stand. The openness of the canopy can be attributed to skid trails, natural openings and the recent pre-commercial thinning. (The thinning may have occurred after the 2008 aerial image was taken.) Harris et. al. recommended keeping duff layers intact and avoid scalping the organic soil surface.

Shovel yarding on wet soils during very wet soil conditions led to severe soil disturbance on a shovel trail in a 1988 harvest unit in the Canyon Spur watershed on Prince of Wales Island. Hillslope gradient ranges from 10 to 30 percent and the shovel trail climbs diagonally across the hill. Mineral soils at the site are 50 to 100 centimeters deep over dense till. The shovel yard operator pulled stumps and attempted to run the machine on mineral soils. Because the soils were very wet and the gradient of the trail is 10 to 20 percent, severe water erosion was occurring down the shovel ruts. To prevent erosion the shovel trail was grass seeded in1990 with a grass seed mixture that included reed canary grass. The site was revisited in 2009. Photographs are available from 1990 and 2009 (Figures 10 and 11).

The on-site investigation and photos show a variety of soil and vegetation conditions on the Canyon Spur shovel trail. Where the trail crossed the road ditch and climbed the road cutbank erosion has been largely arrested by grass seeding. A minor amount of erosion is

Figure 10. Canyon Spur shovel trail in April of 1990 (top) and August of 2009 (bottom).

still occurring at this spot. The ruts were fairly continuous along this trail and in the wet soils the ruts either served to drain the site if there was enough slope, or collect and pond water if the trail gradient was flat. In some areas natural herbaceous vegetation occupies the trail. In one area red alder has gotten started even though a seed source was apparently not present at the time of harvest. In other areas reed canary grass is the dominant vegetation on the trail. Conifers are scarce on the trail compared to the surrounding undisturbed soil (Figure 10), the site has low productivity and even in undisturbed areas conifers can be widely spaced and slow growing.

Where the shovel ruts improved soil drainage soil productivity likely improved. Where shovel ruts collect soil water and hold it soil productivity likely declined as a result of the shovel trail.

Preferential Flow Paths
Water moves through soil in a non-uniform way, using large, connected spaces (macropores) to move the bulk of the flow.

Preferential flow paths are necessary for soils to process water and prevent erosion or ponding of water. Seasonal water tables also form atop impermeable layers like bedrock or dense till. Less commonly a perched water table can also form on the mineral soil surface immediately under the duff layer or atop the Bh horizon in well developed spodosols.

Figure 11. Shovel rut in Canyon Spur harvest unit is still evident and well defined after 19 years.

The soils in the Canyon Spur harvest unit form a seasonal water table atop the dense till. If shovel ruts intercept the seasonal water table erosion can be severe, as it was shortly

after harvest. Rutting that mixes soil horizons, intercepts seasonal water tables or disrupts preferential flow paths in the soil should be avoided.

Investigations of woody debris accumulations

Seven young-growth stands were investigated due to the presence of dense slash mats that can negatively affect soil productivity. Four of the stands were located at Little Coal Bay, one at Winter Harbor, one at Naukati, and one near Thorne Bay. All locations are on Prince of Wales Island.

Prior to 1990 shovel yarding on the Tongass resulted in a variety of different soil disturbance effects. Some operators were clearing trails of stumps and woody debris and attempted to run the equipment on the soil surface. Since most soils do not have the bearing strength to support the equipment, severe rutting similar to the Canyon Spur shovel trial (Figures 10 and 11) was often the result. Other operators were operating the shovel on slash mats or cull log material and in those cases the soil surface was left pretty much intact. Rutting was minimized.

The Little Coal Bay Timber Sale included many stands on gently sloping till covered bedrock hills. Wetlands lie between the hills. The gentle slopes were conducive to shovel yarding in many of the stands. Most of the stands were logged in 1999. In 2009 soil disturbance transects were completed in portions of four of the harvested stands.

Small soil disturbances (less than 100 square feet) occupied less than 1 percent of the areas sampled. Shovel trails occupied 20 percent of the stands sampled. Seventeen percent of the area sampled was classified as woody shovel trail and 3 percent of the area was classified as native tread shovel trail. Aerial views of the woody shovel trails prompted investigation of the effects of woody debris on re-vegetation of these sites (Figure 12).

The Little Coal Bay stands were 10 years old when investigated in 2009. Conifer vegetation both off and on woody shovel trails is 2 to 3 meters tall. There is no apparent difference in conifer growth between sites on or off the shovel trails.

The pre-harvest stands at Little Coal Bay consisted mostly of western hemlock and western red cedar with an understory of blueberry and rusty menziezii. Unharvested stands of this plant association include a lot of cull material and that cull material is typically used to create a slash mat for shovel yarders to operate on. Shovels operating on the cull logs and slash resulted in little soil disturbance but much bark removal. Ten years after harvest these logs have very high reflectance and the eye is drawn to them. What appears to be a heavy slash mat from the air is really a diffuse jumble of cull logs and native soil when viewed on the ground (Figure 12). While slash and cull logs cover a high percentage of the shovel trails there are ample areas of native soil surface on the trails where conifer vegetation can and has become established (Figure 12). The soil investigation in 2009 suggests that there will be no difference in soil productivity and desired vegetation growth on and off the shovel trails.

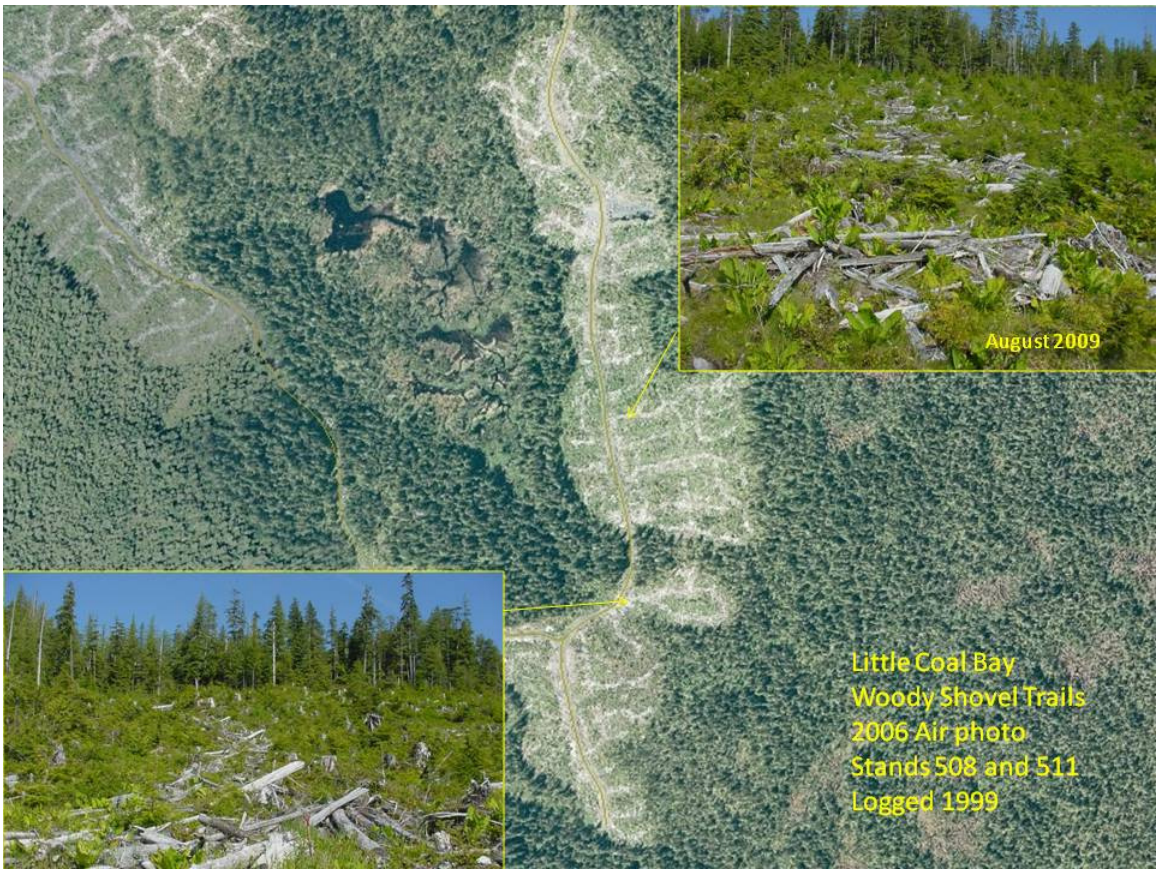

Figure 12. A 2006 aerial view of stands 508 and 511 near Little Coal Bay. Woody shovel trails are easily visible from the air.

In 1994 the Gonzo timber sale was logged via shovel and rubber-tired grapple skidder. In the southern end of the stand shovels were used to pre-bunch logs for the grapple skidder to take to the landing several hundred feet away. To keep the rubber-tired skidder on top of the the soil high volumes of coarse and fine textured slash were used. In 1994 Soil scientists Dennis Landwehr and Terry Brock attempted to take bulk density samples under the rubber-tired skid trail. Samples were taken but due to organic matter pollution few of the samples were usable. Numerous pictures were taken during the yarding operation. The site was revisited in 2009 and observations made and pictures taken (Figure 13).

Unlike the Little Coal Bay woody shovel trails the slash on the Gonzo skidder trail was dense enough to negatively affect conifer plant growth (Figure 13). At age 15 the conifers off the main skidder trail are 5 to 7 meters tall near the landing. On the heavily slashed portions of the trail conifers are absent or less than 2 meters tall (lower right photo in Figure 13). The dense slash mat is negatively affecting regeneration and growth of conifers at this site. Further south on the skidder trail soils become wetter and the site becomes a low productivity forested wetland. In this area slash is not as dense as near the landing and similar to the Little Coal Bay sites the slash is not heavy enough to negatively affect conifer growth. Once again the high reflectance of debarked cull logs and slash material makes the slash look very dense.

North of the landing conifers are dense on the shovel trail but approximately 3 meters shorter than conifers off the shovel trail. Dense slash apparently affected conifer regeneration for a few years and now that conifers are growing on the site they are shorter than conifers growing adjacent to the shovel trail (Figure 13 upper left).

Figure 13. 2006 aerial image of the Gonzo Timber Sale. Images document slashed skidder trail in 1994 and again in 2009.

At Cap Island the cull log pile at the spar tree also resulted in a density of woody material that is negatively affecting regeneration and growth of conifers at that site (Figure 6).

The Naukati commercial thin study site on Prince of Wales Island was originally logged in 1947 via tractor with a 1,050 meter long skid trail to saltwater. About 340 meters of this trail is corduroy trail constructed of small diameter logs. In 2011 the Old Naukati skid trail was investigated for detrimental soil conditions. The trail is still evident on 2006 aerial photos but it is difficult to see. Canopy closure (from adjacent trees) is nearly complete over much of the trail. The trail is easily identifiable on the ground and averages 4.8 meters wide.

Figure 14. Logs used for Corduroy on the 63 year-old Naukati Skid trail.

Figure 15. Area of soil displacement along the Old Naukati Skid trail (Left). Area of mixed mineral soil with rusty menziezii vegetation on the Old Naukati Skid Trail (Right).

Logs used for corduroy are still evident on the trail (Figure 14). Other portions of the trail that were not slashed consist of soil displacements (Figure 15 left). On yet other parts of the skid trail upper soil horizons and duff layers were mixed (Figure 15 Right).

On the Old Naukati Skid Trail soil conditions that apparently had an effect on conifer regeneration were the displacement of upper soil horizons and the burial of soils via a dense corduroy road. In both of these cases very little conifer regeneration or growth is occurring on the skid trail. It is likely that regeneration was delayed to the point that adjacent trees shaded the trail causing further lack of regeneration and growth (similar to skid trails in 50 year-old young-growth on Kosciusko). In the areas of the trail where soils were mixed by tractor traffic the understory vegetation is variable (Figure 14 right). In most areas rusty menziezii was present. In other areas salmonberry was present albeit in much lower amounts.

In the recent Naukati commercial thin study plots yarding was accomplished via a tracked grapple caterpillar tractor. In these young-growth stands the slash is much finer than in Old-growth stands. Due to the fine slash and the weight and dynamic load of the tractor, slash penetration typically extends 25 centimeters or more into the mineral soils. Landwehr and Silkworth (2011a) identified a concern for regeneration and growth of desired vegetation on commercial thin skidder trails. Figure 16 shows the main skid trail

Figure 16. Dense slash mat on the skid trail used to access three of the Naukati commercial thin study plots.

used to access three of the Naukati commercial thin study plots. At this location the skid trail is located on top of the Old Naukati Skid trail. The photo shows a dense slash mat of fine woody material. Bulk density samples did not indicate detrimental soil compaction under the dense slash in Figure 16, however we still anticipate that similar to the Gonzo skid trail the slash is dense enough to retard the growth of desired vegetation. Carbon to nitrogen ratios and soil aeration is likely affected by the fine slash blanket and penetration of slash into the upper mineral soil horizons.

The Winter Harbor Wildlife Thinning stands were shovel logged in 2010. West of the 2050 road the stand lies within the 1000 foot wide beach buffer. The stand was originally harvested via A-frame with spar trees in 1944. The soils at the site consist of less than 1 meter of mineral soil over limestone bedrock. The site is very productive and the thinning was intended to improve deer habitat by reducing the number of stems per acre and increasing the amount of light hitting the forest floor thereby stimulating the growth of understory vegetation. To reduce conifer regeneration on shovel trails and improve wildlife mobility the slash mat was left in place (Figure 17). Due to a high number of small diameter logs in the stand the shovel trails currently look much like the corduroy portion of the Old Naukati Skid Trail (Figure 18) must have looked when it was first constructed 63 years ago.

Figure 17. Corduroy shovel trails in the Winter Harbor Wildlife Improvement thinning unit. June 2011.

Attempts to collect bulk density samples from soils under the Winter Harbor shovel trails failed because slash penetration in the areas of interest extended to bedrock. The heavily corduroyed shovel trails occupy 1.5 acres of the 15 acre stand (10%) west of the 2050 road. Regeneration and growth of conifers and other desirable understory vegetation will likely be delayed on these sites and it is likely canopy closure from adjacent trees will

occur before conifers get established on the shovel trails. Soil productivity and the ability of the soils to produce the desired vegetation is reduced in the area affected by the shovel trails (Figure 17).

One of the objectives of the Winter Harbor Wildlife Thinning project was to increase the amount of light reaching the forest floor and increase side lighting into the adjacent stand The corduroy shovel trails will help maintain side lighting into the adjacent stand. If the Winter Harbor shovel trails create conditions similar to the Old-Naukati Skid Trail, the corduroy trails will not support much understory vegetation or browse for deer for many years. The soils under the corduroy will not be as productive as in the pre-harvest condition because sunlight will not hit the soil surface and respiration (gas exchange) between the atmosphere and the soil will be inhibited.

Figure 18. Naukati Old Skid Trail in the corduroy section. The Winter Harbor shovel trails will likely look like this in 60 years.

Summary

Part1, Monitoring soil and vegetation in 15 year-old stands

The re-monitoring of 15 year-old young-growth stands in 2007 identified several key points regarding identification of soil disturbances detrimental to soil productivity.

The longevity of soil disturbance on the landscape is related to type of soil material exposed, landscape position, and repeated disturbance from natural sources. The

definition of a detrimental soil condition needs to take into account soil type, landscape position, and potential natural disturbance agents that may prevent natural recovery of the site.

In areas where detrimental soil conditions still exist 15 years after timber harvest the soil left in these areas consists of cobbly and/or dense subsoil material or bedrock and the site is in a landscape position where the exposed soil does not receive fine soil material or organic matter from adjacent areas. Heavy rainfall, wildlife traffic, snow avalanching and/or snowmelt continue to disturb or erode the site, preventing natural recovery.

Grass seeding on nutrient poor substrates on steep slopes can arrest erosion and help the site trap fine sediments and seeds of woody plants and provide a seedbed for woody plant establishment. Conversely, on disturbed areas in organic soil or richer mineral soils, grass seeding may retard growth of woody plants through grass stand dominance of the site.

The 2007 monitoring indicates that many small soil disturbances, less than about 25 square feet in size are not identifiable after 15 years of recovery and likely not detrimental to woody plant growth even on relatively poor soils. The Tongass' interpretation of the minimum size requirements for detrimental puddling, lack of ground cover, burned areas, altered wetness, and compaction could be changed from 1 foot to 25 square feet with very little risk of missing any detrimental soil conditions.

Small soil disturbances (less than 25 square feet) on landslide prone terrain have contributed to landslides on the forest. Soil quality standards need to consider the landscape position for contributing area and other slope stability attributes.

Part 2, Monitoring soil and vegetation in 50 year-old stands
The soil quality monitoring in 50+ year-old young-growth stands also identified several key points related to soil type, size and severity of soil disturbance and it's effect on desired plant growth.

Productive soils with relatively nutrient rich subsoil horizons may tolerate more severe and more extensive areas of soil disturbance before a change in desired vegetation growth is obvious. Limestone soils in particular have a higher nutrient availability at depth when compared to soils of mixed mineralogy on the Tongass. Severe soil displacements on limestone still resulted in the loss of the ability of the site to produce the desired vegetation at the desired growth rates. In the absence of red alder severely disturbed sites support salmonberry, ferns, elderberry and depending on site conditions devil's club. Soil displacements less than about 100 square feet in size were rarely identified in highly productive 50 year-old stands. Most detrimental soil conditions noted were 12 to 14 foot wide skid trails that were tens of feet in length. In tractor logged areas soil displacements from tractor skid trails can occupy more than 10 percent of the stand.

Bulk density samples in the 50-year old stands and in recent tractor logging indicates soil compaction is not an issue in these stands. Coarse textured soils with high organic matter

content and low natural bulk density are the main reasons soil compaction is not a concern in most Tongass soils.

Detrimental soil conditions in 50 + year old young-growth stands were primarily soil displacements and soil erosion. Soil displacements occurred on primary tractor skid trails and cable yarding corridors, especially between spar trees and the yarder. Typically these displaced areas were 10 feet wide or wider and tens of feet long. Soil erosion often occurred for several years after timber harvest in the displaced areas on sloping ground as evidenced by small gullies and ephemeral streams in these areas. By age 50-years soil erosion is almost entirely arrested.

On highly productive soils canopy closure has occurred over the skid trails. On lower productivity conifer dominated sites or on gravelly outwash soils canopy closure has not occurred over the skid trails or the canopy is red alder. On moderately disturbed sites where upper soil horizons were mixed by yarding activity there is a noticeable difference in desired vegetation composition and density. Based on this monitoring soil disturbance should be minimized on young gravelly outwash soils with little nutrient capital at depth. More work needs to be done to determine if the difference in desired vegetation growth is the result of delayed regeneration or changes in soil nutrient availability.

The absence of a red alder seed source in the vicinity of the many of the 50+ year-old stands resulted in dense conifer growth. If an alder seed source is present slight or moderate severity soil disturbance over extensive areas can create an alder dominated stand or mixed alder/conifer stand. Without intervention red alder will persist in these stands for more than 40 years. Where an alder seed source was present during the initial harvest (Vank Island and Luck Lake) the stands are either alder dominated or include a high component of alder today.

Soils in unharvested limestone stands have thicker duff layers than soils in adjacent, comparable harvested stands. It is possible that timber harvest helped to reduce duff thickness through either microbial stimulation or mechanical compaction by harvest or snow load. The duff reduction may positively or negatively affect soil productivity depending on the mechanism of reduction. More work needs to be done to understand why the duff layer is thicker on soils over limestone in unharvested stands than in harvested stands. Since fungi are the primary decomposers, woody debris and fungal inventories may be logical starting points.

Soils in unharvested limestone stands generally have thicker duff layers than soils in unharvested stands on soils with mixed mineralogy. Possible explanations for this phenomenon include differences in recalcitrance of leaf litter caused by different plant associations growing on the unharvested limestone soils. Many of the unharvested limestone soils experience catastrophic windthrow every 200 years or more leading to dense, even-aged conifer stands with a moss understory. The moss understory likely decomposes at a slower rate than litter from a blueberry and herbaceous understory. More work needs to be done to understand why the duff layer is thicker on soils over

limestone in unharvested stands than in other unharvested stands on soils with mixed mineralogy.

In the Vank Island stands the duff thickness is generally thinner than other stands measured due to the high amount of deciduous vegetation in these stands. Loess soils may also be better invertebrate and microbe habitat than coarser textured soils. For example, earthworms were more common in the loess soils on Vank Island than in other soils sampled in this monitoring and may be playing a role in duff reduction.

Stands with severe soil disturbances
Shovel ruts tend to either improve soil drainage by carrying water away from the site or impede soil drainage by interrupting preferential flow paths in the soil or by intercepting the seasonal water table in the soil. Seasonal water tables are common atop the dense till that occurs in many soils at variable depths. Preferential flow paths occur at various depths in the soil and help the soil process water and prevent erosion or ponding of water. Rutting that mixes soil horizons, intercepts seasonal water tables, or disrupts preferential flow paths in the soil should be avoided. Preferential flow paths typically occur atop the dense till and less commonly atop the Bh horizon or just under the duff layer. Where soil drainage is improved soil productivity generally increases and where soil drainage is impeded soil productivity is reduced. Rutting should avoid interception of seasonal water tables or disruption of preferential flow paths or seasonal water tables, especially on soils that are not well drained.

Areas of soil displacement greater than 100 square feet in size generally resulted in reduced growth rates and different plant communities than adjacent undisturbed sites. On gravelly nutrient poor soils the effects of soil displacement are more pronounced and appear to be longer lasting.

Stands with dense slash accumulations
Dense slash mats can negatively affect conifer regeneration and growth but the slash mat has to be pretty dense. In the Little Coal Bay harvest units the slash mat does not appear to be dense enough to inhibit regeneration and growth of the desired vegetation. In the Gonzo Timber sale and on the Old Naukati Skid trail the slash mat and corduroy skid trail appear to be affecting regeneration and growth of conifers. Based on those observations the recently constructed Winter Harbor shovel trails and the Commercial Thinning Study Skid Trails will negatively affect the regeneration and growth of conifers and other desired vegetation. Slash mats can easily be broken up or fluffed by the shovel operator during the last pass out of the unit.

Recommendations
The definition of a detrimental soil condition needs to take into account soil type, landscape position, ecological setting and potential natural disturbance agents that may prevent natural recovery of the site. The current Regional Soil Quality Standards and Tongass interpretation (Landwehr 1993a, 2009) are a one-size-fits all standard and does not consider different size criteria, landscape position, or soil nutrient capital for defining

detrimental soil conditions on different soils. A revision of the Tongass' interpretation of the Regional Soil Quality Standards is justified based on this fact alone.

The Tongass should consider changing the minimum size requirements for all detrimental soil conditions to at least 25 square feet. The Tongass should consider inherent soil productivity and nutrient capital at depth when determining if a soil disturbance is detrimental. Sites with deep, productive soils can tolerate more extensive and severe soil disturbances better than sites with thin, dense, or cobbly soils. The minimum size criteria for detrimental soil conditions need to consider the site's susceptibility to mass movement. Soil disturbances less than 25 square feet have contributed to the occurrences of landslides (Landwehr 1998, Personal observations by the authors).

The decision as to whether or not to grass seed a site for erosion control needs to take into account soil type, erosion potential and the potential for grass dominance of the site. Grass seeding can help rebuild organic matter and grass stands can trap seeds and fine soil particles helping to rebuild soil productivity on nutrient poor sites. Limit grass seeding to areas where soil erosion is a concern and the soils are somewhat nutrient poor. Limit grass seeding on organic soils and very productive soils with low erosion potential. On small soil disturbances in rich organic soils, grass can dominate the site and limit woody vegetation establishment.

The presence or absence of red alder in the vicinity of the stand needs to be considered when creating a soil management prescription for a stand. The vegetation in the stand can be greatly influenced by the amount of soil disturbance allowed and the seed sources in the vicinity of the disturbance.

Severe soil displacements that remove nutrient rich duff and upper mineral soil horizons over areas larger than 100 square feet should be avoided on all soils.

On coarse textured soils similar to those at Thomas Bay and Yakutat even mixing of nutrient rich soil horizons and duff should be avoided. More work needs to be done to better understand vegetation response to soil disturbance on these sites and changes to soil nutrient availability following soil disturbance.

The concept of beneficial soil disturbance should be investigated on sites deemed susceptible to paludification.

Where post harvest disturbance data is available, more time should be spent documenting soil conditions and stand growth in older second-growth stands to determine which soil disturbance conditions are truly detrimental to woody plant growth.

Due to highly variable soil conditions in old tractor logged stands, a soil scientist should field verify existing soil conditions prior to undertaking stand treatments that will potentially disturb soils.

Future monitoring should include stem analysis that determines tree age and growth rates so that a determination can be made as to whether observed slower growth rates on disturbed sites are the result of delayed regeneration or reduced soil productivity. LiDAR may be another tool for monitoring stand growth response to soil disturbances over extensive areas.

More work needs to be done to understand why the duff layer is thicker on soils over limestone in unharvested stands than in harvested stands. The work needs to consider duff composition and duff density. Potential causal agents include fungal and microbial community stimulation via soil warming or mechanical compaction by snow load. Both potential causal agents should be investigated.

Shovel ruts mix the upper horizons of the soil and can either drain the soil by carrying water away from the site or disrupt flow paths and impede soil drainage making the site wetter. Rutting that is deep enough to intercept the seasonal water table or disrupt preferential flow paths in soils needs to be avoided. Typically the seasonal water tables and preferential flow paths occur just above dense till horizons or bedrock, but can also occur in the Bh horizon just under the duff layer in the soil profile. In the absence of site specific soils information and as a practical measure avoid creating ruts. Any rut more than 12 inches deep could be considered a severe impact on most soils.

Dense slash mats and corduroy roads should be fluffed after use is complete.

Support research designed to validate the effects of soil conditions on tree growth.

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