University of British Columbia

Faculty of Forestry

The Potential Effects of Tethered-Based Forest Harvesting Systems on Soil Disturbance in Coastal British Columbia

Jacob Atherton

FRST 497 – Graduating Essay

Final Submission on January 7, 2019

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Abstract

While there are a variety of forest harvesting systems, there are few able to operate within the constraints of the increasingly harder to access timber supplies found in the mountains of the coastal region of British Columbia. While ground-based systems can access the more flat, unbroken terrain, steeper mountainous areas are limited to aerial-based systems, cable-based systems, and tethered-based systems, the latter being the focus of this paper. Tethered-based systems, namely tethered feller-bunchers, operate through working with a winching system upslope from the machine that allow for increased traction when operating (Sessions et al., 2017). This allows for these machines to operate on steeper slopes than their untethered counterparts (Sessions et al., 2017). While this method is generally more efficient and cost-effective compared to cable-based and aerial-based systems, it is important to note the effect of these machines on the soils in which they operate (Sessions et al., 2017). This paper assesses the issues associated with operating this machinery on steeper slopes. Research and knowledge on soil disturbance using ground-based harvesting methods, coupled with steep slope soil characteristics, will be used to examine the potential negative effects for harvesting with tethered-based system on soil disturbance, soil compaction, and slope stability.

Keywords: Forest Harvesting Systems, Soil Compaction, Soil Disturbance, Slope Stability, Tethered Feller-Buncher, British Columbia, Forestry

Acknowledgements

The author would like to thank the many people that contributed to the success of this paper. Their insights and expertise were greatly appreciated and added valuable context and wisdom to this paper. First, thanks is due to Dr. Dzhamal Amishev of FPInnovations, whose input not only guided this paper into a current, useful direction, but also opened my mind to conflicting research in this field. Recognition is also given to Professor Gary Bull, Dr. Stefania Pizzirani, and Devyani Singh, whose critical guidance throughout this course brought a wide range of criticisms and insights that had not been previously considered. Additional gratitude is due to Dr. Dominik Roeser for reading a draft version of this paper to insure its accuracy and success. Finally, sincere thanks is given to my father, Kevin Atherton, for spending time in his earned retirement recommending a variety of improvements to insure that this paper was clear, concise, and interesting. Any errors found within this paper are solely those of the author and are not representative of the respected people mentioned above.

1. Introduction

Forest machinery, such as skidders, forwarders, feller-bunchers, and harvesters have long been used to efficiently cut and transport logs to forest roads where they are picked up by logging trucks. While this process is more efficient than a motor-manual harvesting method — the use of chainsaw for felling — having large machinery in forests results in increased soil and forest disturbance, including soil compaction and displacement (Zinkevičius, Steponavičius, Vitunskas, & Činga, 2012). Heavy forest machines often compact the soils they operate on and have lasting effects on the trails they create and the surrounding environments (Froehlich & McNabb, 1984). These effects include tree mortality, decreased stand growth, and impacts on log yield (Brais, 2001; Froehlich & McNabb, 1984; Murphy, Firth, & Skinner, 2004).

Timber harvesting costs are expected to increase and decreases in timber availability due to climate change are also anticipated (McKenney et al., 2012). With these constraints, forest professionals are likely to find novel ways in which to harvest these stands cost-effectively. Although cable-based harvesting systems are common, this method is often more costly, and less efficient than ground-based systems (Spinelli, Magagnotti, Aminti, Francesco, & Lombardini, 2016). While ground-based systems, tracked and wheeled machines without winch-assist, can operate across the stand with ease, cable-based systems, relatively stationary machines with cables used to transport logs out of harvest areas, are limited to the path of their cables, and often require motor-manual harvesting methods in order to fell and buck the logs before cable transport (Visser & Berkett, 2015).

One relatively new harvesting technique is the use of a tethering system to allow ground-based machinery, specifically feller-bunchers, to access steeper sites. This method combines the increased speed found with ground-based machinery, compared to motor-manual methods, with the versatility of ground-based machinery, compared to cable-based systems. While there is an abundant amount of research on the effects of ground-based forest machines on soils (Allman et al., 2015; Horn et al., 2004; Lousier, 1990; Murphy et al., 2004; Picchio et al., 2012; Poltorak et al., 2018; Tavankar et al., 2017), the effect on the soil by tethered systems has yet to be comprehensively assessed. Through combining existing knowledge on soil disturbance on steep slopes with that of soil compaction from ground-based harvest systems the effect of this harvesting method on soil can be better understood. This paper will analyze and compare these areas of study to better understand how tethered harvesting systems affect soil disturbance, soil compaction, and slope stability within the coastal region of British Columbia.

2. The Coastal Region of British Columbia

Forest planning and practices in Coastal British Columbia are very complex (Bunnel & Dunsworth, 2004). From the high cost of logging to the unique environmental characteristics of the area — being a temperate rainforest — has created a difficult scenario for forest professionals to operate within (Bunnel & Dunsworth, 2004). The coastal region of British Columbia comprises the western-most portion of British Columbia, from the 49th parallel to the borders of Alaska and the Yukon (Jungen & Lewis, 1986).

Vegetation is a coniferous blanket forest, including biogeoclimatic [BEC] zones of Coastal Western Hemlock, Coastal Douglas-fir, Mountain Hemlock, Engelmann Spruce – Subalpine Fir, and Alpine Tundra (Jungen & Lewis, 1986). The generally steep terrain found within the area leads to unstable terrain where the development of soils is hindered by the slow creep of surficial materials (Jungen & Lewis, 1986). Fortunately, the forests within these steeper areas of coastal British Columbia are competent in holding these processes in check, until disturbances — such as forest harvesting — interrupt this naturally stabilizing force (Jungen & Lewis, 1986).

With respect to soil, Coastal British Columbia is subject to relatively high-levels of precipitation and moderate to cool temperatures (Jungen & Lewis, 1986). Ferro-Humic and Humo-Ferric Podzols dominate much of the coastal region in B.C. which are identifiable based on their thin/lack-of Ae horizon and thick dark reddish B horizon rich in iron, aluminum, and organic matter (Jungen & Lewis, 1986). These soils are generally medium to coarse textured, generally lack horizons in which clay can accumulate, and are highly susceptible to leaching (Jungen & Lewis, 1986). Figure 5 and 6 in Appendix 1 show a geographical breakdown of the general locations of these soil classes along the coast of British Columbia. While the medium to coarse texture of these soils do reduce compaction somewhat, their susceptibility to soil disturbance by the use of heavy forest machinery has been shown to be measurable beyond three decades (Lousier, 1990).

3. Methods

This paper is a literature review of soil disturbance, in the setting of forest operations in Coastal British Columbia with respect to the use of tethered feller-bunchers. This paper uses references from peer-reviewed journal articles, personal communications, government reports, government and industry websites, books related to topics found within this paper, legislation of forest practices in British Columbia, and guidelines for activities in forest operation from professional associations.

The majority of this paper refers to peer-reviewed articles, which are used in all areas that describe technical details associated with the interaction of machines with soil and the associated disturbance they cause. Books and government reports were used for general knowledge on the area of study as well as for definitions on soil classifications. Legislation and guidelines were primarily used to show the forms of management applicable to forest operations in British Columbia. Websites were only used to describe concepts, such as biogeoclimatic zones, and further describe areas where tethered feller-bunchers may be of use. There is a lack of peer-reviewed articles on the subject of timber supply in British Columbia in relation to slope constraints. Website references were not used in the results or discussion of this paper to adhere as close as possible to currently accepted scientific evidence.

The year of publication of referenced material was not a limiting factor for this paper. As tethered feller-bunchers are only recently being used and studied, these papers are quite current (Visser & Berkett, 2015; Visser & Stampfer, 2015; Thompson & Hunt, 2016). Papers and books on soil processes and disturbances date farther back (Jungen & Lewis, 1986). These papers are mostly wide-ranged and provide general knowledge of the area of interest. Recommendations found in the discussion portion of this paper use the most current soil disturbance data and machine-based management techniques that could be found. The location of study in peer-reviewed articles was also not limited, due in part to the lesser amount of pertinent literature directly correlating to the area of interest in this paper, the coastal region of British Columbia. Country of publication was also not limited as international papers were found to have very useful information in regards to forest machinery commonly used in British Columbia.

4. Management of Steep Slope Soils

Two key areas affecting soils on steep slopes, and in need of consideration and management, are soil erosion and slope stability. By assessing both aspects of these soil disturbance types, a better understanding of their link with forests and forest harvesting can be identified allowing for a meaningful connection between harvest techniques and soil disturbance. It is also important to note that steep slopes are a major portion of the fibre pool in Western Canada and are the source of more than a quarter of the allowable annual cut of British Columbia (FPInnovations, 2018).

4.1 Soil Erosion

Soil erosion due to forest harvesting is of major concern; its effects include soil leaching into water systems, transportation of debris from forest operations, and decreasing slope stability (Alaoui, Rogger, Peth, & Blöschl, 2018; van Beek, Cammeraat, Andreu, Michovski, & Dorren 2008; Norris et al., 2008). Soil erosion is common on hillslopes and removes fertile topsoil, this has negative effects when erosion acts at a rate faster than soil formation and weathering processes (Norris et al., 2008). Soil erosion is known to be increased through human land use activities (Norris et al., 2008), such as forest operations. This provides reasoning for soil erosion to be of heightened concern when operating on steep slopes.

4.2 Slope Stability

Slope stability has often been a concern in forest operations, from failing forest road systems, to slope constraints for machine use and access. Terrain Stability Assessments [TSA] are a common method within the industry to assess slope constraints and provide best practices for the completion of forest harvesting at the site level (APEGBC & ABCFP, 2010). The stands in which harvesting occurs are effective mitigation agents in slope stability issues through their root system anchoring and absorbing water, the ability for their stems to support above-ground movement, and the interception of precipitation through their leaves (Stokes et al., 2008). Forest harvesting, by removing these natural barriers to slope movement, decreases slope stability and therefore increases the negative effects associated with ground-based machine movement.

4.3 Current Management

A variety of methods are available for managing ground-based forest harvesting impacts on soil disturbance. The TSA allows for a standard among forest operations that lists problem areas within a harvest unit, outlining specific concerns and harvesting constraints for these areas

(APEGBC & ABCFP, 2010). While TSAs provide important information on soil stability, soil erosion and soil compaction are not commonly under consideration.

The Forest and Range Practices Act [FRPA] regulates soil disturbance limits and rehabilitation requirements for compacted soils (FRPA c. 35, 2018). FRPA states that soil disturbance cannot affect areas greater than 5% of the standards unit, an area within a block undergoing similar management methods, for sensitive soils, 10% for non-sensitive soils, and 25% of the area covered by a roadside work area (FRPA c. 35, 2018). FRPA also requires rehabilitation of compacted soils when the affected area was created by forest harvesting, is within the area to be reforested, and is a minimum of 1 ha in size (FRPA c. 35, 2018). Furthermore, FRPA requires that rehabilitation must include the removal or redistribution of woody materials exposed on the surface and that are concentrating subsurface moisture, de-compact compacted soils, and return displaced surface soils (FRPA c. 35, 2018). In order to avoid erosion into streams, wetlands or lakes, as well as a variety of areas identified by the Lieutenant Governor in Council, FRPA also mandates the placement of woody debris on exposed soils or the revegetation of the affected areas (FRPA c. 35, 2018).

In regards to steep slope operation, the International Labour Office [ILO] has provided limitations on the operation of certain machines (ILO, 1998). These limitations vary based on chassis type, highest constraints are found with rubber-tired skidders and constraints decrease with crawler tractor machines (ILO, 1998). It is recommended that rubber-tired skidders or forwarders do not exceed slopes of 35%, crawler tractor, feller-buncher, and excavator harvester-type machines do not exceed 40% slopes, and ground-based forest machines specifically designed for steep slopes, such as tethered feller-bunchers, do not exceed slopes of 50%. These limits are also asserted by WorkSafeBC (c. G26.16, 2018) as the present restrictions, unless manufacturer's maximum slope operating stability limits are known or "a qualified individual conducts a risk assessment of that operation" and "written safe work practices acceptable by the Board are developed and implemented to ensure the equipment's stability during operation".

5. Ground-Based Forest Systems and Soil Compaction

5.1 Ground-Based Forest Machines

Tractive machines used in current forestry practices displace and compact soil as they operate, this soil disturbance results in decreased stand growth (Froehlich & McNabb, 1984).

These machines, including skidders, and harvesters, commonly operate on either wheeled or tracked chassis (Allman, Jankovský, Messingerová, Allmanová, & Ferenčík, 2015). Both chassis types result in soil compaction, but to different extents, which instigate different recommendations for use based on soil sensitivity to compaction. There is also a correlation between machine size and soil compaction and displacement; larger, heavier, machines have an increased effect on the soils in which they operate (Horn, Vossbrink, & Becker, 2004).

5.1.1 Feller-Buncher

One machine commonly used in ground-based forest operations is the feller-buncher, which is a tracked machine wielding a specialized head for grappling, cutting, and bunching trees. This machine operates in two varieties, independently and with winch-assist, also known as tethered. This tethering system allows for its operation on steeper slopes, beyond that capable, or safe, in independent operations.

Figure 1. *953K Tracked Feller Buncher from John Deere shown in operation (John Deere, 2018).*

Figure 1 depicts a feller-buncher operating in a relatively flat, unbroken terrain, where this machine is best suited. The ability for these machines to grapple many smaller stems at a single time greatly increase its productivity.

5.2 Soil Compaction

Soil compaction caused by the use of ground-based forest machines has lasting effects on the forest (Brais, 2001; Lousier, 1990; Tavankar et al., 2017; Murphy et al., 2004). Soil compaction not only increases risks of slope movement and stability issues, but also decreases the growth rate, and increases mortality, of trees grown within areas of disturbance (Brais, 2001; Tavankar et al., 2017). Because of this, it is important to take measures that either prevent this compaction from occurring, or mediate its impact post-harvest. These measures include the use of designated skid trails, brush mats, and proper machine selection for chassis type and weight. (Allman et al., 2015; Horn et al., 2004; Poltorak et al., 2018).

6. Tethered-Based Forest Harvesting Systems

6.1 Tethered Feller-Buncher

A tethered, or cable-assisted, feller-buncher uses tension in a wire rope, anchored upslope, to assist with traction while operating on steep terrain (Sessions, Leshchinsky, Chung, Boston, & Wimer, 2017). Tethered feller-bunchers are favourable in comparison to motor-manual techniques due to their greater productivity and safety and are increasingly being used internationally (Sessions et al., 2017). Although an international roll-out of these systems has occurred there is still little knowledge of machine limitations and site operating conditions (Sessions et al., 2017).

Figure 2*. Cat 552 Feller-Buncher tethered to an excavator with a shovel embedded in the ground operating in steep slope terrain (Siegmund Excavation, 2018).*

Tethered feller-bunchers use one of two winching mechanisms: integral winching systems, those installed on the feller-buncher; or on a separate winch carrier, installed at a landing or clearing on top of the harvesting area (Sessions et al., 2017). When using the integral winching system, the winching mechanism is usually attached to a stump, deadman, or mechanical anchor (Sessions et al., 2017). When a separate winch carrier is used, the carrier equipment is usually attached to a mobile anchoring system, such as an excavator-type machine with its blade or shovel embedded into the ground (Leshchinsky, Sessions, & Wimer, 2015; Sessions et al., 2017). Both systems operate through limiting cable tensions to levels that are considered operationally acceptable (Sessions et al., 2017).

Visser and Stampfer (2015) demonstrate a formulaic approach to describe the improvements seen when using a tethered machine compared to a machine without tethering. Figure 3 shows the general conditions for a roll over to occur, where if the centre-of-gravity [CoG] is upslope from the pivot point [PP] the feller-buncher will not tip (Visser & Stampfer, 2015). Figure 4 indicates the advantages of a tethered system where the basic physics is that gravity [G], forcing the machine down, should not exceed the traction force [T] (Visser & Stampfer, 2015). The cable tension [C] adds to this traction force increasing slope operability and decreasing rollovers through the avoidance of loss in traction (Visser & Stampfer, 2015). The downward force [W] is separated into the product of W by the sine angle [Wg] and the normal force on the ground [Wn] (Visser & Stampfer, 2015).

As seen in Figure 4, by increasing C, rollover can be reduced through this uphill force. By increasing this force, rollover can be prevented as long as this force is capable of holding the CoG above the PP.

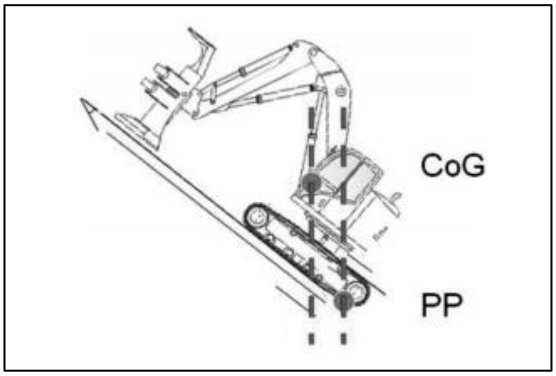

Figure 3. *Assessing the stability of feller-bunchers on steep slopes using CoG and PP (Fig. 6 in Visser & Stampfer, 2015).*

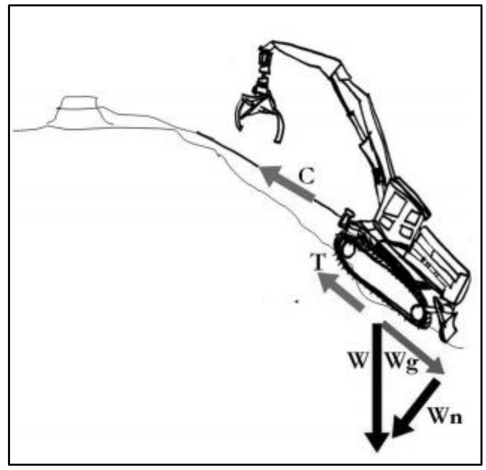

Figure 4. *A schematic diagram of the forces occurring during tethered machine operation on steep slopes where T is increased by C (Fig. 8 in Visser & Stampfer, 2015).*

7. Discussion

7.1 Potential Impacts of Steep Slope Operation

With the increased slope stability issues of machine operation on steep slopes, it is likely that tethered-based harvest systems will have a negative effect on the soils in which they operate, including increased soil erosion. In order to manage for this, and in order to remain within the regulations set out within FRPA, it is suggested to take soil disturbance into account when setting a limit on the slopes in which these machines can operate. Dr. D. Amishev, a Senior Scientist in Fibre Supply at FPInnovations, maintains that there are many interrelated factors to consider when setting machine limitations (personal communication, December 6, 2018).

While increased soil disturbance and compaction is seen among tethered-harvesting systems, compared to cable-based systems, according to Amishev there are net benefits associated with these disturbances (personal communication, December 6, 2018). Tethered-based systems allow for an increase in tree patches, compared to cable-based systems, as deflection is not required (personal communication, December 6, 2018). These patches are ecologically and hydrologically beneficial to the stand (personal communication, December 6, 2018). Although these net benefits have been identified, whether forest professionals will leave these patches is unknown, and ultimately at their discretion.

Research suggests that this soil disturbance may provide benefits to tree and stand growth, especially in *Pseudotsuga menziesii* (Mirb) Franco [Douglas-fir] (Ares et al., 2005). New research, provided by Amishev, also suggests that while soil compaction and erosion can lead to overall site degradation, benefits can also be found in reducing competition (personal communication, December 6, 2018). This contradicts earlier work which finds that negative effects outweigh benefits in this situation (Brais, 2001; Lotfalian et al., 2010; Murphy et al. 2004; Tavankar et al., 2017). As cost-benefit analyses will likely differ depending on soil and climatic characteristics, it is important for more research to be conducted around which forces would prevail. Although Amishev asserts that Douglas-fir benefits from this soil disturbance and compaction (personal communication, December 6, 2018), species with less resilient roots and stems are less likely to benefit, the severity of which is yet to be known.

As tethered-based harvesting is relatively new, it is also important to mention that the long term effects of this system are yet to be seen in the forests in which harvesting has occurred. With increased compaction of soils, rooting restrictions may occur as ability for these roots to extend laterally will be inhibited. This in turn may result in less effective soil retention by these stands which may hinder slope stability and increase soil erosion. Ares, et al. (2005) find that in certain cases, soil water holding capacity and unsaturated water flow increase with soil compaction. Although increased capillary action in soils may increase water retention, the decreased porosity in compacted soils reduces this water holding capacity. And, although unsaturated water flow may increase the supply of nutrients and water to roots, this also increases soil erosion, potentially having negative effects on slope stability.

While legislation, such as FRPA, is in place to mitigate the effects of ground-based machinery, there have been little-to-no updates with the introduction of tethered-based systems. These systems, with the increased slope in which they operate, are at a higher risk of landslides, as well as heightened levels of soil erosion and degradation seen in off-road machine use (Visser & Hamish, 2015).

7.2 Limitations and Recommendations

While this paper aims to combine current research and knowledge from soil compaction of ground-based harvest systems with steep slope operations, and restrictions, of tethered-based systems, some limitations must be identified. There is a lack of peer-reviewed research on tethered systems, limiting the range in which the paper can discuss its effects on soil disturbance. No research was found on the long-term effects of tethered feller-buncher, this being in part due to the new nature of this harvesting method. It is also important to note that, by using a tether, soil disturbance is less than that found in ground-based harvest operations when operating within an area that both systems can function. This is due in part by the ability for the tethered system to avoid sliding, slipping, and digging farther into the soil.

This paper also did not bring into discussion comparisons between tethered harvesting methods and aerial harvesting methods (i.e. helicopter-assisted logging), as this method is much more expensive, and has considerably lower soil disturbance (Bigsby, 2012). The latter due predominantly to the lack of machines on the ground, as falling is usually completed using motor-manual methods. Although this technique is a common harvesting method, its use was considered in this paper but was removed from its scope as it did not add much useful information with respect to comparison with the tethered-based method.

8. Conclusion

A tethered-based harvesting system provides a cost-effective alternative to cable-based systems while allowing for higher levels of production than motor-manual methods. Although having its benefits, little is known about the effects of these systems on the steep soils on which they operate. It is recommended that more research is completed on the long-term effects of soil disturbance by tethered systems. This research will prove useful in the long term success of these stands, including rooting depth, understory regeneration, and species composition. Furthermore, per Amishev's research (personal communication, December 6, 2018), this paper recommends an increased awareness towards soil disturbance when setting operational limits, alongside other interrelated factors in slope stability not discussed.

The large area designated as steep-slope fibre supply in British Columbia offers a large region in which the use of tethered feller-bunchers would likely be successful economically. As this technology advances, and its operating range increases, it is important to understand the underlying risks associated with steep slope harvesting. The lack of long-term research on the effects of using tethered-based harvesting systems should also be taken into consideration. Increasing thresholds for maximum operating slopes should not only take into consideration machine capabilities, but also the effect on environmental processes, such as soil disturbance, soil compaction, and slope stability.

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Appendices

Appendix 1

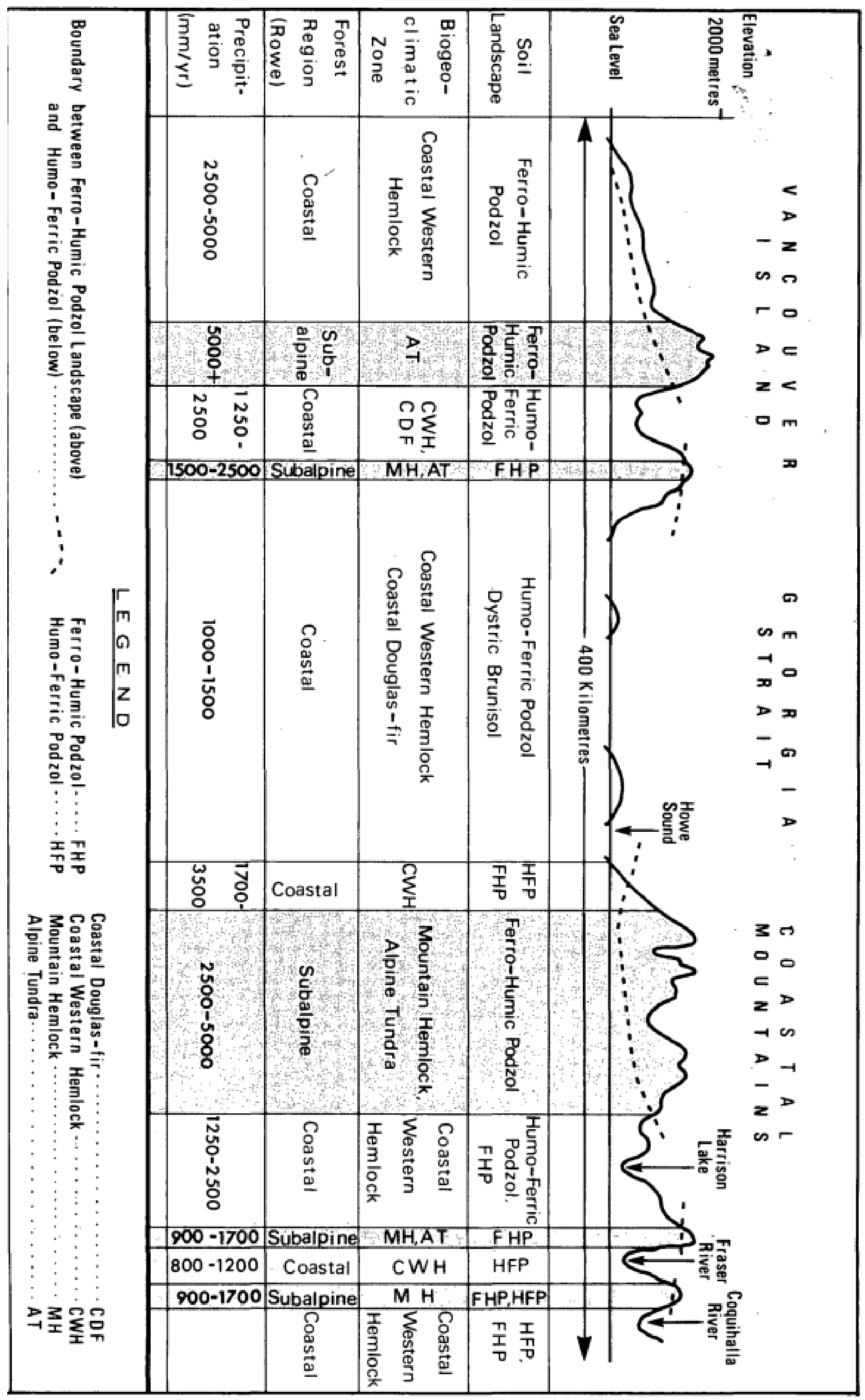

Figure 5. *The soil landscapes across the southern coast along latitude 49°30′N (Figure 3.3.1 in Jungen & Lewis, 1986).*

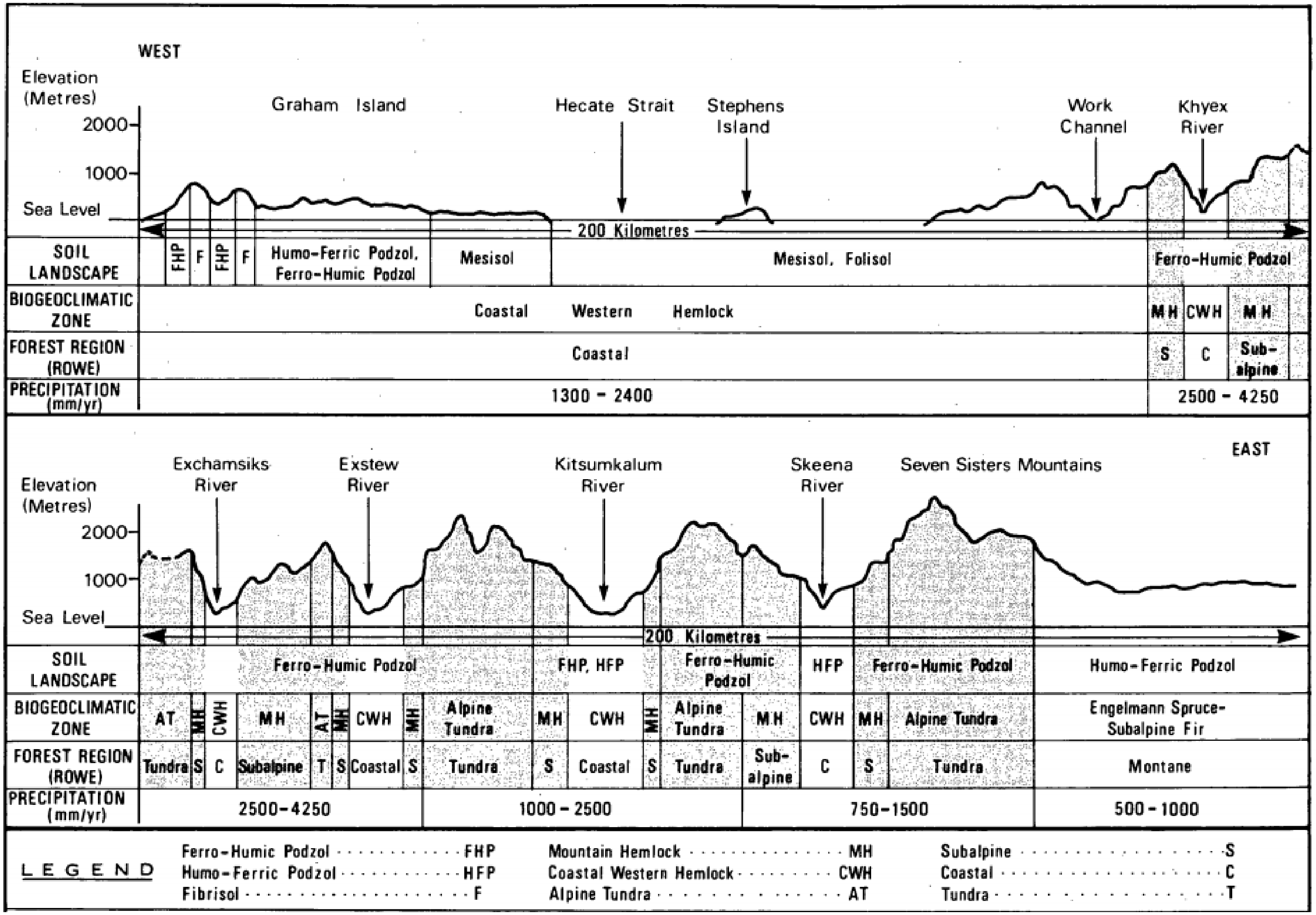

Figure 6. *The soil landscapes across the northern coast (Figure 3.3.2 in Jungen & Lewis, 1986).*