FRST 497

Natural Regeneration on Coarse Woody Debris

Graduation Essay

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4/18/2011

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Abstract:

In the Pacific Northwest temperate forest, coarse woody debris provides a great substrate for natural regeneration of many conifer species. Logs in decay class III and IV are most suitable for seedling growth. Seedling establishment and early survival rate are higher on nurse logs than on forest floors because of favorable microsite and seedbed material. The advantage of this regeneration pattern is most significant under closed-canopy condition. However, nutrient limitation and temporal changes in substrate availability enable few seedlings to grow into saplings or mature trees at later stages. In forest management, snags and coarse woody debris should be maintain at a certain level to sustain this natural regeneration pattern and maintain structure diversity of temperate rainforest in the Pacific Northwest.

Key words:

Decayed wood, seedling establishment, seedling survival, nutrient dynamics, soil microbes

Introduction

Natural regeneration is an important process to forest succession and forest dynamics. It could happen on different substrates which include forest floor, mineral soil or even Coarse Woody Debris (City of Surrey, 2010). In temperate conifer forest, natural regeneration on CWD is a common phenomenon to many tree species. Compared with tropical forest, where decay rate is accelerated by favorable biotic and abiotic conditions, the drier summer and cooler winter in

Pacific Northwest keeps the wood decay rate at a low level that decaying wood can accumulate and provide establishment habitat for tree seedlings (Gonzalez et al, 2008). Also, angiosperms tend to have a faster decay rate compared with gymnosperms because of differences in chemical and physical structure (Harmon et al, 1986). People seldom pay attention to this natural process, maybe because it is commonplace in the Pacific Northwest. However, this unique natural regeneration pattern improves seedling recruitment, diversifies forest structure, and accelerates nutrient cycle and energy flow. This essay reviews previous papers on this topic and provides a synthesis of information and knowledge to address the importance of this mechanism. This paper describes the key process following a chronological order of seedling establishment, seedling survival and further development. Major factors and components in each process are addressed in each part. Finally, the paper concludes with a discussion of study methods, limitations, and suggestions for CWD management.

What determines successful seedling establishment on decayed wood?

For many conifer species, seedling occurrence is higher on decayed wood than on forest floors and undisturbed soil, especially at an early stage. Favorable substrate characteristics, unique species selection and advantageous rooting conditions are all contributing elements to successful seedling establishment.

Log as a substrate

Coarse woody debris is generally defined as dead and downed wood such as logs, stumps, large branches and coarse roots, in all stages of decomposition (City of Surrey, 2010). Although a scientific definition is hard to find, this term usually refers to down woody debris greater than 7.5 cm in diameter and 1 meter in length. It does not include self-supporting dead trees, exposed live tree roots or dead roots in the soil (Stahl et al, 2002). A "nurse log" is CWD with trees, plants and seedlings growing on it. Many studies indicate a plant succession on nurses. Lichen-liverwort (e.g.*Cladonia-Lepozia* spp.) covers the log surface first, then followed by moss, herbaceous species and tree seedlings (McCullough, 1948). Studies show bryophytes occupy 90% of the bark surface within 15 years of log fall, compared with the peak of tree seedling establishment happening between 15-25 years (Harmon, 1986). The delay is because tree seedlings cannot establish on freshly fallen logs because the substrate is too hard to penetrate. In addition, the moisture and chemical components of log substrates are not suitable for seedling establishment at an early stage (Narukawa et al., 2003).

Log distribution and Decay Class

Generally speaking, the CWD biomass in Pacific Northwest temperate forest is related to stand development. At the beginning of a secondary forest succession, the residual logs from previous disturbance account for most of the CWD on the forest floor. As the stand develops, the decay of fallen wood can't be fully compensated by the new input from gap disturbance. Therefore, the total volume of CWD declines. At the end of the succession, a catastrophic disturbance event or gap formation in old-growth forest results in large mortality which contributes to the down wood on the floor (Spies et al., 1988; Sturtevant et al., 1997).

Coverage by rotting logs on forest floors differs from region to region. In the Pacific Northwest, the coverage of decayed wood in *Pseudotsuga menziesii* (Mirb.) Franco and *Tusga heterophylla*

(Raf.) Sarg.forest varies from 10% to 30% (Harmon, 1989) which is higher than the average of 4-6% in other regions of the world (Grahamand et al, 1982). The dynamic forest ecosystem in the Pacific Northwest contains various disturbance types and seral stages which results in high occurrence of tree fall and diverse structure of the forest floor. Decay class is used to classify downed wood according to physical and biological characteristics. Different standards are used in difference places around the world. In the Pacific Northwest, a five-stage classification system is used to describe the status of decaying wood in *Pseudotsuga menziesii* and *Tusga heterophylla* forests (See Table 1). Many studies indicate that Class III and Class IV are the most common stages for seedling establishment (Motta et al. 2006). In these classes, the log is soft enough for seed to penetrate, and the nutrient in sapwood is also available for seedlings to reach. Few seedlings can establish on Decay Class I and Decay Class V. The distribution of logs with appropriate decay class varies from stand to stand which mainly depends on disturbance type and stand stage (Takahashi et al., 2000; Harmon et al, 1989). Young forests with early seral stage tend to have more fallen logs in decay classes I and II. Mature stands usually have more decayed wood in decay classes III to V.

Table 1. Decay Class Description for downed wood (from Solins, 1982)

Character	Class description				
	I	II	III	IV	V
Bark	Intact	Mostly intact	Sloughing or absent	Detached or absent	Detached or absent
Structural integrity	Sound	Sapwood somewhat decayed; heartwood mostly sound	Heartwood mostly sound; supports own weight	Heartwood rotten, does not support own weight, branch stubs pull out	None
Branch system	Current-year twigs present	Larger twigs present, branch system entire	Large branches present, longer than log diameter	Branch stubs present, shorter than log diameter	Absent
Invading roots	Absent	Absent	Sapwood only	Throughout	Throughout

Species Differences

Species differences are important from two different perspectives: different seedling species vs. different log substrates. In term of seedling occurrence, many studies demonstrate a preference for decayed wood all over the world (Chris et al, 1974; Narukawa et al, 2003; Motta et al, 2006; Lusk, 1995). In Pacific Northwest temperate forests, *Picea sitchensis* (Bong.) Carr. and *Tusga heterophylla* (Raf.) Sarg. seedlings occur much more frequently on fallen logs than on mineral soil (Szewczyk et al., 1996), especially in crown closure stage. It was reported that Tusga seedlings. were absent on forest floors with appreciable depth of forest litter and could only regenerate well on fallen wood with sufficient moss layers (Christy et al., 1984; Friesner et al, 1944). *Tusga* seeds are small. They are sensitive to litter burial and can be easily retained in crevices and holes on logs (Simard et al., 2003). Other common conifer species found growing on decayed wood include: *Picea engelmannii* Parry ex Engelm, *Abies lasiocarpa* (Hook.) Nutt, *Thuja plicata* Donn ex D. Don, *Abies amabilis* (Dougl.ex Forbes), *Picea glauca* (Moench) Voss, etc. (Harmon et al, 1989). In boreal forest, *Picea engelmannii* and *Abies lasiocarpa* are all prevail on rotten wood seedbed; however, *Abies* spp. is less dependent on wood substrate compared with *Picea* spp. (Brang et al., 2003). A study shows that the survival rate for *Abies* is higher on buried log than on unburied log (Simard et al., 2003). Although logs provide advantageous habitat for some species, they are inferior seedbeds for other species; for example maple and red alder prefer the forest floor over rotten wood for regeneration (McGee et al., 1997). Some species have special substrate requirements. For example, a study in Japan shows that small-diameter (<20cm) logs are not suitable habitat for *Picea* spp. (Narukawa et al., 2003)

In terms of log substrate difference, *Picea sitchensis*, *Tusga heterophyla* and *Pseudotsuga menziesii* logs were compared in Harmon's study (1989 Jan.). Bark fragmentation rate was highest for *Tsuga heterophyla*, and slowest for *Pseudotsuga menziesii*. This is probably because the heartwood of *Pseudotsuga* contains fungi-toxic compounds which slow down the decay rate (Scheffer and Cowling, 1966). This delay of bark fragmentation may improve germination rate and reduce the mortality of tree seedlings at the early stage compared with the other two species. Correspondingly, bryophytes cover 85% of *Pseudotsuga* log surface at year 19, compared with 11 to 13 years for *Tsuga heterophylla* and *Picea sitchensis* (Harmon, 1989). *Tsuga heterophylla* logs are generally nutrient poor and its seedlings usually establish on *Pseudotsuga menziesii* logs in decay class III (Minore, 1972; Christy et al, 1984). Different log species also have different nutrient contents. *Tusga heterophola* generally has low nutrient content in all elements except calcium. *Picea stichensis* has the highest nutrient content among the three species. However, the differences among them are relatively small compared to the difference with nutrient-rich mineral soil or forest litter (Minore, 1972)

Seed Germination and Rooting

Timing is an important factor for seed to germinate on decayed wood. A good year with ample seed rain is critical for recruitment, independent of the substrate. Because of the low coverage of fallen logs on the forest floor, only 10% of the seeds from seeded trees fall on logs. In compensation, however, 1.3% of the emerging seedlings on logs survive at the end of the first year compared with only 0.02% on soil (Harmon, 1989). Although the establishment rate is still low on rotten logs, with respect to the large amount of seed produced by mature tree species, the number of seedling on rotten wood at germination stand is considerable. The germination rate also varies from season to season. It is substantially affected by the seasonal weather condition of the year and the availability of the substrate (Nash et al, 1995). A study shows that autumn-winter survival rate for *Picea glauca* seedlings is higher on nurse logs than on the forest floor (DeLong et al, 1997).

Successful germination on a fallen log depends on the surface material. Studies show that thin moss or litter layers on logs are the best germination sites for seeds of all species (Santiago, 2000). The density of total seedling biomass increases as the moss biomass increases at the early stage. The coverage of the moss layer on logs increases faster than the depth of the moss layer (Harmon, 1989). Therefore, a thin moss layer can quickly cover the log and creates suitable environment for seed to germinate. Compared with bare wood surface, moss and duff layers on logs provide better retention for seeds, especially for smaller seeds like *Tsuga* spp. A rough but soft mossy surface can protect seeds from windblown, rain splash and predation. The extra duff layer on top can add more nutrients for seeds. A bare wood surface without moss may also provide chances for seed to germinate through tree holes and crevices on the bark which could retain certain moisture content (Zielonka, 2006). Harmon's study (1989) showed that the chance of seed germination improved as the depth and angle of holes and crevices from the vertical increase and as width decreases. A shallow hole was less effective in terms of retaining seeds regardless of the width of the hole or crack.

As seeds germinate, the radical penetrates the soil or alternative substrate and starts to establish. Soil physical characteristics are more important than nutrient availability at the establishment stage (Milthorpe and Moorby, 1974). Penetration resistance is mainly affected by bulk density, aggregate size and water potential of the substrate (Nash et al, 1995; Lindstrom et al, 1974). Increasing bulk density will result in decrease in void space within the substrate, therefore reducing the oxygen and water trapped in the substrate. Aggregate geometric diameter (i.e. aggregate size) could be reduce by increasing soil bulk density, however, it only plays a small role compared with bulk density, which may permanently shut down rooting activity when the density is too high (Nash et al, 1995). Appropriate water potential within a range is also critical for root elongation (Lindstrom et al 1974). In the case of seed germination on rotten logs, the moss layer provides an ideal environment for rooting because of its low bulk density and porous structure, which retain moisture and warm air. The thickness of the moss layer only affects penetration speed and seed can eventually penetrate the moss layer to reach rotten logs (Harmon, 1989).

What factors affect seedling survival rate and further development?

Available resources and ideal microclimate make CWD an excellent substrate for seedling growth. Although seedling establishment and short-term survival rate are higher on nurse logs than on other substrates, long-term seedling survival rate is ambiguous. Many studies indicate a lack of saplings and mature trees regenerated on nurse log (Harmon et al, 1989; Gary et al, 1997; Minore, 1972; Szewczyk et al, 1996). Bark fragmentation, nutrient limits and competition may be the leading factors to explain the seedling decline at late growing stages.

Physical Factors

As mentioned before, bark fragmentation is an important process for most fallen logs. Seedlings may slough off during this process if they haven’t developed a strong root system. Associated moss layers will also be lost during this process. However, after the bark fragmentation, a new moss layer can quickly establish itself again on the bare wood surface and a second peak of seedling density on the log may appear. The bark fragmentation of *Pseudotusga menziesii* is delayed to coincident with the self-thinning process of seedlings on decayed wood; therefore it has a minimal impact on the seedling density growing on it. Another physical factor affecting the survival rate is toppling from the logs. As seedlings grow into saplings and young trees, log geometry can’t accommodate the expansion of seedling root system and the rapid increase of seedling weight. Therefore, toppling off is commonplace if the root of the seedling has not yet reached the mineral soil beneath the logs (McGee et al, 1997). Also, whether a seedling growing on rotten logs can reach a mature stage is also affected by the degree of decay when the seedling establishes. If the rotten log is already in an advanced decay stage and starting to fall apart, the chance of toppling off is high since the seedling may not have enough time to develop a strong root system to anchor into the soil before the substrate disintegrates and disappears (Lemon, 1945). However, seedlings may recover after they fall off the logs if the surrounding soil substrate is still suitable for them to re-establish. (Harmon et al, 1989; Zieloka, 2006)

Ecological Factors

Tree Canopy and light

The tree canopy affects seedling survival on rotten logs in two different ways: litter fall and crown closure. Although nurse logs have advantages in litter shedding, the advantage is not absolute. In aspen stands, conifer seedlings growing on both forest floors and nurse logs tend to be smothered by the large leaf surface and synchronized leaf fall in the autumn. However, seedlings on nurse logs have a fast growth rate in the spring because of high light penetration before new leaves grow (Simard et al., 2003). In conifer stands, *Thuja plicata* needles contain toxic compounds which may retard seedling growth on all kinds of substrates under the canopy (Strobel et al, 2005). Crown closure changes the light availability reaching the ground. Studies found that reducing the light level more than 25% can significantly impair the survival rate of young seedlings regardless of nutrients and microclimate (Harmon 1989 Jan.). A similar study found that the survival rate peaked at 70%-80% crown closure and growth rate declined when crown closure is above or below this range (Harmon, 1987). In Pacific Northwest mature forest, canopy closure is usually around 80%, thus regeneration on nurse logs could have great importance since it stands a better chance to capture more light on the elevated surface. Similar results can be found in literature: among the canopy shading test for different regeneration substrates, the advantage of decayed wood substrate over other substrates was maximized at the closed-canopy stage (Gary et al, 1997).

The actual level of light that reaches the surface of nurse logs can be further reduced by moss cover (Harmon, 1989). One strategy for seeds to overcome the further light reduction is to have cotyledons embedded within the moss layer instead of the decayed wood below. Studies found it was root length instead of substrate that was significantly affected by shade; therefore, receiving enough light to support root growth in order to reach the nutrient is critical for seedling survival. Substrates mainly affected seedling height (Minore, 1972).

Moisture and temperature

Moisture condition is another important factor for seedling survival, and it is strongly related to temperature. Decayed wood performs better in moisture retention compared with litter and organic soil (Bulmer et al, 2007). As wood density decreases, the area to volume ratio grows and the opening of tracheids forms a capillary system that substantially increases the water holding capacity of logs (Käärik 1974; Sollins et al. 1987). Small-seeded species (e.g. *Picea glauca, Tusga heterophylla*) contain fewer nutrients and tend to develop small radicals; therefore, they prefer a substrate with high moisture content (Korstain, 1937). The litter layer on the forest floor tends to dry fast in hot weather condition and the moisture level is always fluctuating which makes it difficult for seedlings to adapt to and survive at a young age (Minore, 1972). A scientific experiment found that there was no difference in seedling survival between wood and litter substrates in greenhouse conditions where moisture level remained high (Gary et al, 1997). Mineral soil also has stable moisture content, but it is less abundant in forest compared to CWD except after a disturbance event.

Summer heat and drought is another factor which kills young seedlings in the Pacific Northwest. With large canopy openness, the ground temperature can be as high as 50°C which is high enough to cause direct damage to seedlings (Gary et al, 1997). Decayed wood not only has a lower surface temperature but also provide a shady microsite to prevent substrates from dying out (Gary et al, 1997).

Competition

One of the most obvious advantages of regeneration on decayed wood is that there is little competition with vegetation on the ground. Both above-ground and below-ground competitions affect seedling growth. The belowground competition mainly relates to root development. Studies show that naturally occurring logs in gaps were relatively less occupied by roots compared to soil in the gaps (Zielonka, 2006). In terms of above-ground competition, the dense moss and shrub layer on forest floor can easily outcompetes young seedlings during establishment stage, whereas the competition on logs is minimal. Therefore, nurse logs provide a unique niche for seedling development. However, competition among established seedlings with newly arrived seedlings, moss and other vegetations on logs may be unavoidable at the late growth stage, especially for nutrients. On decayed wood, seedlings are usually less shaded by ground vegetation and can obtain enough resources for seedling growth. Studies found that moss mat should be thinner than 5 cm in order to not disturb seedling growth (Harmon et al, 1989). A thick moss layer competes for nutrients from precipitation, dust and rain splash with seedlings and it dries out quickly in the hot summer.

Physiological Factors

Nutrient dynamics

Decayed wood is considered relatively nutrient poor compared with mineral soil and litter. This is one of most significant factors restricting seedling growth. Many studies show that although seedling establishment is better on decayed wood than on the forest floor, there is lack of mature trees developed from decayed wood compared with the forest floor (Zielonka, 2006). And also, the biggest and heaviest seedlings are always found on litter or mineral soil instead of rotten wood regardless of the seedling age (Szewczyk et al, 1996). Nutrient limitation may be an explanatory factor in this observation. Whether a seedling can grow into a mature tree may depend on the success of root development into mineral soil beneath the log to reach more available nutrients. Therefore, some studies suggest that small logs may provide a better chance for advanced seedling growth (Narukawa et al, 2003). However, large logs with moss layers may provide more stable surface area for seedling establishment (McGee et al, 1997).

Nutrient dynamics is very complex in CWD, however, compared with other nutrient pools; it only contributes 5% of N and P nutrient release to the soil, which is insignificant (Laiho et al, 1999). Despite of this, CWD still plays an important role in nutrient exchange between seedlings and soil substrate. Unfortunately, there are few studies available to neither quantify the original nutrient level within the wood at the beginning of decomposition nor trace the nutrient flow from CWD to users (Scott et al, 2001). Both vegetation and wood decay fungi are potential competitors for the nutrients. Potential inputs of nutrients in CWD include precipitation, litter fall, root ingrowths, animal input, fungal translocation and nitrogen fixation (Solins et al, 1987). The nutrient loss pathway could include leaching, animal transfer, fungal translocation, and plant uptake. Fungal translocation can import or export nutrients from the soil to CWD or the other way around (Scott et al, 2001). The nutrient level fluctuates by log species and nutrient elements.

Nitrogen is considered the most limiting nutrient for seedling growth. Some studies indicate an increase in nitrogen content in the CWD (Aumen et al, 1990; Laiho et al, 2004). This could be achieved through nitrogen immobilization and nitrogen fixation etc., although the impact of the latter is small compared with the former mechanism (Zimmerman et al, 1995). Another advantage for decayed wood in terms of increasing nitrogen level comes from its chemical properties. Lignin in wood remains polymerized through decay and can act as a binding agent for phenolics which are found to deplete available nitrogen by binding proteins, amino acids and ammonium. Except for this indirect way to increase the nitrogen level, decaying wood also shows a strong chemical affinity to nitrogenous compounds (Ponge et al, 1998). Although the nitrogen level increases within decayed wood, how much available nitrogen can be used by seedling growth is more important to us rather than the overall level. Nitrogen consumption by microbes is related to decomposition rate. To degrade the C in a log, they must maintain a certain C: N ratio to produce hydrolytic enzymes.

Another interesting finding from research indicates that nutrient flow is also related to the original nutrient level with in the log. For example, *Picea sitchensis* is originally rich in N and P, therefore the of N and P content in the log is almost stable, whereas pine and fir logs showing an increased N and P level because of the low starting point at the beginning (Raija et al, 1999).

The role of Soil Microbes

Soil microbes can affect seedling growth in positively and negatively ways. One positive effect comes from mycorrhizal fungi (McGee et al, 1997). It is found that decayed wood is a favorable spot for mycorrhizal fungi because of its high moisture content during the summer (Kropp, 1982). The suitable environment on rotten logs makes occupation very fast and efficient. Seedling growth can benefit from the mycorrhizal fungi through nutrient and chemical transport by fungi hyphae.

Also, wood decay fungi degrade lignin and cellulose into small compounds for plant uptake. Except providing food sources for seedlings, the decayed log also serves as a refugee for fungal pathogens. Both damp-off and opportunistic soil fungi were reported less in decayed wood which were nutrient poor and less chemically reactive (O'Hanlon-Manners, 2004). A pathogenicity test of ungerminated *Picea engelmannii* and *Abies lasiocarpa* seeds suggested a casual relationship between black mold and the low survival rate on forest floors during winter (Zhong et al. 1999). Only a few fungi species can break down cellulose and lignin. Most of them are saprotrophic and play little impact on growing seedlings. As wood decay proceeds, more nutrients are available for plant uptake. In advanced decay stages (Class 4 and 5), wood substrate is very similar to mull humus and considered ideal substitute for fine soil (Ponge et al, 1998).

However, the beneficial mechanisms of soil microbes are only important when logs are initially in contact with soil instead of being completely suspended (Zimmerman et al, 1995). Perched logs will lose many important pathways of nutrient flow and chemical exchange. Although, decayed wood is a safe place for seedling to grow, there is also some negative impact from the decay process. Competition for available nutrients and nutrients immobilization by soil microbes could both negatively affect seedling growth. One study found that some free-living saprotrophic decay fungi were present in the root system of healthy conifer seedlings. Although no direct damage can be observed, there is a potential threat to retard seedling growth (Vasiliauskas et al, 2007). Brown-rot fungi damage the wood cell structure dramatically. The decay process may soften the substrate for root penetration, but also, add structural instability to young seedling growth.

Discussion

Limitation in Scientific Study

Most of the scientific studies on this topic are at the stage of describing the phenomenon instead of exploring the mechanisms of the natural regeneration pattern. Many experiments were conducted to verify the already-noticed high establishment and survival rate of regeneration on nurse logs, whereas few studies examined the ecological and physiological mechanisms involved in this process thoroughly. Comparative studies of different gap sizes, moisture and temperature regimes associated with natural regeneration on nurse logs are more frequently found and tend to be more easily monitored than nutrient flow, wood decay process and soil microbes which are invisible and hard to detect (Herrmann, et al, 2008) Therefore, more studies are to be expected to discuss the physiological factors affecting the process.

Among descriptive studies on seedling establishment and survival rate, different study methods may have implications at different levels. The basic level refers to studies focusing on basal area of available downed wood, decay class distribution, and seedling density on decayed wood by species (McGee et al, 1997, Szewczyk et al, 1996; Christy et al, 1984). The results from these studies establish the basic understanding that logs in certain decay classes provide a better substrate for certain species to establish compared with other substrates. The second level includes studies discussing seedling height, root length, microclimate and tree canopy (Gary et al, 1997; Simard et al, 2003, Weaver et al, 2009). These studies connect the regeneration pattern with available resources (i.e. light, moisture, and nutrient) and favorable environment (i.e. seed retention, competition). The third level of studies portrays the regeneration pattern from the perspective of stand development and forest dynamics. Zielonka's study in 2006 used the age structure of seedling regeneration growing on cross-dated logs to retrospect of the colonization occurring over the past few decades. The effect of historical natural disturbance, seed rain fluctuation and stand development on seedling growth can be examined. In general, future studies should address this natural phenomenon from both temporal and spatial standpoints.

Also, long-term studies should be established to monitor stand development, nutrient dynamics and the performance of seedling growth on rotten logs in a whole life cycle. In this way, a more accurate understanding of this regeneration pattern can be achieved. For example, in order to answer the question why there is few saplings or mature trees generated on nurse logs, a long-term observation could be able to demonstrate whether the old seedlings are replace by a new cohort of seedlings regularly or the seedlings have already reached maturity but have been growing at a very slow growth rate caused by nutrient limitation. Also, mature trees may develop from a log substrate which is no longer identifiable. These uncertainties could be addressed by establishing permanent research plots.

Recommendation on forest management

The study of natural regeneration on rotten logs sheds light on forest management strategies. First of all, a certain amount of CWD should be maintained on the ground to diversify natural regeneration patterns and provide establishment substrate for certain conifer species. Enough standing dead trees should be maintained to ensure enough input of CWD in future stands. CWD also provides wildlife habitats to many species and enhances ecosystem integrity since they are an important component of the forest ecosystem. Secondly, harvesting methods may affect the effectiveness of this regeneration pattern. Clear cutting exposes regeneration into full light condition under which the advantage of regeneration on nurse log is absent (Weaver et al, 2009). A gap disturbance is proved to be most effective for regeneration on CWD. Therefore, shelterwood system and partial cutting could be suggested based on this perspective. Thirdly, artificial regeneration on nurse logs can simulate the natural process. Therefore, CWD can be used as a microsite option for seedling establishment in tree planting activities.

Other opportunities beyond the forest sector may also be explored. Fine decayed wood provides a good substrate for agricultural and gardening uses. The optimal moisture content and available nutrients from advanced decomposition could make it a hospitable substrate for plant and crop growth. One study found that oxidation-reduction potentials (Eh) of wood substrate were even higher than soil horizons (Santiago, 2000). Substantial Carbon stock in Coarse Woody Debris may indicate an opportunity to reserve the carbon stocks in them rather than slash burning (Harmon et al, 1991). Rapid development of bio-fuel production may also provide alternatives to make a good use of them. One approach is to produce a liquid fuel by enzymatically hydrolyzing carbohydrate polymers in biomass to sugars and fermenting them to ethanol (Wilson, 2009). Similar studies are currently being conducted in many institutes.

Conclusion

This essay examines natural regeneration pattern on decayed wood to illustrate the competitive advantage of this process compared with common regeneration pattern on forest floors and soil.

Both substrates and microsite provide good chances for seedling establishment and immediate growth. However, long-term, experimental research is needed to understand the interaction of seedling growth with temporal and spatial change of environment and substrates. Advises on forest management activities can be drawn upon this essay and alternative future opportunities of utilizing coarse woody debris includes agriculture seedbed, carbon storage and biofuel production etc.

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