Tree thinning for the restoration of the Fuelwood Forest in the Chrystal Creek watershed

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Table of contents

Abstract

A small early successional forest, known colloquially as the “Fuelwood Forest,” and located at the north reach of the Crystal Creek watershed, has been identified by the Galiano Conservancy Association as requiring restoration. Our project examines the history, ecological conditions, and potential restoration options for this site. Presently, the Fuelwood Forest consists almost entirely of Douglas fir (*Pseudotsuga menziesii*) trees of similar sizes and ages (approximately 60 years old) with compacted soils and invasive grasses which restrict the growth of other species, leading to very little diversity or ecological value in the site. In order to determine a restoration strategy for this ecosystem, we first determined what the historic conditions and community composition may have been at this site prior to human disturbance. We assessed the soil moisture regimes (SMR) and soil nutrient regimes (SNR) of soil pits dug on site and concluded that this area is characteristic of the CDFmm (moist maritime coastal Douglas fir zone) site series. Using this information, we can determine what type of species may have been located in the Fuelwood Forest pre-disturbance. This information paints an image of the site’s history and allows us to determine what type of ecosystem we should be restoring the Fuelwood Forest to. We also observed historical imagery to make predictions about the Fuelwood Forest’s current composition. Because of the lack of diversity within the Fuelwood Forest, prescribed tree thinning should take place in order to accelerate forest succession, increase vegetative diversity and improve the resilience of the site. Studies have shown that prescribed thinning of forests can positively contribute to the output of a watershed (Dan Keppen, 2020; Saska et al., 2017) and aid in the growth of trees, accelerating ecological succession (Kuehne et al., 2015; Plummer et al., 2012) along with numerous other benefits. During our site analysis, we observed the slope, tree diameters and species present in six sample plots. We found that currently, there are about 597 Douglas fir stems per hectare within the Fuelwood Forest. This is high compared to the average mature Douglas fir forest which has a density of only about 246 Douglas fir stems per hectare with approximately 3-9m between trees (Heritage Forest, 2013; American Forest Foundation, n.d.). So, in order for this plot to better represent the historical reference ecosystem, we propose that the density of Douglas fir trees is reduced by 58.8%. While some trees will have to be removed using other methods, approximately 40% of the trees on the site are small enough to be felled using a pulley system which mimics natural processes, limits the use of fossil fuels, and makes the restoration process less invasive.

1.0 Introduction

1.1 Site description and overview:

Situated on the traditional territories of the Penelakut, Lamalcha, Hwlitsum, and Tsawwassen First Nations, Galiano is a long, narrow island located within the southern Gulf Islands in the Strait of Georgia, off the east coast of Vancouver Island. It is within the coastal Douglas-fir (CDF) biogeoclimatic zone and exhibits a Mediterranean climate with warm, dry summers and rainy winters (Eco-Action Proposal, n.d.; Hamann-Benoit, 2014). Our project area can be found on the property of the Millard Learning Center, a 76 hectare property containing built infrastructure, a road and path network, food and forage forests, two seasonal creeks, and over 32 hectares of mature forest (MLC website, n.d). More specifically, our project site is located within the 28 hectare Chrystal Creek watershed, which includes a gradually-sloping valley between sandstone ridges and drains into Chrystal Cove (see *figure 1*) before emptying into the Trincomali Channel (Eco-Action Proposal, n.d.). This watershed presents an interesting restoration opportunity because it is located entirely on the property of the Millard Learning Center, therefore, they have full control over it and can monitor and regulate activities, events and processes that take place within it.

This restoration project is set to take place in the Fuelwood Forest: a one hectare wooded area in the upper part of the Chrystal Creek watershed. Its position is described on the map below (*figure 1*). The Fuelwood Forest has some unusual characteristics. Pictured on the map in figure 2 below, the larger more southerly situated area highlighted in red has relatively low diversity and is almost entirely composed of evenly aged Douglas fir (*Pseudotsuga menziesii*) trees. Below the canopy of Douglas fir trees, there are few species in the understory, shrub and herbaceous layers. There is a lot of grass growing in the area though, and many of the grass species are non-native and reflective of a dry environment. This low-diversity strip will be the main target for restoration efforts. Running alongside this strip and highlighted in orange in figure 2 below is a relatively higher diversity stand which much more closely represents a more typical coastal Douglas fir forest on Galiano Island at this seral stage. Despite being immediately beside the low-diversity strip of forest, this slightly depressed area of the site has much more moisture in its soils, supporting a fairly dense undergrowth of salal (*Gaultheria shallon*), sword fern (*Polystichum munitum*), bracken fern (*Pteridium* species) and other shrub and herbaceous species. It also has many western redcedar (*Thuja plicata*) and red alder (*Alnus rubra*) trees of various sizes and ages.

It is possible that soil compaction caused by previous logging and agriculture in the low-diversity part of the site is responsible for the abrupt and drastic change in the forest structure between the two forest strips. Compacted soil can hinder the growth of understory and shrub species and restrict the movement of water into the soils, which instead runs off into the high-diversity site (Ahmed *et al.,* 2004). Furthermore, hyperabundant deer have been identified as a concern on Galiano Island as they can prevent some species from growing beneath the canopy due to high levels of herbivory. This combined with the compacted soils makes it difficult for understory, shrub or herbaceous species to be established.

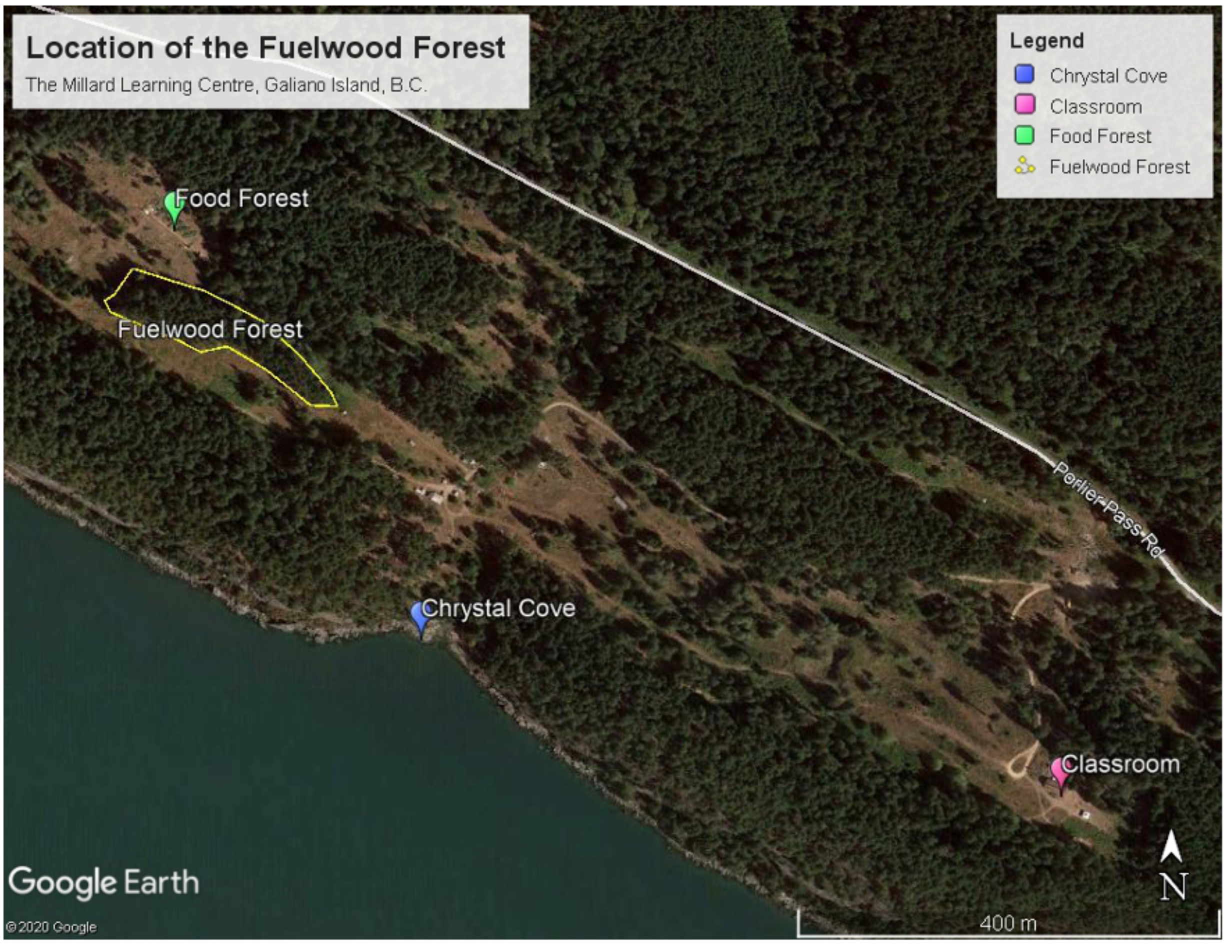

Figure 1: A map of the Millard Learning Centre on Galiano Island, including the location of the Fuelwood Forest, which is outlined in yellow (Google, 2020).

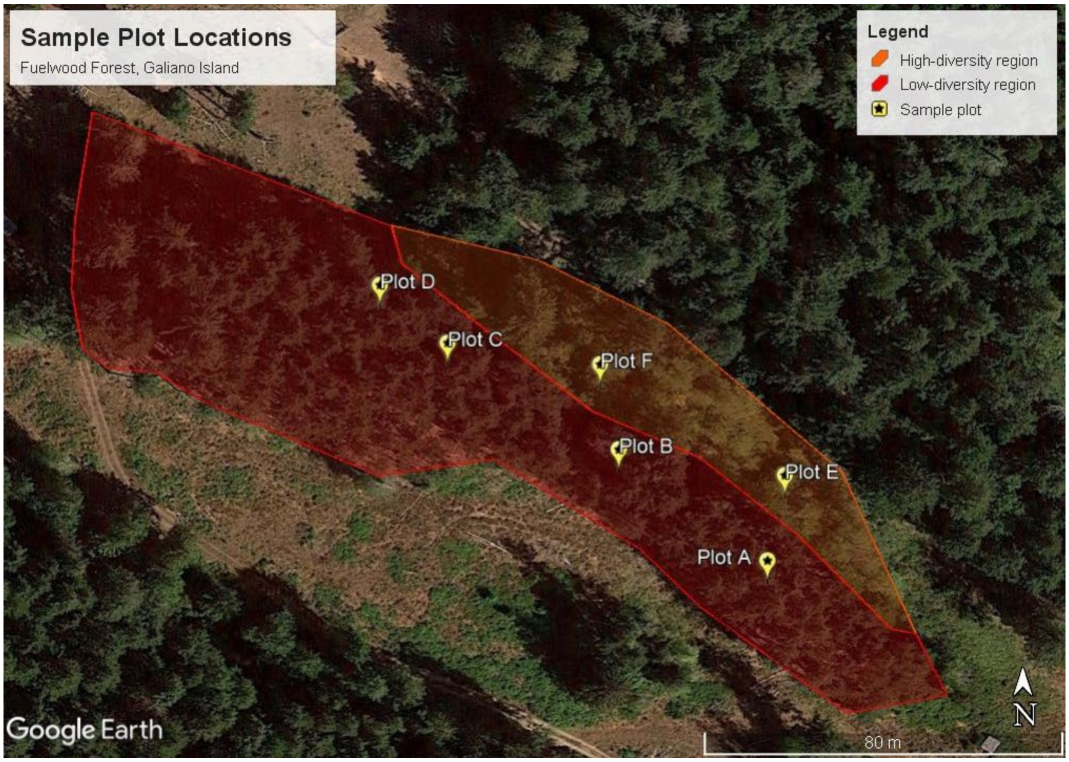

Figure 2: A map of the Fuelwood Forest site. The more southerly situated area highlighted in red is of very low diversity, while the more northerly situated site highlighted in orange has a higher level of diversity (Google, 2020).

1.2 Site history

Little information has been documented about the history of the Fuelwood Forest, making determining a historical reference challenging. The land on which it is situated has changed owners several times over the past decades. Each owner added roads, structures, and fencing, and used the land for various purposes including logging and small-scale agriculture. A set of aerial survey images spanning from 1930 to 2013 show changes in forest cover on our site over that time. Figures can be seen in appendix 3 of this report. In 1930 (figure 3), the area currently referred to as the Fuelwood Forest was open and had an absence of trees. We can infer that this is because it had previously been cleared and was used as an agricultural site at the time. In 1962 (figure 4), there was some infilling of trees in the plot. Trees continued to encroach the site and, by 1972, it was nearly completely forested (figure 5). This trend continued until 2002 (figure 6), when many of the trees disappeared because the land was being used for forestry at that time. A section of trees in this area was left behind by the loggers and is now known as the Fuelwood Forest. With this information, supported by previous studies and our analysis of core samples from some Fuelwood Forest trees, we can estimate that the forest is about 58 years old.

To further our knowledge of the site's history, soil pits were dug in order to analyze the soil stratification, structure, and composition. Results indicated that the Fuelwood Forest has a rich to very rich (R-VR) soil nutrient regime (SNR), 5-7f soil moisture regime (SMR), and therefore falls into the moist maritime coastal Douglas fir (CDFmm) biogeoclimatic subzone. This indicates that the Fuelwood Forest had likely consisted of species characteristic of the CDFmm biogeoclimatic subzone in the past .

The trees in the Fuelwood Forest are of similar sizes and ages, are almost all the same species, and they are densely spread across the site. This makes us suspect that they may have been intentionally planted, perhaps with the intent of later being logged and sold. Alternatively, once the site was abandoned and no longer being tended to or used for agriculture, trees suddenly began encroaching on the site simply because they suddenly had the opportunity to do so, again resulting in a low diversity of ages and sizes. Either way, the resulting forest now suffers from compacted soils, low levels of coarse woody debris, and low diversity, all of which contribute to a poorly functioning forest ecosystem that does not support the Chrystal Creek watershed. Due to large amounts of human disturbance in its past, intense browsing from hyperabundant deer, and tough understory competition with densely growing invasive velvet grass, the Fuelwood Forest has been unable to recover naturally (Doyle-Yamaguchi, 2016). To design a restoration project well suited to this site, we can compare the historical information that we have gathered to the current state of the Fuelwood Forest.

1.3 The problem

As mentioned above, years of anthropogenic disturbances in the Chrystal Creek watershed have resulted in low biodiversity. Logging, agriculture, and the creation of roads by previous landowners have resulted in compacted soils, and drainage ditches have disrupted natural moisture regimes and runoff. There is very little coarse woody debris to contribute to the soil, and the site has relatively little microtopography. Dominated by similarly-aged, densely growing Douglas fir trees, the Fuelwood Forest does not support interspecific or intraspecific diversity. The loss of biodiversity in an ecosystem has various negative implications, including the loss of resilience. Resilience refers to an ecosystem's ability to recover from external threats, including major disturbance events such as storms and climate change (Hill, 2016). In other words, healthy forests have groups of species that perform essential functions; a high diversity of these species allows ecosystems to be resilient to disturbances because it creates a redundancy of functions. This allows ecosystems to recover more rapidly after a disturbance event because some species with similar functions may withstand some disturbances better than others (Thompson, 2011).

1.4 Why thin a forest

There are many reasons why thinning the trees in the Fuelwood Forest would be a beneficial restoration tactic to improve the functioning of the Chrystal Creek watershed. First, forest thinning helps to drive the ecosystem towards late-successional functioning more quickly (Kuehne *et al.*, 2015; Plummer *et al.,* 2012). In a study by Plummer and colleagues (2012), thinned stands of young redwood and Douglas fir displayed improved tree vigor, growth (both radially and in height), and stability which helps to improve the stand's response to future restoration efforts. Thinning also helps to improve the growth of understory species and improves recruitment of new trees by allowing more sunlight into the system and improving soil quality (Bailey and Tappeiner, 1998).

Removing trees from a dense forest can also help increase densities of small mammals in the treated areas, especially if you retain the woody debris generated in the process (Converse *et al*., 2006). Forest thinning can also increase soil respiration rate by 43% in mixed-conifer forests due to altered microclimate and the increased woody debris, which is indicative that soil microbe diversity has been improved (Concilio *et al.,* 2005). We also expect that the action of pulling over some trees should work to de-compact the soil in the thinned area and create some microtopography as the roots rip up to disturb the soil. Leaving behind some of the stems and woody debris created through thinning should also help the soil to recover and provide improved habitat.

Thinning the Fuelwood Forest could also be helpful in contributing to the restoration of the Chrystal Creek watershed as a whole by improving water flow and water quality downstream. According to Dan Keppen (August 19, 2020), forested areas in upper watersheds that received prescribed thinning to reduce wildfire risk saw substantial increases in streamflow and water availability. Similarly, a study by Saska and colleagues (2017) found that prescribed thinning in the forested headwaters of central Sierra Nevada increased the mean-annual runoff by 14%.

With the effects of climate change, it is more important than ever to restore and protect our ecosystems. As the summers on Galiano Island become increasingly warm and dry, it is essential for the Chrystal Creek watershed's hydrology to be restored in order to improve the resilience of native ecosystems, and their ability to withstand the changes that climate change will bring.

In order to gain a better understanding of the site's history and to determine a historical reference system for our restoration project, data was collected from six sample plots created in the Fuelwood Forest. This information was then used to make suggestions for restoration efforts, mainly the thinning of trees in order to create spaces for other species to grow and therefore increase biodiversity.

2.0 Goals and objectives

Objective 1: Describe a historical reference ecosystem for the Fuelwood Forest.

- Document the soil nutrient regimes (SNR) and soil moisture regimes (SMR) of soils in sample plots within the fuelwood forest. Using this information and a field guide for site identification, determine the biogeoclimatic zone associated with the soil type and the recommended species for this zone.

Objective 2: Improve the composition, structure, and function of the Fuelwood Forest, using the biogeoclimatic zone determined in objective 1 as a reference ecosystem.

a) Determine how many Douglas fir trees should be removed from the Fuelwood Forest.
  - Estimate the present tree-density by counting the number of trees in sample plots and calculating the tree density of those plots.
  - Review literature, including past projects on the Fuelwood Forest, to determine the target density and spacing of Douglas fir trees based on the reference ecosystem.
  - Calculate how many trees should be removed based on the current versus target density and spacing of trees.

b) Provide recommendations on tree removal techniques (falling, girdling, pulling over).
  - Measure the diameters of a sample of trees.
  - Estimate what the maximum diameter and height of trees are that the pulley system can be safely used for.
  - Use this information to determine how many trees the pulley system should be used on. Remaining trees can be removed through girdling.

c) Make recommendations for the use of the wood removed from the Fuelwood Forest.
  - Determine whether selling some of the wood as firewood is feasible by answering the following questions:
    - Is there a need for firewood on Galiano Island?
    - Is there a cost-benefit to selling the wood?
    - Is the wood in reasonable condition to be sold as firewood?
  - Make recommendations for leaving woody debris, including some chipped and some more whole material on the forest floor in order to increase soil nutrient levels and provide habitats for other species.

d) Make recommendations for further projects, including the potential for planting understory species and excluding deer from the space in order to allow these understory species to be successfully established.

3.0 Methods:

3.1 Site Assessment

On November 10th, 2020, an assessment was made of the Fuelwood Forest site. In order to gain an understanding of the Fuelwood Forest's composition while capitalising on the few hours that we had to analyse the site, six circular plots within the forest – each with a 10 meter radius – were randomly selected to be analysed. Four of the plots (plots A, B, C and D) are in the low-diversity region of the forest while the fifth and sixth plots (plots E and F) are in the higher-diversity section of forest. See figure 2 for the locations of these sample sites.

For each circular plot, the North, East, South, and Western points were marked with pink flagging tape. Then, the slope and aspect were found using a clinometer and compass, respectively. Next, observations were recorded about the percent cover and species present in each layer of the forest: the canopy, understory, shrub, herbaceous and grass/sedge layers (see appendix 1 for results).

In the center of each plot, a soil pit was dug in order to analyze the composition, nutrient and moisture regimes, and stratification of the soil layers. Adam Huggins, Restoration Coordinator for the GCA, joined us and loaned his expertise. We followed various procedures including the graininess test, moist cast test, stickiness test and worm test in order to determine the soil nutrient regimes (SNR) and soil moisture regimes (SMR) of each plot (see appendix 1 for results).

The distance from each tree to the centre pit was measured clockwise around the circular plot starting in the North, along with compass coordinates in order to distinguish the location of each of the trees for our data. The diameter at breast height (DBH) was then found using DBH tape for all Douglas fir trees in each plot (see Appendix 2 for data).

One or two trees close to the center of each plot were flagged using blue flagging tape and cored using an increment borer. To estimate tree ages, the rings from the removed sections of the trees were counted by at least two people. Both the lowest and highest number of rings was recorded for each tree, giving us a range of possible tree ages. The heights of the flagged trees were also found using a clinometer and basic trigonometry.

3.2 Determining the historical reference ecosystem

In order to determine a historical reference ecosystem to use in the site's restoration, we analysed the soil information found during the site assessment. Using "A Field Guide for Site Identification and Interpretation for the Vancouver Forest Region: Land Management Handbook Number 28" (Green and Klinka, 1994), the SNR and SMR were coss-referenced to determine which biogeoclimatic zone and site series the soil is representative of, as well as what species were likely found in the Fuelwood Forest in the past. This provides us with a historical reference and determines the type of ecosystem that the Fuelwood Forest should be restored to.

We also analysed historical aerial imagery of the site to gain a better understanding of its history. We first identified the current location of the Fuelwood forest in images from various years. Then, we observed and recorded the differences to this area in each of the photos. We made predictions about what may have happened based on these observations.

3.3 Treatment planning

In order to determine how many trees should be removed from the Fuelwood Forest, we calculated the area and average number of trees per plot. We used those values to calculate the number of trees per hectare, or tree density. The tree density was then compared to the target number of Douglas fir trees expected to be found in our mature Douglas fir forest reference ecosystem.

In order to determine how many trees could be removed with the pulley system, we compared the DBH of the trees found during the site assessment to the maximum diameter that the system can be used on, as indicated by Scholz and colleagues in "Restoring the Forest in a Young Coastal Douglas-fir Plantation" (2004).

4.0 Results

4.1 Biogeoclimatic zone and recommended species

Site category (for entire site): Moist Maritime Coastal Douglas-fir Subzone (CDFmm)

Site Series:

Plot	Site Series - CDFmm
A	12 - CwBg Vanilla Leaf
B	12 - CwBg Vanilla Leaf
C	12 - CwBg Vanilla Leaf
D	06 - CwBg Foamflower
E	14 - Cw Slough Sedge
F	12 - CwBg Vanilla Leaf

Table 1: Site series for each plot assessed.

For specific species recommendations for each site series, refer to table 1 and Green and Klinka (1994). For a list of species currently present in each layer of the forest for each sample plot, see appendix 1.

4.2 Treatment planning

For diameter and location data of each tree within the sample plots observed, see appendix 2.

Plots A, B, C and D (low diversity region):

	Plot A	Plot B	Plot C	Plot D	Average
Average tree diameter at breast height (DBH)	36.6cm	29.8cm	35.5cm	35.8cm	35.2cm
Number of trees with DBH less than 30cm (can be felled with pulley system)	5	12	7	6	7.5
Proportion of trees small enough to fell with pulley system	25%	70.6%	30.4%	40%	40%

Number of trees larger than 30cm (cannot be felled with pulley system)	15	5	16	9	11.25
Proportion of trees too large to fell with pulley system	75%	29.4%	69.6%	60%	60%
Number of trees in plot	20	17	23	15	18.8
Plot area	314.16m^2	314.16m^2	314.16m^2	314.16m^2	314.16m^2
Tree density (trees per hectare)	636.6	541.1	732.1	477.5	596.8
Range of age estimates of cored tree(s)	58-64	53	58-60	56	53-64
Average tree age estimation	61	53	59	56	58.3

Table 2: Tree diameter, density and age data used for treatment planning in the low diversity region of the Fuelwood Forest.

Plots E and F (high diversity strip):

	Plot E	**Plot F**	**Average**
Average tree diameter at breast height (DBH)	30.6	20.4	25.37
Total number of trees in plot	16	17	16.5
Plot area	314.16m^2	314.16m^2	314.16m^2
Tree density (trees per hectare)	509.3	541.1	525.2

Table 3: Tree diameter and density data for the high diversity region of the forest.

5.0 Discussion:

5.1 Historical reference

Using the data collected during the site assessment, we were able to build an understanding of the Fuelwood Forest's past. By coring trees in the low-diversity region, we found that their ages range from 53 to 64, with an average age of 58.3 years. Note that the tree rings were close together and often difficult to count, so there may be slight discrepancies between our estimates and the actual tree ages, especially in the predicted range of tree ages. Nevertheless, we can use this data to predict that the forest is about 58 years old.

The soil samples collected did not reflect the type of vegetation that was currently present on site, especially in the low-diversity section of the Fuelwood Forest. The soils are indicative of the Moist Maritime Coastal Douglas fir (CDFmm) biogeoclimatic subzone, and so likely once had a vegetation community composition typical of that zone. More specific site series were also found for each sample plot (see table 1), which indicate more specifically which species may have been found there in the past. Given this information, we now have a historical reference ecosystem – a target that can be used for ecological restoration. Douglas fir forests on the Gulf Islands that are also part of the CDFmm biogeoclimatic subzone will be used as a historic reference to guide our restorative actions, and give us an image to strive towards.

Using estimated tree ages and aerial imagery, we can make predictions as to why the Fuelwood Forest does not currently resemble a typical forest in the CDFmm biogeoclimatic subzone. Two possible hypotheses could explain the current high-density and low-diversity composition of this forest:

(1) These trees were intentionally planted here about 58 years ago with the intent of producing firewood or lumber. This would explain the relatively low diversity in tree ages and high density of Douglas fir trees, which would not generally occur naturally.

(2) The area was cleared for agriculture then simply revegetated naturally once abandoned. This would explain the slight yet evident variations in tree ages. This second hypothesis is more strongly supported by historical aerial imagery.

Figure 3 (appendix 3) shows that in 1930, the area now known as the Fuelwood Forest was a cleared field without trees. This is our oldest image of the plot, and although we cannot tell for sure, we can predict that this area was cleared for agriculture. In 1962 (see figure 4 in appendix 3), a few trees began to appear scattered across this plot. This may be because it was no longer being used for agriculture, giving way for trees to be established. This was about 58 years ago, which coincides with our estimated average tree age, solidifying our prediction that the forest is about 58 years old. Trees continued to encroach the site and, by 1972, it was nearly completely forested (see figure 5 in appendix 3). This trend continued (see figure 6 in appendix 3) until 2002, when many of the trees were removed because the land was being used for forestry at the time. A section of trees in this area was left behind by the loggers and is now known as the Fuelwood Forest.

5.2 Density and diversity of trees in the Fuelwood Forest

With six red alders, one western redcedar, and 75 Douglas fir trees across the entire 1256.64m^2 of sample plots observed in the low-diversity strip of the Fuelwood Forest (plots A, B, C and D), we can conclude that the density of Douglas fir trees in this area is about 597 stems per hectare. The percent canopy and grass/sedge covers were high for all of these plots, with little to no understory, shrub, or herbaceous covers.

The density of Douglas fir trees in this site is high in comparison to mature Douglas fir forests, which usually only have about 246 stems per hectare (Scholz *et al.,* 2004). This indicates that about 59% of the trees, or about 351 stems should be removed across the entire one hectare site. The more diverse portion of the Fuelwood Forest (plots E and F) has a larger percent cover of understory, shrub, and herbaceous growth compared to the drier, less diverse strip of the Fuelwood Forest. Average DBH of the diverse trees in these plots was found to be 25.4cm, but ranged as high as 76.2cm. See Appendix 1 at the end of the report for the full range of tree DBH. This area also has a smaller stem density of 525.2 trees per hectare. This density is higher than the target of 246 stems per hectare, but still closer than the plots in the low-diversity section of the Fuelwood Forest. Because of its increased diversity and lower density of trees, we can conclude that plots E and F are closer to the reference ecosystem; however, improvements can still be made.

5.3 Tree diameters

Most trees in plots A, B, C and D have a diameter close to 35cm (average DBH). A tree must be less than 30cm to be felled with the pulley system. Only 40% of the trees in these plots meet this criteria, while the other 60% of trees are too large to be felled this way. Other methods will need to be used on larger trees (see *section 6.1 tree removal*).

6.0 Treatment proposal:

6.1 Tree removal

As mentioned above, the removal of Douglas fir trees from the Fuelwood Forest should take place in order to meet the target density of 246 stems per hectare. This will amount to about 59% of the trees being removed in total. The low-diversity section of the forest should be targeted as a priority since it currently has a very high density of Douglas fir trees and very few species in the other forest layers, besides grasses and sedges. Only Douglas fir trees should be pulled, leaving behind all the red alder and western redcedar trees to help improve the diversity of the stand.

In order to minimize negative site impacts and fossil fuel use in the thinning process, as many trees as possible should be felled using a pulley system such as the one described in a 2004 paper by Scholz and colleagues. In summary, two nearby large trees are selected to be used as a pivot tree and a spar tree. A chain is run from the spar tree, around the pivot tree then to the tree that is to be pulled. Finally, the chain is raised from the spar tree, slowly snapping roots and pulling down the tree targeted for removal (Scholz *et al.,* 2004). This technique works to mimic natural processes such as windfall, adds habitats for other species, creates microtopography, and helps to decompact some of the soil (Scholz *et al.,* 2004). Using this system as opposed to bringing in heavy machinery will help to minimize disturbance in the area, prevent further damage and compaction to the soil, and minimize damage to the “keeper” trees (Scholz *et al.,* 2004). In order to further reduce any damage during the project, tree removal should occur in mid to late summer when the soil is dry and the tree bark is less susceptible to serious damage (Heritage Forest, 2013; American Forest Foundation, n.d.).

Many of the trees in the Fuelwood Forest exceed the 30cm DBH threshold that is safe to use the pulley system on. The upper, drier strip of the Fuelwood Forest has an estimated stem density of 597 trees per hectare. Only an estimated 40% of those trees are small enough to be felled by pulley. Furthermore, trees must be situated in an ideal location with both a large pivot tree and spar tree located nearby in order for the pulley system to work (A. Huggins, personal communications, November 10, 2020). As a result, there will be few trees where the pulley system can be used. Other methods, such as girdling or topping selected trees, will have to be used on many of the trees removed from the Fuelwood Forest. Girdling (also called ring-barking) is the transverse cutting across the phloem of a stem, which in this case would be the removal of bark and some inner wood around the circumference of a tree. This prevents vertical transportation of water and nutrients from occurring, slowly killing the tree (Allaby, 2019). Like the pulley system, this method is minimally invasive and reduces fossil fuel emissions. If it is deemed necessary to further reduce the number of standing stems in the forest, it would be acceptable to use a chainsaw to fell a few of the trees, though an electric chainsaw, a manual axe or saw, or some other carbon neutral technique would be preferred.

In the more diverse strip of the Fuelwood Forest, there are many trees that are small enough to thin using the pulley system if the arrangement and position of the other trees allow this technique to be successfully implemented. The tree density is also lower here than in the less diverse strip with an estimated density of 525 trees per hectare. It should be relatively easy to pull down enough trees using carbon neutral techniques for this project. Overall, since this strip already has much higher diversity than the upper strip and does not suffer from soil compaction, not much needs to be done here over the course of the project.

6.2 Soil decompaction and CWD

The soils in the fuelwood forest have been subject to compaction through human activity such as logging and agriculture in the site’s history. This has restricted the growth of the forest’s shrub layer and increases runoff from the site rather than allowing the absorption of rainfall. Soil compaction is often not permanent, and should subside over time through natural processes such as the swelling of clay particles, freezing and thawing cycles of soil moisture, microbial processes, and the growth of plant roots through the soils which can open pores, lower density, and aerate the soil (Ampoorter *et al.,*2011). However, this natural decompaction process can take several decades, and in some cases won't occur at all (Ampoorter *et al.,* 2011). This is evident in the fact that our forest is still suffering from the effects of compact soils decades after the initial disturbance.

The process of felling some of the forest's trees by uprooting them with a pulley system should help to loosen the soil and improve plant growth and ecosystem functioning in the low density strip of the Fuelwood Forest. Hopefully, natural soil decompaction processes will take over from there to further improve the quality of the site. There is an old road cutting through the high diversity forest strip, however, which will greatly benefit from mechanical decompaction. It currently experiences highly compact soils which are unable to support any plant growth besides invasive creeping grasses.

Tilling can be used to de-compact soils by improving the soil pore system which consists of interconnected channels and spaces between soil particles (Berch *et al.,* 2002). This can be done with the use of a winged subsoiler which attaches to the back of a tractor to till the soil as it drives along (Berch *et al.,* 2002). This will be an effective method to use on the old logging road situated in the lower forest site. If this equipment cannot be acquired or borrowed from any Galiano Island community members, another possible soil decompaction technique involves the use of a backhoe. This is not the preferred technique, however, as extra care should be taken to prevent the mixing of stratified soil layers in order to preserve topsoil (Berch *et al.,* 2002).

After decompaction, the addition of coarse woody debris (CWD) created from the thinning process will be beneficial in aiding the recovery of the soil (Scholz *et al.,* 2004). Around 50-60% of the stems that are felled will be processed to sell as firewood as a means of funding the project (see the Budget section below for more details), but the remaining stems as well as any wastes left over from firewood processing should remain in the forest to contribute to the soil, and improve the microtopography and habitat in the forest. The branches from the processed trees should be scattered throughout the site to aid in this as well, and their stumps and roots will also be left in place.

6.3 Planting native species below the canopy

Once forest thinning and decompaction have been completed on the old road, native species should be planted in the herbaceous and shrub layers. Disturbance to soils can sometimes encourage the growth of invasive species in that area, so care will need to be taken to remove any invasive plants until the native grasses and shrubs are established. Cages and fencing should also be used until plantings are established in order to protect them from the abundant deer on the island. In order to direct the growth of this forest towards our reference ecosystem, species that are consistent with the CDFmm biogeoclimatic subzone should be selected for planting. For future research, the site series of each plot (table 1) can be used to decide which plants should be planted across the Fuelwood Forest.

6.4 Monitoring

Photo Monitoring plots will be set up in the centre of each of the circular plots that were made during the site assessment. Brightly painted rebar will be staked into these locations to allow easy and accurate location of the plots. Photos should be taken facing North, East, South, and West immediately before and after thinning occurs, and then at least once a year afterwards in order to monitor the progress and the health of the fuelwood forest. Notes should be taken about plant community structure on each visit, and those notes coupled with the pictures will track changes in plant community composition and diversity over time. Photos and corresponding notes on the plant community should be uploaded onto a computer and organized into separate subfiles for each year in order to easily keep track of the data over the years.

7.0 Timeline:

November 2020: Site assessment
June 2021: First round of photo-monitoring
July 2021: First round of thinning
September 2021: Site decompaction, scattering of CWD, native plantings
October 2021: second round of photo-monitoring

8.0 Budget:

Fortunately, due to the nature of this project there is a chance for some built-in funding through the sale of firewood generated through thinning the forest. Harvesting some of the stems to sell as firewood during the project can generate funds to cover costs associated with tree falling, wood removal, and other restoration efforts.

Cost-profit estimates have already been established through a previous project proposal for forest thinning on Galiano Island (Heritage Forest, 2013). It is estimated that six paid positions will be generated through tree thinning in the Fuelwood Forest. Two fallers could process six cords of firewood per day at a total rate of $750 per seven hour shift. Three people would be required to haul out the wood to the logging road using wheelbarrows for a total cost of $420 per day. This brings the total cost of hiring these six workers to $1170 per day. One cord of Douglas fir wood could sell for between $250 and $300, and if we sell three chords per day, or half of the trees that we pull (we want to leave a substantial amount of stems in the forest in order to contribute to the habitat and soil quality of the system), gross revenue could range from $750 to $900 per day. Though we would not bring in a net revenue, firewood sales could fund the bulk of the cost of hiring these workers. We could completely offset the cost of hiring paid workers if we were willing to part with 60% of our pulled stems to raise between $1000 to $1200. To try to make up for the lost coarse woody debris in the forest, we could scatter the branches from the processed stems and leave the stumps and roots behind to make some contribution to habitat complexity and soil quality.

Service	**Dollars per day**
Two Fallers	– $750
Three log haulers	– $420
Sale of Firewood	+ $750-1200

Table 4: Estimated costs and revenue associated with tree removal.

9.0 Conclusion

Decades of human-caused degradation to the Fuelwood Forest on Galiano Island has led to reduced diversity and compromised ecological functions and now requires restorative intervention to better thrive. Based on samples taken, we have found that the soils on this site are characteristic of the CDFmm biogeoclimatic subzone, which can be used as a reference ecosystem type. Our site assessment revealed a high density of similarly-aged Douglas fir trees. This lack of diversity reduces the forest's resilience and ecological value, but forest thinning has the potential to improve the forest by creating space for more species to grow in the understory, shrub and herbaceous layers of the forest. We recommend that as many trees as possible are felled using a pulley system and girdling, which mimic natural processes such as windthrow and occasional natural tree deaths. These removal techniques should help to decompact soil and create more complex habitat spaces and wildlife trees. Removing so many trees in this manor could lead to an overwhelming amount of fallen stems laying in the system, but approximately half of these trees will be removed and processed in an attempt to cover the costs of this project through firewood sales. Woody debris left on the forest floor will increase the soil nutrient content, provide habitats and further help with the establishment of shrub and herbaceous layers. To conclude, using a forest in the CDFmm biogeoclimatic zone as a reference ecosystem, the Fuelwood Forest should be thinned to allow for a greater diversity of species and therefore be more resilient and contribute to restoring ecosystem services to the Chrystal Creek watershed.

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11.0 Appendix

11.1 Appendix 1: Site assessment data from sample plots in the Fuelwood Forest.

	Plot	A	B	C	D	E	F
Location	Northing	5419974.866	5420000.004	5420023.905	5420036.768	5419993.646	5420018.929
	Easting	465020.34	464986.834	464949.034	464933.749	4650204.114	464982.988
	Slope / aspect	3° / 53° NE	3° / 80°E	3° / aspect 90°E	5° / 150°SE	1° / 308°NW	5° / 280°W
Percent cover / species present	Canopy	45% / all Douglas fir	50% / 2 red alder, 1 western redcedar, many Douglas fir	40% / 1 red alder, many Douglas fir	60% / 4 red alder, many Douglas fir	25% / Red alder, Western red cedar, Douglas fir, Grand fir	30% / Red alder, Douglas fir
	Understory	No species present	No species present	No species present	No species present	2% / 2 small Western red cedar trees	2% / 2 small Western red cedar trees
	Shrubs	No species present	No species present	30% / salal, bald hip rose	40% / stinging nettle, bracken fern, salal, Oregon grape	No species present	30% / salal, bald hip rose
	Herbaceous	5% / honeysuckle, trailing blackberry, Oregon grape	5% / trailing blackberry, Canada thistle, sword fern, bracken fern	34% / sword fern, bracken fern, honeysuckle, trailing blackberry	10% / sword fern, trailing blackberry, bull thistle, honeysuckle, galium spp., vanilla leaf, holly	60% Stinging nettle, trailing blackberry, sword fern, field mint	Sword fern, stinging nettle, trailing blackberry, foxglove, hawthorn
	Grasses & sedges	70%	65% / Blue wild rye, orchard rye	15%	2% / Blue wild rye, orchard grass	30% / blue wild rye, crab grass, sedges, common rush	No species present
Soils	SMR (soil moisture regime)	5f-6f	5f-6f	5f-6f	5	6f-7f	5f-6f
	SNR (soil nutrient regime)	R-VR	R-VR	R-VR	R	R-VR	R-VR
	Site Series -	12 - CwBg Vanilla Leaf	12 - CwBg Vanilla Leaf	12 - CwBg Vanilla Leaf	06 - CwBg Foamflower	14 - Cw Slough Sedge	12 - CwBg Vanilla Leaf

	CDFmm						
Flagged tree	Age estimate	58-64 years	53 years	58-60 years	56 years	84 years	
	Hight	34m	33.8m	36.6m	36.25m		

11.2 Appendix 2: Tree location and diameter at breast height (DBH) data from sample plots.

Plot A:

Tree	Species	Distance from center (m)	DBH (cm)	Direction
1	Douglas fir	5.8	34.3	55°N
2	Douglas fir	9	38	56°N
3	Douglas fir	8.8	51.7	50°N
4	Douglas fir	9.6	23.7	45°N
5	Douglas fir	8.8	36.2	93°E
6	Douglas fir	8.8	16.3	130°SE
7	Douglas fir	7.6	49.4	143°SE
8	Douglas fir		40.3	101°E
9	Douglas fir	4.35	41.8	157°SE
10	Douglas fir	7.5	23	177°S
11	Douglas fir	6.6	39.1	180°S
12	Douglas fir	4	32.5	211°SW
13	Douglas fir	4.9	57.2	280°W
14	Douglas fir	9.4	32.3	290°W
15	Douglas fir	8	21.5	315°W
16	Douglas fir	9.5	39.2	315°W
17	Douglas fir	5.6	30.4	340°W
18	Douglas fir	3.7	47.2	
19	Douglas fir	8.25	46	347° NW
20	Douglas fir	7.7	29.9	352°NW

Plot B:

Tree	Species	Distance from center (m)	DBH (cm)	Direction
1	Douglas fir	5	15.9	343°N
2	Douglas fir	8.4	28	20°N
3	Douglas fir	9.5	65.1	55°NE
4	Douglas fir	8.6	51.7	71°E
5	Douglas fir	6.1	25.9	83°E
6	Douglas fir	2.66	28	78°E
7	Douglas fir	6.26	17.5	120°SE
8	Douglas fir	6.26	37.8	121°SE
9	Douglas fir	3.16	47.2	128°SE
10	Douglas fir	1.4	20.9	170°S
11	Douglas fir	1.7	53.2	170°S
12	Douglas fir	8.56	23.8	172°W
13	Douglas fir	5.5	24.8	280°W
14	Douglas fir	8.75	19.1	280° W
15	Douglas fir	4.12	15.2	300°W
16	Douglas fir	5.85	16.6	310°W
17	Douglas fir	5	15.9	332°NW

Plot C:

Tree	Species	Distance from center (m)	DBH (cm)	Direction
1	Douglas fir	9.7	53.3	55°NE
2	Douglas fir	7.5	41.5	59°NE
3	Douglas fir	3.2	50.5	65°NE

4	Douglas fir	10	54.2	75°E
5	Douglas fir	7.63	47.8	130°SE
6	Douglas fir	9.13	28.2	110°E
7	Douglas fir	9	19.7	160°S
8	Douglas fir	4.1	26.9	170°S
9	Douglas fir	3	46.1	205°S
10	Douglas fir	8.26	15.5	205°S
11	Douglas fir	4	20.5	207°S
12	Douglas fir	9.9	45.9	150°S
13	Douglas fir	9.65	61	142°SE
14	Douglas fir	9.6	17.6	1245°SW
15	Douglas fir	7.6	43.3	220°SW
16	Douglas fir	5.83	22.7	230°SW
17	Douglas fir	3.75	27.5	233°W
18	Douglas fir	9.45	44.3	254°W
19	Douglas fir	8.7	44.8	265°W
20	Douglas fir	8.04	44.8	265°
21	Douglas fir	1.6	39.5	297°NW
22	Douglas fir	8.55	43.8	273°W
23	Douglas fir	8.3	30.3	365°

Plot D:

Tree	Species	Distance from center (m)	DBH (cm)	Direction
1	Douglas fir	6.7	53	53°N
2	Douglas fir	1.9	34.3	102°E

3	Douglas fir	5.8	33	120°SE
4	Douglas fir	7.4	23.5	154°SE
5	Douglas fir	8.1	24.5	165°S
6	Douglas fir	7.1	33.4	170°S
7	Douglas fir	5.3	49.1	191°S
8	Douglas fir	5.4	42	233°SW
9	Douglas fir	6.6	20	244°SW
10	Douglas fir	8.1	47	285°W
11	Douglas fir	6.3	25.1	292°NW
12	Douglas fir	5.8	24.7	327°NW
13	Douglas fir	2.4	52.3	358°N
14	Douglas fir	4.3	22.9	343°N
15	Douglas fir	8.1	51.8	343°N

Plot E:

Tree	Species	Distance from center (m)	DBH (cm)	Direction
1	Western red cedar	8.3	5	22°N
2	Western red cedar	7.8	6.9	23°NE
3	Western red cedar	5.7	34.5	96°E
4	Western red cedar	6.3	38.5	96°E
5	Red alder	8.5	46.5	109°E
6	Douglas fir	8.6	24.8	132°SE
7	Red alder	4.6	29.4	140°SE
8	Red alder	4.3	39.6	170°S

9	Douglas fir	7.8	76.2	238°SW
10	Western red cedar	8.5	36.5	247°SW
11	Western red cedar	8.5	26.8	256°W
12	Red alder	7.2	21.6	258°W
13	Western red cedar	5.8	25.9	284°W
14	Red alder	4.4	21.8	295°NW
15	Red alder (recently died)	5.7	24.65	298°NW
16	Red alder	6	31.2	349°N

Plot F:

Tree	Species	Distance from center (m)	DBH (cm)	Direction
1	Red alder	2.3	9.5	92°E
2	Red alder	2.4	31	93°E
3	Douglas fir	28.5	9.5	93°E
4	Douglas fir	2.2	13.5	145°
5	Red alder	9.1	32	162°
6	Douglas fir	6.6	12.7	175°
7	Douglas fir	7.14	21.3	180°S
8	Douglas fir	7.38	7.1	187°S
9	Douglas fir	4.5	18.5	188°S
10	Red alder	7.25	24.5	205°S
11	Douglas fir	4.1	9.3	205°S
12	Douglas fir	6.4	8.6	205°S

13	Red alder	6	19	225°
14	Douglas fir	6.1	54	270°W
15	Red alder	7.3	26.5	280°W
16	Red alder	7.9	24.2	306°
17	Red alder	5.14	26.3	340°

11.3: Appendix 3 - historical aerial photography

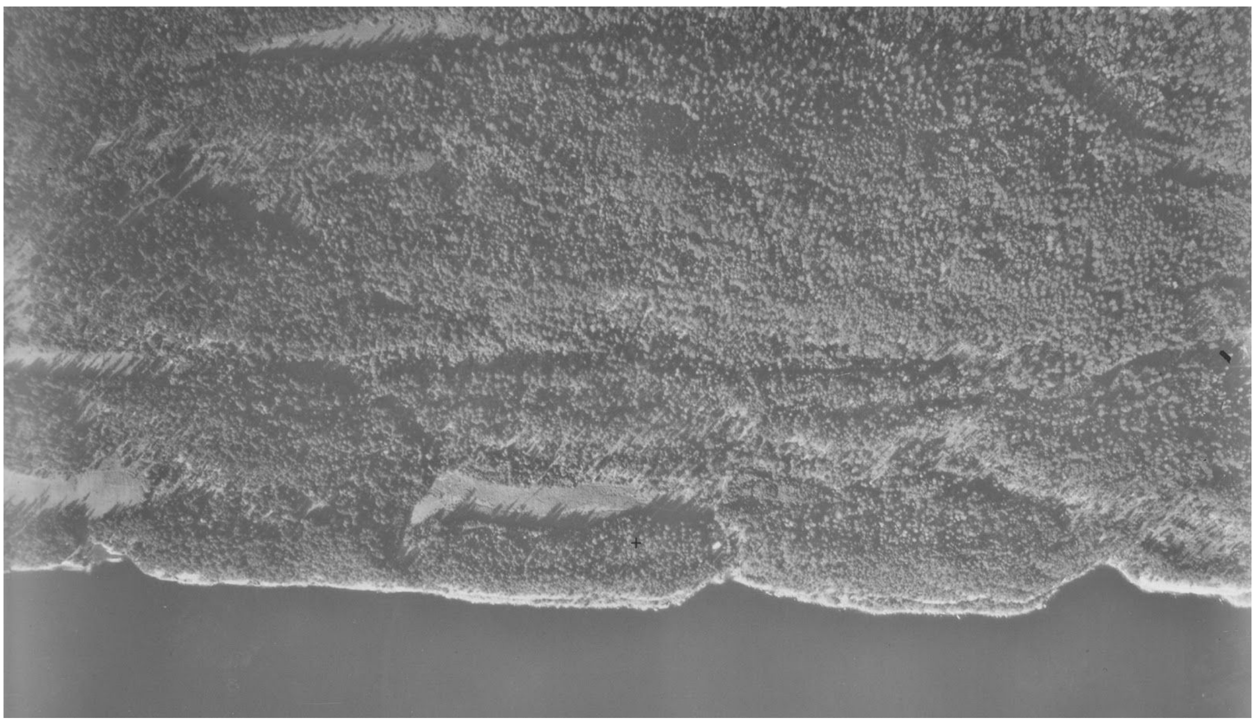

Figure 3. Aerial photograph of the area around the Fuelwood Forest in what is now the Millard Learning Centre. 1930.

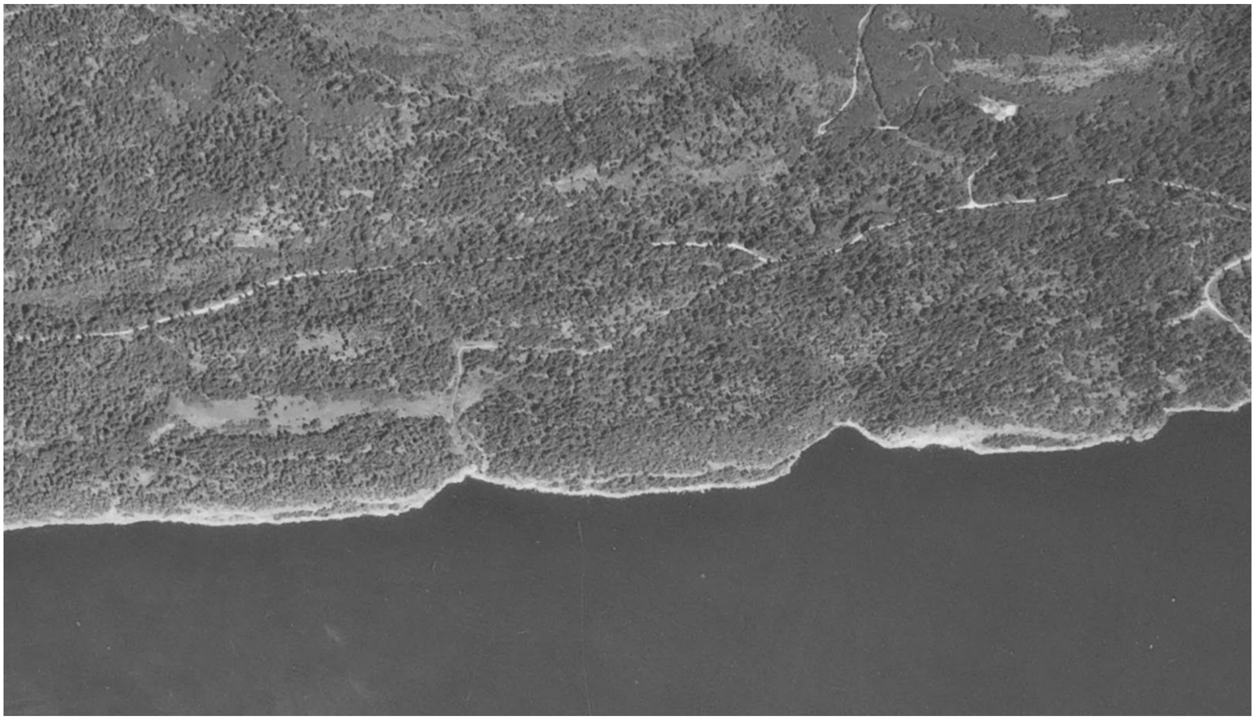

Figure 4. Historical Aerial photograph of the area around the Fuelwood Forest in what is now the Millard Learning Centre. 1962.

Figure 5. Historical Aerial photograph of the area around the Fuelwood Forest in what is now the Millard Learning Centre. 1972

Figure 6. Historical Aerial photograph of the area around the Fuelwood Forest in what is now the Millard Learning Centre. 2002