Participatory Restoration of the Mill Site
Galiano Learning Centre

Technical Report 2014

Presented
to
Dr. Valentin Schaefer

Restoration of Natural Systems
ER390

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EXECUTIVE SUMMARY

The Mill Site, located at the entrance of the Galiano Learning Centre, was the object of a participatory restoration project led by the Galiano Conservancy Association. The 0.25-hectare site was used as a portable sawmill and log staging area for a decade, and was found in a heavily degraded state when the GCA acquired the property in 2012.

Five goals compatible with the Galiano Learning Centre Management Plan were established for the site: 1. Re-establish ecological integrity in consistence with the CDFmm subzone, 2. Provide educational opportunities and contribute to ecological restoration science, 3. Engage the community, 4. Aesthetically improve the site and honour the transformative power of the restoration process, and 5. Create low-impact parking space to accommodate the needs of the Galiano Learning Centre.

A baseline assessment revealed that the risk of severe hydrocarbon contamination was unlikely, but confirmed that a section of the site was severely compacted, probably inhibiting root penetration. Also, the site and the adjacent areas had been clear-cut in the early 2000s, and the ground had been levelled for its industrial use. As a result of the compaction, altered topography, and lack of vegetative cover and soil organic matter, the soil was in a very poor structural and functional state, and infiltration and drainage were largely inhibited. Furthermore, many invasive species seemed to be rapidly encroaching the perimeter of the site. Also, the previous use of the site had left an important legacy of Western redcedar off-cuts and other industrial refuses.

In a first place, the site thus had to be cleaned up. Salvageable material was transferred to a different area, garbage was collected, and the piles of cedar debris were chipped and transferred off-site for use in trails and other projects. In late winter of 2014, a small section of the site was re-contoured and the central part was de-compacted to a depth of 1m using an excavator and following the 'rough and loose' method. $167m^3$ of primarily red alder woodchips were brought to the site and spread as a 10cm thick mulch. 6 m^3 of salvaged forest litter was incorporated to the woodchips as an inoculum of soil and LFH organisms. Salvaged coarse woody debris were scattered at a density of $100m3 \bullet ha^{-1}$, and three large logs were inserted vertically to emulate snags.

A total of 426 plants were brought from the GCA Native Plant Nursery, including 72 red alders. 2.3m^3 of mature compost containing 1.5% nitrogen were delivered to the site to amend the plants with an additional source of nutrients, in particular to mitigate the risk of nitrogen deficiency during the establishment period. The plants were individually amended with an average of 3 liters of compost, and they were caged for protection from deer herbivory.

A 0.024-hectare experimental area was embedded within the restoration design to assess the differential effect of compost, young forest inoculum and mature forest inoculum on the recovery of soil and plant health. The perimeter of the plot was fenced, which will allow comparing the effect of an exclosure and individual cages on the plant recruitment success on the site.

In parallel, hand pulling and the creation of a shade-barrier using live stakes and sheet mulching were conducted to control the expansion of a reed canarygrass population present in the wetland adjacent to the site. A total of 71 live stakes of several riparian species were as a result incorporated to the restoration project.

The project was realized through the organization of multiple community work parties, and perhaps most importantly, with the continued involvement of a group of elementary school students from the Galiano Community School.

25 indicators, corresponding to the five goals of the project, are recommended for monitoring the restoration process as well as to evaluate and communicate success. Some of these will allow comparing vegetation and soil characteristics with the baseline and reference site conditions. Importantly, several photopoint monitoring stations have been established.

Initial observations indicate that the site has been effectively de-compacted and that infiltration and drainage have already started to improve. Aesthetical improvements are already undeniable, and the topographic and structural complexities of the site have been effectively enhanced. Perhaps most importantly, over 150 volunteer-days were spent on the Mill Site so far, and it is hoped that this has allowed the development of long-lasting bonds and reciprocal healing between the people and this little piece of land.

1. DEFINITIONS & ASSUMPTIONS

Agronomic grasses: refer to grass species that were not identified during this study, but assumed to be largely invasive exotic grasses, usually introduced for agricultural purposes.

Ecological integrity: defined as the range of natural conditions defining the composition, structure, function, processes and resilience of a given ecosystem.

Ecological restoration: defined by the Society for Ecological Restoration as the "process of assisting the recovery of an ecosystem that has been degraded, damaged, or destroyed."

Invasive species: though I acknowledge the fact that native species can sometimes become invasive, the use of the term in this report refers to exotic invasive species, that is, species non-native to the Pacific Northwest. Also, I repose on the assumption that an invasive species is generally 'bad' in terms of its effect on the ecological integrity of an ecosystem, recognising that this is probably an over-simplification, and that we will increasingly have to consider them as constituents of novel ecosystems.

Natural: though my philosophical stance is that humans are an integral part of nature and that restoration efforts must include human needs, the use of the term natural in this report generally exclude human agency, or refers to pre-colonization conditions or trajectories.

Natural recovery: defined as the ecological recovery of a site without any direct human assistance, presuming a recovery that will bring the ecosystem back within a similar range of conditions and on a similar ecological trajectory that were found prior to the anthropogenic disturbance.

Resilience: defined as the ability of an ecosystem to recover its properties and functions following an episodic disturbance.

We: the use of the first person plural in this document refers to both the Galiano Conservancy Association and I, whereas the singular is used to express my personal opinions and arguments.

2. INTRODUCTION & BACKGROUND

2.1 Galiano Island

Galiano Island is located in the southern Gulf Islands of British Columbia, lying in the middle of the Strait of Georgia, in the Georgia Depression (Islands Trust Fund 2013). The Island is characterized by warm dry summers and mild wet winters and receives an average of 920mm of rainfall annually, most of it during winter (ibid).

2.2 The Galiano Conservancy Association

Founded in 1989, the GCA (Galiano Conservancy Association) is one of the oldest community-based land trusts of the province, and has the mandate to conserve and restore the natural environment of the Island, while providing the community with hands on educational opportunities as well as possibilities to develop a deeper connection with the ecosystems they inhabit (GLCMC 2013). The organization has been fulfilling its mandate through the direct purchase of properties, the formation of cooperative partnerships with landowners, the implementation of restoration and long-term ecosystem monitoring programs, the establishment of its own native plant nursery, and perhaps most importantly, by delivering hundreds of educational workshops with the local community and off-island youth groups.

2.3 The Galiano Learning Centre

In February 2012, the GCA purchased DL57 (District Lot 57), a 76-hectare parcel of land that was acquired for conservation purposes and as the site that would become the home of the Galiano Learning Centre (GLCMC 2013). As stated in the Galiano Learning Centre Management Plan (ibid), the principal goals and objectives of the Learning Centre revolve around six axes:

- *Practicing ecological stewardship;*
- *Creating opportunities and providing facilities for learning, research and innovation;*
- *Contributing to local food security;*
- *Contributing to local economic development;*
- *Providing public access;*
- *Creating opportunities for recreation.*

This property, acquired through matching funds of the Natural Areas Conservation Program of Nature Conservancy Canada, is seen as a critical addition to a network of over 500 hectares of protected areas forming the Mid-Island Conservation Network, to which it will be connected through a cross-island trail (GLCMC 2013). DL57 encompasses almost two kilometers of nearly unbroken shoreline forest facing the Trincomali Channel, one of the largest remnants in the entire Gulf Islands (GLCMC 2013).

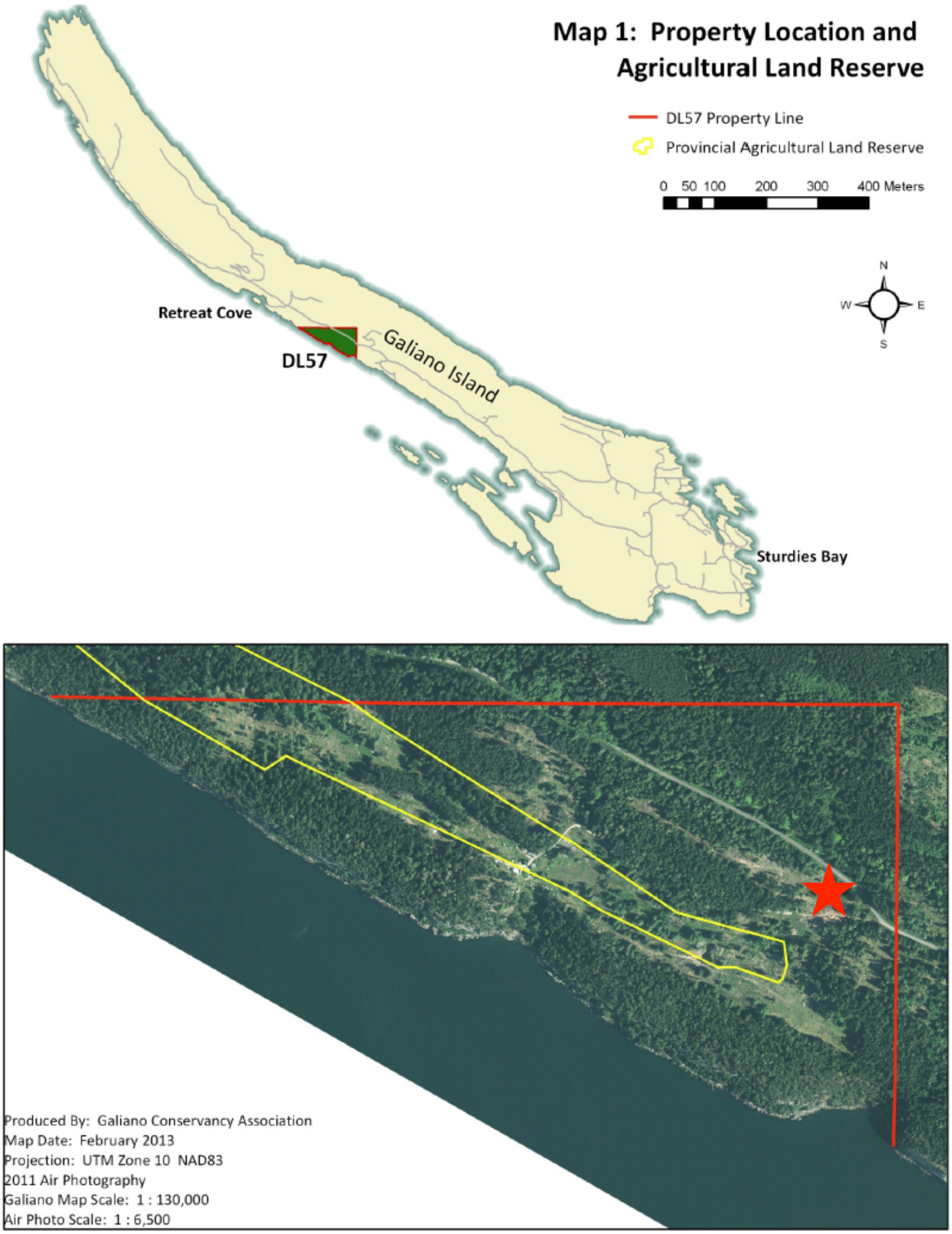

Figure 1. Location of the Galiano Learning Centre (DL57) on Galiano Island. The location of the Mill Site is indicated with a red star on the bottom image. *Source: GLCMC (2013)*

2.4 The Mill Site

48.93016°N
123.46722°W[1]

Located at the main entrance of DL57 and visible from Porlier Pass Rd., the Mill Site is a 0.25-hectare, bowl-shaped area that was used for the operation of a portable sawmill and log staging area between 2001 and 2011. The site was occupied by what appears to be a mature forest until 2001 (Figure 3a). It is part of the Coastal Douglas-Fir moist maritime BEC subzone and of the Southern Gulf Islands Ecosection. Its surficial geology falls within the Gabriola formation, composed primarily of the hard arkosic arenite sandstone, but comprising a minor fraction of more easily erodible conglomerate constituted of siltstone and shale (Islands Trust Fund 2013; Muller 1980). The Mill Site embodies two very different types of soil. The first one, encompassing the north and east part of the site and constituting the wetter area, consists of the imperfectly drained Brigantine soils, relatively shallow (30-100cm) loamy sand or sandy loam marine or fluvial deposits overlying silty clay loam to silty clay marine deposits that are more than 100cm deep (Green et al. 1989). The second type is the Saturna group, well drained sandy loam to loamy sand, formed of colluvial or glacial drift material shallower than 100cm, overlying sandstone bedrock (ibid). It occupies the south-western portion of the Mill Site.

The Mill Site, being heavily degraded and located at the main entrance of the property, was immediately perceived as holding some of the greatest potential to showcase innovative and participatory ecological restoration activities at the Galiano Learning Centre. As such, realizing a project that was true to the GCA's work and vision was critical.

We initially believed that contamination with petroleum hydrocarbon would constitute a challenge that would need to be directly addressed in the restoration process. However, a thorough literature review conducted by three RNS students in the spring of 2013 as part of the ER411 course, as well as sampling and analysis of a seepage area located below the Mill Site in the fall of 2013, led us to assert that the probability that the soil was significantly contaminated was very small. Also, this was corroborated by the fact that William Campbell, the previous owner of the property and operator of the portable sawmill, had not witnessed any significant spillage event. As a result, the primary concern for the site became soil compaction.

2.4 Soil compaction

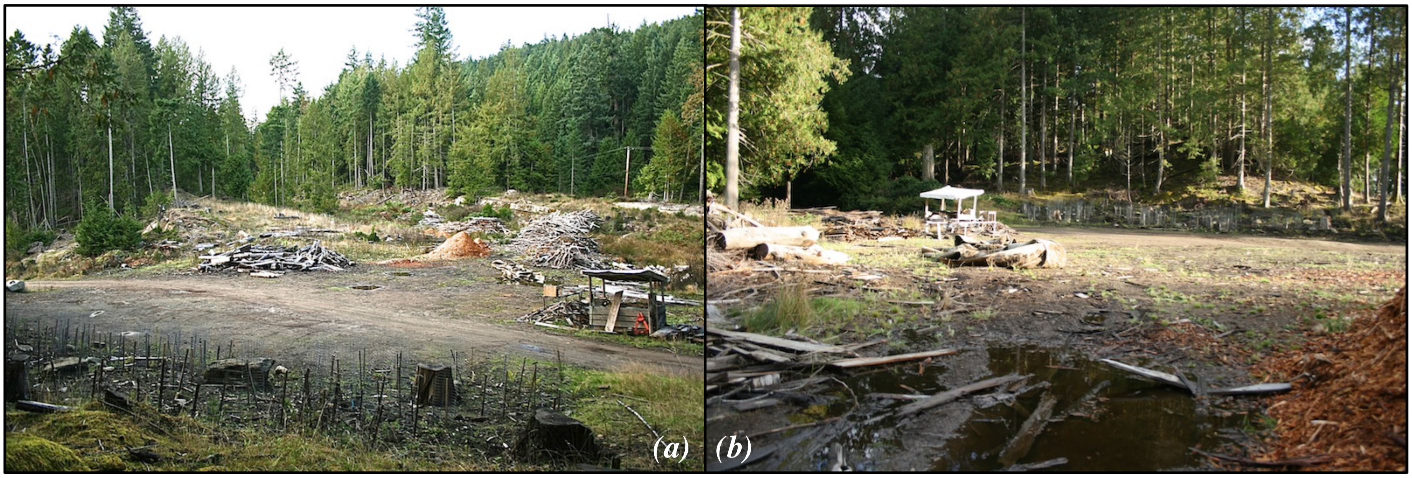

Figure 2. (a) Looking north at the Mill Site; **(b)** Surface pooling due to soil compaction (*Photos taken on September 22nd, 2013*)

Soil compaction can be defined as an increase in bulk density, that is, mass per unit volume of dry soil, including pore space, generally expressed in Mg/m^3 (Brady & Weil 2008). It is a frequently encountered problem resulting from the use of heavy equipment in forestry and agricultural activities (ibid). Clayey soils, because of their cohesion and plasticity, are especially prone to compaction and puddle formation, while sandy or otherwise coarse-textured soils generally resist compaction (ibid). Compacted soils have a decreased total porosity, which becomes largely occupied by micropores, with a net loss in macropores and larger micropores (ibid). As a result, they have restricted aeration, limited infiltration and drainage, reduced water holding capacity and available water content, and more water is consequently lost as surface runoff (ibid). Moreover, compaction results in a slower movement of water and nutrients within the soil, and may lead to the buildup of toxic gases and exudates (ibid). All of this equates to a poorer environment for soil organisms, including plant roots (ibid). Also, because compacted soils also have a higher strength, root penetration and development becomes mechanically inhibited when bulk densities exceed 1.45 Mg/m^3 in clay soil, and 1.85Mg/m^3 in loamy sand soil (ibid).

Figure 3. Aerial photographs of the Mill Site dating from **(a)** 1998 and **(b)** August 2011

3. GOALS & OBJECTIVES

Five primary goals were established for the project (numbers), sub-divided into several objectives (letters). It is important to note that many of these goals are interrelated and probably synergistic in nature. The goals and objectives are consistent with the Galiano Learning Centre Management Plan (GLCMP 2013).

1. **Re-establish ecological integrity on the site, in consistence with the Coastal Douglas-fir moist maritime biogeoclimatic zone;**

    1a. Composition: re-establish a diverse and representative selection of early successional native plant species; limit colonization by invasive plant species to the greatest practical extent; re-establish a healthy soil microbial community;

    1b. Structure: re-establish soil structural integrity (Seybold et al. 1999): specifically, de-compact the soil and increase soil organic matter in order to regain a healthy soil structure that is conducive to the growth of a diversity of indigenous soil micro-organisms and fungi and that will support the establishment of early successional native plant species; re-establish key above-ground structural components such as coarse woody debris and dead standing trees;

    1c. Function: re-establish soil functional integrity (Seybold et al. 1999), including life-supporting functions such as air circulation and nutrient cycling and storage, as indicated by healthy plants, and a thriving fungal and invertebrate community; re-establish hydrological functions: infiltration and subsurface drainage, as indicated by the absence of surface pooling;

    1d. Processes: the site becomes self-sustaining and there is an evident integration with adjacent areas, as well as signs of successional development (e.g. establishment and growth of late successional tree species and mature understory herbaceous and bryophyte species) development of mycorrhizal associations between plants and fungi;

    1e. Resilience: the ecosystem is able to recover without assistance following natural ranges of disturbances (e.g. drought);

2. **Develop and incorporate educational and research opportunities into the restoration process, rendering them compatible with the ecological goals;**

    2a. Form partnerships with university students for the planning, implementation and monitoring phases of the project;

    2b. Seize opportunities of incorporating research into the restoration design and contribute to ecological restoration science and practice;

3. **Provide rich experiential opportunities for the Galiano Island community that encourage a sense of connection with the Learning Centre;**

    3a. Involve the students of Galiano Community School in all phases of the project;

    3b. Encourage the participation of volunteers of all ages through the organization of work parties;

    3c. Create publicly accessible interpretive signage on the site;

4. **Aesthetically improve the site while honouring the past and memorializing the transformative power of the restoration process;**

    5a. Dispose of the cedar debris and other industrial refuses;

    5b. Re-establish native vegetation cover;

    5b. Establish a series of photopoint images at the interpretation kiosk;

5. **Maintain a cleared area suitable for parking and access driveway**

    4a. Set aside sufficient space to accommodate a maximum of 16 standard vehicles;

    4b. Eventually incorporate low-impact parking technology (e.g. geoblocks) in order to minimize detrimental effects such as compaction as well as long term risk associated with the import of petroleum contaminants;

4. FILTERS TO RECOVERY

Several conditions and processes found on the Mill Site as it was inherited by the GCA acted as filters to its natural recovery. A striking feature of the site was the very large amount of Western redcedar (*Thuja plicata*) off-cuts and woody refuses, a legacy from the portable sawmill. In addition, the site was littered with other industrial remnants.

We assumed the filters to the natural recovery of the site to be primarily related to soil compaction. The compaction resulted in a high soil bulk density and strength, which clearly resulted in very poor infiltration and which most likely inhibited root penetration. In addition, compacted soil tends to be anaerobic, a condition detrimental to both plant roots and soil microorganisms (Brady & Weil 2008). Also, the largely barren and exposed soil was probably susceptible to extremes of temperatures, especially given the flattened condition of the ground and the absence of topographic heterogeneity.

Secondly, a lack of humified or readily decomposable organic matter in the soil led to a poor nutrient status, while contributing to the poor physical and biological properties of the soil.

Thirdly, many invasive species surround the site, and leaving it to natural recovery might have set the stage to a complete take over by a combination of Scotch Broom (*Cytisus scoparius*), invasive grasses, Himalayan blackberry (*Rubus discolor*) and thistles (*Cirsium* spp.).

Fourthly, the browsing pressure by deer, which is elevated on Galiano Island, can affect the ability of certain preferred species to regenerate, such as Western redcedar. This effect of deer on initial species regeneration on the site is likely to entail cascading impacts on the type of ecosystem that will in the long run be found on the site.

Also, it must be mentioned that these filters were probably acting in concert. For example, certain invasive species are less palatable to deer than their native counterparts, accentuating the probability of an invasive species rapidly becoming dominant.

5. RECOVERY SCENARIOS

In order to select the best approach to restoring the site, we initially considered the different recovery scenarios that seemed plausible for the Mill Site.

5.1 Passive restoration

As the expression implies, we could have decided to let the site heal itself without intervention. However, we believe that the strength of the filters to recovery just described was such that they were acting as a barrier to recovery. In fact, the site might have evolved towards an alternate, grass-dominated stable state, which we consider undesirable for this site, and which appears to be the ecological status of many logged areas on DL57. In other words, we assumed that without intervention, the site would have stagnated in a highly degraded, unproductive and invasive species-dominated state for a very long time, a condition incompatible with the land management goals established for the Galiano Learning Centre.

5.2 Minimal intervention

Since we believe that soil compaction was the principal filter preventing a quick recovery of the site, an alternative option would have been to solely address this condition with mechanical de-compaction, leaving the remainder of the recovery in the hands of natural processes. This is the recommendation that was made to us by David Polster, who suggested a 'rough and loose' treatment in late summer, after which the seeds of the pioneer species red alder (*Alnus rubra*) would have been able to germinate on the site. This would have initiated a natural succession by enriching the soil with organic matter, fixing nitrogen and providing structural habitat. This could have been supplemented implementation of measures to control invasive species. This approach can minimize the costs of intervention, and its effectiveness has been proven in other locations (D.F. Polster, personal communication). However, it would have meant very little human intervention, and thus very little community engagement, an important goal of this project. Also, I suspect that an insufficient amount of red alder seeds would have colonized the site without assistance.

5.3 Holistic participatory restoration

This is the restoration option that was selected for the site and that is documented in this report. It involved a participatory site clean-up, mechanical de-compaction of the soil, coarse woody debris (CWD) and snag incorporation, organic matter and nutrient enrichment, participatory planting and invasive species control, and the

Figure 4. The benchmark of the Y-axis is the pith of this stump

establishment of an experimental area with an elementary school group. Deliberate efforts were put into engaging the community with the restoration process and into stimulating the development of strong relations between people and the Mill Site.

6. BASELINE AND REFERENCE SITE ASSESSMENTS

6.1 Methods

6.1.1 Baseline assessment

Establishing a geo-reference grid

In a first place, we established a geo-reference grid consisting of an X and Y-axis. It proved useful for mapping the ecological communities of the site and provided a reference system for localizing soil and vegetation assessments as well as the restoration prescriptions. The benchmark point from which the Y-axis was established is the pith of the stump shown on Figure 4. A flagged re-bar stake was installed in front of the stump. The 0m mark of the Y-axis was established at exactly 20m north from the pith. A compass was used to position the axes. The intent was to orient the Y-axis on a true north alignment. Unfortunately, the declination used on the compass was 14°E, a mistake from my part, as the actual declination used should have been 16.5°E[1]. Therefore, the Y-axis is oriented at 2.5°E (true north), and the X-axis is oriented perpendicularly, at 92.5°E (true north). The 0m-mark on the X-axis was established at exactly 10m west of the Y-axis.

Mapping the ecological communities

Using the geo-reference grid and my ground observations of soil and vegetation, I created a map including 10 ecological communities (polygons), as shown in Figure 5. The following table summarizes the key ecological characteristics of these 10 communities, as found when I conducted the baseline assessment in the fall of 2013. The table also includes the assumed site series and their relative proportion based on my observations of soil and vegetation characteristic

[1] NRC Magnetic Declination Calculator : URL http://geomag.nrcan.gc.ca/calc/mdcal-eng.php (accessed 02 March 2014); Mill Site coordinates used

Table 1. Description of the 10 Ecological Communities of the Mill Site

Polygon #	*Description*	*Site Series (%)*
1	The central part of the area, clear-cut in the early 2000s and used as the main milling and log staging area, compacted and very little vegetation cover, a soil texture and moisture gradient from southwest to northeast, with coarser and drier soil towards the south, area where most of the debris piles were located	06 (60%) 04 (40%)
2	The wetland edge, was clear-cut in the early 2000s, dominated by rushes and agronomic grasses, hummocky terrain with great variations in in soil moisture regime, large stumps indicate that it was a productive site, water table reaching the surface for a few weeks in the winter, transitioning to a wetland community comprising a small pond near Porlier Pass Road, which is home to a cattail (*Typha* sp.) and small-flowered bulrush (*Scirpus microcarpus*) community, in which dwell many Pacific chorus frogs (*Pseudacris regilla*)	06 (50%) 04 (30%) 11 (20%)
3	The western slope, was clear-cut in the early 2000s, largely dominated by agronomic grasses, with some regeneration of Douglas-fir (*Pseudotsuga menziesii*), western redcedar, dull Oregon-grape (*Mahonia nervosa*) and salal (*Gaultheria shallon*), a dry south-facing section and a moister, north-east facing area	01 (70%) 04 (30%)
4	Area with deep, rich and well-drained soil just below the rocky ledge, was clear-cut in the early 2000s, some log staging and debris piles, dominated by common rush (*Juncus effusus*), agronomic grasses and salal, home to some very healthy Scotch broom individuals (prime habitat for the species), some regeneration of trees closer to the forest	04 (80%) 01 (20%)
5	Similar to the central area, but more advanced successional stage, being closer to the forest edge and probably left untouched for longer, some compaction but less severe than in Polygon 1, the south portion will be used as the future area for the garden kiosk	04
6	Western edge of a little remnant of mature Western redcedar – salal-dominated forest	04
7	North-facing slope that was re-contoured and planted with the Galiano Community School in 2012-2013	01
8	Relatively young secondary forest (~75 years old), very little understory vegetation, assumed zonal soil conditions for the CDFmm	01
9	Rocky outcrop with areas of extremely shallow soil, sun-exposed and very dry, some dull Oregon-grape and arbutus (*Arbutus menziesii*) regeneration, agronomic grasses are abundant	02
10	The beginning of the rocky ledge area, south facing and dry, clear-cut in the early 2000s, where most of the Scotch broom population is found, a fair amount of salal, dull Oregon-grape and Douglas-fir regeneration, dominated by agronomic grasses	02

Figure 5. Ecological communities of the Mill Site. The shaded polygons represent the central area (P1), the wetland edge (P2), and the dry slope (P3). These are the three areas where detailed vegetation inventories were conducted. The circled numbers refer to the site series of the CDFmm BEC subzone. SGI refers to the Gulf Islands Ecosection. Many of these polygons encompass more than one site series. The dashed lines represent the X and Y-axes used to geo-reference the baseline assessment. The red dots mark the 0m mark on the axes. Note that the wetland extends to the right, beyond the boundary shown on the figure.

Vegetation

A plant species checklist was completed for the three main ecological areas of the site, the central area (Polygon 1), the wetland edge (Polygon 2) and the western slope (Polygon 3) (Figure 5). The presence of fungi was also noted. A 1m x 1m plastic frame (i.e. quadrat) was used to estimate species percent cover in each of the three polygons. Three quadrats were conducted for Polygons 1 and 3, and two for Polygon 2, by randomly casting the frame on the ground. The percent cover of each species present within the quadrat was estimated. When the frame landed onto a recently disturbed area (i.e. a few days to a few weeks), it was moved to the closest equivalent area. An estimate of the percent of exposed soil and woody debris cover was also noted for each quadrat. The location and unique photograph number of each quadrat on the grid system was noted (i.e. X,Y coordinates). Polygon 2, the edge of the wetland, is the area for which the assessment is most likely to be incomplete, as the grass cover was dense, and many small species had no reproductive structures visible at the time of the assessment.

Soils

Compaction

In order to quantify the degree of compaction, I used the soil excavation and replacement method described in Maynard & Curran (2007), using water instead of glass beads for measuring the volume of soil sampled, an alternative approach validated by Doug Maynard (D. Maynard, personal communication). I used a modified clod method to measure the bulk density of three soil clods sampled in the most compacted area of the site[2]. However, the clods were not covered with paraffin, and the amount of water absorbed by the soil is assumed to be negligible. For both methods, the soil samples were first dried in an standard oven at 100°C for 2 hours, leaving the door slightly open, and the final moisture content was removed using a microwave oven[3]. For both methods, the coarse fragment content (>2mm) was removed from the dried soil using a 2mm metal sieve.

[2] The clod method is described in a document available from: http://www.environment.nsw.gov.au/resources/soils/testmethods/bdsc.pdf (accessed 25 September 2013)

[3] The microwave method used for drying the soil samples is described in the following USDA document: URL http://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/nrcs143_019165.pdf (accessed 25 September 2013)

Figure 6. Measuring bulk density using the soil excavation and water replacement method. I used a ruler to ensure that the cavity was completely filled with water. *Photo taken on October 29th, 2014*

Soil texture

We dug several soil pits on the Mill Site. For three of them, I drew a soil profile and hand-textured the different horizons using the identification keys provided in Brady & Weil (2008) and in BCMFR and BCMOE (2010). I conducted laboratory soil texture analysis at the Pacific Forestry Centre facilities, in Victoria, using the Bouyoucos Hydrometer method (see Kalra & Maynard 1991: pp. 42-45).

Soil chemistry

We sampled several locations and depths throughout the central area of the Mill Site as well as the Reference Site. The chemical analysis of the samples was performed at Pacific Forestry Centre facilities by a laboratory technician. The pH was measured using the $CaCl_2$ solution method. Combustion was performed to determine total S. Available ammonium (NH_4-N) and nitrate (NO_3-N) were determined with a colorimetric analysis, using a segmented flow analyzer. David Dunn, head of the chemical services laboratory, can be contacted for more details concerning the analytical methods[4].

6.1.2 Reference site assessment

Choosing a Reference Site

The main reference site (Reference Site 1) was selected across Porlier Pass Road, approximately 100m east of the Mill Site. We selected it primarily based on the similarity between its soil moisture and nutrient regimes and those of the

[4] David Dunn's work email: David.Dunn@NRCan-RNCan.gc.ca

central part of the Mill Site. The site was logged during the past century, about 75 years ago, and regenerated naturally. It constitutes what we believe the Mill Site may look like in about 50 years. I completed vegetation and soil assessments on this site. A secondary reference site (Reference Site 2) was selected to obtain additional bulk density samples. It is located in the area where the soil and CWD activity was conducted with the Galiano Community School in the fall of 2013, about 500m to the northwest of the site. Unfortunately, the season when the vegetation inventory was conducted (October 28th, 2013) meant that many of the herbaceous species of the understory of the Reference Site were unnoticeable. I would recommend re-conducting the vegetation assessment in late spring or early summer for a more complete portrait. The reference sites were selected to provide general guidance, as opposed to rigid restoration end-points.

Vegetation

We established a 20 x 20m quadrat in Reference Site 1 and estimated vegetation % cover for the entire plot according to the categories described in Table 2.

Table 2. Vegetation Layers Used for the % Cover Assessment in the Reference Site

Code	*Strata*	*Description*
A	Trees	>10m
B	Shrubs	Woody < 10m
C	Herbs	All non-woody plants
D	Bryophytes	Mosses and lichens growing on soil

Soils

The soil of Reference Site 1 was characterized using the same methods as the ones described for the Mill Site. One soil pit was dug, from which one sample was brought to the laboratory for particle analysis and two for chemical analysis. Only the bulk density was measured in Reference Site 2, following the soil excavation and water replacement methodology.

6.2 Baseline and reference site assessment: RESULTS

6.2.1 Baseline assessment: VEGETATION

The following tables present the species identified in the species checklist and % cover assessments of polygons 1, 2 and 3. Certain species remain unidentified, but these were photo-documented and specimens were put in a plant press. I intend to complete the identification before handing the report to the GCA.

Table 3. Polygon 1 Species Checklist (Central Area of the Mill Site)

Latin Name	*Common Name*	*Notes*
Acer glabrum	Douglas maple	Small seedling
Agrostis stolonifera	Creeping bentgrass	
Arctium minus	Common burdock	
Cirsium arvense	Canada thistle	
Cirsium vulgare	Bull thistle	
Daucus carota	Wild carrot	
***Funaria* sp.**	Moss sp.	
Galium triflorum	Sweet-scented bedstraw	
Holcus lanatus	Common velvetgrass	
Hypochaeris radicata	Hairy cat's-ear	
Juncus effusus	Common rush	
Leontodon saxatilis	Hairy hawkbit	
Lotus purshianus	Spanish clover	
Madia sativa	Chilean tarweed	
Matricaria discoidea	Pineapple weed	
Matricaria recutita	Wild camomile	
Mycelis muralis	Wall lettuce	
Navarretia squarrosa	Skunkweed	
Plantago major	Common plantain	
Plantago sp.	Plantain sp.	Species 53
Polygonum aviculare	Common knotgrass	
Polystichum munitum	Swordfern	
Pseudotsuga menziesii	Douglas-fir	
Rubus spectabilis	Salmonberry	
Rumex acetosa	Common sorrel	
Rumex sp.	NA	Species 55
Senecio sylvaticus	Wood grounsel	
Stellaria media	Common chickweed	
Thuja plicata	Western redcedar	
Trifolium repens	White clover	
Urtica dioica	Stinging nettle	
Verbascum thapsus	Mullein	
***Veronica* sp.**	Veronica	
Vicia sativa	Common vetch	
Species 16	NA	*Phacelia* sp.?
Species 17	NA	*Antennaria* sp.?
Species 26	NA	*Persicaria* sp.?
Species 44	NA	
Species 49	NA	Grass sp.
Species 50	NA	Moss sp.
Species 51	NA	Grass sp.
Species 52	NA	Grass sp.
Species 56	NA	Grass sp.
Species 58	NA	
***Aleuria aurantia* (fungus)**	Orange peel fungus	
Fungus sp.	Puffball sp.	

Table 4. Percent Cover in Quadrat 1, Polygon 1 (*location: 13E, 10N; photo # 9656*)

Species	*% cover*
Polygonum aviculare	1
Stellaria media	<1
Species 44	<1
Species 49	2
Species 54	<1
Species 56	<1
TOTAL	3
Woody debris	3
Barren soil	95

Table 5. Percent Cover in Quadrat 2, Polygon 1 (*location: 8E, 10N; photo # 9657*)

Species	*% cover*
Arctium minus	2
Agrostis stolonifera	<1
Holcus lanatus	<1
Hypochaeris radicata	<1
Leontodon saxatilis	1
Polygonum aviculare	<1
Senecio sylvaticus	<1
Thuja plicata	<1
Species 16	1
Species 17	<1
Species 49	<1
TOTAL	6
Woody debris	4
Barren soil	90

Table 6. Percent Cover in Quadrat 3, Polygon 1 (*location: 17E, 16N; photo # 9658*)

Species	*% Cover*
Agrostis stolonifera	<1
Cirsium vulgare	<1
Juncus effusus	<1
Leontodon saxatilis	<1
Lotus purshianus	<1
Matricaria discoidea	<1
Navarretia squarrosa	<1
Plantago major	<1
Polygonum aviculare	<1
Stellaria media	<1
Trifolium repens	<1
Species 16	2
Species 17	<1
Species 49	2
Species 54	<1
TOTAL	8
Woody debris	3
Barren soil	90

Table 7. Polygon 2 Species Checklist (Edge of Wetland Area)

Latin Name	Common Name	Notes
***Agrostis* sp.**	Bentgrass sp.	
Arctium minus	Common burdock	
***Carex* sp.**	Sedge sp.	
Cirsium arvense	Canada thistle	
Cirsium vulgare	Bull thistle	
Crepis capillaris	Smooth hawksbeard	
Daucus carota	Wild carrot	
Digitalis purpurea	Common foxglove	
Epilobium minutum	Small-flowered willowherb	
Equisetum arvense	Common horsetail	
Equisetum telmateia	Giant horsetail	
Fern sp.	Fern sp.	Species 2
Galium triflorum	Sweet-scented bedstraw	
Gaultheria shallon	Salal	
Grass spp.	NA	Densely covering most of the area
Hypochaeris radicata	Hairy cat's-ear	
Juncus effusus	Common rush	
Leontodon saxatilis	Hairy hawkbit	
Lichen sp.	Lichen sp.	
Madia sativa	Chilean tarweed	
Moss sp.	Moss sp.	
Mycelis muralis	Wall lettuce	
Navarretia squarosa	Skunkweed	
***Persicaria* sp.**	NA	
Phalaris arundinaceae	Reed canarygrass	
Polystichum munitum	Swordfern	Largely on top of hummocks
Prunella vulgaris	Common selfheal	
Pseudotsuga menziesii	Douglas-fir	Side of stump
Pteridium aquilinum	Bracken fern	
Ranunculus repens	Creeping buttercup	
Rubus leucodermis	Black raspberry	
Rubus spectabilis	Salmonberry	
Rubus ursinus	Trailing blackberry	
Scirpus microcarpus	Small-flowered bulrush	
Taraxacum officinale	Dandelion	
Thuja plicata	Western redcedar	
Trifolium repens	White clover	
Urtica dioica	Stinging nettle	
***Veronica* sp.**	Veronica sp.	
Vicia sativa	Common vetch	
Species 19	NA	

Table 8. Percent Cover in Quadrat 1, Polygon 2 (*location: 37E, 27N; photo # 9659*)

Species	***% Cover***
Cirsium arvense	3
Equisetum telmateia	2
Grass spp.	75
Juncus effusus	25
Rubus ursinus	5
Scirpus microcarpus	10
TOTAL	100
Woody debris	0
Barren soil	0

Table 9. Percent Cover in Quadrat 2, Polygon 2 (*location: 46E, 24N; photo # 9660*)

Species	***% Cover***
Cirsium arvense	1
Equisetum telmateia	4
Galium triflorum	<1
Grass spp.	50
Juncus effusus	30
Moss spp.	10
Rubus ursinus	10
Taraxacum officinale	<1
Vicia sativa	1
TOTAL	98
Woody debris	0
Barren soil	2

Table 10. Polygon 3 Species Checklist (Western Slope)

Latin Name	***Common Name***
Anaphalis margaritacea	Pearly everlasting
Arctium minus	Common burdock
Cirsium vulgare	Bull thistle
Citysus scoparius	Scotch broom
Digitalis purpurea	Common foxglove
Galium trifidum	Small bedstraw
Gaultheria shallon	Salal
Grass spp.	NA
Holcus lanatus	Common velvetgrass
Hypochaeris radicata	Hairy cat's-ear
Juncus effusus	Common rush
Lotus purshianus	Spanish clover
Madia sativa	Chilean tarweed
Mycelis muralis	Wall lettuce
Polystichum munitum	Swordfern
Pseudotsuga menziesii	Douglas-fir
Pteridium aquilinum	Bracken fern
Ranunculus uncinatus	Little buttercup
Rosa gymnocarpa	Baldhip rose
Rubus discolour	Himalayan blackberry
Rubus leucodermis	Black raspberry
Rubus ursinus	Trailing blackberry
Rumex acetosa	Common sorrel
Senecio sylvaticus	Wood groundsel
Thuja plicata	Western redcedar
Trifolium repens	White clover
Urtica dioica	Stinging nettle
Verbascum thapsus	Mullein
Vicia sativa	Common vetch
Species 17	NA
Species 49	NA
Species 57	NA
Fungus sp.	NA

Table 11. Percent Cover in Quadrat 1, Polygon 3

(*location: 0E, 14N; photo # 9662*)

Species	*% Cover*
Cirsium vulgare	8
Grass spp.	5
Holcus lanatus	40
Hypochaeris radicata	5
Lotus purshianus	<1
Rubus ursinus	1
Rumex acetosa	5
Trifolium repens	2
Verbascum thapsus	1
Vicia sativa	1
Species 17	1
Species 57	1
TOTAL	98
Woody debris	0
Barren soil	2

Table 12. Percent Cover in Quadrat 2, Polygon 3

(*location: -5E, 1N; photo # 9663*)

Species	*% Cover*
Gaultheria shallon	40
Holcus lanatus	25
Hypochaeris radicata	4
Mycelis muralis	10
Pseudotsuga menziesii	4
Rosa gymnocarpa	<1
Thuja plicata	<1
Vicia sativa	1
TOTAL	90
Woody debris	3
Barren soil	7

Table 13. Percent Cover in Quadrat 3, Polygon 3

(*location: -18E, 39N; photo # 9664*)

Species	*% Cover*
***Aster* sp.**	1
Cirsium arvense	1
Grass spp.	10
Holcus lanatus	40
Juncus effusus	35
Pteridium aquilinum	30
Ranunculus uncinatus	<1
Rubus leucodermis	2
Urtica dioica	<1
TOTAL	99
Woody debris	10
Barren soil	1

6.2.2 Reference site: **VEGETATION**

The vegetation assessment results for Reference Site 1 are indicated in table 14.

Table 14. Percent Cover Per Vegetation Stratum in the Reference Site

Strata	*Latin Name*	*Common Name*	*% Cover*	*Notes*
Trees	*Abies grandis*	Grand fir	7	
	Acer macrophyllum	Bigleaf maple	3	
	Alnus rubra	Red alder	15	
	Pseudotsuga menziesii	Douglas-fir	30	

	Thuja plicata	Western redcedar	10	
	TOTAL		**60**	
Shrubs	*Alnus rubra*	Red alder	3	
	Cytisus scoparius	Scotch broom	<1	Near the edge of the road
	Gaultheria shallon	Salal	40	
	Pseudotsuga menziesii	Douglas-fir	10	
	Rubus spectabilis	Salmonberry	9	
	Rubus ursinus	Trailing blackberry	5	
	Thuja plicata	Western redcedar	25	
	Vaccinium parviflorum	Red huckleberry	2	
	TOTAL		**75**	
Herbs	*Asplenium viride*	Green spleenwort	<1	
	Carex sp.	Sedge sp.	3	Species 61 (*Carex aquatilis*?)
	Polystichum munitum	Swordfern	50	
	Pteridium aquilinum	Bracken fern	1	
	TOTAL		**50**	
Bryophytes	*Eurhynchium oreganum*	Oregon beaked-moss	10	
	Other moss spp.	NA	15	
	TOTAL		**25**	

6.2.3 Results: **SOILS**

Examining the soil profiles confirmed that the site had been previously levelled, with the presence of an organic matter enriched horizon at about 0.5m below the current soil surface near the wetland. This re-asserted the need for re-contouring the slope of this area in order to ameliorate surface drainage.

The soil analysis results of the Mill Site and of the two reference sites are combined in the following tables in order to facilitate comparison.

Soil texture

Table 15 presents the laboratory results for the soil particle (texture) analysis obtained with the Bouyoucos Hydrometer Method.

Table 15. Mill Site Laboratory Soil Particle Analysis

Location	*Coordinates*	*% Silt and Clay*	*% Clay*	*% Sand*	*Texture Triangle**
P1 (0-5)	30E-10N	21	11	80	Loamy sand, edge of sandy loam
P2 (20-40)	10E-16N	41	21	60	Sandy clay loam
P2 (40-bottom)	10E-16N	53	30	48	Clay loam
P2 (40-bottom)	10E-16N	49	27	52	Sandy clay loam, close to loam
P3 (10-70)	10E-1,8N	17	12	84	Loamy sand
R1 (20-30)	NA	47	26	54	Sandy clay loam
Control	NA	74	31	27	Clay loam
Blank (2%)	NA	0	0	0	NA

* from BCMFR & BCMOE (2010)

Bulk Density & Compaction

Table 16 presents the bulk density results for the Mill Site and the reference sites. I indicated the texture from the laboratory results when available (from Table 15), and otherwise from the hand-texturing assessments.

Table 16. Bulk density of Mill Site and Reference Sites Samples, Including the Modified Clod Results

***Site Coordinates** (mE-mN)*	***Depth Range** (cm From Surface)*	***Bulk Density** (g/cm3)*	***Texture** (For Interpretation)*	***Notes***
10E-0N	0-4	**1.49**	Loamy sand	
10E-0N	5-9	**1.43**	Loamy sand	
10E-5N	0-4	**1.62**	Loamy sand	
10E-5N	6-11	**1.48**	Loamy sand	
10E-10N	0-7	**0.91**	Sandy clay loam	High % organic matter, explaining lower BD
10E-15N	0-5	**1.35**	Sandy clay loam	

10E-15N	6-11	**1.43**	Sandy clay loam	
10E-20N	0-5	**1.28**	Clay loam	
10E-20N	4-9	**1.63**	Clay loam	
C1*	0-10	**1.54**	Clay loam	
C2	0-10	**2.17**	Clay loam	
C3	0-10	**1.86**	Clay loam	
R1**	5-10	**0.27**	Organic	Humus horizon
R1	10-20	**0.88**	Mixed organic/mineral	Interface of humus and mineral horizon
R1	10-20 (replicate)	**0.89**	Mixed organic/mineral	Interface of humus and mineral horizon
R1	20-30	**1.20**	Sandy clay loam	
R2	6-12	**0.20**	Organic	
R2	14-21	**0.69**	Mixed organic/mineral	Interface of humus and mineral horizon

*C1, C2 and C3 refer to the clod method used to measure bulk density**R1=Reference site 1, R2= Reference site 2

Soil chemistry

Table 17 presents the laboratory analysis results or pH, Ca, Fe, Mg, Mn, P, S, as well as available ammonium (NH_4-N) and nitrate (NO_3-N). Values of particular interest have been bolded in the table.

Table 17. Concentration in minerals, available nitrogen (NH4-N and NO3-N), and pH of Mill Site and Reference Site Soil Samples

Site	*Depth Range (cm from Surface)*	*Coordinates (X,Y) (mE,mN)*	*Ca (g/kg)*	*Fe (g/kg)*	*K (g/kg)*	*Mg (g/kg)*	*Mn (g/kg)*	*P (g/kg)*	*S (g/kg)*	*pH (CaCl2)*	*Available NH4-N (mg/kg)*	*Available NO3-N (mg/kg)*	*Notes*
P1*	(0-5)	30,10	6,18	18,02	1,19	5,31	0,65	0,93	0,19	5,03	2,09	0,19	
P1	(43-55)	30,10	8,63	19,38	1,32	4,87	1,45	0,87	0,44	5,06	2,12	**29,04**	Original soil surface, humus
P2	(0-15)	10,16	8,21	21,90	1,14	6,26	1,20	1,15	0,53	4,82	2,36	0,41	
P2	(15-20)	10,16	4,95	18,53	1,13	5,35	0,61	0,54	0,26	4,73	4,29	**13,44**	Original soil surface, humus

P2	(20-40)	10,16	4,10	22,74	1,13	8,17	0,39	0,17	**0,06**	4,66	**48,79**	8,67	Waterlogging, reducing conditions and high clay = high $NH4^+$
P2	(40-bottom)	10,16	4,60	30,23	1,58	9,42	0,47	0,18	**0,06**	4,54	**32,33**	<0.01	Waterlogging, reducing conditions and high clay = high $NH4^+$
P2	(40-bottom)	10,16	4,44	30,69	1,51	9,32	0,47	0,18	**0,06**		**31,32**	0,11	Waterlogging, reducing conditions = high $NH4^+$
P3	(0-9)	10, 1.8	6,17	19,38	0,95	5,24	1,17	1,15	0,17	5,15	1,54	2,30	
P3	(10-70)	10, 1.8	4,60	16,94	0,78	5,78	0,40	0,39	0,08	5,21	0,47	3,62	
R1	(10-20)	NA	5,19	20,88	1,22	4,77	**0,21**	0,73	**1,19**	**3,74**	4,37	**54,45**	Humus, organic acids, low pH
R1	(20-30)	NA	3,54	18,07	0,61	5,02	**0,20**	0,13	0,13	4,42	1,61	3,03	
S1*	(10-20)	8.5, 38	**11,19**	27,24	2,19	8,19	0,81	**1,29**	0,79	5,22	2,89	**<0.01**	High Ca and P (related), low $NO3^-$ from immobilization
S2	(0-5)	8.5, 38	**10,04**	25,58	2,23	7,40	1,29	**1,25**	0,41	5,38	3,40	**0,08**	High Ca and P (related)), low $NO3^-$ from immobilization

*S1 and S2 refer to the samples obtained underneath the slash pile

6.3 Baseline and reference site assessments: **DISCUSSION**

The bulk density results indicated that at least some areas exceeded the critical values beyond which root development is strongly inhibited, that is, 1.45 Mg/m^3 in clay soil, and 1.85Mg/m^3 in loamy sand soil (Brady & Weil 2008).

The soil analyses indicated low available mineral nitrogen content. This is not surprising, considering that the LFH (litter, fermentation, humus) horizon was either buried or scraped off from the site when the previous owner levelled it, and that virtually no vegetative cover had had the chance to re-develop. Both mineral and organic forms of nitrogen are strongly associated with humidified organic matter in soils (Brady & Weil 2008). This was clearly visible in the much higher nitrate values (by about one order of magnitude) obtained for the horizons we identified as buried LFH and Ah. Moreover, the presence of such large amount of un-decomposed Western redcedar debris seems to have resulted in the immobilization of the already little amount of nitrogen available, as indicated by the extremely low values obtained for the samples taken underneath the slash piles. These results confirmed our decision to import a source of nitrogen onto the site, in the form of compost (see Restoration Process).

One of our suspicions prior to the soil analysis was that the soil underneath the slash piles could have been strongly acidified by the presence of such a large amount of Western cedar debris. The results, however, indicated pH levels comparable or higher for the soil sampled at the Mill Site, compared with Reference Site 1. In fact, the lowest pH value (3.74) obtained came from a sample taken in the humus layer of Reference Site 1, presumably resulting from centuries of generation of organic acids from the decomposing organic litter, causing severe leaching of the base cations.

The field and laboratory results concurred in indicating a soil texture gradient, from a loamy sand near the entrance road to a clay loam towards the middle of the site. This corroborates with the map of the British Columbia Soil Survey that I consulted (Green 1989), and proved critical in selecting the microsites for the nursery plants that were brought to the Mill Site.

7. RESTORATION PROCESS

As part of the restoration process, we intervened on three main areas of the Mill Site: the central area, the experimental plot, and the wetland edge. The experimental plot is embedded within the matrix of the central area, and these two together formed this essence of this restoration project. They largely overlap with Polygon 1 on Figure 5, though the southern portion was left aside for use as road access and parking space. The eastern edge of Polygon 2 as well as Polygon 4 were included in the treatments of the central area. The wetland edge was the object of different restoration approach, seen as complementary to the intervention carried in the central area. It corresponds to Polygon 2 on Figure 5, though the reed canarygrass (*Phalaris arundinacea*) control was carried several meters beyond the boundary shown on that figure.

7.1 Restoration process:

METHODS

7.1.1 Site preparation

The GCA organized several work parties to transfer the salvageable cedar off-cuts to a different location on DL57 and to collect other mill refuses. One of the most important preparation phases for the site was to chip the substantial piles of mill off-cuts and small woody debris and transfer the chips to an off-site location. A tub grinder was used in combination with a fine filter to transform the woody debris into usable woodchips. These are temporarily stored in a small parking area to the southwest of the site, and they will be used as mulch on trails, camping sites, and distributed to community members for use in gardening projects. Importantly, we decided not to incorporate the cedar chips into the soil of the Mill Site itself, because we suspected that such a large quantity of cedar would have had a sterilizing effect on the soil.

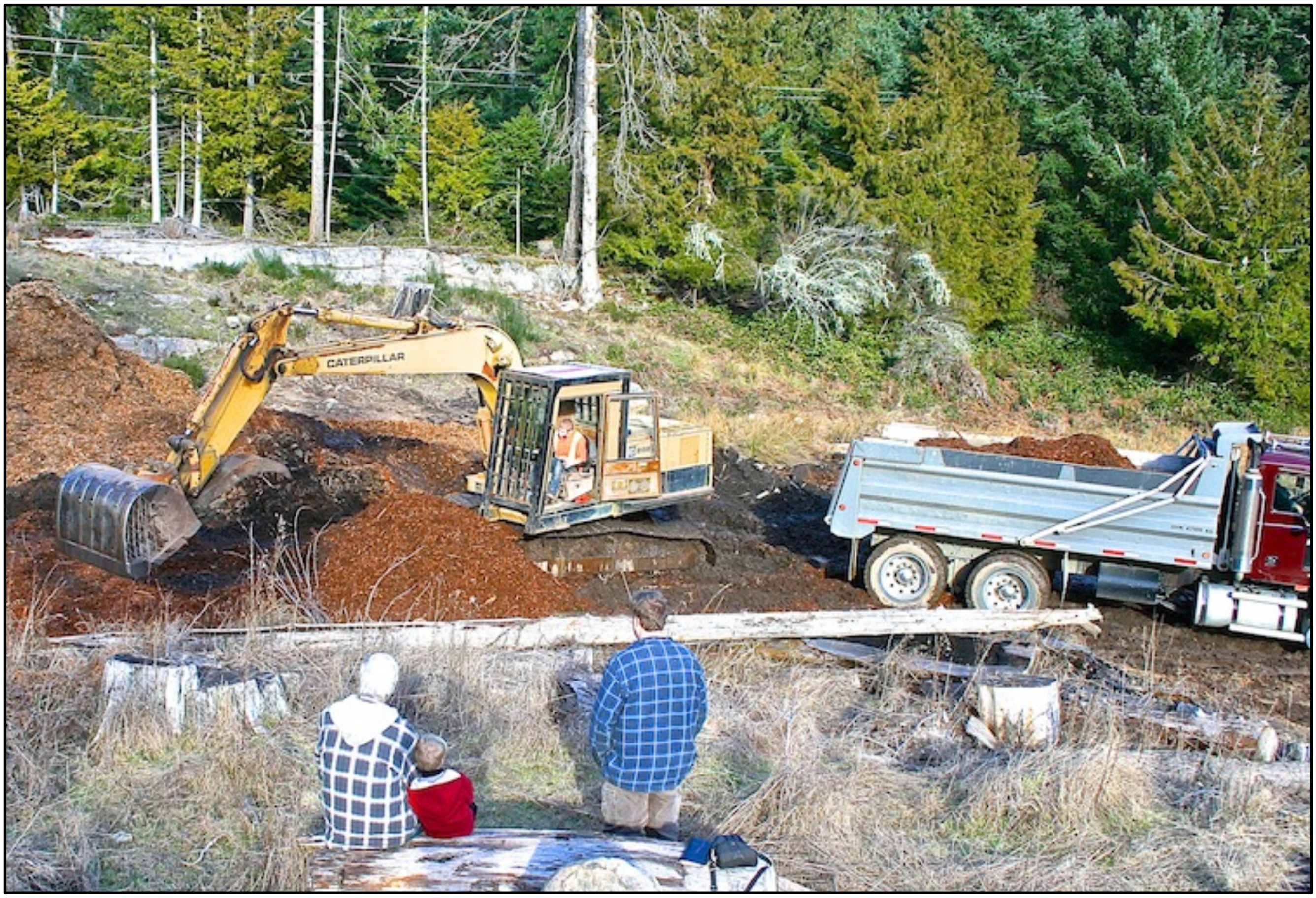

Figure 7. Restoring for posterity; excavator work never fails to impress, regardless of the generation (*Photo taken on February 14th, 2014*)

7.1.2 Forest litter salvaging and transplant

We organized a work party to salvage forest litter from a future mine expansion site located in a young secondary forest, containing both deciduous and coniferous stands. In total, 120 garbage bags were transferred to the Mill Site, each filled with about 50 liters of forest litter, for a total of 6000 liters, or $6m^3$. They contained roughly equal amounts of coniferous and deciduous forest litter. Part of the forest litter was manually pre-mixed in the first piles of woodchips that were brought to the site in order to initiate inoculation with microorganisms.

7.1.3 Permanent photopoint monitoring

Several permanent photopoint monitoring stations were established around the Mill Site. In this section, I report the procedures that were used for the first photo-monitoring phase of the wetland area, on November 25th, 2013. These are consistent with the procedures used for the other photopoint locations. Refer to the Appendix for a complete list of the equipment needed to establish a photopoint monitoring station.

Procedures

The tripod was installed just to the south of the wetland, on a site about 1m higher than the average wetland elevation in order to obtain an overlooking perspective. It was levelled and set at 1.36m above ground level (measured from the very top of the tripod perpendicularly to the ground). The GCA's camera (model Canon SX20) was installed on the tripod. The yellow graduated meter board was then placed in three locations (pushed into the ground until reaching the 0 mark). The meter board was positioned at exactly 10m (horizontally) from the center point of the tripod. The azimuth of the three locations (middle, left and right) was measured by stepping 2m away from the camera and aiming through the center of the camera with the compass. The values are reported in Table 18. Again, the declination used on the compass was 14°E, a mistake from my part as the actual declination used should have been 16.5°E[5]. The camera used was set on the Av mode with an F of 5.6. Importantly, it was set on a 5 second timer mode to avoid movement and increase the quality of the image. Two photos were taken at each position and the unique photo numbers were recorded (Table 18). Four permanent rebar stakes were driven into the ground and labelled with pieces of yellow flagging tape, localizing the tripod and the three positions of the meter board. The coordinates of the tripod are 38.66mE, 11.76mN on the georeference grid.

Table 18. Azimuths and Photo Numbers for the First Phase of the Wetland Photopoint Monitoring

Position	*Azimuth (°)*	*Photo #*
Middle	1	136-3531/32
Left	316	136-3534/35
Right	51	136-3536/37

7.1.4 Slope re-contouring

Using a clean-up bucket on a Cat 315 excavator, Fred Stevens, owner of Stevens'

[5] NRC Magnetic Declination Calculator : URL http://geomag.nrcan.gc.ca/calc/mdcal-eng.php (accessed 02 March 2014); Mill Site coordinates used

Excavating, pulled back some of the filling material that had been transferred by the previous owner to level the upper edge of the wetland. It was brought back to the extraction area, a small cut bank on the south-eastern side of Polygon 3.

7.1.5 De-compaction

The compacted areas of the site, corresponding to the central area and a small section of the skid trail going north from the site, were de-compacted to a depth of 1m by Fred Stevens, using a Cat 315 excavator and following the 'rough and loose' method described in Polster (2013). He reached the edge of Polygon 3 to the west, and the edge of the established common rush population along the wetland edge. The 'rough and loose' approach has the advantage of increasing the topographic heterogeneity of a site, greatly improving infiltration and creating a multitude of microsites that can support a diverse array of plant species (ibid). The method consisted in using the digging bucket of the excavator to open holes in the soil, releasing half the soil back in the holes, and half in between, spacing the excavations by half a bucket width. Also, care was taken when excavating the holes to shatter the material between them. The process of making the holes and releasing the soil was continued until the reasonable operating swing of the excavator was reached. Fred Stevens then backed up with the excavator by about the width of a hole, and repeated the process, making sure to line up the holes in the new row with the space between the holes and mounds on the previous row. This resulted in a 'rough and loose' configuration, or a mosaic of mounds and depressions throughout the surface of the site.

Figure 8. **(a)** Rough and loose de-compaction, with the excavator bucket reaching about 1m in depth; **(b)** 2m-deep pit dug for anchoring a snag in the ground. Considering that pools of water were covering the soil surface, the absence of water in the excavation confirms that there was very little subsurface percolation, probably due to a combination of anthropogenic surface compaction and the natural occurrence of a restricting layer, the blue clay horizon visible at mid depth; **(c)** a 15m-tall snag being installed in the ground; **(d)** proud excavator operator Fred Stevens, 'heroe' of the day (*photos taken on March 4th, 2014*)

7.1.6 Re-building soil organic matter: WOODCHIPS

Fred Stevens and his employees delivered eight truckloads of medium grade (3-6cm length) red alder woodchips and three truckloads of coarse grade (5-15cm length) mixed woodchips to the Mill Site. The later mixture was composed of Douglas-fir, bigleaf maple (*Acer macrophyllum*), red alder, bitter cherry (*Prunus emarginata*), arbutus, and trace amounts of Western redcedar. Each truckload contained 20 cubic yard, for a total of 220 cubic yards (167m^3) of woodchips.

The astonishingly skilled Fred Stevens was able to spread the woodchips on the loosened soil surface with the excavator, immediately following the de-compaction of each sub-section, starting from the north of the site and progressing gradually towards the entrance road. The entire operation was largely completed in one day. The woodchips were brought to the site for three main reasons. First, their decomposition will contribute to re-building the soil organic matter content while adding some nutrients. Second, they will provide physical protection to the soil by absorbing raindrop impact and by moderating temperatures. Third, the thick mulch layer, averaging 8 to 10cm in depth, will hopefully mitigate the colonization by invasive species such as Scotch broom.

7.1.7 Coarse woody debris and snags

A large pile of logs and stumps formed part of the Mill Site legacy. It was purposefully kept on the site and dispersed by Fred Stevens during the de-compaction treatment, immediately after the woodchips, and using the same approach. In addition, three logs were inserted vertically in the ground to emulate snags.

7.1.8 Re-building the pool of nutrients: SOIL AMENDMENT

About three cubic yard (2.3m^3) of composted green waste, containing 1.5% of nitrogen, were delivered and used on the site. The compost used was the Premium Mix kind (75%: compost, 25%: sand), purchased from Peninsula Landscape Supplies, located on the Lower Mainland. About three liters were added with each plant, primarily to supply nitrogen in a slow-release form, but also to nourish the soil microorganisms and plants with other macro and microelements and ameliorate the soil physical properties (e.g. improved aeration and moisture retention capacity). The compost was added directly into the holes around the root ball of each plant. A broadcast treatment would have resulted in more nitrogen losses and could have stimulated the growth of nitrogen-loving invasive species, such as reed canarygrass (*Phalaris arundinaceae*) (Tu 2004). Also, the use of a quick-release source of nitrogen (i.e. mineral fertilizer) could have resulted in significant leaching of the nutrient into the wetland area, where the reed canarygrass is found.

7.1.9 Re-vegetating

Nursery stock

A total of 426 plants were brought from the Galiano Conservancy Association Native Plant Nursery, including 187 trees, 170 shrubs and 69 herbs. These numbers include the vegetation used in the wetland and experimental areas. The participatory planting took place on ten different days, one in the fall of 2013 for the wetland area, the rest during late winter and early spring of 2014. In most cases, we individually positioned the containerized nursery plants on suitable microsites prior to the planting activities. The main habitat considerations were drainage, nutrient regimes and aspect. Species and quantities are indicated in Table 23, in the Results section. Details concerning sizes of container and costs can be found in the Appendix.

Salvaged plants

Fred Stevens brought a full truckload of salvaged swordferns (*Polystichum munitum*) to the Mill Site, totalling about 30 large-sized ferns with a root ball of roughly 50cm in diameter. About half of them were subdivided with spades before getting planted. The salvaged material also enclosed a few salal seedlings and a significant amount of forest litter, which certainly contained countless plant propagules and soil microorganisms. One salvaged swordfern was added to each experimental cell (see below).

7.1.10 Experimental area

Because of the incredible opportunity we had at hand, and because contributing to the development of ecological restoration science was one of the goals, we embedded an experimental area within the restoration project to determine the differential effect mature compost and forest litter inoculum would have on the recovery of the soil health and concomitantly on plant growth. The experimental area was de-compacted and covered with the same amount of woodchips as the rest of the site.

We hypothesized that inoculating the woodchips with forest litter would stimulate the reconstitution of a healthy soil foodweb, through the interplay of several microorganism-mediated processes that would accelerate the cycling of nutrients present in the woodchips and provide symbiotic relationships, such as mycorrhizal associations with fungi, that would favour plant establishment, growth and overall health. This effect could be especially pronounced given the low nutrient conditions found in the un-amended soil. Furthermore, we wanted to determine whether young (~50 yr.) versus mature (~250 yr.) forest inoculums would differ in the effect they would have on soil and vegetation. This stems from the understanding that microbial assemblages tend to greatly differ between forests of different developmental stages, and we hypothesized that this difference would in turn alter the effect the inoculums can have on soil revitalization. A compost treatment containing 1.5% nitrogen was included as a treatment in the experimental design, in order to determine which would be more beneficial to the site in the short term, as well as over time. We also incorporated three control cells, in which neither compost nor forest inoculum was added to the soil.

*Experimental area: **TREATMENTS***

Three treatments and one control, comprising three replicates each, were included in the experimental design, as shown in Table 19.

Table 19. Treatments Included in the Experimental Design

Treatment	*Code*	*Description*
Control	C	Planting with no additional inoculation or amendment (i.e. no forest litter or compost)
Young inoculum	Y	Raking in shallowly and homogeneously young forest inoculum (1:1 conifer & deciduous ratio) over the entire cell prior to planting
Mature inoculum	M	Raking in shallowly and homogeneously mature forest inoculum over the entire cell prior to planting
Compost amendment	A	Amending the individual plants with mature compost, adding 3 liters of compost in the ground with each plant (using identical nursery containers for consistency)

*Experimental area: **LAYOUT***

The design includes 12 cells of 5 x 4m (20m^2 each), for a total of 240m^2, or 0.024ha. The treatments were attributed to cells so that they would be evenly distributed throughout the experimental area, to account for the gradient in soil properties (change in soil texture, hence in nutrient and moisture regimes). For example, no two adjacent cells received the same treatment. The small number of replicates did not allow randomizing the design completely. A one-meter buffer zone, in which no forest inoculum was added, was left between each row and column, as well as around the entire experimental area. A compass, a measuring tape and 24 re-bar stakes were used to establish the outer perimeter, and a string was used to delineate the cells and buffer zones, by running the string along the sides of each row and column. The columns are oriented on a 10° axis (true north), and the rows are perpendicular (compass set to a of 16.5°). The layout of the experimental area is depicted in Figure 19.

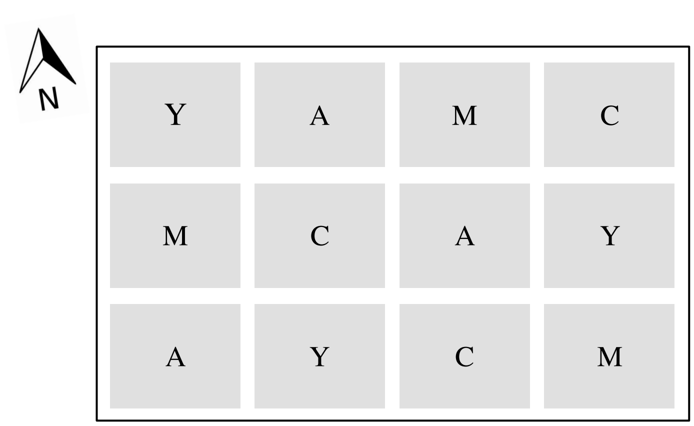

Figure 9. Layout of the experimental area: cells are depicted in gray and buffer zones in white. Y= young inoculum; A= compost amendment; M= mature inoculum; C= control

*Experimental area: **PLANTING***

A group of students from the Galiano Community School, accompanied by teachers and parents, came to the Mill Site to help with the planting of the experimental area on March 11th, 2014. We explained to the children in simple terms the rationale behind this long-term scientific experiment they were contributing to establish. We also demonstrated the correct way of putting the plants in the ground. The class was subdivided into groups, each one planting a column under the supervision of at least one adult (Figure 10). Each treatment globally included the same selection and number of species, but we voluntarily allowed for variation between cells, in part to be able to select the appropriate microhabitat for each species within the treatment area. For example, salal was systematically planted on well-drained microsites located on the north aspect of CWD or small mounds. Prior to the activity, we had placed each containerized plant on an appropriate microsite, and we re-planted about 50% of them during a quality control session immediately after the group activity. Species and quantities are reported in Table 20.

Table 20. Species and Quantities Included in the Experimental Area

Species Name (Latin)	*Species Name (common)*	*Qty. Per Treatment*	***Total***
Abies grandis	Grand fir	1	4
Alnus rubra	Red alder	3	12
Pseudotsuga menziesii	Douglas-fir	2	8
Thuja plicata	Western redcedar	1	4
Tsuga heterophylla	Western hemlock	1	4
TREES		**8**	**32**
Gaultheria shallon	Salal	8	32
Holodiscus discolor	Ocean spray	1	4
Mahonia nervosa	Dull Oregon-grape	1	4
Polystichum munitum	Swordfern	9*	36
Symphoricarpos albus	Snowberry	1	4
Vaccinium ovatum	Evergreen huckleberry	1	4
SHRUBS & HERBS		**18**	**72**
GRAND TOTAL		**29**	**116**

*Three of these are salvaged specimens brought by Fred Stevens

Figure 10. Kids and adults at work in the experimental area. *Photo taken on March 11th, 2014*

7.1.11 Herbivory protection

Deer being very abundant on Galiano Island, protecting the plants from browsing was seen as essential for the survival of the plants, minimally during the establishment phase.

Caging

The majority (>80%) of the plants brought from the nursery were individually caged with 1.3m-high cylinders of 5-cm metal mesh, held in place with two 60cm-long rebar pins or cedar stakes. The cages were assembled during several work parties throughout the fall and winter (Table 25). Two diameters of cage were used, 40 and 60cm, the later being used for larger saplings, most often Western redcedar. Dull Oregon-grapes were not caged, as they do not constitute a preferred deer browse.

Fencing

A seven-feet black plastic mesh deer fence was installed around the perimeter of the experimental area, with 2 x 2-inch cedar poles positionned every 10 feet. The corners were braced and the tops joined with 1 x 2-inch cedar poles. The installation was completed during the week of March 24th, 2014.

Figure 11. Foreground: individual 1.3m-high cages installed around the nursery plants; background: 7-feet tall deer exclosure installed around the experimental plot. Note that the black deer mesh is not visible on the photo.

7.1.12 Restoring the wetland

Reed Canarygrass Control

While conducting the baseline assessment, I realized that reed canarygrass (*Phalaris arundinaceae*) was present around the edge of the wetland area, though its population was relatively contained still, with about 20% cover in the lower part and <1% cover in the upper part. The aggressive behaviour of this invasive grass species being well documented, and the suppression efforts often leading to unsatisfactory results in completely dominated ecosystems (Kim et al. 2006), we decided to act pro-actively and try to prevent the species from becoming dominant in this part of the site.

Removal

In the upper part of the wetland, where the watertable reaches the soil surface only briefly every winter, only two small patches of reed canarygrass were localized, each occupying 0.25m^2. Given the small size of the patches and the propitious soil conditions, we decided to remove them by hand digging on November 10th, 2013. The watertable was then 15-25cm below the soil surface, and the soil was very moist and easily crumbled apart. The clumps were carefully dugout and loosened using pitchforks, and clods were dismantled by hand to remove every piece of rhizome that could be detected. The creeping underground stems were radiating on average by one meter away from the above ground clump of reed canarygrass. We did not use spades and shovels, as these would have sectioned the rhizomes and more fragments would have been inevitably left behind. The material removed was stored in garbage bags and burnt by the entrance road several weeks later. These two patches of exposed soil were planted and sheet mulched during a planting work party with the Galiano Community School, on November 27th, 2013.

Suppressing and out-shading

In the lower part of the wetland, where the watertable is at or slightly above the soil surface for a few weeks to several months every wet season, the reed canarygrass population currently has a cover of approximately 20%. We did not consider hand pulling as an option, because of the amount of soil disturbance it would have caused, and because thoroughly removing all the rhizomes was likely not possible given the size of the patch and the wetness of the soil. Therefore, a combination of live staking and sheet mulching was used to try to suppress the reed canarygrass population on its upper fringe, and prevent its encroachment towards the upper side of the wetland by creating a shade barrier. Live staking with willows has been found to reduce the biomass of reed canarygrass by 68% after two years in a wetland edge previously dominated by the species, with a 60cm-spacing of the live stakes being most effective (Kim et al. 2006).

Being unable to locate enough willows from which to harvest cuttings, I collected material from several species known to have good or excellent rooting ability when used as live stakes, largely basing myself on the results presented in Darris (2002). On average, the cuttings were 1m long and had a diameter varying between 2 and 4cm. Smaller stems are not recommended for live propagation directly in the field, as their carbohydrate reserves might not be sufficient to sustain the plants while the root system gets established (D.F. Polster, personal communication). I followed the guidelines for collecting native plant propagation material described in GOERT (2004), prioritizing populations located directly on or near DL57, given that the population or the individual in question was deemed vigorous enough to withstand the harvest. While I was conscious of the fact that including several genotypes is ideal, I had to be strategic and collect in function of the availability of each species. For example, all red-osier dogwood (*Cornus sericea*) stakes came from an abundantly coppicing individual located within the GCA's nursery. I salvaged the portions of the plant parts that were too small to be used as live stakes and struck them in the propagation boxes of the nursery, contributing to the inventory of hardwood cuttings. A total of 71 live stakes were planted on the Mill Site, 30 of which were used to create the shade barrier in the wetland area. The others were scattered in the upper edge of the wetland, as well as in wet areas of the main site. Table 24 reports the species and quantities brought to the site. No rooting hormone was used, partly because there is little evidence that it would have produced any positive outcome, and also because the soil was completely saturated when the cuttings were inserted. Ideally, live stakes are inserted to 75-80% of their length into the ground to maximize their chances of survival (Polster 2011). This ensures that a balanced root to shoot ratio is obtained, and that the roots can still easily access the watertable during the dry summer months (ibid). Unfortunately, I was only able to insert the stakes used in the shade barrier to an average of 50% of their length into the ground, partly because I did not use the optimal tools and techniques, and partly because of the presence of a hardpan layer 40-50cm below the wetland surface. The stakes inserted in the main section of the Mill Site, however, were optimally installed.

For the shade barrier, the stakes were inserted following a diamond pattern, with a spacing of 60cm (Figure 12). The area was then sheet mulched with a single layer of overlapping pieces of corrugated cardboard covered with about 8cm of coarse woodchips, composed of a mixture of red alder, Douglas-fir, bigleaf maple, bitter cherry and arbutus (Figure 12). This mulch layer is expected to play two roles. First, we predict that it will directly suppress the reed canarygrass underneath by blocking the light and forming a physical barrier. Second, adding carbon to soils is believed to reduce the competitive advantage of reed canarygrass by reducing the amount of available nitrogen, typically favouring native species over the invader (Tu 2004). These effects will hopefully provide a competitive advantage to the species used as live stakes and allow for a rapid development of a canopy.

Only a minority (< 20%) of the live stakes used in the project have thus far been protected from deer browsing with the cylindrical cages, and it would certainly be advisable to increase this proportion. Also, incrementally extending the shade barrier into the reed canarygrass population by incorporating more live stakes (preferably including a higher proportion of willows in the future) would certainly contribute to controlling the spread of the species. It must be remembered however that reed canarygrass is wide spread on Galiano Island, and extensively present on DL57, especially along ditches near the Cove. Hence, the propagule pressure will remain strong, and continued efforts might be necessary to prevent it from dominating the wetland, at least until a well-developed canopy is established.

Figure 12. An attempt at controlling the spread of reed canarygrass by creating a shade barrier with live stakes and sheet mulching; reed canarygrass population in the background. (a) Corrugated cardboard layer; (b) 8-10cm-thick mixed woodchip layer laid on top of the cardboard. *Photos taken on March 4th and 5th, 2014*

*Restoring the wetland: **ADVANCING SUCCESSION***

The upper part of the wetland edge, being largely dominated by agronomic grasses, was the object of a planting activity that aimed at accelerating the establishment of a range of early and mid-successional species. A group of elementary-grade students from the Galiano Community School came to the Mill Site on November 27th, 2013. Under the supervision of GCA staff members, the children were given the task to locate appropriate microsites for the individual species and plant them in several clusters, using habitat cards that had been created for the activity. The hummocky terrain of this area proved perfect for introducing the concept of microsite, with extreme differences in moisture being evident between the top and bottom of the hummocks. A sheet mulch layer, consisting of pieces of corrugated cardboard overlaid with dead bigleaf maple leaves and red alder woodchips, was created around the majority (>80%) of the plants that were put in the ground that day. We installed this mulch layer with the intention of suppressing the grasses and allowing the nursery plants to get established. We hope to initiate a rapid development of a canopy that will out-shade the grasses. Finally, we hand-dispersed CWD pieces throughout the area that had been planted, to increase structural complexity and ecological function. Species and quantities are reported in Table 21.

Table 21. Species and Quantities Planted in the Upper Wetland Edge on November 27th, 2013

Species (Latin name)	1gal	2gal	5gal	TOTAL
Abies grandis		2		2
Acer macrophyllum	1	1		2
Alnus rubra	4			4
Pseudotsuga menziesii		1		1
Thuja plicata		3		3
Tsuga heterophylla	1			1
TREES TOTAL				**13**
Cornus stolonifera	4	1		5
Crataegus douglasii		3		3
Oemleria ceraciformis	3			3
Philadelphus lewisii	2			2
Physocarpus capitatus	3			3
Rubus parviflorus	2			2
Rubus spectabilis		2	1	3
Salix lucida	2			2
Sambucus racemosa	1			1
Viburnum edule	1			1
SHRUBS TOTAL				**26**
Polystichum munitum	43	15		58
HERB TOTAL				**58**
GRAND TOTAL				**96**

7.2 Restoration process: RESULTS

This section summarizes the key results of the restoration process in terms of photopoint monitoring, soil, CWD, vegetation, and participation.

7.2.1 Photopoint Monitoring

Figure 13 displays a repeat series of two photos taken before and after the site clean-up, de-compaction, spreading of woodchips, and incorporation of CWD and snags. These photos do not constitute the official repeat photopoint pictures that will be used for the monitoring, explaining the slight deviation in angle.

7.2.2 Soils

We have not repeated bulk density measurements since the site was de-compacted. However, it appears reasonable to assume that the treatment was effective. Also, signs of improved infiltration and subsurface drainage became visible almost immediately following the completion of the treatments.

7.2.3 Estimating CWD volume

I estimated the coarse woody debris volume per surface area using a circular fixed area plot, the 'sausage' method, described in Gove and Van Deusen (2011). According to this procedure, I included all pieces of wood whose longitudinal central axis was intercepted by the plot cord, including the whole length, even if only a fraction fell within the plot. I only considered pieces of an average diameter of at least 9cm. Since many of the debris were remnants of planks with non-cylindrical shapes (~20% of pieces), I had to visually estimate their circular equivalent in order to record measurements and include them in the calculation. The average diameter and the full length were recorded. Three plots were conducted, their centers being located approximately 15m from each other (i.e. 15 large foot steps). A 3.99m tree planting plot cord was used, yielding plots of $50m^2$. Table 22 summarizes the measurements and calculations. The average volume density is $106.3m^3 \cdot ha^{-1}$, though there appears to be significant variation on the site.

Table 22. Volume of Coarse Woody Debris Per Surface Area Added on the Restored Site

Plot #	*Number of Pieces / $50m^2$*	*Volume (m^3) of CWD / $50m^2$*	*Volume ($m^3 \cdot ha^{-1}$)*
1	14	0.7847	156.9
2	19	0.2543	50.86
3	17	0.5551	111.0
AVERAGE	17	0.5314	106.3

Figure 13. Approximate repeat photographs taken on (**a**) September 22nd, 2013 and (**b**) March 5th, 2014. The three snags are visible on the bottom photograph. Note that these photos are not the official photopoint monitoring ones, but personal picture I took during the project, explaining the slight deviation in angle.

7.2.4 Vegetation

Table 23 presents the total number of plants that were brought from the Galiano Conservancy Native Plant Nursery. The species are sub-divided into three categories: trees, shrubs and herbs. The total number and species of live stakes used at the Mill Site are reported in Table 24.

Table 23. Species and Quantities of Plants Brought from the GCA Native Plant Nursery *(March 14th, 2014)*

Category	*Latin Name*	*Common Name*	*Quantity*
Trees	*Abies grandis*	Grand fir	24
	Acer macrophyllum	Bigleaf maple	6
	Alnus rubra	Red alder	72
	Arbutus menziesii	Arbutus	2
	Pseudotsuga menziesii	Douglas-fir	46
	Thuja plicata	Red cedar	31
	Tsuga heterophylla	Western hemlock	6
Trees total			**187**
Shrubs	*Amelanchier alnifolia*	Saskatoon berry	6
	Cornus sericea	Red osier dogwood	5
	Crataegus douglasii	Black hawthorn	7
	Gaultheria shallon	Salal	44
	Holodiscus discolor	Oceanspray	12
	Mahonia nervosa	Dull Oregon grape	14
	Oemleria cerasiformis	Indian-plum	3
	Philedelphus lewisii	Mockorange	4
	Physocarpus capitatus	Pacific ninebark	4
	Rosa gymnocarpa	Baldhip rose	7
	Rosa nootkana	Nootka rose	18
	Rubus parviflorum	Thimbleberry	5
	Rubus spectabilis	Salmonberry	19
	Salix lucida	Pacific willow	4
	Sambucus racemosa	Red elderberry	1
	Symphorocarpus albus	Snowberry	4
	Vaccinium ovatum	Evergreen huckleberry	4
	Vaccinium parviflorum	Red huckleberry	5
	Viburnum edule	Highbush cranberry	4

Shrubs total			**170**
Herbs	Polystichum munitum	Swordfern	69
Herb total			**69**
GRAND TOTAL			**426**

Table 24. Species and Quantities of Live Stakes Used at the Mill Site

Species	***Harvest Location***						***Total per Species***
	DL57		***Nursery***		***Other***		
	Qty.	***Location***	***Qty.***	***Location***	***Qty.***	***Location***	
Cornus sericea			21	In nursery			21
Philadelphus lewisii			3	In nursery			3
Physocarpus capitatus	11	Near Cove			5	Medical Clinic	16
Salix scouleriana	3	Near Cove					3
Sambucus racemosa	4	Near house at Cove	1	Across the road	15	Keith's house and Porlier Pass Rd. south of DL57	20
Symphoricarpos albus			3	In nursery	5	Medical Clinic	8
GRAND TOTAL							**71**

7.2.5 Participation

Table 25 summarizes participation to the key events of the restoration project. The community work party events are annotated with an asterisk. I fall within the category of 'student intern'. So far, over 150 volunteer-days have been spent on the project, a day consisting of at least 2-3 hours spent on the site carrying restoration activities.

Table 25. Timeline and Summary of Participation to Major Events (Past and Future)

Activity	*Date (dd/mm/yyyy)*	*Participants*	*Staff*	*Kids*	*Teachers / Parents*	*Volunteers*	*Student Interns*	*TOTAL Participants*
Initial proposal and fundraising	2012-2013	Keith Erickson GCA staff						
*Initial chipping	July 2013	Fred Stevens GCA staff Volunteers	2			5		7
*Site clean-up work party	06/10/2013	GCA staff Volunteers Student intern	1			6	1	8
Baseline assessment	Sept.-Oct. 2013	Student intern						
Reference site assessment	Sept.-Oct. 2013	Student intern						
Soil and CWD activity with school group	28/10/2013	GCA staff Student intern Galiano Community School	4	16	2		1	23
*Cage building work party	03/11/2013	GCA staff Volunteers	3			3		6
*Forest litter salvaging and clean-up work party	09-10/11/2013	GCA staff Student intern Volunteers	4			4	1	9
*Wetland planting work party with the school	27/11/2013	GCA staff Galiano Community School	5	27	9	1		42
Final chipping & transfer	Feb. 2014	Fred Stevens Steven's Excavating staff Keith Erickson						
Alder woodchips delivery	20/02/2014	Fred Stevens Steven's Excavating staff						
Slope re-contouring, site de-compaction, woodchip and CWD spreading, snag installation, mixed woodchip delivery	03 to 05/03/2014	Fred Stevens Keith Erickson Student intern						
*Planting + caging work party	10/03/2014	GCA staff Volunteers	3			6		9

*Experimental area work party with the school	11/03/2014	GCA staff Galiano Community School Student interns	4	28	10		2	44
*Planting and caging work party	14/03/2014	GCA staff Volunteers Student interns	3			3	2	8
*Planting, live staking and caging work party	15/03/2014	GCA staff Volunteers Student interns	2			2	2	6
*Planting, caging and wrap-up	March 24 – 28 2014	GCA staff Student Interns Volunteers	3			2	1	6
*Trail building	TBA							
*Kiosk building	TBA							
*Experimental area fence building	24/03/2014	GCA staff Student intern	3				1	4
Community celebration	08/05/2014	GCA staff GCA Board of directors Galiano community Galiano Community School Student interns Donors						
Monitoring + adaptive management	2014-2015…	GCA staff Student interns						

7.3 Restoration process: DISCUSSION

7.3.1 De-compaction

The mounds and depressions created on the Mill Site have an amplitude averaging 0.3-0.4m, considerably less than the 1m usually prescribed for a ‘rough and loose’ de-compaction (D.F. Polster, personal communication). Still, we are confident that the treatment was effective in achieving the desired goals of reduced bulk density and increased topographic heterogeneity, and that it will make a significant contribution to improving infiltration and drainage. Also, the ‘smoother’ surface was more compatible with the participatory planting activities that we organized, especially with the Galiano Community School.

By re-contouring a small section of the site and dealing with soil compaction, we are hoping to re-establish the soil-water relations of the site and contribute to restoring hydrological patterns for DL57 in general. Perhaps most importantly, improved hydrological functions will certainly enhance the growing conditions for the vegetation throughout the year, providing better drainage during the wet months and increased water holding capacity during the dry summer months.

7.3.2 Soil organic matter

"Most soil recovery mechanisms are biologically mediated" *(Seybold et al. 1999)*

Importing such a large amount of organic matter, in the form of woodchips, on the Mill Site was seen as critical for re-establishing the structural and functional integrity of the soil in the longer term. Indeed, organic matter is the single most important factor contributing to soil aggregation, a characteristic of a well structured and healthy soil (Brady & Weil 2008).

A network of pores is found within and between aggregates and influences many of the soil properties, including air and water movement, and the activity of plant roots and soil organisms (ibid). Decomposed organic substances promote flocculation with silicate clays and iron and aluminum oxides, forming microaggregates (<0.25mm) (ibid). In addition, organic matter sustains the activity of soil organisms (e.g. burrowing organisms), which play critical roles in the formation and stability of soil macroaggregates and biopores (0.25-5mm) (ibid). In particular, fungal hyphae enmesh soil aggregates and exude glue-like compounds, such as glomalin, that effectively cement these macro-aggregates together (ibid). Lastly, organic matter has a low bulk density and a very high porosity (e.g. the bulk density of compost is 4Mg/m3), effectively lightening the soil (Brady & Weil 2008). In a sense, then, the organic matter can be seen as enhancing the ability of surface soils to resist future compaction (Seybold et al. 1999).

Also, applying organic matter onto the soil surface (i.e. mulching) reduces evaporative loss, increases moisture-holding capacity and moderates temperatures (Bulmer et al. 2002).

In addition to enhancing the soil physical and biological properties, the woodchip layer is seen as critical for limiting the colonization of the site by invasive species. This is especially important since the de-compacted soil will be more suitable to all plants, not just the native species we are trying to get established. By cleaning the site and improving the soil properties, we have re-opened many ecological niches, and mulching with woodchips is seen as a way to mitigate their colonization while the nursery plants are establishing and forming a canopy layer.

7.3.3 Nitrogen

Nutrient poor organic material, in particular woody waste with its C:N ratio, may lead to a temporary nitrogen depletion period in the soil as it becomes decayed by soil microorganisms, especially so when incorporated into the soil (Bulmer et al. 2007). This period may last a few months to a few years, and is likely to entail nitrogen deficiencies in plants if no adequate supply of nitrogen is available, especially for seedlings (Hallsby 1995). The most common symptom of nitrogen deficiency is leaf chlorosis (Brady & Weil 2008). This phenomenon, in combination with the initially low nitrogen status of the soil, is the reason why we decided to import compost on the site. Adding compost is known to mitigate this temporary nitrogen immobilization (Bulmer et al. 2002). Also, the inoculation with forest litter will hopefully accelerate decomposition and liberate the nitrogen contained in the woodchips more rapidly.

Certain plants, like members of the alder genus (*Alnus*), host a specialized group of bacteria in their root system, *Frankia*, which have the ability to fix atmospheric nitrogen into soluble forms that are available to plants, explaining why these species can thrive in low-nitrogen soils (Brady & Weil 2008). In the Pacific Northwest, the colonization of nitrogen-poor sites by red alder eventually leads to the build-up of the nitrogen pool in the soils, but this process may take several years (Brady & Weil 2008). This explains why 40% of the trees we selected for the site (72 out of 177) are red alders. This will hopefully allow this natural process to ameliorate the soil chemical characteristics over time, rendering it suitable for other species. Also, we expect the red alders and bigleaf maples to outgrow and create a semi-open canopy under which the other tree species included in the project will develop and eventually form the mid to late successional canopy.

7.3.4 'Do no harm' principle

As one of the most important guiding beacons of any restoration project, the 'do no harm' principle has served its role throughout the realization of this project. For example, naturally regenerating Western redcedar seedlings were salvaged and brought to the GCA's Native Plant Nursery.

The principle has however forced me to sometimes reconsider decisions and evaluate the consequences with humility. For example, the water of the pond quickly became very turbid when machines were being operated for the transport of the woodchips and the de-compaction of the soil. Judging from the colour, the water seemingly became laden with tannins, potent natural substances. Fortunately, the water cleared relatively quickly after the operations were terminated. This might nonetheless have affected certain inhabitants of the pond, such as Pacific chorus frog eggs or larvae if they were present.

Also, any material exported from the site may have unintended consequences elsewhere. For example, the mountains of Western redcedar woodchips that were displaced are now lying closer to the well. Though I doubt that this will pose a significant risk, careful monitoring of the water might be necessary to ensure that its concentration in tannins does not exceed safety limits, if these piles are left standing for a long period of time.

7.3.5 Experimental area

It would have been interesting to include a treatment combining amendment and inoculation, as I suspect that there could be a combined effect on soil and plant health. This effect, however, could be either synergistic or antagonistic. For example, the compost might provide essential nitrogen for the establishment of the saplings in the first year, which may be critical in ensuring the survival of the plants during the initial nitrogen depletion period. Also, the nitrogen depletion might be initially more moderated in cells where no inoculum was added, as the decomposition process will presumably be accelerated by the inoculation. On the other hand, the addition of compost could hinder the formation of symbiotic associations between the plants and soil microorganisms. For example, it is well acknowledged that heavily fertilized agricultural soils can inhibit the formation of associations between arbuscular mycorrhizal fungi and crops (Liu et al. 2000). I suspect, however, that the nature (i.e. slow-release nutrients) and amount of amendment added will not be sufficient to cause such an effect.

7.3.6 Limitations

Several factors might affect our ability to detect differences between the treatments in the experimental area. These include the small number of replicates, variations in soil characteristics, variation in the initial vigour of the plants (e.g. red alder salvaged versus propagated from seed), variation in the size of container (i.e. larger containers holding more potting soil than smaller ones, supplying more nitrogen), the fact that two types of woodchips were laid on different sections of the plot, and the fact that some young forest inoculum was inadvertently spread within the buffer zone along the north side of the perimeter. Additionally, the salvaged swordfern added in each cell contained of small amount of inoculum. Lastly, we presume that the woodchips spread in the experimental area had no forest litter pre-mixed in them, but there might have been a small quantity.

8. MONITORING

"An ecosystem has recovered – and is restored – when it contains sufficient biotic and abiotic resources to continue its development without further assistance or subsidy" (Society for Ecological Restoration)

8.1 Conceptual framework

Monitoring is an extremely important, yet often overlooked phase, in any ecological restoration project. In Figure 14, I recommend a conceptual model to help guide the future monitoring of the Mill Site. I include two ecosystem functions that were not mentioned as part of the objectives, pollination and the provision of wildlife habitat, as these are critical to proper ecosystem functioning and may prove relatively easy to monitor.

Monitoring soil characteristics might prove especially difficult, and I suspect that vegetation health might become a surrogate indicator of soil health, as these are closely related. However, it must be acknowledged that during the early stages of the recovery of a site, abiotic factors, in particular rainfall, might override the importance of ecosystem functions in determining the survival of vegetation, as was observed in a study looking at survival of *Pistacia lentiscus* in Mediterranean steppes (Maestre et al. 2006).

Not only is monitoring technically challenging, but evaluating the success of a restoration project is inevitably subjective. In order to pre-establish a framework for evaluating success, I advise the use of a scorecard system in conjuncture with the monitoring indicators. For example, 4 points could be attributed to each of the 25 indicators included in Figure 14, using a qualitative scale for assigning individual scores: 0=no improvement, 1=slight improvement, 2=moderate improvement, 3=good improvement, and 4=excellent improvement. The points would then be added, yielding an overall score out of a possibility of 100 points. Also, as opposed to the use of a single threshold value for the interpretation, I suggest the establishment of success brackets or categories. For example a score located between 60 and 75 could signify satisfactory, and 75-90 excellent. Evidently, this evaluation system will necessitate refinement. Also, a time frame should be pre-established for the monitoring of the indicators.

Figure 14 presents the 25 proposed indicators and accompanying monitoring methods. The monitoring framework is structured in function of the goals and objectives that were initially established for the project, and I based myself on Box 24: 'When has restoration succeeded' in Keenleyside et al. (2012). References and a possible monitoring schedule are provided for some of these indicators.

Figure 14. Conceptual framework for monitoring and evaluating the success of the restoration process

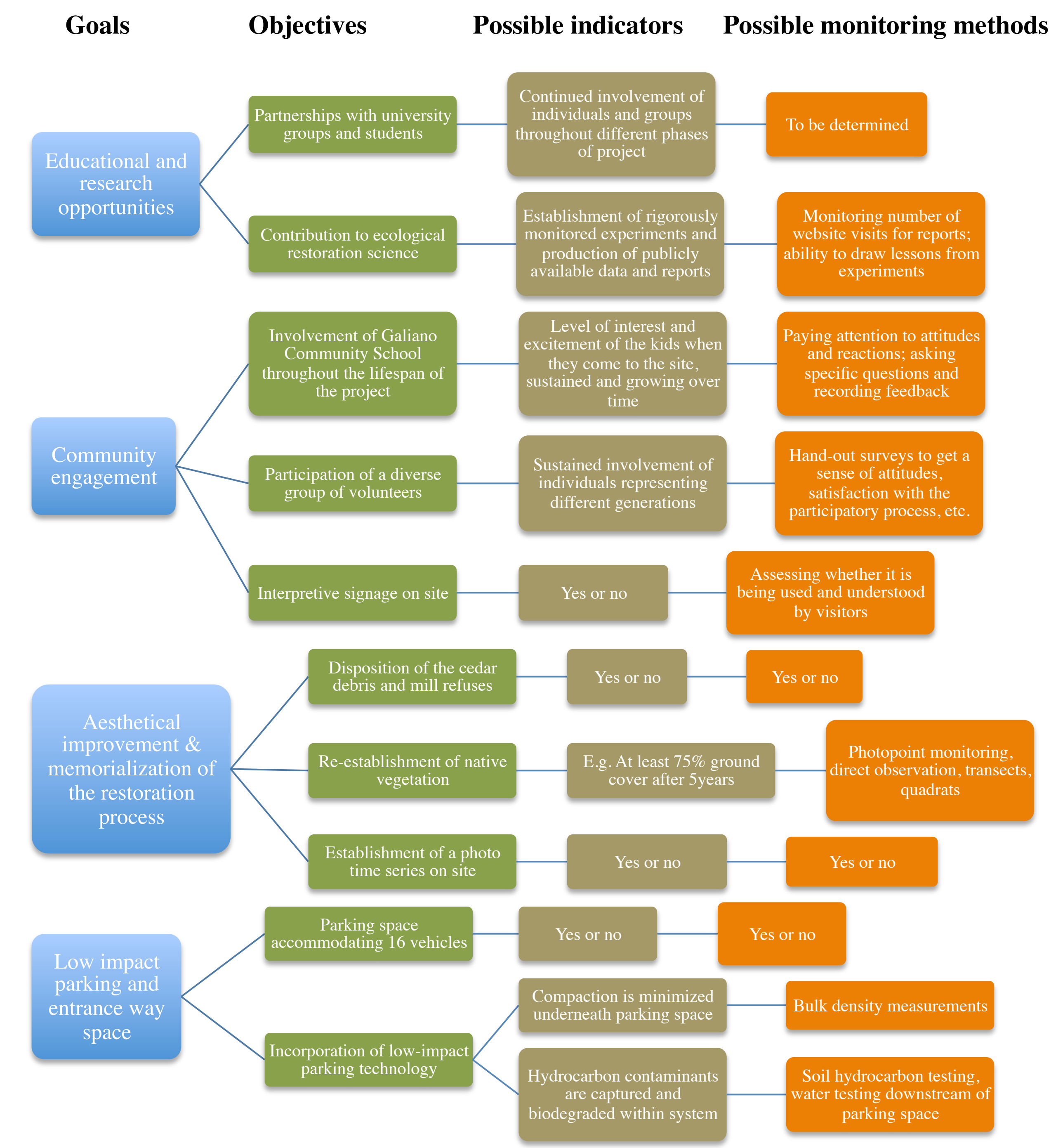

Figure 14 (continued). Conceptual framework for monitoring and evaluating the success of the restoration process

8.2 Experimental area

Being fenced and subdivided into individual cells, the experimental area will prove especially suitable for more detailed ecological monitoring, particularly for vegetation. Furthermore, the individuals plants introduced in the plot will be identified with aluminum tags, allowing for long-term monitoring and differentiation from natural recruitment. In Table 26, I recommend four ecological criteria for monitoring the plot, each subdivided into several parameters, along with suggested frequency and method of measurement. An initial set of measurements should be taken this spring or summer, in order to account for the initial variability in size and vigour of the planted individuals. The Galiano Conservancy Association hosts each year a group of German forestry student interns. These would constitute excellent candidates for conducting the annual data collection and analysis. The two criteria that are independent from the initial species assemblage that was planted in each cell (i.e. criteria 2 & 4) will be measured on a per cell basis, allowing for statistical analysis to be performed. However, the two criteria influenced by the initial species mixtures (i.e. criteria 1 & 3) will have to be pooled at the treatment level, since species mixtures varied between cells, but were identical at the treatment level.

Lastly, comparing natural recruitment between the main site and the experimental area will allow assessing the impact of deer browsing on natural regeneration, the fence installed around the experimental plot forming a complete deer exclosure.

Table 26. Monitoring Indicators and Parameters for the Experimental Area

Ecological Criteria	*Indicators (Unit)*	*Frequency of Measurements*	*Tools*	*Notes*
1. Vigour of planted individuals	Height and height increments (cm)	Annually	Measuring tape, clinometer	
	Width of crown at widest point (cm)	Annually	Measuring tape, clinometer	
	Diameter of main stem (mm)		Calliper	Initially at ground level, eventually at dbh for trees (1.3m)
	Qualitative and/or quantitative health assessments (e.g. chlorosis)	Annually	Foliar nitrogen content and photosynthetic rates (gas exchange) would be excellent ways to monitor plant health	

2. Natural recruitment of native species	Species presence and number of individuals	Annually	Visual counts	
	Percent cover of each species	Annually	Visual estimates, possibility of subdividing the cells in $1m^2$ subunits using string or plastic frame	
3. Total biomass	Total canopy cover in each cell	Annually	Visual estimates	
	Leaf area index (LAI)		LAI2000	Would probably be the best way to measure vegetative cover, but the instrument is expensive and its manipulation can be relatively complex
4. Colonization by invasive and exotic species	Species presence and number of individuals		Visual counts	
	Percent cover of each species	Annually	Visual estimates, possibility of subdividing the cells in $1m^2$ subunits using string or plastic frame	

9. CONCLUSION

It appears too early to draw any firm conclusion as to whether the ecological goals of the restoration project were fully achieved. However, we can confidently attest, without having re-measured the bulk density of the soil yet, that the compaction problems were largely resolved by the rough and loose treatment. Infiltration seems to have already augmented, though we expect it will continue to improve as plant roots grow and the soil organisms recolonize the site. Also, aesthetical improvements are already flagrant. Perhaps most importantly, however, is that participation has been fruitful throughout the entire realization of the project, and it appears that this will be propelled into the years to come, as the heart and energy of many young and less young people have become entwined into the destiny of the Mill Site.

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12. APPENDIX

Table 27. Container Size and Costs of Plants Brought from the GCA Native Plant Nursery

Category	*Latin Name*	*4-inch*		*1 gallon*		*2 gallon*		*5 gallon*		*Total Cost*
		Order	Cost	Order	Cost	Order	Cost	Order	Cost	
Trees	***Abies grandis***	0	0	21	210	2	40	1	40	290
	Acer macrophyllum	0	0	5	50	1	20	0	0	70
	Alnus rubra	0	0	72	720	0	0	0	0	720
	Arbutus menziesii	0	0		0	2	40	0	0	40
	Pseudotsuga menziesii	0	0	45	450	1	20	0	0	470
	Thuja plicata	0	0	18	180	13	260	0	0	440
	Tsuga heterophylla	0	0	6	60	0	0	0	0	60
Shrubs	***amelanchier alnifolia***	0	0	0	0	6	120	0	0	120
	cornus stolonifera	0	0	4	40	1	20	0	0	60
	Crataegus douglasii	0	0	0	0	7	140	0	0	140
	Gaultheria shallon	0	0	34	340	7	140	3	120	600
	Holodiscus discolor	0	0	2	20	10	200	0	0	220
	Mahonia nervosa	0	0	14	140	0	0	0	0	140
	Oemleria cerasiformis	0	0	3	30	0	0	0	0	30
	Philedelphus lewisii	0	0	4	40	0	0	0	0	40
	Physocarpus capitatus	0	0	4	40	0	0	0	0	40
	Rosa gymnocarpa	0	0	6	60	1	20	0	0	80
	Rosa nootkana	0	0	14	140	4	80	0	0	220
	Rubus parviflorum	0	0	5	50	0	0	0	0	50
	Rubus spectabilis	0	0	2	20	16	320	1	40	380
	Salix lucida	0	0	4	40	0	0	0	0	40
	Sambucus racemosa	0	0	1	10	0	0	0	0	10
	Symphorocarpus albus	0	0	0	0	4	80	0	0	80
	Vaccinium ovatum	0	0	4	40	0	0	0	0	40
	Vaccinium parviflorum	0	0	3	30	2	40	0	0	70
	Viburnum edule	0	0	4	40	0	0	0	0	40
Herbs	***Polystichum munitum***	10	50	44	440	15	300	0	0	790
GRAND TOTAL		**10**	**50**	**319**	**3190**	**92**	**1840**	**5**	**200**	**5280**

Table 28. Summary of the Budget for the Restoration of the Mill Site

Category	*Description*	*Amount*
Wages (staff)	Coordination, education, planning, treatment, monitoring	$19, 035
Hired professionals	Machine work (excavator, chipper), water analysis	$7,717
Restoration material	Include nursery plants, compost, fence, cages, education material, work parties supplies (e.g. refreshments)	$7,720
Honorarium	Student interns	$2,100
Delivery	Trucking of plants, compost, and woodchips to the site	$2,004
TOTAL		**$38,586**

Table 29. Summary of the In-Kind Budget for the Restoration of the Mill Site

Category	*Value*
Volunteer labour	$10,325
Consultants	$9,325
Equipment	$7,530
Supplies and material	$5,796
Management	$4,200
Transportation	$600
TOTAL	**$37,776**

Table 30. Permanent Photopoint Monitoring Equipment List

PPP Equipment
GCA's camera (Canon SX20)
Yellow meter board
Adjustable tripod
Four rebar stakes
Flagging tape
Compass set to correct declination
Notebook
Pencil
Permanent marker or ideally aluminum tags to label re-bar stakes