Ecovoltaics: An Integrative Concept of Restoration and Renewable Energy for the Galiano Conservancy Association

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1.1 *Introduction: Ecovoltaics and Restoration*

Since time immemorial, the sun has been earth's power plant in the sky. Without it, our planet would be a lifeless ball of ice and rock (NASA, 1981). Its energy warms our seas, generates weather, and grows the plants that provide oxygen. While it has taken 21st-century technology to capture our planet's oldest source of energy, a quick transition towards solar and away from fossil fuels is needed to ensure environmental health. As this transition occurs, it is vital to create cohesive and reciprocal relationships between energy extraction and ecological integrity. Ecovoltaics can serve as a model for such relationships: where solar energy extraction benefits from ecological Restoration and vice versa.

This restoration plan-of-action will connect ecology to energetic processes and showcase solar energy's potential to help society reconnect with land while restoring degraded ecosystems. This integrative approach highlights the multifaceted ways energy extraction can be perceived: from saving money and shifting away from fossil fuels to coalescing renewable energy into the landscape. By developing an ecovoltaic system, the Galiano Conservancy Association can fulfill their commitment to ecological restoration, work towards net carbon neutrality, and inspire Galiano Island residents to adopt similar practices.

1.2 *What are Ecovoltaics?*

The term "ecovoltaics" refers to the co-development of the same area of land for both solar photovoltaic power, as well as for ecological restoration. While the term is novel, its inspiration stems from agrivoltaics, where the same relationship applies to photovoltaic power and agricultural crops (P. Santra et al., 2017; Hernandez et al., 2019). The coexistence of agricultural crops (or in our case, restored native plants) and solar panels suggests a mutual sharing of light between these two forms of production (Hernandez et al., 2019).

Moreover, there are technical benefits for power production: as a panel temperature rises, its output current increases exponentially, while the voltage of output decreases linearly (Tonui, Tripanagostopoulos, 2007). Hence, heat reduces the solar panel's conversion efficiency. In temperate climates, the vegetation beneath and around the panels creates an insulative layer against extreme temperature fluctuations while retaining rainwater. As plant evapotranspiration takes place, it removes heat from the panels through enthalpy. The result is a cooler system that functions more efficiently. This applies to both ground and roof panels, as restoring and implementing new vegetation cover can help buffer the effects of fragmentation (Kohler et al., 2015). Such a shift in thinking can produce ecological co-benefits for solar energy production, making more sustainable and a better fit in landscape.

1.3 *Literature Review*

Because deliberately using vegetation to cool solar panels is a relatively new concept, there has yet to be significant quantitative evidence to support the validity of the technique. In most cases, studies examined the effects green roofs had on solar panel efficiency, while there was little to no research conducted on ground-level panels. For example, a study conducted by Ascione et al. (2013) verified the benefits of green roofs for the building sector. Warm climates had the most significant increases in efficiency 11%, while cooler climates saw as little as below a 0% change (Ascione et al, 2013). Another study conducted by the University of Hong Kong found an increase of 4.3% in efficiency on a PV-green roof compared to one that was bare (Sui, Munemoto, 2007).

Beyond increases in efficiency, we identified a gap reflecting a one-dimensional view of energy extraction. Hernandez et al. (2019) overview a variety of approaches to combining solar energy generation and plant growth, referring to these projects as “techno-ecological” synergistic systems (TESs). The benefits include water quality, food system resilience, increases in photovoltaic (PV) module efficiency and, of course, carbon sequestration and supporting shifts towards alternative fuel sources. Most importantly, these systems can help mitigate and adapt to global environmental change. They promote the use of negative space for PV and filling areas with crop production and low-growing pollinator species, often suggesting farmers use drought-tolerant species for regions with low precipitation and dry summers. Water retention strategies include drip irrigation and reduce overall operational costs. This would be most beneficial in range-voltaic systems that incorporate pastures and grazing species for livestock and dairy production. Following these TES principles, the authors suggest that energy consumption for the United States can be largely supported by solar energy, in conjunction with utilizing empty land for crop production as yields decline from global climate change (Ray et al., 2019). The authors state,

> “The diffuse and overlapping nature of land degradation and solar energy resources globally provides opportunities for land sparing in an era where land is an increasingly scarce resource. Notably, we found that degraded lands in the US comprise over 800,000 km2...Here, the most degraded sites could produce over 1.6 million GWh yr–1 of potential PV solar energy (38.6% of total US consumption of electricity in 2015)”.

This quote points to our identification of a gap in the literature: using empty land for solar energy and agricultural opportunities is suggested solely for ecosystem services. Restoration is a supplementary benefit rather than an important focus; the use of degraded land for continued agricultural exploitation negates the longevity of a system. They instead emphasize that e.g. pollinator species can improve insect diversity and range-voltaic systems can provide animal welfare, but this should go further to suggest restoration of entire land systems. This is what we suggest our project for the Conservancy can do: this plot is a small example of the benefits to be gained from implementing large, community-linked solar fields and restoration initiatives.

Our project is modelled after a similar design in Germany by Kohler et al. (2002). This paper investigated if plant evapo-transpiration actually increases solar energy efficiency. Their design pertained to flat-roofs in an urban setting, and the authors found an increase of efficiency, as the plants absorbed heat from the buildings. This provides incentive to test if a similar efficiency gain can be done for ground panels; Hernandez et al. (2002) suggest PV module efficiency can be gained through lusher agricultural plants underneath and surrounding solar arrays. Combining the information from both of these papers provide a foundation for our design project: of using lusher native forest species for restoration underneath ground solar panels.

While these studies show promise, it is important to acknowledge that the numerical gains in efficiency are highly dependent on environmental conditions such as climate, slope, and distance from the ground (Hernandez, 2002). Our solar panels are several metres above the ground, and with the substitution of grasses with native species, there is no parallel study to estimate efficiency from. The gains are thus unknown and will have to be monitored; our estimates are based off the aforementioned studies and adjusted to account for variation (Table 4A).

1.4 *Restoration & Ecovoltaics*

Ecovoltaics exemplifies a relationship where human-made innovations and the natural world create a reciprocal relationship in a novel assemblage. As the arrays absorb energy from the sun, it distributes the extra energy back into the grid, while creating the conditions for the natural and human world to thrive. Solar panels are often seen as an eyesore and require significant space. Ecovoltaics challenges this assumption and creates an area of both beauty and utility. Over time, solar panel arrays can at least partly integrate into the landscape.

1.5 *Our Project*

Our project will attempt to implement an ecovoltaic system on Lot 57 of the Galiano Island Conservancy, also known as the Millard Learning Centre. Currently, there is an array of solar panels installed near the main entrance of the property and adjacent to the new Program Centre building. Because the panels are already installed in this location, we will focus on regrowing the native vegetation below the panels and in the surrounding area.

This project will fulfill the Galiano Conservancy's vision to bring awareness, connectedness and responsibility for nature into all facets of development and energy, while also accommodating the appeal of aesthetics and efficiency that are important for the community. The social benefits of this solar-restoration initiative are threefold:

(a) bolstering the philosophy of creating technology that functions *with* our environment rather than against/in domination of it, joining an era which moves against technology causing environmental destruction (Capra, 1996).

(b) the positives of sustainable development and mitigating atmospheric carbon buildup;

(c) promoting an attractive way for community members to participate in amalgamating renewable energy with their property's landscape, both improving efficiency, saving money, and facilitating ecosystem restoration.

While our group's outlook on the results of the project is optimistic, the site is located on an old mill-site with highly degraded soil. Given such degradation, it may be difficult for some native species to thrive and develop the dense vegetation required for photovoltaic efficiency gains. Preparation of the land before planting and a monitoring program thereafter are ways to buffer potential glitches in our plan, outlined in the following sections. We therefore suggest that implementing ecovoltaics at the Millard Learning Centre can increase solar panel efficiency, restore degraded land, inspire community and support the Conservancy's commitment to ecological restoration and carbon neutrality.

1.6 *Goals*

We have identified five main goals for our project. Our first and second goals are to increase solar panel efficiency and restore degraded land. These must be understood as interdependent: they create synergistic effects, such as improving biodiversity and ecosystem quality *while* increasing solar efficiency through plant evapo-transpiration. Using secondary research, we were able to quantify our estimated increases for solar panel efficiency based on similar projects (Hernandez et al., 2019; Kohler et al., 2002). With this information, we can create a chronology on what we plan to observe over a 5-year time period, in terms of increased energy efficiency and restoration (see Table 6). Our third goal is implementing a monitoring program that observes the growth of the system, taking place over five years (Table 6). This monitoring program will be frameworked in consideration of the Conservancy's time to work on this project, and will include the use of cost-effective materials and restoration methods to achieve low management. This means using native plant species that can be propagated from existing assemblages on the property, utilizing the soil already present and designing arrangements that require less pruning and water rescues under the arrays. These conditions will then fulfill our fourth goal of improving biodiversity and, in turn, improving soil quality to enhance stability of the system. Because our plot is located at the conservancy's entrance, the site will hopefully inspire the public to pursue similar projects while educating them how to do so. This will complete the fifth goal of education and spreading the Conservancy's vision, passing along knowledge to the community, and creating an atmosphere of support for zero-carbon energy extraction that coexists with restoration. In short, our goals are:

1. Restore degraded land.
2. Increase solar panel conversion efficiency incrementally until plateauing at 5 years.
3. Low-management methods through a monitoring program.
4. Enhanced richness in species, including insect and songbird diversity, and improved soil quality.
5. Engage community through education and displays.

NOTE: Because each goal is multi-faceted and requires several measurable objectives to be considered successful, we have included a list of accompanying objectives in Table 6.

Secondary Goals (Literature Review)

Hernandez et al. (2019) also describe the multifaceted benefits of "techno-ecological synergistic" systems, reflecting our idea of ecovoltaics. The authors highlight some positive outcomes from our goals and objectives for the project. We note specifically their data on "solar energy generation with ecological restoration and/or pollinator habitat systems", and "agrivoltaic systems co-located with crop production". We also take note of the benefits rangevoltaic systems have for animal welfare, and consider this in improving insect and understory songbird diversity. The synergistic outcomes of combining these energetic and ecological processes are as follows:

(1) reductions in air pollution;
(2) biological control;
(3) carbon sequestration and storage;
(4) climate regulation;
(5) energy equity and/or security;
(6) erosion prevention and maintenance of soil fertility;
(7) fuel diversity;
(8) food production;
(9) habitat for species
(10) human health and well-being;
(11) maintenance of genetic diversity;
(12) pollination;
(13) water-use efficiency;
(14) water quality.

Our selected plant species are based on manifesting these goals of improving biodiversity, supporting shifts to alternative fuels and improving ecosystem services for humans. Quantifying these aspects will depend on location and plant choice, so monitoring for improvements and relying on our objectives framework to adjust strategies and adapt will be necessary. Table 6 reframes our goals empirically, within the context of outlining other aspects of our plan.

2.1 Site Analysis

2.2 *Historical Conditions of Site*

The three solar panel arrays included within this study are located at the entrance to the Millard Learning Centre (MLC) at 48°55’47” N, 123°28’03” W (DL57). The solar panels lie on highly degraded land which previously was used as a logging sawmill between 2001 and 2011 (Hamann-Benoit, 2014). The logging activities have led to compact soils and uneven terrain, which can negatively affect plant growth in the area (Lesturgez et al., 2004). According to an analysis conducted by Hamann-Benoit (2014), the soil beneath the solar arrays can be categorized as well-drained sandy loam to loamy, and is accompanied by an underlayer of sandstone bedrock. Broadly defined, the proposed restoration site falls within the Coastal Douglas-Fir moist maritime biogeoclimatic zone, and these data will serve to guide the plant prescriptions chosen for the site (Hamann-Benoit, 2014). It should also be noted that the panels do not have an automated tracking system (for sunlight as it moves from east-west each day), emphasizing the importance of implementing ecovoltaics to maximize efficiency.

2.3 *Current Conditions of Site*

The three solar panel arrays are positioned on a raised ridge on the northern side of the MLC’s main entry road. The panels are situated on uneven terrain with incline increasing towards the most western panel. Specifically, the first and second array are situated at a similar elevation; the third array is situated on a raised ridge measuring ~0.6 m higher in elevation (Fig. 2A). The stand of the third array has been adjusted so that its photovoltaic cells are at the same height as the other two solar arrays, but the incline has created varying soil conditions. Each solar panel array measured 8.15 m by 3.45 m, resulting in 28.12 m^2 of ground cover per panel (Fig. 2A). In addition to the soil impacts from the sawmill industry, the panels obstruct sunlight from reaching the soil from approximately 12 noon onward. Observations of the site show that rainwater, which drains from the middle line of the photovoltaic cells as well as from the bottom, has created lines of erosion across the center and southerly perimeter of the plots (Fig. 2B). Furthermore, the plots contain “dry zones” and “wet zones” due to the run-off from the divide in the photovoltaic cells (Fig. 2B). This poses difficulty for creating a comprehensive plant prescription for the varied conditions found in one plot.

Figure 2A. Proposed restoration site at the Millard Learning Centre. The solar panel arrays are outlined in blue and numbered from 1 to 3. The red highlighted area represents the area which will undergo restoration. The measurements of the arrays are in metres.

In order to study these effects, a Kestrel handheld weather meter was used to determine the temperature, humidity and dewpoint under each array. Kestrel measurements were taken at 9:00 am, 12:00 pm, 2:00 pm, and 4:00 pm to account for any changing conditions associated with the sun’s position (Table 2A). The Kestrel meter was positioned on the ground in the center of each plot, and allowed to acclimatize for three minutes before measurements were taken. Due to time restraints, further readings could not be measured; it is suggested that at minimum of a week’s worth of seasonal Kestrel readings are collected in order to accurately described how the conditions of the sites change throughout the day, and the season.

Figure 2B. Photograph of conditions underneath the first array. Image 1 shows a close view of the erosion line caused by the solar array runoff. Image 2 shows the erosion line, as well as the evident separation between the parts of the plot which receive run-off, and the parts of the plot which do not receive any run-off water. The yellow dashed line outlines the erosion line which runs through the centre of the plot. The red dashed line outlines the dry zone which does not receive any run-off rainwater.

Table 2A. Kestrel measurements of solar arrays from June 29 to June 30. The measurements were taken by placing the kestrel on the ground in the center of the site. The kestrel was allowed to acclimatize for three minutes before measurements were taken.

Kestrel Reading for Array 1	**9:00 am**	**12:00 pm**	**2:00 pm**	**4:00 pm**
Temperature (ºC)	23.5	20.0	22.8	23.7
Relative Humidity (%)	54.2	57.5	50.3	49.0
Dewpoint (ºC)	13.0	10.9	11.4	11.7
Kestrel Reading for Array 2	**9:00 am**	**12:00 pm**	**2:00 pm**	**4:00 pm**
Temperature (ºC)	24.5	20.7	21.8	22.2
Relative Humidity (%)	50.0	53.7	54.0	54.3
Dewpoint (ºC)	11.8	10.9	11.8	12.5
Kestrel Reading for Array 3	**9:00 am**	**12:00 pm**	**2:00 pm**	**4:00 pm**
Temperature (ºC)	20.8	21.0	22.8	23.6
Relative Humidity (%)	65.1	56.4	54.3	51.1
Dewpoint (ºC)	13.4	11.0	11.9	12.6

Additionally, sample holes were dug in each array plot to observe the soil composition. The sample holes measured 0.3 m deep; the holes were dug conservatively as the solar panel wiring was buried at an unknown depth. Further observations regarding the plant species within each plot were identified, and the species’ percent ground cover was estimated (Table 2B).

Table 2B. Field observations of the plant species present, and the soil composition of the plots beneath the three solar arrays. Observations were made at 12:00 pm June 29, 2019. The Sample holes measured ~0.3 m deep due to the underground wiring.

Conditions	**Plant Species Present**	**Estimated Ground Cover per Species (%)**	**Total Ground Cover (%)**	**Sample Hole Observations**
Array 1	Black cap raspberry (*Rubus occidentalis*)	12	20	Sample hole revealed live roots, some rocky substrate and dry soil.
	Bull thistle (*Cirsium vulgare*)	5		
	Cleaver (*Galium aparine*)	2		
	Unidentified grasses	1		
	Plant Species Present	**Estimated Ground Cover per Species (%)**	**Total Ground Cover (%)**	**Sample Hole Observations**
Array 2	Bull thistle (*Cirsium vulgare*)	2	5	Sample hole revealed no live roots, considerable rocky substrate and dry to moist soil.
	Cleaver (*Galium aparine*)	2		
	Unidentified grasses	1		
	Plant Species Present	**Estimated Ground Cover per Species (%)**	**Total Ground Cover (%)**	**Sample Hole Observations**
Array 3	Cleaver (*Galium aparine*)	<1	<1	Sample hole revealed no live roots, extreme rocky substrate and dry soil.
	Unidentified grasses	<1		

Due to the wires present beneath the solar panel arrays, an additional hole was dug ~1.2 m deep directly North of the photovoltaic arrays. The soil characteristics were used as an additional test for composition (Fig. 2C). A soil assessment guide, which includes a graininess test, a moist clay test and a taste/stickiness/worm test was utilized to assess the sample plot's soil composition (Fig. 2C). Further studies may need to be done in-lab (e.g. alkalinity testing).

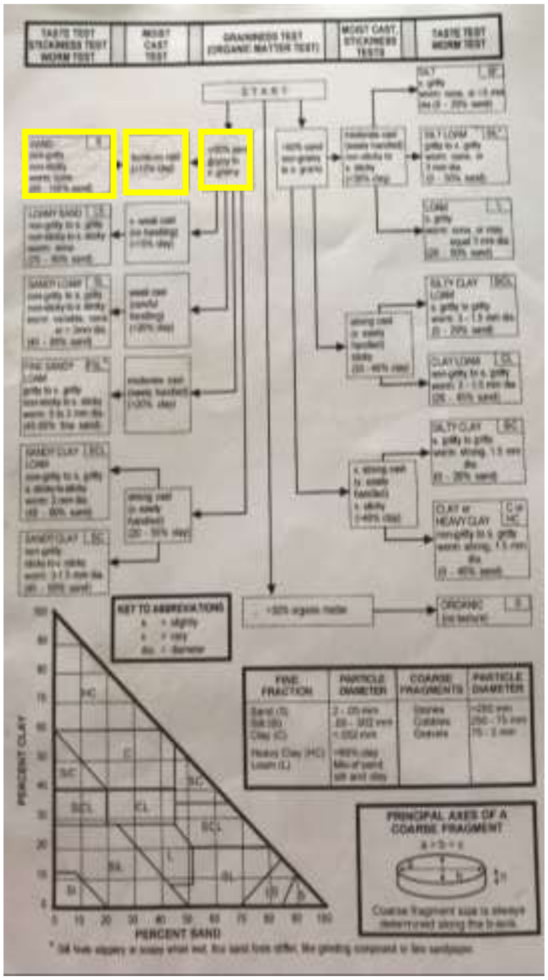


Figure 2C. Soil assessment guide using the graininess test, the moist clay test, and the taste test/stickiness test/worm test. The yellow highlighted boxes indicate the results of each test for the ~1.2 m sample plot

3.1 Results of Site Assessment

The data presented in Table 2A illustrates a pattern throughout the day for each array. The data for array 1 and array 2 show that the temperature is initially high at 9:00 am, and decreases at 12:00 pm; the temperature continues to increase from 12:00 pm to 4:00 pm. For array 3, the temperature steadily increases throughout the day. Observations of the restoration site revealed that sunlight was able to directly reach the soil under arrays 1 and 2 during the morning hours due to the sun's angled position near Summer solstice when the observations were taken; this may account for the temperature spike in the morning hours. Array 3 only received a fraction of the sunlight that bathed arrays 1 and 2 during the morning hours, which may account for the fact that array 3 does not experience a temperature spike at 9:00 am. The measured relative humidity for array 1 increased from 9:00 am to 12:00 pm, then decreased over the remainder of the day. The relative humidity for array 2 continually increased throughout the day, whereas the relative humidity for array 3 continually decreased. Further observations are required to distinguish if there is a pattern present.

The results from Table 2B. indicate that array 1 contains the highest plant diversity. The soil composition within array 1 presented a low volume of rocky substrate which has allowed for the species present to develop a root system (Fig. 3). The plot under array 2 is composed of dry, sandy soil and a considerable volume of rocky substrate which has led to fewer species abundance (Fig. 3); this plot appears to contain the driest soil our of all three photovoltaic arrays. Array 3 is found on the most difficult soil from a restoration view, as there is extensive rocky substrate and dry soils that have prevented even weedy species from invading the area (Fig. 3). Finally, the results from Figure 2C indicate that the soil is composed of 85% to 100% sand.

Figure 3. Images 1 to 3 depict the ~0.3 m sample hole dug in the plots beneath arrays 1 to 3, respectively. Plot 1 shows a considerable amount of root structures. Plot 2 shows rocky substrate near the surface and drier soils. Plot 3 shows extensive rocky substrate across the 1 ft. depth.

The data collected, as well as the observations of the proposed restoration site, indicated that the plot beneath array 1 may be able to sustain plant species found within the historical forest ecosystem as it receives morning sunlight, receives water run-off, and already sustains an underlying root system. The results from the plot beneath array 2 indicated that hardy plant species may survive as it receives morning sunlight and run-off, but has considerable rocky substrate within the sandy soil. The plot that lies beneath array 3 will pose the greatest restoration challenge; the plot does not receive adequate sunlight, and the dry, sandy soil contains a high volume of rocky substrate. Hardy, drought-tolerant species may be able to persist in this plot.

4.1 *Reasoning for Plant Prescriptions*

Surveying and measuring the plot was done prior to selecting plant species in order to understand what species are best suited to the conditions and will facilitate successful restoration. Based on findings from our site analysis, we aim to restore the ecosystem conditions by selecting native plant species acclimatized to dry terrain, low moisture and shade. For each of the three solar arrays ("array" referring to the area underneath one rack and panel and the 1-meter area extending from its farthest point), we have prescribed an ecosystem "type", characteristic of the similar ecological variation on Lot 57 (e.g. marshland, forest, dry terrain). We have selected a variety of different plants for two reasons: one is to accommodate the existing conditions on the plot, and second is to display to the public the variety of ways they can implement ecovoltaics with their solar panels. Plant growth factors are also considered, with optimal heights to facilitate evapo-transpiration but to not shade or inhibit solar panel function. As mentioned in the previous sections, the conditions under the three panels are actually quite variable in soil quality/type and moisture, leading to the following prescriptions (Table 4):

1. Solar Array 1 on the easternmost point of the plot has higher moisture and more nutrient-rich conditions, evident in the current assemblage of a black cap raspberry bush and various weeds. We have therefore, based on the higher plant density, decided to use forest species for this plot. Our species choices are well-suited for higher moisture (compared to moisture in other panels) and shaded conditions, such as salal (*Gaultheria shallon*), bracken fern (*Pteridium aquilinum*) and dull Oregon grape (*Mahonia aquifolium*) (Table 4). These lush and bushy shrubs grow to ideal heights of 1 metre or less; taller species, such as Bracken fern, will ideally be placed directly under the solar panel where there is more room to grow, and salal and dull Oregon grape to be planted along the low-hanging panel front and along the sides. Water retention management suggestions will be discussed below.

2. Solar Array 2 located in the center of the two other arrays has medium moisture and low-quality soil conditions, similar to Solar Array 3. There are weeds beginning to sprout and the soil is rocky (medium-sized substrates). To be cost-effective, we wanted to use a native flowering plant framework in selecting suitable plant species for this more difficult terrain (Table 4). We wanted to attempt a native flowering plant array as, in accordance to the facet of community engagement in ecological restoration, this type of aesthetically-pleasing, garden-like plot is more inviting to

residents in taking on this project. Furthermore, these plants facilitate pollinator species and can increase bee and insect diversity (Hernandez et al. 2019). A selection of plants such as nodding onion (*Allium cernuum*), sea blush (*Plectritis congesta*), wooly sunflower (*Eriophyllum lanatum*), and blue-eyed grass (*Sisyrinchium littorale*) will experiment what propagates successfully, and can be used as a proxy for future projects in similar environmental conditions.

3. The third plot is extremely dry and filled with larger substrates. The soil is sandy and there is much lower moisture compared to the other array conditions. Therefore, we prescribe drought-tolerant species such as bearberry (*Arctostaphylos uva-ursi*), stonecrop (*Sedum divergens*), nodding onion (*Allium cernuum*) and mixed bunch grasses (Table 4). Lower-height plants will similarly sit near the front of the panels and the taller plants (which will need to be more shade-tolerant) will be planted directly underneath. Stone crop may need to be managed for height, and suggestions for this will be discussed in the following section.

4. Many residents will have roof panels instead of ground panels (due to size). This applies to Lot 57 as well, as there is an array of panels on the roof of the Learning Centre located downhill of our plot (see Map). Green roofs, as was employed in the study by Kohler et al. (2002), was the original technique for using vegetation to increase efficiency and can similarly be employed for the roofs of the Learning Centre. As it is not a flat roof, bunch grasses and mosses (immotile, low-management species) can be used instead of tall shrubs and herbaceous grasses. Protecting the integrity of this historic building is of higher priority, so species selection, propagation and management will take additional care and planning (see below).

Table 4. Reasoning behind the prescribed species for each array ecosystem. The conditions and soil composition of each array was assessed and compared to species that could survive in the unique conditions. Plant habitats, soil moisture regimes and any tolerances/intolerances were assessed through E-flora BC and *Plants of Coastal British Columbia*.

	Prescribed Species	**Reasoning**
Solar Array 1	Salal (Gaultheria shallon)	Salal is able to survive in dry forests with a minimum soil moisture regime of 0 (very xeric). Additionally, salal is shade tolerant.
	Bracken fern (*Pteridium aquilinum*)	Bracken fern is able to propagate in disturbed, open areas. It is able to survive in a minimum soil moisture regime of 0, and is shade tolerant.
	Dull Oregon grape (*Mahonia aquifolium*)	Dull Oregon grape is able to survive in dry open slopes, with a minimum soil moisture regime of 0. It is shade tolerant.
	Prescribed Species	**Reasoning**
Solar Array 2	Nodding onion (*Allium cernuum*)	Nodding onion is found in dry rocky bluffs with a minimum soil moisture regime of 0. It is usually shade-intolerant, but the array receives significant sunlight in the morning hours.
	Sea blush (*Plectritis congesta*)	Sea blush is able to survive in dry rocky sites with a minimum soil moisture regime of 0.
	Woolly sunflower (*Eriophyllum lanatum*)	Woolly sunflower is found in dry meadows and rocky slopes. It has a minimum soil moisture regime of 0.
	Prescribed Species	**Reasoning**
Solar Array 3	Bearberry (*Arctostaphylos uva-ursi*)	Bearberry is found in dry and exposed, often rocky, sites. It can survive in a minimum soil moisture regime of 0.
	Stonecrop (*Sedum divergens*)	This native stonecrop is found in dry rocky cliffs with a minimum soil moisture regime of 0.

🟧	Mixed bunchgrasses - Hair Bentgrass (*Agrostis scabra*) - California Oatgrass (*Danthonia californica*)	These bunchgrasses are found in dry, rocky conditions.

5.1 *Outline of Restoration Plan*

The successful propagation of the plants mentioned above and improvements in solar efficiency will become evident over time. Each of the three solar arrays and the roof panels require different plans in terms of preparation and propagation, but all lead to the same goal of a self-sustaining system. Below we have outlined step-by-step our plan for restoration on our plot. It should be noted that due to the increase in droughts and the low access to hydration, water rescues may be required throughout each period and onwards to ensure plant survival. These rescues may come in the form of manual watering or a pipe system from the bioswale adjacent to our plot (see Recommendations).

Prior to discussing the specifics of each solar array, we have suggested a design for the overall plot. Between the three solar arrays, we suggest implementation of a path around and behind the solar panels for both public access and maintenance. This will allow the addressing of our social goals mentioned in the Introduction – the engagement of the community in sustainable projects and providing education to support alternative fuels. Cedar-chip trails will provide a barrier between the solar arrays and discourage the spread of invasives, providing aesthetic and natural substance. Figure 5A illustrates the suggested paths around the solar panels. The black square represents the junction box, the mainframe for repairs, and will allow the Conservancy to easily access the box without having to maneuver around plants and shrubs.

Fig. 5A Illustration of paths around site to access general maintenance and for public observation of plant propagation.

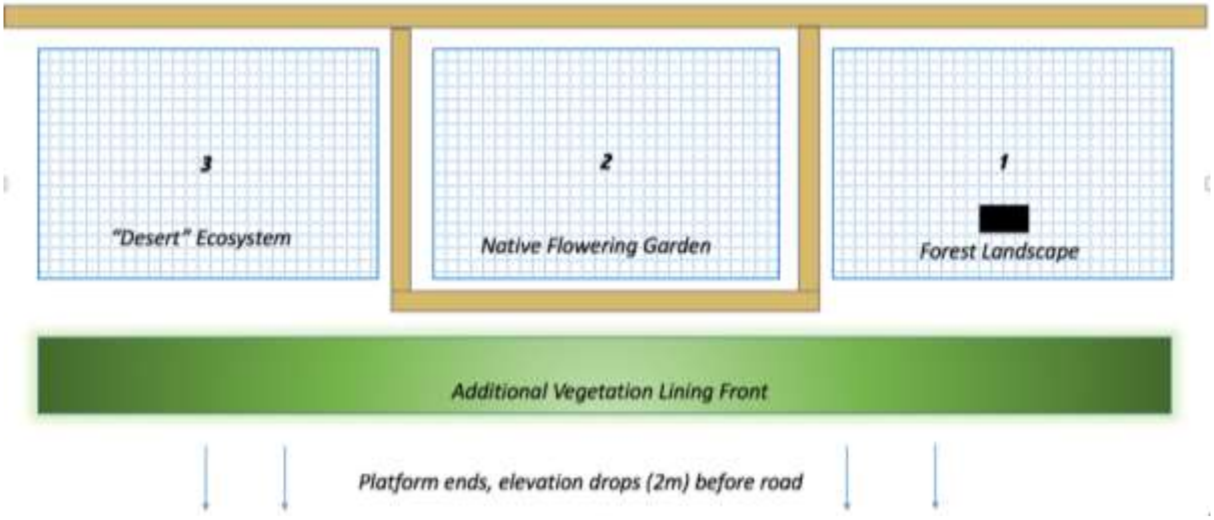
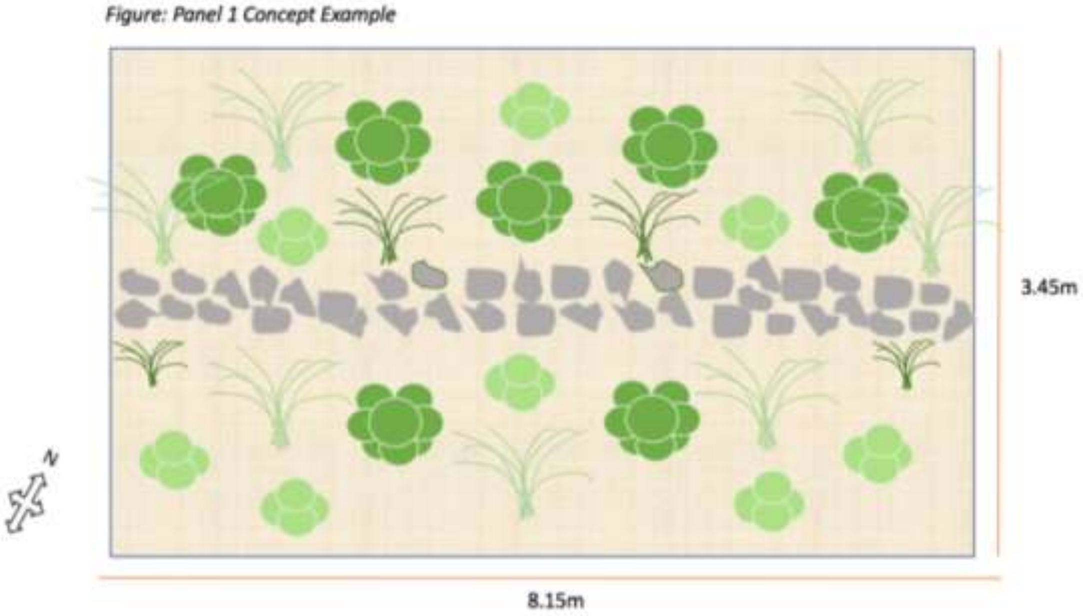


Figure 5B represents the suggested design for one of the solar arrays, shown in Table 4 as *Forest Landscape.* Small light green boxes represent *Mahonia nervosa,* large green represents *Gaultheria shallon* and the grass-like structures represent *Pteridium aquilinum.*

Figure 5B. **"**Forest landscape" prototype.



5.2 *Forest Microclimate, Native Flowers and Shrubs and Pseudo-Desert Ecosystem*

With the plot design in mind, the propagation of plants can begin; pathways will be implemented after initial planting is completed. For the individual solar arrays, the first step, in Period 1, is to prepare the plot. This requires (a) removal of weeds and invasive species around and under the panels, including the black-cap raspberry bush. For the first panel (the Forest Microclimate), the gap in the solar panels has naturally created a central drainage (see image) with smaller rocky substrates, and we advise to leave this as is. For the second and third panels (Native Flowers and Shrubs and the Pseudo-Desert Ecosystem), the soil contains far rockier substrates and lower soil quality, which will require rearrangement into natural drainages and/or removal. The next step is (b) soil preparation, including digging to prepare for plant propagation and introduction of fresher soil. The final step for the first six months is planting: salal (*Gaultheria shallon*), dull Oregon grape (*Mahonia nervosa*), and bracken fern (*Pteridium aquilinum*) in a diverse arrangement under and around the first solar array; nodding onion (*Allium cernuum*), sea blush (*Plectritis congesta*), woolly sunflower (*Eriophyllum lanatum*), and blue-eyed grass (*Sisyrinchium littorale*) for the second array, and; nodding onion (*Allium cernuum*), bearberry (*Arctostaphylos uva-ursi*) and mixed bunchgrass for the third array.

In period two, minimal observations will need to be done to survey the soil quality and plant growth. Watching for invasives is key to ensure restoration takes place, and this may entail manual work to remove the invasives. We strongly protest the use of non-organic pesticides and herbicides. Water rescue may be necessary if this period crosses the summer months. We selected highly drought-resistant native species for the third array and it will have to be monitored for adaptability. The ideal outcome here is for plant growth to be stable and soil quality to increase.

Period three encompasses the first two years where low management can begin as plant growth is occurring and ecosystem stability rises. Pruning for height may need to occur, but overall the system is becoming well-adapted to the conditions.

Period four continues this low management phase. Reaching the three-year point, the system begins to self-sustain. Ecological integrity is plateauing as songbirds, pollinators and insects habituate to the plants. Solar efficiency at this time begins to peak and plateau as well. Management for plant height and width is minimal and does not inhibit maintenance/public trails.

By period five, the systems are self-sustaining. Solar efficiency is at a maximum. Water rescue may be necessary during the summer months.

5.3 *Solar Efficiency*

It should be noted that our estimates for solar efficiency are based off of Kohler et al. (2002) and Hernandez et al. (2019), where very different experiments were carried out on a variety of different solar panels and environments. The former saw a ~24% increase for vegetated roof panels; this is why we estimate a higher rate of efficiency for the Learning Centre solar panels. Hernandez et al. (2019), in contrast used, data from a variety of centers using PV in the United States and accumulated their efficiency data. They state that agrivoltaics increases panel efficiency, while a pollinating-species approach does not, and ground panels with this prescription have much less efficiency to be gained than from lusher vegetation or roof panels. This owes to why we estimate lower efficiency increases for the ground panels overall. We decided not to estimate variation between the three ground panels, despite different plant prescriptions, as we do not have a robust body of data that suggests any of these plants will either increase or leave solar panel efficiency unchanged.

Table 5 illustrates our goals for the project. The succession periods are divided into five sections, pertaining to the chronological development of the restoration plan over five years and onwards.

Table 5. Restoration and Efficiency Goals for the Solar Panel Arrays over a 5-year period. Arrays are sectioned based on ecosystem "type". The top subsection within each period refers to restoration objectives. The bottom refers to the aimed increases of solar panel efficiency.

Plot	**Solar Array Type**	**Period 1** *(propagation period)*	**Period 2** *(succession period I)*	**Period 3** *(succession period II)*	**Period 4** *(succession period III)*	**Period 5** *(self-sustaining)*
Time (months)		**1-6**	**6-12**	**12-24**	**24-36**	**36-60+**
1	***Forest Microclimate***	Removal of weeds. Soil preparation and plant propagation. Six months for initial growth.	Observe for growth and invasives, and remove if assemblages appear. Water rescue. Soil richness increases.	Low management phase begins: water rescue in phases and managing height of plants.	Continue low management System begins to self-sustain. Plants are at optimal height, invasives are omitted and plant growth does not inhibit cedar trail.	Self-sustaining. Water rescue during drought/ summer months.
		-	3%	5%	7%	10%
2	***Native flowers and shrubs***	Removal of weeds. Soil preparation: removal and reorganization of rocky substrates for natural drainage. Plant propagation.	Observe for growth and invasives, and remove if assemblages appear. Water rescue. Soil richness increases.	Low management phase begins: water rescue in phases and managing height of plants.	Continue low management System begins to self-sustain. Plants are at optimal height, invasives are omitted and plant growth does not inhibit cedar trail.	Self-sustaining. Water rescue during drought/ summer months.
		-	3%	5%	7%	10%
3	***Pseudo-Desert Ecosystem***	Removal of large rocky substrates and reorganize to create a natural drainage. Plant propagation.	Observe for growth and invasives, and remove if assemblages appear. Water rescue. Soil richness increases.	Low management phase begins: water rescue in phases and managing height of plants.	Continue low managementSystem begins to self-sustain. Plants are at optimal height, invasives are omitted and plant growth does not inhibit cedar trail.	Self-sustaining. Water rescue during drought/ summer months.
		-	3%	5%	7%	10%

Our restoration plan requires several steps but will ultimately lead to low-management and a self-sustaining system. The goal is to have a restored area that increases solar efficiency, aesthetic appeal, and can educates the public. We emphasize that this is a restoration project and our main focus is on restoring the degraded and disturbed area under and around the solar panels, reducing the problem of dust on the driveway and increasing biodiversity. Solar panel efficiency is the experimental portion of this project, and recommendations for monitoring this will be discussed in the following section.

6.1 *Management and Monitoring Program*

The restored ecosystems should be closely monitored and managed by the Galiano Conservancy Association, ecologists/field experts, and/or university students over the five-year period, or until it is deemed to be self-sustaining. A self-sustaining system should have high resilience and integrity, characterized by consistency with the surrounding environment and overall landscape (Suding *et al*., 2015). Specific monitoring towards the completion of the previously outlined goals should be implemented. We have outlined our objectives, and options for constructive analysis if goals are not achieved (e.g. a certain species did not grow due to conditions, or solar panel efficiency is not increasing as per our determined target), pointing to our section for solutions of adaptation and mitigation of error (following table). Below is Table 6A, outlining several monitoring and further management strategies that could be employed for the three restored ecosystems.

Table 6A. Outline of Objectives for the Monitoring Program, based on Goals and Solutions for Error over the course of 5 years.

Monitoring Program Objectives	**Solar Array 1**	**Solar Array 2**	**Solar Array 3**
Water Management	Natural rock formation acts as drainage. Water rescue.	Natural rock formation acts as drainage. Addition of burlap or cardboard facilitates retention from rainfall. More water rescue than Array 1 and 2 might be necessary through periods 1 to 3.	Natural rock formation acts as drainage. Addition of burlap or cardboard facilitates retention from rainfall. Water rescue, but the species are highly drought-resistant so this will be monitored bi-monthly.
Soil Quality	Addition of large/coarse woody debris which increases nutrient levels within the soil through a nurse-log effect	Addition of large/coarse woody debris which increases nutrient levels within the soil through a nurse-log effect	Addition of large/coarse woody debris which increases nutrient levels within the soil through a nurse-log effect
Plant Vitality and Success	Monitor which species are surviving in the challenging conditions, and adaptively manage for an ecosystem containing these species	Monitor which species are surviving in the challenging conditions, and adaptively manage for an ecosystem containing these species	Monitor which species are surviving in the challenging conditions, and adaptively manage for an ecosystem containing these species
Invasive Removal	Actively monitor and promptly remove invading weedy species until plant prescription fills in the plot	Actively monitor and promptly remove invading weedy species until plant prescription fills in the plot	Actively monitor and promptly remove invading weedy species until plant prescription fills in the plot
Trail Maintenance	Check the wood-chip trail for any damage/debris biweekly. Wood chips should be replenished with wear-and-tear	Check the wood-chip trail for any damage/debris biweekly. Wood chips should be replenished with wear-and-tear	Check the wood-chip trail for any damage/debris biweekly. Wood chips should be replenished with wear-and-tear

Vascular plant surveys should be conducted to document the overall plant health concerning the vegetative biomass and plant diversity (Shackelford, 2017). Specifically, invading species should be documented and removed if they pose a risk to the restored ecosystems. Rigorous management should not be necessary once the planted species are established. These monitoring strategies should allow for the application of an adaptive management approach and the evaluation of the three restored ecosystems.

Table 6B represents some of the errors that could arise due to variable conditions or unforeseen circumstances. Additional surveillance of the area, such as testing of soil and water retention, should be done prior to planting our selected species to ensure successful propagation. The table outlines likely errors per period and some solutions to these issues.

Table 6B Adaptation and Mitigation of Problems that could arise per period in accordance to Goals and Objectives.

Solar Array Type	**Possible Problems**					**Solutions**
	Period 1	**Period 2**	**Period 3**	**Period 4**	**Period 5**	
Forest Microclimate	Failure to propagate	Invasive growth	More water rescue is required than planned, depending on drought conditions	Continued issues of stunted plant growth, unviable soil conditions	System takes longer to become self-sustaining	1. A failure to propagate leads to use of organic fertilizer 2. Invasive growth buffered through a monitoring program and removal events 3. The need for more water can be fixed with the use of cardboard and burlap for additional nutrients and water retention 4. If growth is stunted, monitoring for plants that are successfully propagating and remove those that fail to grow will be needed. Also can experiment with another species, beginning process from Period 1
Native flowers and shrubs	Failure to propagate	Soil conditions do not comply with selected plant species	More water rescue is required than planned, growth is stunted by soil conditions	Continued issues of stunted plant growth, unviable soil conditions	System takes longer to becoming self-sustaining	
Pseudo-Desert Ecosystem	Failure to propagate	Soil conditions do not comply with	More water rescue is required than planned,	Continued issues of stunted plant growth,	System takes longer to becoming	

		selected plant species	rocky soil conditions prevent planned growth	unviable soil conditions	self-sustaining	5. If system is taking longer to become self-sustaining, low management can still be obtained through using burlap, fertilizer, addition of higher nitrogen-fixing plant species, and annual invasive removals until system becomes sustainable.

7.1 *Recommendations*

In order to ensure that the restoration is effective, the following recommendations should be taken into account. Additional assessment of the site is required before restoration can take place. Further Kestrel measurements and observations should be made regarding the soil composition. Water and soil samples should be acquired and analyzed within a lab to determine overall productivity, limitations and possible erosion from the ridge area. It is essential to assemble a plant prescription around accurate soil conditions to increase the community survivorship. In regards to the rainwater run-off through the division of the photovoltaic cells, it is recommended that a low-cost trough system be built in order to evenly distribute rainwater across the plot. Several photovoltaic systems have included rainwater collection systems (Architizer, 2019; Walker, 2013; Chong *et al*., 2011), but few have outlined a trough collecting system to distribute rainwater run-off to the plants below. A simple set-up could be utilized, such as a household drain gutter with drilled holes which could divert the run-off water to the ‘dry zones’. The designed drain gutter could be attached to the solar array stand, and shouldn’t pose to much of an accessibility issue.

In many respects, this detailed follow up work would make an excellent Restoration of Natural Systems final Diploma (ER 390) project. Our hope is our initial work will create such an opportunity.

7.2 *Acknowledgements*

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