Three Management Objectives to Slow Garry Oak Meadow Encroachment and Restore Taylor's Checkerspot Habitat in Helliwell Provincial Park, Hornby Island, British Columbia.

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Report prepared in Collaboration with B.C. Parks and the Living Labs for Climate Change and Conservation

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For more information about Helliwell Provincial Park visit:
http://www.env.gov.bc.ca/bcparks/explore/parkpgs/helliwell/

Project Summary

Natural and cultural fire suppression has dramatically altered the composition and structure of vegetation in a Garry oak ecosystem located in Helliwell Provincial Park, British Columbia. The lack of frequent low-severity ground fires has resulted in dense patches of non-native grasses, shrubs, and encroaching Douglas-fir trees. The rapid establishment and infilling of Douglas-fir has also created substantial changes to the water table as these trees require large amounts of water for growth. Conifer encroachment and shading in the meadow area, along with lowering of the water table has decreased the spatial extent of meadow and wetland areas. This has created several management concerns such as the loss of Garry oak habitat, which is host to several threatened and critically endangered species including the Taylor's Checkerspot butterfly. We recommend three management actions to slow conifer encroachment in the Garry oak meadow and restore native vegetation: 1) establish preliminary test burns in order to restore a comprehensive prescribed burning program, 2) enhance efforts of mechanical thinning of Douglas-fir encroaching into the Garry oak meadow, and 3) focus restoration efforts on the large sedge-dominated wetland on the west-side of the park. These activities complement current restoration projects in the Helliwell Park and will prepare habitat for the planned release of Taylor's Checkerspots in Helliwell Provincial Park in 2020.

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Introduction, Background, and Objectives

Understanding the ecological and cultural history of an ecosystem is important when developing restoration strategies and long-term monitoring (Higgs, 2005; Jackson and Hobbs, 2009; Higgs et al. 2014). For example, Garry oak (*Quercus garryana*) ecosystems and their associated species are currently threatened by several factors not limited to conifer encroachment (Bjorkman and Vellend, 2010), invasive species (MacDougall et al. 2006; Bennett et al. 2013), and changes to historic disturbance regimes such as fire activity (Gedalof et al. 2006; McDadi and Hebda, 2008; Pellatt and Gedalof, 2014).

Historically, frequent low-severity ground fires played a critical role in maintaining open and diverse meadow habitat (Gedalof et al. 2006). The lack of fire activity in Garry oak ecosystems is likely the most important factor affecting habitat composition and structure and over 100 threatened species that rely on Garry oak ecosystems (Pellatt et al. 2015). Garry oak ecosystems are fire-adapted landscapes (Gedalof et al. 2006; Vellend et al. 2008; Pellatt and Gedalof, 2014) and frequent low-severity ground fires play a critical role in maintaining open and diverse meadow habitat (Gedalof et al. 2006). Following the severe reduction of Garry oak ecosystem sites across their range, the lack of 20th century fire activity is likely the most important factor affecting habitat composition and structure for the approximately 100 threatened species that rely on Garry oak ecosystems (Gedalof et al. 2006; Vellend et al. 2008; Pellatt and Gedalof 2014). One of these species is the Taylor's Checkerspot butterfly (*Euphydryas editha taylori*), which is critically imperilled globally (GOERT 2017), and listed as endangered in Canada (BC Conservation Data Centre 2017; COSEWIC 2017).

Prior to 20th century fire suppression and land use change in this region, First Nations intentionally set low-severity ground fires to support the growth of fire-adapted species, decrease the amount of fuels, and remove fast-growing Douglas-fir (*Pseudotsuga menziesii* [Mirb.] Franco) and shore pine (*Pinus contorta var. Contorta* [Douglas x Loudon]) seedlings and saplings (Boyd 1999; Turner 1999; Beckwith 2004; Turner 2014). Garry oak ecosystems cover less than 5% of British Columbia, but these ecosystems contain the greatest proportion of species at risk in the province, and 100% of remaining Garry oak ecosystems have been directly impacted by roads, agriculture, and urban development (Shackelford et al. 2017).

Taylor's Checkerspot butterflies were historically considered abundant in the southeast portion of Vancouver Island where Garry oak meadows were common (Guppy and Shepard, 2001). Although Taylor's Checkerspot butterflies were extirpated in British Columbia in 2000, an unrecorded population was discovered on Denman Island in 2005. The Denman Island Checkerspot population inhabits a 15-year-old logging clear cut and its numbers have been steadily decreasing for the past decade as successional forest species replace the open logging clear cut (Page et al., 2008). Prior to the Denman Island discovery, the last recorded Canadian sighting of a Taylor's Checkerspot larvae and/or butterfly was in Helliwell Provincial Park on Hornby Island in 1995 (Lilley et al., 2009). A release of transplanted Taylor's Checkerspot larvae is planned for Helliwell Provincial Park in the spring of 2020 (J. Straka, J. Heron, pers. comm).

The lifecycle of Taylor's Checkerspot butterflies demands an array of habitats including open meadows, woodlands, and wetlands (Guppy and Shepard, 2001). Denman Island Taylor's Checkerspot butterflies emerge from pupae in late spring and require access to sunlight for basking, shelter from predators, and sources of nectar from flowering plants such as Woodland strawberry (*Fragaria vesca*), Trailing blackberry (*Rubus ursinus)*, and many other plant species associated with open areas (Page et al. 2009b).The butterflies then lay eggs on wetland vegetation such as marsh and thyme speedwell (*Veronica* spp.), and plantains (*Plantago* spp.)(*Guide to the Stewardship of Taylor's Checkerspot (Euphydryas editha taylori) on Denman Island* 2014). Pre-diapause caterpillars emerge from their eggs in early summer to spin a web around and consume their host plants (Page et al. 2009). The caterpillars then spend the fall and winter in diapause, emerging in March to forage on speedwell and plantain until pupation (Miskelly 2004). Open ground for travel, shelter from predators in the form of coarse woody debris or leaf litter, and sunlight for basking are also important habitat requirements for larval Checkerspots (Page et al., 2008). Overall, habitats with topographic variety, or fringes of sparse trees such as Garry oak are optimal for Taylor's Checkerspot butterflies (Stinson 2005).

Taylor's Checkerspot survival is closely linked to the availability of food sources in the larval and butterfly stages (Miskelly 2004) and the loss of food plant habitat is the number one factor contributing to their decline in British Columbia (Guppy and Shepard and, 2001). The absence of frequent fire activity has likely affected the presence of herbaceous, nectar bearing plants and shrubs that depend on open meadows and sparsely treed woodlands with few overstory conifers (Didham et al. 2005; Hamman et al. 2011). The spatial extent of ephemeral wetlands associated with Garry oak meadows has also decreased during the 20th century as a result of Douglas-fir encroachment compounded by the lack of frequent fire activity. Once established, mature Douglas-fir trees significantly lower the water table in wetlands and dry out soils (Barlow, 2017).

Although there is concern about the negative effects of prescribed fire on butterfly populations, the absence of fire has negatively impacted Taylor' Checkerspot butterfly habitat.

The purpose of this study is to reconstruct the environmental history of a Garry oak ecosystem along a prairie-savannah-woodland gradient in Helliwell Provincial Park on Hornby Island, British Columbia. We used a range of methods and analytical tools, such as reviewing historical documents and aerial photographs, dendrochronology, and spatial analyses in order to assess forest stand composition, density, and structure. We also map the extent of a north-south sedge-dominated wetland complex to assess the suitability of habitat for the reintroduction of Taylor's Checkerspot butterflies. The absence of fire in the park, coupled with conifer encroachment are two of the major concerns for successful habitat restoration and reintroduction of this extirpated butterfly. Although negative perceptions of fire have limited prescribed burning programs in heavily-visited provincial parks such as Helliwell, increased fire risk is one of the greatest and most complex management challenges in the park today. Our report provides a context for assessing proposed management and restoration actions in Helliwell Provincial Park and in threatened Garry oak ecosystems in coastal British Columbia.

Methods

Study area

The study area was situated in Helliwell Provincial Park, located on southeast Hornby Island, British Columbia (approximately 49°31' latitude and 124°35' longitude; Fig. 1). Helliwell Provincial Park encompasses 2900 hectares, 70 of which are terrestrial (the rest being marine) (Balke et al. 2001). The park lies within the Coastal Douglas-fir moist maritime (CDFmm) biogeoclimatic subzone which is characterized by warm, dry summers and mild, wet winters (mean annual temperature 9.9°C, mean annual precipitation 955 mm) (Meidinger and Pojar 1991). The ecosystems in this subzone range from mature coastal Douglas-fir forests to Garry oak savanna, riparian wetlands, and coastal cliffs (Meidinger and Pojar 1991).

Helliwell Provincial Park is comprised of diverse terrestrial habitats including mature Douglas-fir forests, mixed woodlands, sedge-dominated wetlands, coastal bluffs, and Garry oak meadows. The Garry oak meadows are among the northernmost Garry oak populations found in British Columbia (GOERT 2017). Garry oak ecosystems within the park provide habitat for five red-listed and nine blue-listed vascular plants (BC Conservation Data Centre 2017). Additionally, Helliwell Park provides habitat for five rare mammals, twenty rare birds, and two rare invertebrates (Helliwell Ecosystem Based Management Handbook 2001).

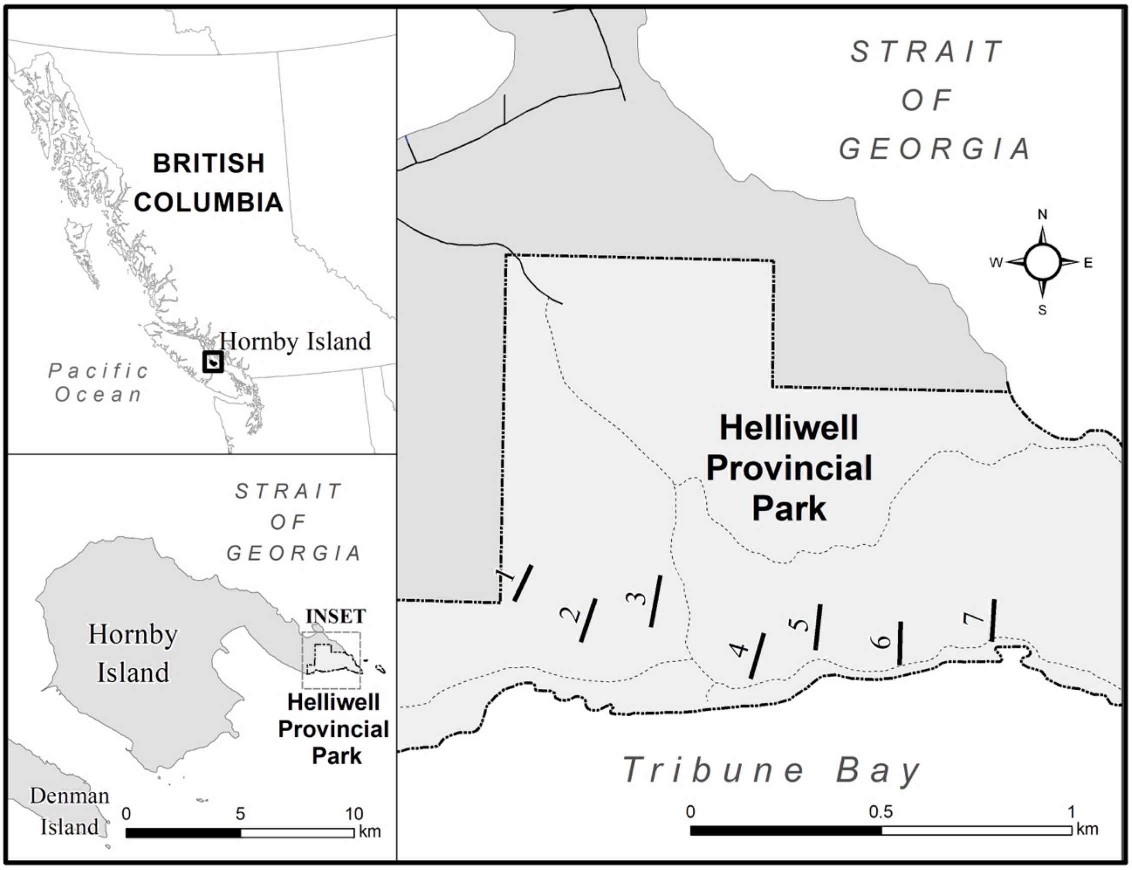

Figure. 1. The location of seven 6 x 75 metre belt transects in the southwest portion of Helliwell Provincial Park located on Hornby Island, British Columbia, Canada.

Reconstructing historic meadow dynamics

A Garry oak meadow (and former habitat for Taylor's Checkerspot's) transitioning to Douglas-fir dominated woodland was selected for our study in Helliwell Provincial park (Fig. 1). The study area extends from open meadow through savanna (containing scattered individual Garry oak, Douglas-fir, and shore pine trees) and into an encroaching Douglas-fir dominated forest. This area has previously been assessed as critical habitat for Taylor's Checkerspot butterflies and other Garry oak dependent red- and blue-listed species (Helliwell Ecosystem Based Management Handbook 2001). In March of 2018, we surveyed six belt transects over a 1500m stretch of forest, starting at the west (49° 31’ 6.9”) corner of the park and running east (49° 31’ 4.7”). The present-day forest edge was divided into 50m intervals and six transect start locations were randomly generated, one start location for each 50m interval (to avoid transect overlap). The belt transects ran perpendicular to the coastline and followed a compass bearing of 15 degrees for 75m (Fig. 1). The meadow area adjacent to the belt transects is currently undergoing thinning and replanting of native vegetation to restore habitat for the planned reintroduction of Taylor’s Checkerspot butterflies in 2020.

Tree ring measuring and analysis

Within each belt transect, increment cores were collected from every fifth tree >15 cm diameter at breast height (dbh). Cores were taken as close to the ground level as possible to accurately estimate the decade of establishment. The diameter, height, species and decay class for every tree >15 cm dbh was identified. Prior to removal, the height, diameter, age, and species of trees removed from the Garry oak restoration area were recorded to assess the composition and structure of infilling species.

In the laboratory, increment cores were mounted on boards and sanded with progressively finer sandpaper to a 600-grit finish. Increment cores were processed using standard dendrochronological techniques (Stokes and Smiley 1968). Samples were first visually crossdated and then statistically verified using the computer program COFECHA (Grissino-Mayer 2001). To accurately determine the decade of tree establishment, we estimated the number of rings missing from the sample by measuring the curvature of the innermost ring using a transparent template and dividing the radius of the missing growth portion by the average growth rate during its period of early development (Villalba and Veblen, 1997).

Mapping stand density

Comparisons of historical and recent aerial photographs were used to assess changes in land use patterns and conifer densities in the park in the latter half of the 20th century. Air photos containing data for all available dates on Helliwell Provincial Park were ordered from GeoBC. Air photos were georeferenced to Bing Satellite Imagery (Bing 2018) with an estimated accuracy of ~5m and five to ten control points were used to situate each photo. Air photos were then digitized in ArcMap 10.5.1 (Environmental System Research Institute 2017) and a layer was created for each year. Individual trees were not digitized unless they were encompassed by scrub and/or brush. The forested area was subtracted from the entirety of the park polygon to assess the meadow extent and the remaining polygons were calculated for each year. To verify field surveys, mapping analyses focused primarily on the west side of the park adjacent to the present-day Garry oak meadow. To reduce clutter on Figure 6, four years (1952, 1972, 1996, and 2014) at approximately twenty-year intervals across six decades were selected to assess land use changes and calculate the historic meadow extent. For access to GIS shapefiles of meadow digitization's for all years listed in Table 1 please contact the authors.

Results

Stand Structure and Composition

Belt transects contained Douglas-fir, shore pine, and Garry oak trees in drier sites and Pacific crabapple (*Malus fusca*), Aspen (*Populus tremuloides*), and western redcedar (*Thuja plicata*) in sedge-dominated wetland sites (Fig. 2). Density of Garry oak trees were significantly negatively associated with the presence of overstory Douglas-fir trees (Fig. 3a, Fig 3b). The median Douglas-fir density in transects was 902 trees per hectare, followed by shore pine at densities of 88 trees per hectare, and Garry oak at 44 trees per hectare (Fig. 4). More than half of the Garry oak sampled in belt transects were dead and located in transitional woodlands proximal to the Garry oak meadow (Fig. 3a, Fig. 3b). Stand density was significantly higher and trees were significantly younger in the first 0-15m of transects running east from the meadow and present-day forest edge (Fig. 4). The majority (85%) of trees established on the western meadow edge in the last 50 years and the transitional zone (0-15m) is comprised of fast-growing Douglas-fir and shore pine saplings (Fig. 5). Counting of branch whorls on saplings confirmed that Douglas-fir trees could reach heights of 3m in less than 10 years.

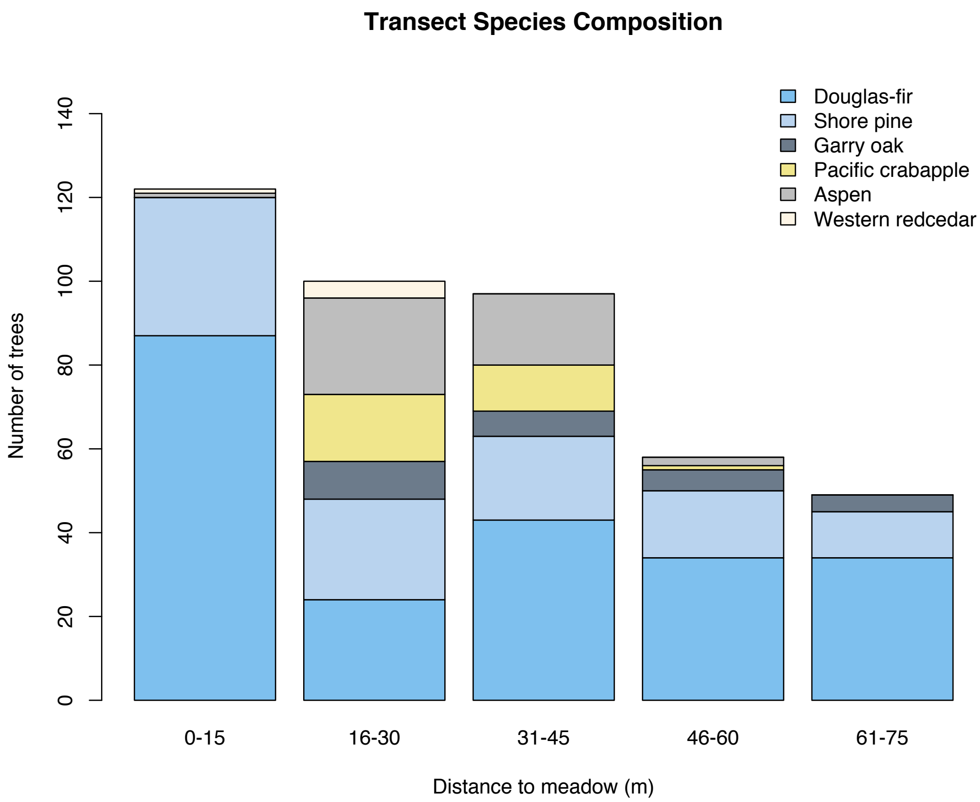

Figure 2. The composition and number of six species of trees located in seven belt transects along gradient of meadow-savanna-woodland habitat. The greatest number of trees were located in the western Garry oak meadow at the present-day forest edge.

Figure 3. a) Garry oak trees located at the present-day forest edge are experiencing overhead shading and infilling by encroaching Douglas-fir and shore pine trees. b) The southwest corner of the park is currently experiencing rapid conifer encroachment. Garry oak trees that were previously growing in open habitats are now being replaced by Douglas-fir and shore pine.

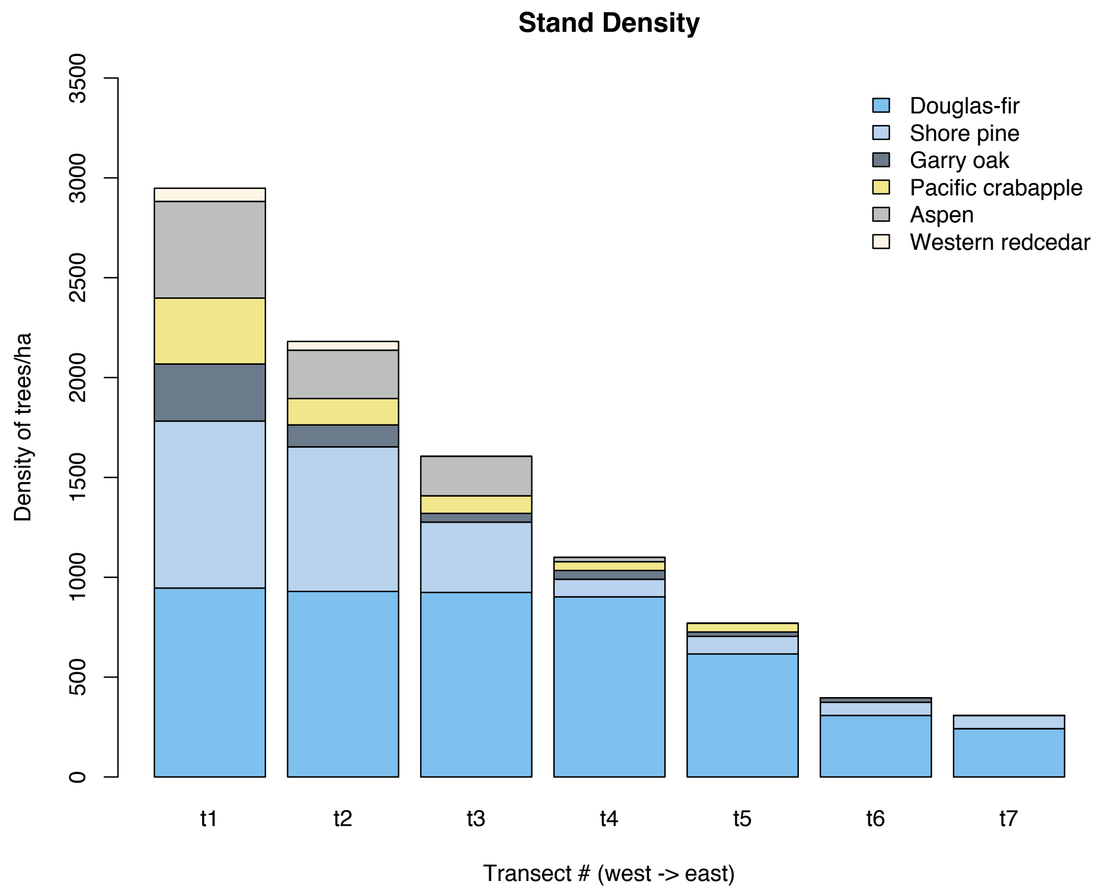

Figure 4. The density of trees was significantly higher in transect one, located on the western edge of the park. Transects 1-4 are currently undergoing thinning and replanting of native species.

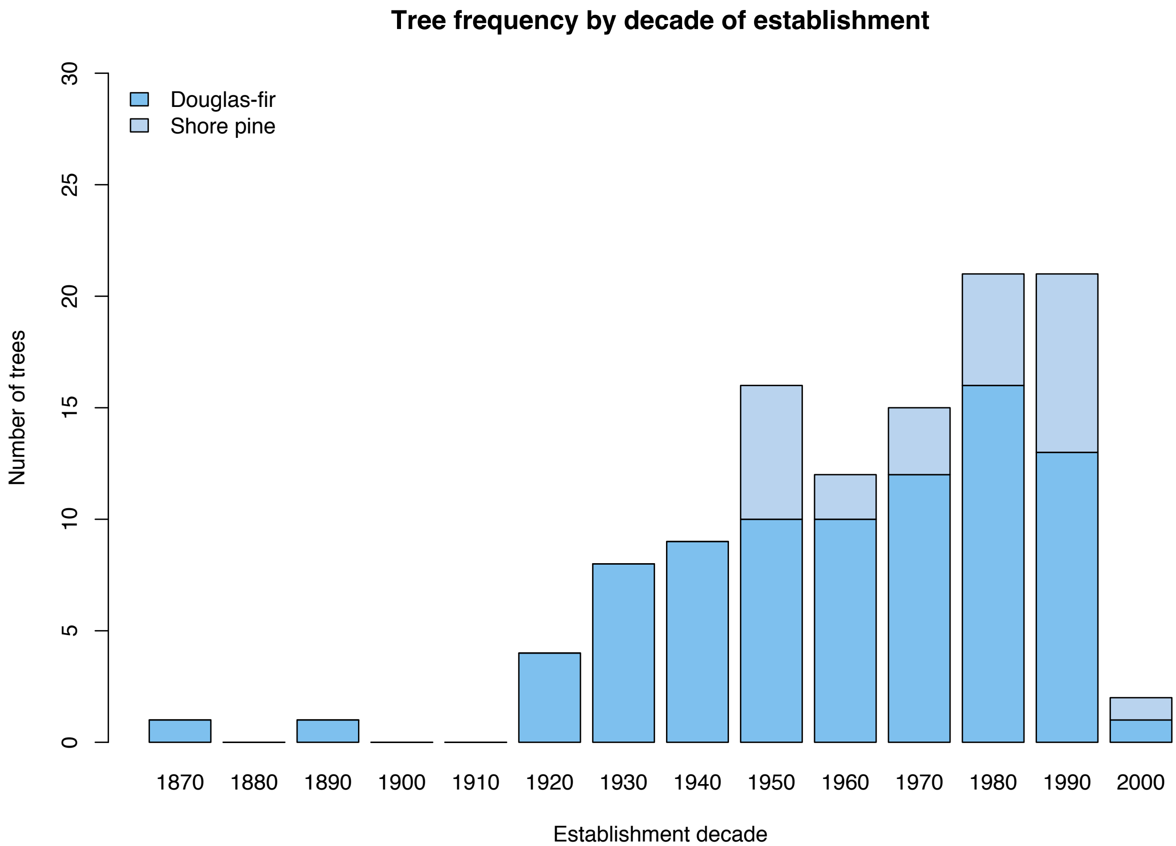

Figure 5. Trees sampled in transects were corrected for coring height and binned into decades of establishment. Ongoing recruitment of Douglas-fir and shore pine trees are recorded throughout the 20th century.

Aerial Photographs and land-use change

The largest extent of Garry oak meadow on Hornby Island was mapped in 1875 (Appendix; Fig. A1, described as "Grassy Hills"). This map was hand drawn prior to the establishment of roads, grazing, and logging. Historic aerial photographs confirm that the spatial extent of Garry oak meadow in Helliwell Provincial Park has decreased more than 50% since repeat photography commenced in 1952 (Fig. 6; Table 1). In 1952, the Garry oak meadow encompassed 211519m^2 in the park (the largest portions located in the southeast corner as well as several large patches to the west and northwest corners) (Fig. 6; Table 1). In the 1960s, several tree islands (isolated patches of young Douglas-fir and shore pine trees) established in the southeast portion of the park. By 1972 the large Garry oak meadow in the west and northwest portion of the park was infilled with trees (Fig. 6). In 1996 several small patches of meadow were re-established in the interior of the park following a >10 hectare fire from an escaped campfire in 1985 (T. Law, pers. comm). By 2014, these interior patches were infilled with Douglas-fir and shore pine and several new patches of young Douglas-fir trees had established in the southeast portion of the Garry oak meadow (Fig. 6). Since 1952, the present-day forest edge has encroached 125m into the Garry oak meadow (Table 1).

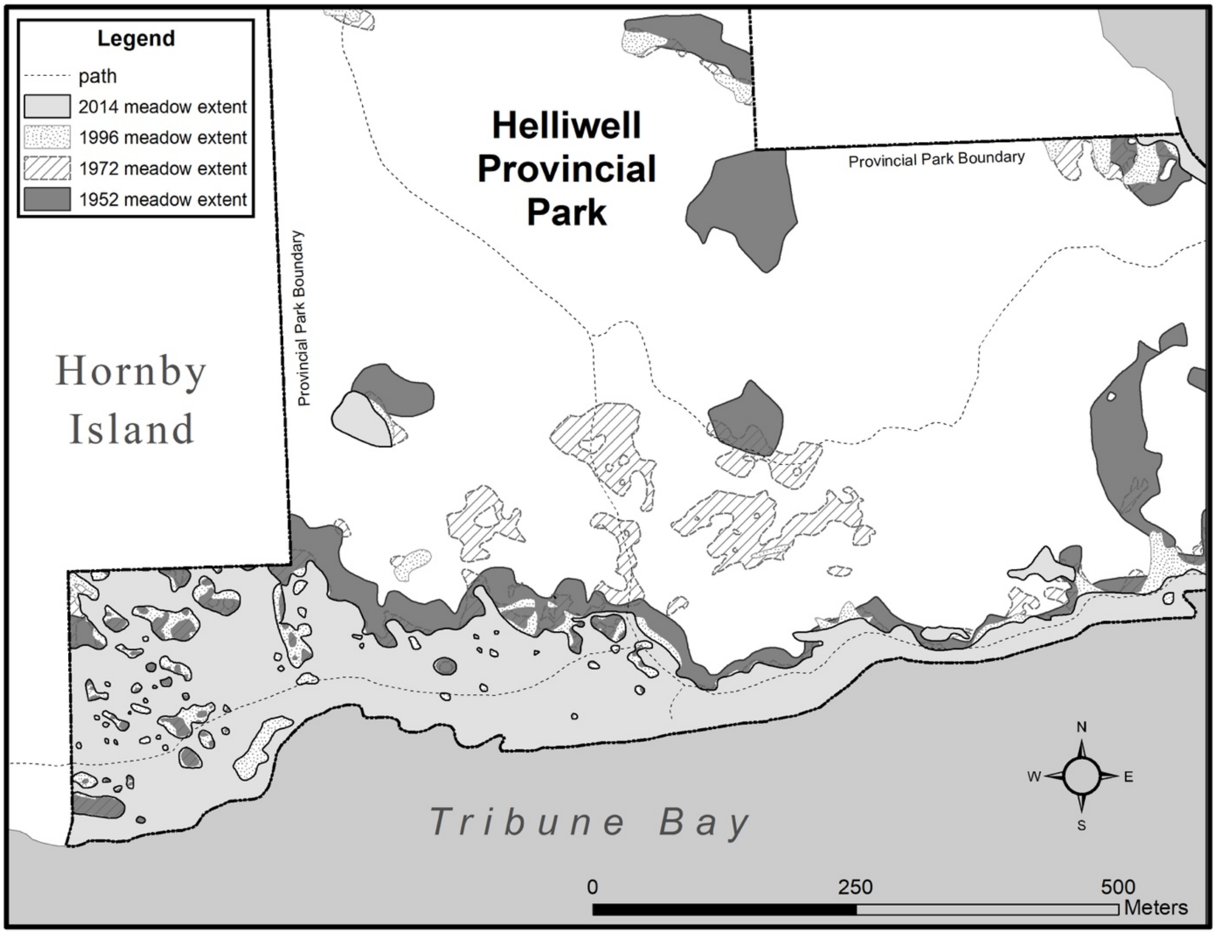

Figure 6. Repeat Aerial photographs from 1952-2014 depict spatial changes in the extent of Garry oak meadow located in the southwest corner of Helliwell Park on Hornby Island, British Columbia, Canada.

Table 1. The year, scale, focal length, media type, and source of air imagery used to map spatial changes in the historic Garry oak meadow in Helliwell Provincial Park, British Columbia, Canada.

Year	Meadow Extent (m^2)	Reference	Scale	Focal Length	Media
2014	93968	08bcd14101_105_25_8bit_rgb	"1:20,000"	80mm	Digital - Colour
2000	136265	Bing Imagery			Image Service
1996	155650	bcb96016_222	"1:40000"	153mm	Film - BW
1988	170045	bcc835_215	"1:10000"	305mm	Film - Colour
1980	166108	BC80102_164	"1:20000"	153mm	Film - BW
1972	194948	BC7406_197	"1:15000"	305mm	Film - BW
1968	197286	BC7077_109	"1:16000"	305mm	Film - BW
1964	219693	BC5097_089	"1:31680"	153mm	Film - BW
1952	211519	BC1499_058	"1:40000"		Film - BW

Discussion

Our results indicate that Helliwell Provincial Park has experienced significant change in the extent of Garry oak habitat throughout the 20th century. Substantial logging, followed by land clearing and livestock grazing, occurred in the park from the beginning of the 20th century until approximately the 1930s. Following the establishment of the provincial park in 1966, several roads were constructed, and a subdivision was built on the western park boundary (Fig. 1). Although the lack of fire evidence in the form of living fire-scarred trees limits the potential to reconstruct historic fire activity in the park (Lepofsky et al. 2003), low-severity fires were likely intentionally set by First Nations in the fall to increase the productivity of meadow habitat where camas grow (Turner 1999; Lepofsky et al. 2003; Beckwith 2004). Ongoing fire suppression and conifer encroachment in the park has resulted in a build-up of fuels, and accidental ignitions from escaped campfires pose the greatest management risk to the park. Reintroducing low-severity burns during cool and humid conditions can negate the adverse effects of fire on sensitive butterfly habitat (Hill et al. 2017).

Stand composition, age, and density

The oldest tree that we were able to successfully core with an increment borer in Helliwell Park established at the beginning of the 18th century (Fig. 7). This tree was part of a stand of approximately 50 old-growth Douglas-fir trees located on the southeast portion of the park. Although we attempted to core roughly 30 old-growth trees to reconstruct the historic climate of the park, the large-diameter, heart rot in the centre of most trees, and large ring-widths made a climate reconstruction using tree-rings unlikely (Speer, 2010).

Figure 7. The oldest tree cored in the park is a Douglas-fir estimated to have established in 1710. This tree is part of a stand of old-growth trees located in the southeast corner of the park.

The majority of tree establishment occurred after 1910, and continuous recruitment of Douglas-fir and shore pine has occurred in the park throughout the 20th century (Fig. 5). Douglas-fir and shore pine have also experienced pulses of recruitment associated with documented decadal warming trends associated with regional climate patterns and fire disturbances documented in the park, such as the 1988 fire which burned several hectares of forest in the south corner of the park (Fig. 8).


Figure 8. This high-density patch of shore pine established after the 1988 fire, which burned several hectares in the south portion of the park.

Our results reveal important information about future stand composition and conifer encroachment in the park. First, conifer encroachment is occurring fastest in the west and northwest areas of the park adjacent to the Garry oak meadow (Fig. 9). Second, Garry oak saplings are only present when overstory conifers are absent and no Garry oak saplings were present in wooded areas. Third, conifer encroachment is likely responsible for the death of more than half of the Garry oak trees present in transects. These trees appear to have been negatively affected by shading as a result of infilling. The highest density of trees greater than 15cm dbh occurs at the present-day forest edge proximal to the Garry oak meadow along the northwest boundary of the park (Fig. 1; Fig. 4). This transitional forest edge is comprised of fast-growing Douglas-fir and shore pine recruits (Fig. 2).

Figure 9. Conifer encroachment is occurring rapidly in the southwest corner of the park near the largest portion of open Garry oak meadow habitat. Picture is the location of transect one.

There are several possible controls on sapling recruitment in the park. Browsing by deer may be suppressing stem growth and trampling by humans and dogs in the meadow may inhibit Garry oak seedlings from transitioning into more mature saplings (Gedalof et al. 2006; Gonzales and Arcese, 2008). The competitive role of invasive grasses may also reduce the availability of below ground resources that Garry oak seedlings historically relied on (Fuchs, 2001). Invasive grasses deplete soil moisture more rapidly than native perennial grasses, which may result in increased seedling stress (Jackson et al. 1998; Gedalof et al. 2001).

There has been considerable infilling of conifers in the Garry oak meadow area since it was first mapped in 1875 (Appendix A, Fig. A1). Digitization and analyses of historical aerial photographs (1952-2014) demonstrate that conifer encroachment is ubiquitous along the southern present-day forest-meadow boundary. By as early as the 1970s, evidence of a closed-canopy forest existed over much of the northwest Garry oak meadow, as well as infilling of conifers in western coastal bluff areas. The establishment of patches of tree islands in the southeast portion of the meadow has rapidly reduced the extent of the Garry oak meadow (Fig. 10).

Figure 10. Ongoing restoration efforts aim to thin high-density patches of encroaching Douglas-fir in the western Garry oak meadow. The majority of high-density patches of trees established within the last 30 years.

Fire Management Concerns

Ongoing fire suppression together with the encroachment of Douglas-fir and shore pine has created a significant management concern in Helliwell Provincial Park. The lack of recent fire activity has increased fuel loads, created a dense shrub layer, and increased the risk of high-severity fire activity along with the potential for interface fires (Fig. 11). The presence of invasive species (grasses, herbs, and shrubs) has also increased the fire-hazard, as these species specifically English holly (*llex aquifolium*) and English Ivy (*Hedera helix*) are more flammable than native plants (Brooks et al. 2004; Bond and Keeley, 2005). Invasive shrubs and grasses can affect the rate of fire spread, flame length, and the resilience of native species to fire activity (Lambert et al. 2010).

Figure 11. Fuel-loading in the shrub layer increases the risk of high-severity, stand replacing fires in the park. Pictured here is an accumulation of windfall and downed coarse woody debris in transect five.

Under natural fire conditions, Garry oak communities retain most fuels in the canopy layer and historically experienced frequent fires through cultural burning associated with camas (*Camas spp.*) management (Turner, 1999; Beckwith, 2004; McCune et al. 2013). Contrary to common perception, Garry oak communities do not easily ignite except when leaf tissue moisture is low (Bond and Keeley, 2005). However, invasive grasses and weedy forb species tend to accumulate in higher densities in disturbed areas (trails, roads, forest edges, etc.) and dry out faster than native plant species (Lambert et al. 2010). Invasive grasses, forbs, and shrubs are prevalent in Helliwell Provincial Park in coastal bluffs, meadows, woodlands, and sedge-dominated wetland areas (Helliwell Ecosystem Based Management Handbook, 2001).

There are very few lightning-ignited fires on Hornby Island, and accidental ignitions by humans are the most common cause of fires (Beck et al. 2005; Parminter, 1999). There have been 36 human-ignited fires in Helliwell Park since 1919, and the majority of these ignitions were from escaped campfires that affected the southeast corner of the park (Parminter, 2009; Helliwell Ecosystem Based Management Handbook, 2001). Although the majority of old-growth Douglas-fir trees have charred bark, very few fire-scarred trees are present (Fig. 12). The lack of fire scarred-trees suggest that fire activity was likely suppressed prior to widespread fire suppression policies implemented in British Columbia in the 1920s (Lepofsky et al. 2003). Historic documents from 1875 indicate that First Nations populations on Hornby were significantly affected by three smallpox epidemics and in 1875, it was estimated that Helliwell Park had not experienced fire activity in more than 100 years (Balke et al. 2001).

Figure 12. An old growth fire-scarred Douglas fir tree located at the border of the wetland complex on the west side of the park. The lack of fire-scarred trees suggests that fire has been suppressed in the park for almost 200 years.

The lack of fire evidence in the form of living fire-scarred trees, limits the potential to reconstruct historic fire activity in the park (Lepofsky et al. 2003). First Nations controlled burning practices had a light footprint, and frequent low-severity fires consumed light and highly combustible fuels, which left little charcoal present in soils (Weiser and Lepofsky, 2009; Turner et al. 2013). The existence of the Garry oak meadow is likely a legacy of centuries, if not millennia, of traditional fire management (Beckwith, 2004; Turner 2014). Fire was intentionally utilized by First Nations to increase the productivity of habitat where camas grows, as well as the abundance of other important food and medicinal plants associated with low-severity fires (Turner 1999; Lepofsky et al. 2003). A secondary or indirect management technique of controlled burning was likely to create fodder (increase the abundance of grasses in the meadow) for game (Boyd, 1999; Turner, 1999; Suttles, 2005). More ethnohistorical research is required to understand the fire history of the park, specifically the spatial and temporal characteristics of historic controlled burning by First Nations and the resulting fire-resilient landscape. Because lightning ignitions are relatively rare, accidental ignitions by humans are the greatest fire risk in the park.

During the fall, Taylor's Checkerspot butterflies are in diapause and the larvae are thought to take shelter under rocks, litter, and coarse woody debris (Page et al. 2009a). Because butterfly populations are closely associated with fire-resilient landscapes, it is possible that diapause larvae can withstand low-severity ground fires (Balke et al. 2001). Annual low-severity fires coupled with other management techniques (such as digging for roots) increases the coverage of herbaceous plants favoured by Taylor's Checkerspot butterflies (Stinson 2005). Additionally, when fire is initiated across diverse ecosystems (such as coniferous forests and riparian areas), it can increase both the density and area of canopy gaps, which increases the number of butterfly species found in an environment (Huntzinger 2003). Because Taylor's Checkerspot butterflies are critically dependent on Garry oak habitat, frequent low-severity fires are beneficial despite the danger posed to diapause larvae.

Fire Management Objectives

The success of reintroducing fire into a Garry oak ecosystem is largely dependent on the site conditions prior to implementing prescribed burning programs (Bjorkman and Vellend, 2010; McDadi and Hebda, 2008). Ecosystems with deep, organically-enriched soils, have shown to be more resilient to prescribed fire at three-year intervals (Gedalof et al. 2008). However, ecosystems like Helliwell Provincial Park, contain relatively shallow, mineral soils with low native species richness (Barlow et al. 2017). Even low-severity fires have the potential to destabilize soils and allow invasive species to establish (Barlow et al. 2017). Encroachment of conifer species complicates the success of prescribed burning, because increased overstory of Douglas-fir decreases understory light, which restricts the establishment of perennial herbaceous species and native grasses (Devine et al. 2007). Conifer species also impact the microclimate of the forest floor, saturating and cooling soils, which can extinguish low-severity ground fires (Devine et al. 2013). Removing encroaching conifers decreases competitive pressure on native herbaceous and grass species and create desirable microclimate for propagation and prescribed burning conditions (Pellatt and Gedalof, 2013).

Future Prescribed Burning

We suggest that several small spot burns (10 x 10 m) could provide a preliminary assessment of the effects of low-severity ground fires on native plant propagation and the abundance and persistence of invasive species. With local public support, this program could be expanded to prescribed burning of one-hectare sites in the open Garry oak meadow for long-term monitoring. It is likely that several repeat prescribed burns are required to re-establish fire-tolerant native plants, which may be lying dormant within the soil (Miskelly, 2004), and restore biogeochemical cycling and oak seedling regeneration in Garry oak meadows (Bjorkman and Vellend, 2010; Pellat and Gedalof, 2013). Taylor's Checkerspot larvae are predicted to be able to withstand light surface fires in winter when they are hibernating deep in the leaf litter (Balke et al. 2001). However, the presence of a substantial amount of larvae outside the burn area should be ensured. There are several fire specialists in the BC Wildfire Service, BC Parks, and Parks Canada that have been trained in establishing burning prescriptions and prescribed burning strategies. There are also opportunities to collaborate with the Comox First Nation, the BC Wildfire Service, and provincial species at risk managers. This project would also be well suited for Living Labs collaboration with an academic institution and a MSc or PhD program.

There are several examples of successful prescribed burning programs in Garry oak ecosystems that combine ecological, cultural, and social values. The Tumbo Island (Gulf Islands National Park Reserve) restoration and prescribed burning program was initiated in 2016 and is co-managed by Parks Canada, Cowichan First Nation, and the Capital Regional District (Barlow et al. 2017). This program focused on mechanical thinning, followed by four 50 x 50 m spot burns and deer fencing on Tumbo Island, a small, uninhabited island south of Saturna Island, B.C. (Barlow et al. 2017). This successful program could serve as a model for Helliwell Provincial Park. There are also several established prescribed burning programs in wetland Garry oak prairies in the Willamette Valley, Oregon (Clark and Wilson, 2001), and in oak savannas on the central coast of California (Peterson and Reich, 2001). Prescribed burning programs have been undertaken in oak meadows and grasslands in the United States for decades and provide important information on how to successfully reintroduce fire in populated areas with complex management concerns.

Habitat restoration in wetland areas

Current restoration efforts in Helliwell Provincial Park are focused on removing dense patches of recently established Douglas-fir trees in the western Garry oak meadow (Fig. 13). This multi-year management objective supports the return of endangered native grasses such as Roemer's fescue (*Festuca roemeri*) and California Oatgrass (*Danthonia californica*), which historically covered large portions of the Garry oak meadow (Helliwell Ecosystem Based Management Handbook, 2001). We suggest that restoration efforts should also focus on restoring the sedge-dominated wetland area that extends a large portion of the wooded area parallel to the western Garry oak meadow (Fig. 13). This wetland complex (30 x 1000 m) provides suitable habitat for the three-dominant species of larval host plants such as marsh speedwell (*Veronica scutellata*), thymeleaf speedwell (*Veronica serpylifolia*), and plantago species (*Plantago lanceolata* and *Plantago major*). Thinning of encroaching Douglas-fir into the wetland area could clear the overhead canopy to the required 20 % openness for butterfly basking habitat. The wetland complex has the ability to support the long-term establishment of larval host plants that are predominantly wetland species, while avoiding the direct effect of human disturbances such as trampling, off-leash dogs, and predators. Human disturbance is most common in the more frequently visited portions of the park: the Garry oak meadow, coastal bluffs, trails, and forest edges (Helliwell Ecosystem Based Management Handbook, 2001).

Figure 13. The sedge-dominated wetland complex extends 30 x 1000 metres along the western Garry oak meadow edge. This ephemeral wetland habitat could be restored to create suitable habitat for the reintroduction of Taylor's Checkerspot butterflies.

Conclusions and Management Objectives

Based on our analysis and results, we have established three management recommendations to help restore the Garry oak meadow and Taylor's Checkerspot habitat in Helliwell Provincial Park. Our recommendations complement ongoing restoration efforts and include: 1) thinning encroaching conifers and reducing shrub layer fuels in the northwest corner of the park to reduce fire risk; 2) reintroduce 10 x 10 m low-severity spot burns to the cleared and restored (replanted native species) portions of the open Garry oak meadow; and, 3) focus Taylor's Checkerspots habitat restoration efforts to the ephemeral, sedge-dominated wetland complex.

The reintroduction of fire through prescribed burning is likely the most effective, timely, and practical restoration technique to enhance Taylor's Checkerspots habitat in Helliwell Provincial Park. Establishing a prescribed burning program also supports several restoration objectives in the park such as decreasing the risk of future high-severity interface fires (Ryan et al. 2013), supporting the re-establishment of fire-adapted native grasses (Keeley, 2004), and restoring Garry oak meadow habitat to several threatened and critically endangered species (Pellatt et al. 2013). A comprehensive proposal for a prescribed burning program that combines traditional ecological and local knowledge with current wildfire science is an important first step to engaging stakeholders with fire restoration efforts and shifting public perceptions of fire from a once-in-lifetime event to a healthy component of forests and protected areas. Understanding the long-term climate, ecology, and human-ecosystem interactions is important to the management and success of future restoration efforts in Helliwell Provincial Park and in other parks and protected areas across British Columbia.

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Appendix

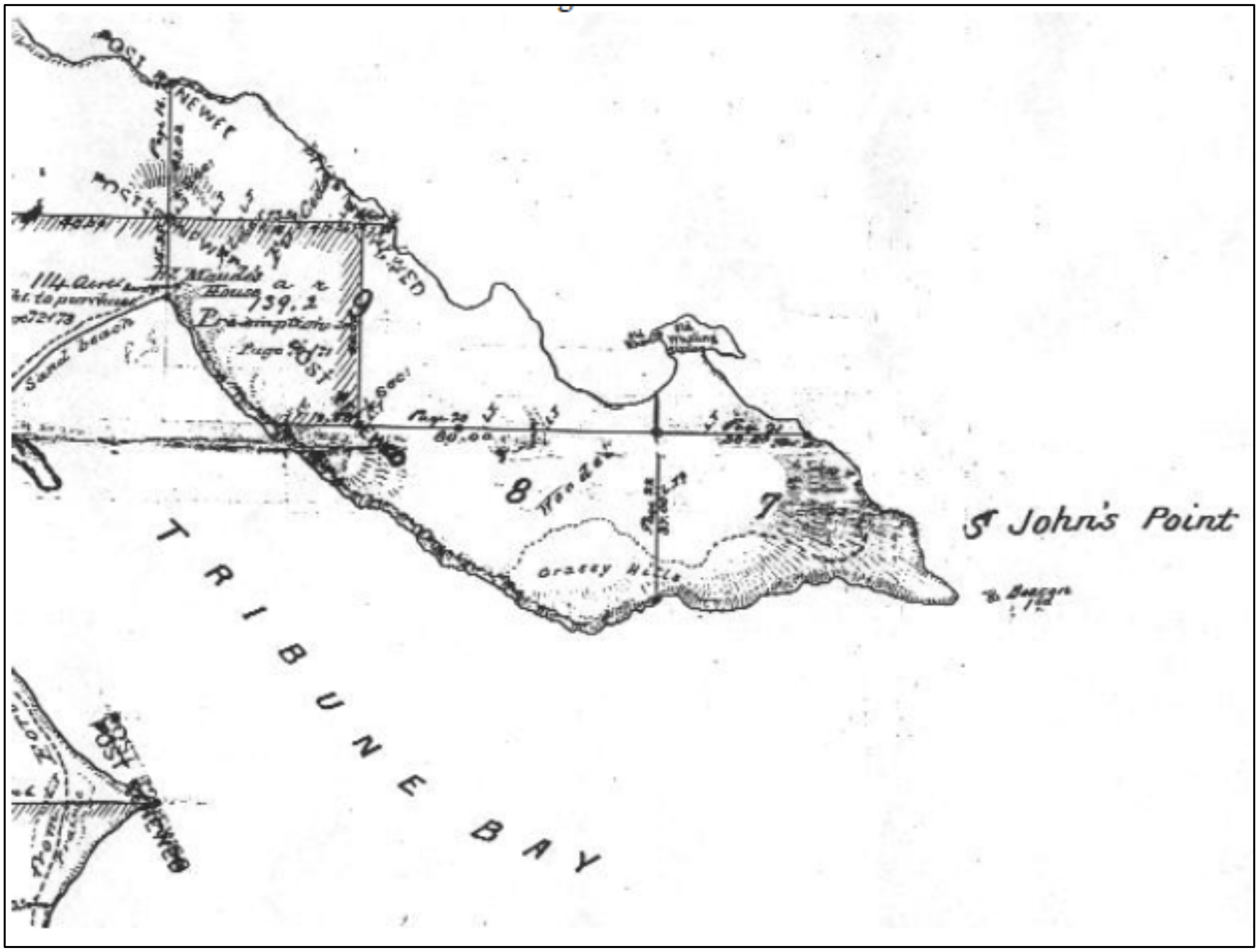

Figure A1. A hand drawn map of what is presently known as Helliwell Park and surrounding areas on Hornby Island, B.C. completed in 1875 by field surveyor Joseph Carey.

Budget

Item	Cost
Accommodation	$450.00
Travel	$1,594.45
Computer storage	$109.00
Mapping research	$1,200.00
Aerial photos	$207.30
Food	$1,198.70
Supplies	$1,311.01
Garbage disposal (Hornby Island)	$7.00
Student salaries	$12,500.00
Conference	$625.00
Total	**$19,202.46**