

**Garry oak ecosystem stand history in southwest British  
Columbia: Implications for restoration, management and  
population recovery**

**by**

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## Abstract

Understanding the ecological history of an ecosystem is essential in the development of management and restoration strategies. For example, the elimination of fire in Garry oak (*Quercus garryana*) ecosystems often leads to encroachment by conifer species like Douglas-fir (*Pseudotsuga menziesii*). We used dendroecological methods to examine history and establishment patterns of three structurally different Garry oak ecosystem stands in southwestern British Columbia, Canada. We then assessed if reintroducing fire is an appropriate management and restoration tool in the different stand types. The combined Garry oak establishment histories from the three sites are broadly consistent with the regional pattern established in other studies. However, recommendations to use fire as a restoration and management tool are site dependent. Local characteristics, such as soil depth and land use change, may be the key to restoration strategies, especially in ecosystems with high fragmentation and challenging growing conditions.

**Keywords:** Garry oak; *Quercus garryana*; British Columbia; ecological restoration; Paleoecology; fire history

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## List of Acronyms

cal yr BP	Calendar Year Before Present
DBH	Diameter at Breast Height
GOERT	Garry Oak Ecosystem Restoration Team
GPS	Global Positioning System
GINPR	Gulf Islands National Park Reserve
LIA	Little Ice Age
MFRI	Mean Fire Return Interval
MWP	Medieval Warm Period
USDI NPS	U.S. Department of the Interior, National Park Service

## Introduction

Garry oak (*Quercus garryana*) ecosystems are home to more than 100 threatened or endangered species, and out of these 55 are listed under the Canadian Species at Risk Act (GOERT 2011). Less than 10% of the pre-European, Garry oak savannah extent remains in British Columbia (Lea 2006). Studies in British Columbia and surrounding areas such as Washington state have found that a variety of factors contribute to the decline of these ecosystems, including: (1) fragmentation and habitat loss from urban and agricultural development (e.g. MacDougall et al. 2004; Lea 2006; Bjorkman & Vellend 2010); (2) introduction of exotic and invasive species (e.g. Fuchs 2001; MacDougall & Turkington 2005; Devine & Harrington 2006; MacDougall et al. 2010; Bennett et al. 2013); (3) ungulate browsing (e.g. Gonzales & Arcese 2008; MacDougall 2008); (4) changes in historic disturbance regimes (e.g. Agee & Dunwiddie 1984; Gedalof et al. 2006; Pellatt et al. 2007; Smith 2007; McDadi & Hebda 2008; Dunwiddie et al. 2011); and (5) climate change during and after the LIA (Pellatt et al. 2007). Some studies suggest changes to the historic disturbance regime is the primary factor which altered the compositional and structural characteristics in coastal Garry oak ecosystems (Agee 1993; MacDougall et al. 2004).

The structure of an ecosystem is shaped by a combination of regional and local stressors. Although sometimes difficult to differentiate, regional stressors such as temperature and rainfall simultaneously impact multiple ecosystems in a region, whereas local stressors, such as soil depth and disturbance, are site specific. In a forested ecosystem, disturbances such as disease, flooding, windthrow, fire, and insect outbreak occur throughout the succession process to produce and maintain the heterogeneity of a stand (Franklin et al. 2002). Different types of disturbances have different effects on an ecosystem, in that they can stop, slow, or accelerate succession (Johnson et al. 2009). An ecosystem that experiences the alteration or cessation of a frequent disturbance becomes susceptible to replacement by other species (Johnson et al. 2009).

Fire has been documented as a critical, historical process within many coastal Garry oak ecosystems, and the introduction of fire suppression is thought to have contributed to the decline of the ecosystem since European settlement. Garry oak ecosystems likely established on southern Vancouver Island and surrounding Gulf Islands 8300 cal yr BP, during past periods of warmer and dryer climate. This ecosystem likely persisted in the subsequent cooler and moister climate because of regular Indigenous burning practices (Pellatt et al. 2001; MacDougall et al. 2004; Pellatt et al. 2007; Dunwiddie et al. 2011; McCune et al. 2013; Pellatt & Gedalof 2014). A fire scar chronology constructed from 1530-1908 in a Garry oak ecosystem on Waldron Island in Washington, United States of America, suggests that fires were frequent prior to European settlement (Sprenger & Dunwiddie 2011). Documented evidence of cyclical burning practices by Indigenous peoples (Boyd 1999) and the dominance of fire-adapted vegetation in remaining intact Garry oak ecosystems further support the theory that fires were more frequent prior to European settlement (MacDougall 2005; Pellatt & Gedalof 2014). Frequent fires would have kept fuel accumulation low and deterred the establishment of non-fire adapted vegetation and Douglas-fir by killing seedlings and saplings (Peter & Harrington 2004). After European settlement, fire exclusion altered historic conditions and allowed for the encroachment of other conifer tree species, like Douglas-fir (Agee 1993; Tveten & Fonda 1999; Thysell & Carey 2001; Pellatt et al. 2007; Sprenger & Dunwiddie 2011).

Extensive efforts have been made to conserve and manage the last remaining intact Garry oak ecosystems in British Columbia, which are found on southern Vancouver Island and in the Gulf Islands National Park Reserve (GINPR) (GOERT 2002; Parks Canada Agency 2006). The GINPR is managed by Parks Canada and takes many different approaches to manage and restore endangered or threatened species and ecosystems within the park. Parks Canada recognizes that active management of degraded ecosystems, such as the Garry oak, is needed to bring the system back into a state that resembles its historic range prior to European settlement.

In 2010, Parks Canada undertook an initiative using “on-the-ground” research to find strategies for restoration, management and population recovery of endangered Garry oak ecosystems on southern Vancouver Island and in the Gulf Islands. Parks

Canada conducted controlled experimental burns on Tumbo Island in GINPR to simulate historical conditions and to allow the ecosystem to become re-established. The goal of the field based research on Tumbo Island is to determine if the re-introduction of fire is a feasible restoration tool by observing how the plant communities of Garry oak ecosystems respond to fire under present conditions, when exotic species, hyperabundant deer, and global change are all threatening the long-term ecological integrity of this ecosystem. Since considerable focus has been placed on the importance of fire in the development, maintenance and restoration of Garry oak ecosystems, Chapter 1 presents a literature review of the relationship between fire and Garry oak ecosystems, and the feasibility of using prescribed burns as a restoration and management tool.

While prescribed fire is one approach to ecosystem management, ecosystems may have several regional and local stressors that contribute to their distribution and structure and therefore also influence how restoration and management is implemented. Understanding historical disturbance, land use, and stand structure can aid in recognizing the contributions of regional vs. local stressors, which may be key in devising an effective management strategy. The goal of Chapter 2 is to compare the development of Garry oak stands at three structurally different sites, by examining the establishment patterns, site classification(s), and site history. Based on the analysis we (1) identify regional and local stressors that influence ecosystem structure, and (2) assess if reintroducing fire is an appropriate management and restoration tool in each stand. Chapter 2 has been written as a draft publication manuscript which explains some of its overlap with this introduction and the conclusion. The Management & Restoration Recommendation section summarizes our recommendations for the potential use of fire as a restoration tool at each site. Finally, the Conclusion section brings together our interpretation of how the regional climate, land-use, and fire histories combine with local disturbances to create unique conditions at each of our three study sites on southern Vancouver Island and in the Gulf Islands.

## **Chapter 1.**

### **The Role of Fire in Garry Oak Ecosystems**

The relationship between fire and Garry oak ecosystems in North America has been extensively researched and reviewed (e.g. Agee 1993; Gedalof et al. 2006; McDadi & Hebda 2008; Bjorkman & Vellend 2010; Engber et al. 2011; Sprenger & Dunwiddie 2011; McCune et al. 2013; Pellatt & Gedalof 2014; Pellatt et al. 2015). Some studies suggest the most significant alteration to this ecosystem has occurred as a result of fire suppression (Agee 1993; MacDougall et al. 2004). As a result, understanding the impact of reintroducing fire as a restoration and management tool is a central focus of many conservation and restoration efforts (e.g. MacDougall & Turkington 2007; Pellatt et al. 2007; McDadi & Hebda 2008).

Several factors are thought to affect the success of a prescribed fire including: fuelbed load, season of fire, burn frequency or burn cycle, composition of species, and encroachment of conifer species. The goal of this chapter is to review literature which describes the relationship between fire and Garry oak ecosystems, and the factors which affect the success of a prescribed fire. The focus of this study is Garry oak ecosystems located in southern Vancouver Island and the Gulf Islands, British Columbia. However, where applicable, information is compiled from the range of Garry oak ecosystems from California, United States of America to British Columbia, Canada.

#### **1.1. Garry Oak Ecosystems and the Historical Role of Fire**

Fire suppression has substantially altered the vegetation structure of several types of Garry oak ecosystems. In deep soil sites, dense patches of non-native grasses, woody shrubs and conifer species can establish. As vegetation establishes and becomes overcrowded, grass and leaf litter increase while bare soil, light penetration,

and accessible soil nitrogen decrease, which changes the microclimate of the understory (MacDougall et al. 2004; Devine & Harrington 2007; MacDougall & Turkington 2007). The limiting factor for many native species in Garry oak ecosystems is access to sunlight. As a result of decreased light penetration, native species are outcompeted by non-native species which have a higher tolerance to shade (MacDougall 2005; MacDougall & Turkington 2007). The establishment of Douglas-fir can result in substantial changes to the water cycle by requiring large quantities of water for growth causing native vegetation to compete for limited water supplies (Stein 1990). These conditions make it harder for “at risk” native plant species to thrive, hence non-native species are able to move in and outcompete them. Cyclical fire disturbances would keep understory vegetation in Garry oak stands at relatively low densities (Peter & Harrington 2004), by eliminating litter and opening up areas where easily outcompeted fire-resistant subordinate grass and forb species can re-establish (Dunwiddie 2002; MacDougall et al. 2004).

The native species found in Garry oak ecosystems have many attributes adapted to fire (Gucker 2007). Garry oak trees are considered a fire-resistant species because of morphological characteristics that decrease the probability of injury or mortality during fire events (Gucker 2007, Devine et al. 2013). Thick, dense bark and fairly low flammability of leaves prevent a large number of Garry oak trees from succumbing to fire. In many cases, the intensity of fire does not damage Garry oak trees enough to cause mortality (Agee 1993). Following intensive fires with high tree mortality, Garry oak trees have the ability to sprout from the root crown or roots (Gucker 2007, Devine et al. 2013, Tveten & Fonda 1999, Sugihara & Reed 1987). In addition, many native herbaceous species found in Garry oak ecosystems do not flower in the summer dry period when fire would naturally be the most frequent (MacDougall & Turkington 2007). Therefore, reproduction and proliferation of many native species is not impacted by the deleterious effects of fire.

To understand the role that fire plays in the persistence of Garry oak ecosystems, researchers have examined paleoecological reconstructions and historical documents, and conducted experiments in which fire is reintroduced. First, paleoecological tools can be used to reconstruct the historical fire frequency in a given

area. Two common proxies are charcoal from sedimentary records and fire scars on tree rings. Charcoal deposits in lake sediments can be used to produce long-term (centennial-to-millennial) fire records, and are most accurate when fires are high severity and stand replacing (Higuera et al. 2011). Fire scars on tree rings can record a higher resolution of fire history than charcoal analysis by detecting lower intensity fire episodes (Pellatt et al. 2007). However, the length of the record is constrained by the life time of the tree. Combining lake sediment charcoal and fire scar records can be used to create a mean fire return interval (MFRI) which is an estimation of the average time between fires. The MFRI provides information about the past role of fire in Garry oak ecosystems and can be utilized by restoration managers as a baseline to determine how often prescribed burns could be implemented to mimic a historical fire regime.

Charcoal and tree-ring studies have produced vastly different MFRI for Garry oak ecosystems located in southern Vancouver Island and the Gulf Islands region. Charcoal-determined MFRI from three studies range from 26-41 years (Pellatt et al. 2015), to 88 years (Lucas and Lacourse 2013), to 318 years (Murphy 2016). In contrast, tree-ring fire scars on trees from nearby Waldron Island, Washington, United States of America, revealed a composite MFRI of 7.4 years from 1700-1879 (Sprenger & Dunwiddie 2011). In addition to inherent differences in temporal resolution between tree rings (annual) and sediment records (decadal), the discrepancy between the MFRI is most likely due to the inability of charcoal records to differentiate between charcoal produced by low intensity fires and charcoal deposited in years when fires did not occur (Higuera et al. 2011). Either way, the MFRI results indicate a history of cyclical fire events in Garry oak ecosystems in this area, supporting the idea that fire played an important role in Garry oak ecosystems.

Second, evidence of indigenous land use supports inferences from paleoecological records that fire played an important role in maintaining regional Garry oak ecosystems. The cyclical fire regime associated with Garry oak ecosystems prior to European settlement has been linked in part to land management activities of local Indigenous peoples (Agee 1993; Turner 1999; Fuchs 2001; Bjorkman & Vellend 2010). Before 1843 (Lothian 1987; McDadi & Hebda 2008), Indigenous peoples had lived on Vancouver Island and the surrounding Gulf Islands for at least 5,000 years (Grier et al.

2009; McCune et al. 2015). Early settlers on eastern Vancouver Island documented many fires between 1843 and 1865, which are believed to have been ignited by Indigenous peoples (Turner 1999; MacDougall et al. 2004). Fires were observed in the late summer and early autumn (Fuchs 2001; Turner 1999) and used in some deep soil Garry oak ecosystems by Indigenous peoples for cultural and agricultural purposes. Food sources such as camas (*Camassia spp*) and certain root species required open grassland and savannah ecosystems to grow (Turner 1999; MacDougall et al. 2004; McDabi & Henda 2008; McCune et al. 2015). Fire may have been used to attract deer to easily accessible open hunting grounds (Boyd 1999). Following European settlement, the combination of introduced disease (Harris 1997) and imposed fire suppression (Turner 1999; MacDougall et al. 2004) ended Indigenous management (Pellatt et al. 2001; McCune et al. 2015) and led to an extreme shift in composition, structure, and function in many types of Garry oak ecosystems (Fuchs 2001).

Lastly, field experiments on southeastern Vancouver Island, British Columbia, point to a long-term influence of fire on Garry oak ecosystems. MacDougall (2005) found that the community response to fire depended on initial stand diversity. Plots with high species richness maintained their diversity of fire-tolerant native plants following the introduction of fire, while plots with low diversity lacked native fire tolerant species and were heavily invaded by exotic species. The experiment suggests that in the past, regular fire disturbance kept the native species diversity high and made it more resilient to invasion by exotic species.

## **1.2. Reintroducing Fire as a Restoration Tool in Garry Oak Ecosystems**

Experimentally reintroducing fire is another tool used to quantify the role of fire in Garry oak ecosystems and has highlighted important differences in responses depending on the initial characteristics of the area burned. Prescribed fire has been recognized as a restoration and management approach since the 1970s (Sugihara and Reed 1987; USDI NPS 2010) and has remained the focus of many conservation and restoration efforts (e.g. MacDougall & Turkington 2007; Pellatt et al. 2007; McDadi & Hebda 2008). The first prescribed burn in Redwood National Park took place in 1980,

and by 1992 a total of 356 acres had been burned in fifteen separate prescribed fires (USDI NPS 2010). These experiments, combined with other studies, showed that the factors affecting the success of a prescribed fire include fuelbed load (Engber et al. 2011), season of prescribed fire (Tveten & Fonda 1999), burn frequency (Tveten & Fonda 1999; USDI NPS 2010), species composition (Tveten & Fonda 1999; MacDougall 2005; MacDougall & Turkington 2007; Stanley et al. 2011), soil depth (MacDougall 2005; MacDougall & Turkington 2007), and encroachment from conifer species (Devine et al. 2007; Cocking et al. 2012; Devine et al. 2013).

The fuelbed load (accumulated understory vegetation) and species composition of the understory can affect the fire intensity and therefore the effectiveness of prescribed burns (MacDougall & Turkington 2007; Engber et al. 2011). An ecosystem in which fire suppression has substantially altered the fuelbed load will respond to fire very differently than an ecosystem experiencing frequent fire. When fire was reintroduced to five structurally different Garry oak ecosystems in Redwood National Park, California, Engber et al. (2011) found the composition and structure of fuelbed material in early successional Garry oak ecosystems (*i.e.* grassland and savannah) promoted fast spreading fires intense enough to kill encroaching woody vegetation and conifer seedlings and saplings (Peter & Harrington 2004). In contrast, fires introduced in late successional ecosystems (*i.e.* invaded conifer woodland communities) showed a higher probability of being extinguished due to the composition and structure of the fuelbed material, thus limiting the ability of the fire to control understory vegetation (Engber et al. 2011; Devine et al. 2013). Reintroducing fire to stands with a dry, dense woody understory can result in mortality of mature Garry oak and lead to high severity, stand replacing fires (Tveten & Fonda 1999; Devine et al. 2013). Thus, successful implementation of prescribed fire must take fuelbed load into consideration.

The season a fire is implemented can affect success. Historically, fires in Garry oak ecosystems occurred between July and October when moisture availability is lowest (MacDougall & Turkington 2007). Although fires could occur at anytime of year, studies have found that fires which occur outside the native species growing season (Gonzales & Clements 2010), or during the non-native species growing season (MacDougall & Turkington 2007), are the most effective at decreasing non-native species without

negatively impacting native species. Prescribed burns in the autumn are more effective at killing fire-sensitive competitors and encouraging native species growth than prescribed burns in the spring (Tveten & Fonda 1999; MacDougall & Turkington 2007). However, because fire has been absent for an extended period, some native species have naturally increased in dominance in Garry oak ecosystems and are sensitive to fire during late summer and early autumn (MacDougall & Turkington 2007). As a result, the phenologies of the most important native species should be considered during restoration efforts when choosing the timing of prescribed burns.

Burn frequency also plays a large part in successful restoration. Charcoal and fire scar records suggest an MFRI that ranges from 7.4 – 318 years in the Gulf Island region (Sprenger & Dunwiddie 2011; Pellatt et al. 2015; Murphy 2016). However, fire scars on tree rings (MFRI = 7.4 years) would likely be the most accurate proxy of MFRI for the purposes of revealing lower intensity fires that are not stand replacing. This estimate is supported by several long-term experiments that found an increase in native plant cover on a burn cycle of 3-5 years (Tveten & Fonda 1999) and 3-7 years (USDI NPS 2010). Furthermore, burn cycles greater than 7 years are unable to kill Douglas-fir and encroaching conifer species as most are able to grow to a height and diameter which does not succumb to low intensity prescribed fire (Engber et al. 2010; USDI NPS 2010; Cocking et al. 2012).

The species composition is an important factor to consider prior to prescribed burn implementation. The response of a Garry oak ecosystem to reintroducing fire can depend on initial ecosystem diversity, species richness, and pre-burn soil depth. Prescribed burning can initially decrease the composition of non-native species (Clark & Wilson 2001; Dunwiddie 2002), and if native species are unable to rejuvenate, then non-native species will re-establish (Tveten & Fonda 1999; MacDougall 2005; MacDougall & Turkington 2007; Stanley et al. 2011). In a study on southeastern Vancouver Island, British Columbia (MacDougall 2005), plots with deep soil and high species richness maintained their diversity of fire-tolerant native plants. In contrast, plots with low diversity which lacked native fire tolerant species, were either moderately or heavily invaded by non-native species depending on soil depth. Communities with low native species richness and shallow soil had no means to resist invasion and were heavily invaded

(MacDougall 2005). The experiment suggests a positive link between repeated fire disturbance, high species diversity, and ecosystem stability (MacDougall 2005) and implies that several burn cycles may be required to restore fire-tolerant, native species diversity in heavily compromised ecosystems.

Lastly, encroachment of conifer species further complicates the success of a prescribed burn. Established conifer species decrease the understory light, growing space, and water, which restricts the establishment of native herbaceous species (Devine et al. 2007; Devine et al. 2013). Garry oak trees become suppressed when overtopped by conifer species. The establishment of conifer species impacts the understory microclimate making conditions cool and damp. If prescribed burns are implemented, the altered understory conditions can extinguish fire and restrict the effectiveness of reintroducing fire (Tveten & Fonda 1999; Devine et al. 2007; Engber et al. 2011; Devine et al. 2013). In addition, competitive pressure from conifer encroachment may compromise native species ability to survive fire (Cocking et al. 2012).

Prior to implementing a prescribed burn, it may be necessary to remove or reduce encroaching conifers. Removing or reducing conifer encroachment reduces the competition with native species for light, growing space, and water, which allows for the re-establishment of herbaceous species (Devine et al. 2007; Devine et al. 2013). Removing Douglas-fir has been shown to increase stem growth, epicormic branching, and acorn production in overtopped Garry oak trees (Devine & Harrington 2006, 2013; Devine et al. 2013). Removing conifer species also restores the understory microclimate conditions to a warmer and drier state, which reduces moisture in the fuelbed and better facilitates controlled burns (Tveten & Fonda 1999; Engber et al. 2011; Devine et al. 2007; Devine et al. 2013). Post removal treatments are recommended to deter the establishment of non-native species which have been shown to opportunistically repopulate areas where conifers have been removed more quickly than native species can (Devine et al. 2007).

### 1.3. Conclusion

In summary, several types of Garry oak ecosystems appear to be historically linked to high frequency fire regimes. The link is supported by attributes in native vegetation, paleoecological evidence, documented history, and experimental reintroductions of fire in Garry oak ecosystem. The vegetation structure of several types of Garry oak ecosystems has been substantially altered by the cessation of fire as a disturbance. Additionally, vegetation that is native to Garry oak ecosystems have attributes that allow them to survive high-frequency fire regimes, including thick bark to withstand fire, low leaf flammability, ability to sprout following a fire, and flowering during seasons with low-fire risks. Paleoecological tree-ring reconstructions have revealed a pattern of high frequency fire during periods when Garry oak ecosystems thrived. While different paleoecological methods produce a range of values, MFRI as frequent as 7.4 years were found from 1700-1879 in a Garry oak ecosystem in nearby Washington, United States of America. To further support the pattern found by paleoecological reconstructions, historical documentation reveals the use of fire during Indigenous land use practices (e.g. agriculture and hunting practices).

Experimentally reintroducing fire to understand the role of fire in Garry oak ecosystems is largely dependent on specific conditions within the target site. Reintroducing fire to early successional, intact Garry oak ecosystems tends to kill encroaching and invasive species because the fuelbed promote fires. In sites with a high frequency of fire, native biodiversity is kept high and the ecosystem is made more resilient to invasion by exotic species. In contrast, late successional Garry oak ecosystems generally extinguish fire due to the low flammability of the fuelbed, thus limiting the ability to control understory vegetation making it more susceptible to invasion by exotic species. Taken together, these factors suggest that the Garry oak ecosystem was at one-time dependent on fire for its maintenance and structure.

Based on the outcome of experimentally reintroduced fire and implemented prescribed burns, researchers and managers have identified multiple factors which can determine the success of a prescribed burn. First, reintroducing fire to stands with a dry, dense woody understory can result in mortality of mature Garry oak and lead to high

severity, stand replacing fires. In contrast, reintroducing fire to stands with moist understory and heavy Douglas-fir encroachment will extinguish the fire. Second, the phenologies of target native species influence the ideal time to implement burns. In general, prescribed burns in the autumn are more effective at killing fire-sensitive competitors. Third, implementing prescribed fire every 3-7 years ensures that the majority of encroaching conifer species will succumb to fire. Fourth, ecosystems with deep soil and high species richness with abundant fire tolerant native species tend to have a higher ability to resist invasion from non-native species. However, if the ecosystem has low native species richness and shallow soil, the combined effect can destabilize the ecosystem allow non-native species to establish. Finally, removing encroaching conifer species decreases competitor pressure on native species and increases understory light, growing space, microclimate temperature and water availability. Successful implementation of prescribed fire must consider all of these factors above and include them in a Fire Management Plan.

Understanding the effects of fire suppression and assessing the possible benefits of fire restoration address two important questions involved in restoring Garry oak ecosystems in British Columbia, but several challenges to implementation remain. First, the majority of the remaining Garry oak ecosystems in British Columbia are a mosaic of scattered single remnants or patchy stands, and the application of practices used on large continuous ecosystems may not be effective. Second, many Garry oak ecosystems in British Columbia are located in urban areas where implementing fire may receive public opposition. In this case, it may not be feasible to burn large areas but only small patches. Would burning small patches simulate the necessary conditions to yield positive results? A third challenge in British Columbia involves the limited recruitment of Garry oak trees since the mid-1900s. The only recruitment of Garry oaks that has occurred in British Columbia since 1950, without direct human intervention, is on small islands (Pellatt & Gedalof 2014). Thus, a key question involves understanding why only limited recruitment has occurred in these ecosystems, and assessing whether site-specific factors (i.e. local stressors) or climate drivers (i.e. regional stressors) play an important role. Chapter 2 addresses these issues by providing an in-depth look into three Garry oak ecosystems in British Columbia, and considering how they contribute to a successful management and restoration strategy.

## Chapter 2.

# Garry Oak Ecosystem Stand History in Southwest British Columbia: Implications for Restoration, Management and Population Recovery

## 2.1. Abstract

In Garry oak (*Quercus garryana*) ecosystems, the elimination of fire has often led to encroachment by conifer species like Douglas-fir (*Pseudotsuga menziesii*), and so fire is often proposed as a restoration tool. However, understanding other historical contributions to ecosystem structure is essential for developing comprehensive restoration strategies. We used dendroecological methods to examine establishment patterns at three structurally different Garry oak stands in southwestern British Columbia, Canada, and assessed the applicability of fire as a restoration tool. The combined Garry oak establishment histories from the three sites are broadly consistent with a regional pattern of Garry oak establishment in the 1700s and Douglas-fir encroachment in the late 1800s, following European settlement and fire suppression. However, site-specific stressors shape individual site structure and influence whether fire is a beneficial management tool. The Somenos Marsh site has a history of Indigenous land use, where regular burning practices maintained the Garry oak savannah prior to European settlement. This site would be well-suited for fire reintroduction. In contrast, the Tumbo Cliff site lacks a history of frequent fire, and Douglas-fir encroachment is limited by shallow soils and drought. Here, prescribed fire is only recommended following removal of large Douglas-fir and more detailed investigation of local conditions. Finally, at the Tumbo Marsh site, changing marsh conditions in the early 1900s (and not frequent fire disturbance) enabled the establishment of Garry oak and Douglas-fir. Here, fire might be implemented following a detailed vegetation survey and experimental restoration plan design. These results emphasize the importance of understanding site-

specific establishment patterns, history, and stressors when developing management and restoration strategies.

## 2.2. Implications

- Garry oak and Douglas-fir recruitment correspond with the end of the Little Ice Age Period (LIA) after the collapse of Indigenous populations but in some cases prior to European settlement. This expansion of trees after the LIA is consistent with the general collapse of Indigenous populations in the Americas.
- A clear relation among Indigenous occupation, subsequent European settlement and the development of oak woodland occurs at the Somenos Marsh site. Supporting research indicates the importance of Indigenous land management in the development of many Garry oak ecosystems.
- Regional climate, edaphic conditions, and periodic fire likely drives the characteristics of dry, shallow soil Garry oak woodlands. Prescribed burning by Indigenous peoples was not likely an important contributing factor. These sites require a more cautious approach to prescribed fire.
- Garry oak can establish and grow quickly when conditions are favorable, as observed at the Tumbo Marsh site after conditions changed from a saltwater tidal flat into a freshwater marsh environment.
- The combination and comparison of site level historical records, site characteristics, and dendrochronological data within the region provides a greater understanding the local and regional factors that shape the structure of these ecosystems. This information can be integrated into a restoration and fire management strategy for each site.

## 2.3. Introduction

Garry oak (*Quercus garryana*) ecosystems are home to more than 100 threatened or endangered species, and out of these 55 are listed under the Canadian Species at Risk Act (GOERT 2011). Less than 10% of the pre-European, Garry oak savannah extent remains in British Columbia (Lea 2006). Several factors contribute to the decline of these ecosystems, including: (1) fragmentation and habitat loss (e.g. MacDougall et al. 2004; Lea 2006; Bjorkman & Vellend 2010); (2) exotic and invasive species (e.g. Fuchs 2001; MacDougall & Turkington 2005; Devine & Harrington 2006;

MacDougall et al. 2010; Bennett et al. 2013); (3) ungulate browsing (e.g. Gonzales & Arcese 2008; MacDougall 2008); (4) changes in historic disturbance regimes (e.g. Agee & Dunwiddie 1984; Gedalof et al. 2006; Pellatt et al. 2007; Smith 2007; McDadi & Hebda 2008; Dunwiddie et al. 2011); and (5) climate change during and after the LIA (Pellatt et al. 2007). The combination of these threats has degraded the ecological integrity of Garry oak ecosystems (Pellatt et al. 2007) in British Columbia and left a mosaic of scattered single remnants or patchy stands (Erickson 2000; Fuchs 2001).

Fire appears to have been an important disturbance mechanism for Garry oak ecosystems. The establishment of Garry oak ecosystems occurred on southern Vancouver Island and surrounding Gulf Islands approximately 8300 cal yr BP, during past periods of warmer and dryer climate (Pellatt et al. 2001). As the climate subsequently became cooler and moister, this ecosystem is thought to have persisted because of Indigenous burning practices (Pellatt et al. 2001; MacDougall et al. 2004; Pellatt et al. 2007; Dunwiddie et al. 2011; McCune et al. 2013; Pellatt & Gedalof 2014). A fire scar chronology constructed from 1530-1908 on nearby Waldron Island in Washington indicates that fires were frequent in Garry oak ecosystems prior to European settlement (Sprenger & Dunwiddie 2011). Evidence of cyclical burning practices by Indigenous peoples (Boyd 1999) and the dominance of fire-adapted vegetation in remaining intact Garry oak ecosystems further suggests that fires were more frequent prior to European settlement (MacDougall 2005; Pellatt & Gedalof 2014). Frequent fires would have kept fuel accumulation low and deterred the establishment of non-fire adapted vegetation and Douglas-fir by killing seedlings and saplings (Peter & Harrington 2004). European colonization brought the onset of disease and pan-American genocide to Indigenous people in North America (Boyd 1999). The decrease in human population potentially resulted in an expansion of forest due to the cessation of Indigenous land management, which potentially decreased CO<sub>2</sub> levels and cooled the climate (Nevle et al 2011; Kaplin 2015), altering the ecological trajectory of Garry oak ecosystems. Combined with the effects of fire exclusion enforced by European settlers, the eventual infilling of Garry oak and encroachment of conifer tree species occurred.

Conservation and recovery actions are targeting remaining Garry oak ecosystems in British Columbia, which are primarily found on southern Vancouver Island

and in the southern Gulf Islands (Figure 2.1; GOERT 2002; Parks Canada Agency 2006). The GINPR contains Garry oak ecosystems and is mandated to maintain and restore the ecological integrity of the ecosystems and “at-risk” species within the protected area. One of Parks Canada’s goals is to re-establish prescribed fire as a tool to restore Garry oak ecosystems, while recognizing past Indigenous land management practices. In 2010, Parks Canada began an experimental restoration project, which involved conducting controlled experimental burns on Tumbo Island in the GINPR in 2016. The goal of the field-based research is to determine if re-introducing fire is a feasible restoration tool given present day stressors such as exotic invasive species, hyperabundant deer, and global change.

While prescribed fire is one approach to ecosystem management, several other regional and local factors can also contribute to ecosystem distribution and structure. Understanding historical disturbance, land use, and stand structure of a particular site can aid in recognizing which stressors are most important in devising an effective management strategy. The goal of this study is to compare the development of Garry oak stands at three structurally different sites, by examining the establishment patterns, site classification(s), and site history. We then assess (1) whether reintroducing fire is an appropriate management and restoration tool in each stand, and (2) which regional and local stressors are important for informing management and restoration strategies.

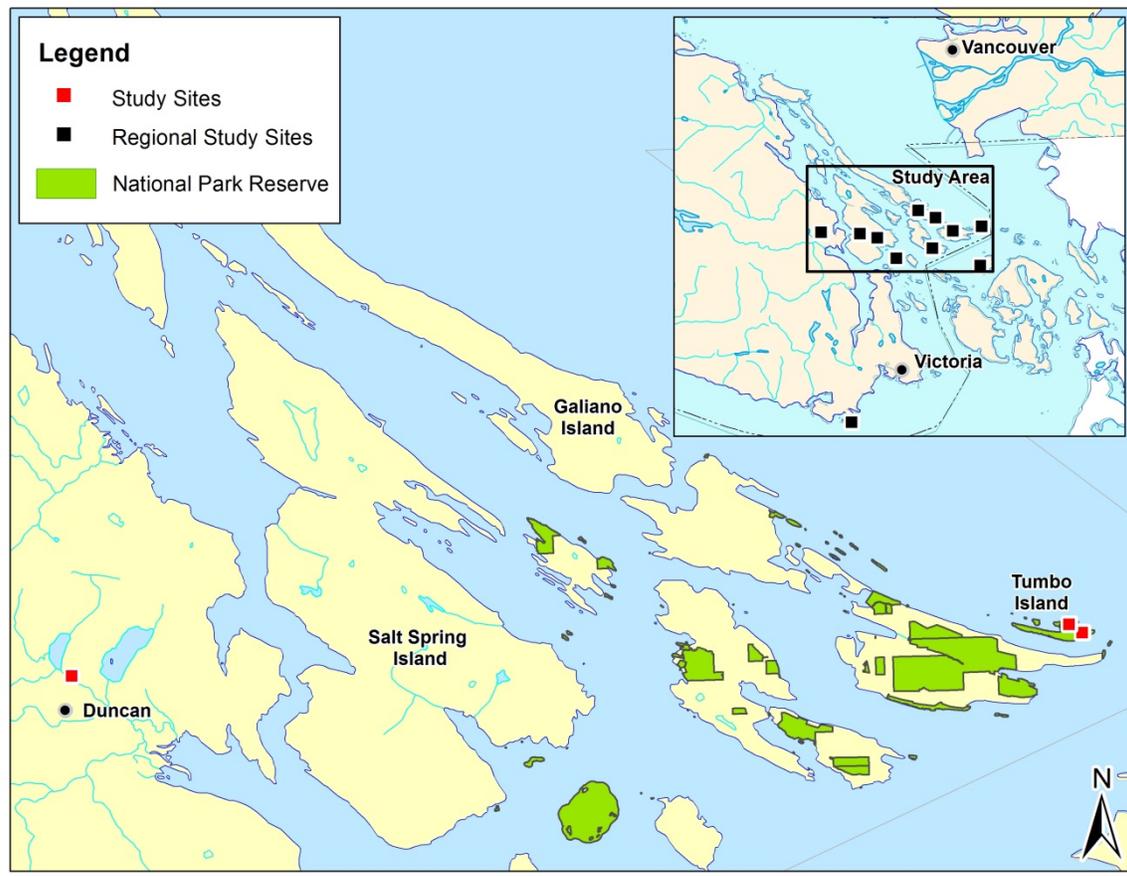
## **2.4. Study area and Garry oak habitat**

Garry oak is an umbrella species for a wide variety of vegetation in xeric and mesic environments, from open savannah and mixed stand woodlands to closed canopy forests (Fuchs 2001; GOERT 2011). Mature Garry oak are shade intolerant and on deep soil sites are easily out-competed by other, faster-growing tree species (Stein 1990; Pellatt et al. 2007). In present day, Garry oak is most common on sites that are too arid or exposed for other tree species, but it can also tolerate extended periods of both flooding and drought and is found in very moist areas, including wetlands and flood plains (Stein 1990).

British Columbia represents the northern most extent of the Garry oak range along the Pacific Coast of North America (Stein 1990). Here, Garry oak ecosystems are located in the rain shadows of the Olympic and Vancouver Island mountain ranges, in association with the driest part of the Coastal Douglas-fir biogeoclimatic zone (Nuszdorfer et al. 1991). Coastal Douglas-fir (*Pseudotsuga menziesii*), Western Redcedar (*Thuja plicata*), Grand fir (*Abies grandis*) and Arbutus (*Arbutus menziesii*) are usually found in the Coastal Douglas-fir biogeoclimatic zone (Nuszdorfer et al. 1991). However, the dominant species in the southern Gulf Islands depends on nutrient regime and soil moisture (Nuszdorfer et al. 1991). Located between elevations of 0 to 200 m, Garry oak is the only native oak in British Columbia and Washington. Garry oak ecosystems in southern Vancouver Island and Gulf Islands are primarily found in small patchy stands that differ in disturbance history, slope gradient and position, and moisture regime (Sugihara et al. 1987). As a result, the plant communities in different Garry oak ecosystems vary substantially (Fuchs 2001; GOERT 2011).

## **2.5. Study Sites**

Three study sites were chosen within or near GINPR based on structural characteristics that best represented the range of different Garry oak ecosystems in British Columbia (Figure 2.1). The study sites had structural characteristics that encompassed a savannah and meadow community, a deep soil woodland community, and a shallow soil, rocky outcropping, Douglas-fir community.



**Figure 2.1 Study area, showing southern Vancouver Island, southern Gulf Islands and Gulf Islands National Park Reserve.**  
 Study area, showing the southern Gulf Islands, Gulf Islands National Park Reserve, and the three study sites (red squares) including two study sites on Tumbo Island and one study site on Vancouver Island (Somenos Marsh). Inset shows location of the regional study sites (black squares) discussed in the text including Vancouver Island (Rocky Point) (Gedalof et al. 2006), Anniversary Island (Smith 2007), Brackman Island (Smith 2007), Georgeson Island (Smith 2007), Tumbo Island (Smith 2007), South Pender Island (Smith 2007), Saturna Island (Smith 2007), Salt Spring Island (Smith 2007), Vancouver Island (Cowichan Garry Oak Preserve (Smith 2007), Waldron Island (Point Disney) (Dunwiddie et al. 2011) and Salt Spring Island (Crow's Nest Ecological Research Area (Jordan & Vander Gugten 2012). Reproduced with permission of the Province of British Columbia.

### 2.5.1. Somenos Marsh

Somenos Marsh (Figure 2.2) is located on the south side of Somenos Lake on southern Vancouver Island, approximately 2 km north of Duncan, BC (48.48°N, 123.42°W). As part of the Somenos Wildlife Management Area, the site is managed in accordance with the Somenos Management Plan 2001, which involves mowing, mulching and pulling invasive shrubs and herbaceous species (Williams & Radcliffe

2001; GOERT 2011). The Garry oak ecosystem that surrounds Somenos Marsh is characterized by wet, deep sandy loam soil. The area is imperfectly drained and in the growing season the soil can be saturated for extended periods of time (Christie et al. 1985). Some Douglas-fir encroachment can be found on the perimeter of the Garry oak meadow.

Using the GOERT (2012) classification scheme, Somenos Marsh likely fluctuates between a Deep Soil, Wetter Garry Oak Community or Deep Soil, Average Moisture Garry Oak Community, depending on time of year (Table 2.1). Using the scheme of Erickson & Meidinger (2007), Somenos Marsh might also be considered a deep soil Garry oak woodland or a parkland community type.



**Figure 2.2. Somenos Marsh study site.**  
(a) Aerial view of Somenos Lake study area and Somenos Marsh study site (red square).  
(b) Somenos Marsh study site showing management efforts to control invasive shrubs and herbaceous species. (a) Reproduced with permission of the Province of British Columbia.

### 2.5.2. Tumbo Island

Tumbo Island is a small (1.1 km<sup>2</sup>), uninhabited island located close to the United States border in the Strait of Georgia and northern Puget Sound (Figure 2.1). It was acquired by Parks Canada in 1997 and included in GINPR in 2003. Tumbo Island had a brief history of exploratory coal mining and fox farming in the late 1800s and early 1900s (Parks Canada 2004). Some associated logging and tree removal occurred to build

structures for the coal mines or fox farm (Parks Canada 2004). The two study sites on Tumbo Island are located approximately 600m apart (Figure 2.3).



**Figure 2.3 Tumbo Island study sites**

(a) Aerial view of Tumbo Island study area. The red squares signify the locations of (b) Tumbo Cliff, (c) Tumbo Marsh and (d) previous study location of Smith (2007). Bottom panel (b) picture of Tumbo Cliff study site and (c) picture of Tumbo Marsh study site. (a) Reproduced with permission of the Province of British Columbia.

### ***Tumbo Cliff***

“Tumbo Cliff” is located on the south-eastern perimeter of the island (Figure 2.3b). The area is classified as undifferentiated bedrock and contains a rocky outcrop with areas of shallow soil and exposed bedrock (Kenney et al. 1988). The study site has an average slope of 25%, with three distinct plateaus where the majority of trees are

located. The Garry oak are located within the shallow soil where rapid draining occurs. Upslope from the cliff, the forest develops into a mixed stand of Douglas-fir, Arbutus, and lodgepole pine (*Pinus contorta*). Only three pine trees are located in the study site. Douglas-fir encroachment in the study site results in crowding and overtopping of most of the Garry oak on the cliff side. The Garry oak are small, with an average diameter at breast height (DBH) of less than 30 cm. Many fire scars are present on large veteran Douglas-fir and standing dead trees. No Garry oak seedlings or saplings were listed in previous vegetation surveys from 2010 and 2013 (M. Pellatt 2013, Parks Canada Agency, personal communication), and all Douglas-fir seedlings are heavily grazed by deer.

The Tumbo Cliff site is a combination of Douglas-fir and Coastal Bluff communities (Table 2.1) (GOERT 2012). The Douglas-fir Community is dominated by coniferous species with some Garry oak and Arbutus and occupies approximately 75% of the area furthest from the cliff. The Coastal Bluff Community occupies the shallow soils on the plateau closest to the cliff. The south facing cliff could also be considered a Scrub Oak Community (Erickson & Meidinger 2007).

### ***Tumbo Marsh***

“Tumbo Marsh” is located on the eastern central portion of Tumbo island on the perimeter of a freshwater *Typha*-dominated marsh (Figure 2.3c). The site is bordered by a sloping, closed canopy Douglas-fir and Arbutus forest with rapidly draining sandy soils to the west and savannah to the east of the marsh (Kenney et al. 1988). The study site is a mixed stand of Garry oak, Douglas-fir, lodgepole pine saplings, and young trees, but it contains several Garry oak, many of which are large (>1m in diameter). A small percentage of the oak is overtopped and crowded as a result of Douglas-fir encroachment.

The Tumbo Marsh site is best classified as either a Deep Soil, Wetter Garry Oak Community (Table 2.1) (GOERT 2012) or a Riparian or Wetland Marsh Garry oak ecosystem. The site is flat with a poorly drained, deep sandy loam soil. Its location adjacent to Tumbo Marsh results in year-round inundation with water, meaning the soils remain saturated for extended periods of time (Kenney et al. 1988).

**Table 2.1. Site characteristics and classification(s) for Tumbo Cliff, Tumbo Marsh and Somenos Marsh**

Site Name	Site Characteristics	Site Classification
Somenos Marsh	Deep soil Flat (0-5% slope) Mean annual precipitation ~1361mm/yr (Duncan, BC) Garry oak dominant, few Douglas-fir (n=3) Wet, deep sandy loam soil Imperfectly drained	1) Deep Soil, Wetter Garry Oak Community or Deep Soil, Average Moisture Garry Oak Community depending on amount of precipitation
Tumbo Cliff	Steep slopes along ocean Primarily shallow soil Average slope (~25%) Mean annual precipitation ~812 mm/yr (Saturn, BC) South facing 25% rock outcrop and shallow soil overtop of bedrock dominated by Garry oak >50% mixed stand Douglas-fir, Arbutus and lodgepole pine <25% sandy loam over top bedrock, dominated by Douglas-fir and salal	1) ~ 25% Coastal Bluff Community 2) ~75% Douglas-fir Community
Tumbo Marsh	Deep soil Flat (0-5% slope) Mean annual precipitation ~812 mm/yr (Saturn, BC) Garry oak and Douglas-fir Poorly Drained, sandy loam	1) Deep Soil, Wetter Garry Oak Community

## 2.6. Stand Structure Field Methods

Dendroecological (tree-ring) analysis was used to reconstruct the approximate establishment dates of the three stands. At each site, we conducted a general observational survey, extracted tree cores, measured DBH and diameter at core height, and collected GPS coordinates of each tree cored. Within each study area, representative plots were set out for sampling structural characteristics. 50 m x 75 m plots were set out at Somenos Marsh and Tumbo Cliff sites, and the entire Garry oak meadow (~50 m x 50 m) was sampled at Tumbo Marsh. Although present in the Tumbo Island study areas, Arbutus trees were not sampled due to the inability to discern annual growth rings and therefore also age of establishment (Gedalof et al. 2006; Smith 2007).

At Somenos Marsh and Tumbo Cliff, we collected two increment cores from each tree, one at DBH and the other as close to the base as possible, to allow for efficient and accurate crossdating and establishment date determination (Speer 2010). At Tumbo Marsh, only half of the trees had two cores taken from them, to restrict destructive sampling in the GINPR. Sample selection strategies were kept consistent within each site, but differed slightly at each site because of different site characteristics (described below).

### **2.6.1. Somenos Marsh**

Garry oak dominated the Somenos Marsh site, with only three individual Douglas-fir. Garry oak are known to reproduce by vegetative sprouting (Sugihara & Reed 1987; Hermann & Lavendar 1990; Hanna and Dunn 1996; Fuchs 2001). Therefore, if two Garry oak trees were located within 1 m of each other and had approximately the same DBH, one tree out of the group was randomly selected for sampling. Otherwise, all Garry oak (n=38) and all Douglas-fir (n=3) were sampled in the plot.

### **2.6.2. Tumbo Cliff**

Douglas-fir and Garry oak dominated the plot, with only three lodgepole pine. Because the original intent of the research was to reconstruct fire history, all large Douglas-fir were sampled, while smaller diameter Douglas-fir were randomly selected (total Douglas-fir n=24). All Garry oak (n=14) and lodgepole pine (n=3) were sampled.

### **2.6.3. Tumbo Marsh**

This site was dominated by large-diameter Garry oak, small-diameter Douglas-fir, and one lodgepole pine. Many of the randomly selected Garry oak (n=5) at this site had a large diameter and exposed lobate root growth at the base of the tree. To ensure the pith or near the pith was reached and the root growth did not impact the core, the Garry oak trees (n=10) were cored at DBH. To maintain consistency, Douglas-fir trees (n=10)

were also cored at DBH. To restrict destructive sampling, only half of the trees had 2 cores taken from them.

## 2.7. Stand Structure Laboratory Methods

In total, 190 increment cores (71, 84, 35 from Somenos Marsh, Tumbo Cliff and Tumbo Marsh, respectively) were collected, dried and assessed for soundness. Of these, eighty-eight Garry oak and Douglas-fir cores had large areas of rot or damage and were not added to the analysis. Increment cores that contained limited areas of rot (<3 cm) were mounted and sanded with progressively finer sand paper until growth width ring boundaries were clearly visible, following standard procedures (Speer 2010). Prepared cores were rubbed with white chalk to accentuate ring boundaries and scanned at a resolution of 2400 dpi using a Microtek ScanMaker 9800XL, and ring widths were analyzed using CooRecorder (Larsson 2011a).

A combination of standard dendrochronology techniques (Speer 2010) and the program CDendro (Larsson 2011b) was used to crossdate and statistically verify ring dates. CDendro was used to create a master chronology for each site and each tree species. The accuracy of crossdating was then assessed using COFECHA (Holmes 1983), which estimated the intercorrelation between all tree ring series used in the master chronology (Holmes 1983, Speer 2010).

If all trees at a given site are affected by the same regional climate events, a high series intercorrelation indicates annual rings have been assigned to the correct years. In this study, the dominance of site specific conditions over tree ring growth meant that crossdating between the three different sites and different species was not achievable. As a result, five separate master chronologies were created from 73 cores (Table 2.2).

**Table 2.2. Summary of COFECHA output**

Study Site	Species	# of Series Measured	Time Period of Measured Series	Avg. Mean Sensitivity	Series Intercorrelation
Tumbo Cliff	Garry oak	13 (1 no pith or rings of	1762-2012	0.265	0.482

Tumbo Cliff	Douglas-fir	16 (3 no pith or rings of curvature)	1829-2012	0.305	0.577
Tumbo Marsh	Garry oak	10 (1 no pith or rings of curvature)	1798-2012	0.201	0.457
Tumbo Marsh	Douglas-fir	8	1911-2012	0.297	0.550
Somenos Marsh	Garry oak	26	1752-2013	0.240	0.605

Of the 73 cores used in the master chronologies, five hit the pith and 63 had rings of curvature. The remaining five increment cores did not contain the pith or have rings of curvature and thus were used for crossdating samples within the master chronology but not in final stand structure analysis. For the 63 cores which had rings of curvature, CooRecorder (Larsson 2011a) was used to estimate the pith, and then a pith estimator was used to confirm the estimation (Applequist 1958, Speer 2010).

For Tumbo Cliff and Somenos Marsh sites where two cores per tree were collected, 46 of 68 trees sampled had only one successful core at DBH. In this case, we estimated the average number of missing rings at DBH from trees that had two successful cores. The number of years between the bark end and pith was estimated for each pair of cores (base and DBH). The difference between these two estimates was averaged for each species at each site. This average number of missing rings was then added to the cores taken at DBH (Z. Gedalof 2016, University of Guelph, personal communication). Tree ages were estimated for all trees sampled, and then tree ages were grouped into 10 year cohorts to account for possible uncertainties in age estimates.

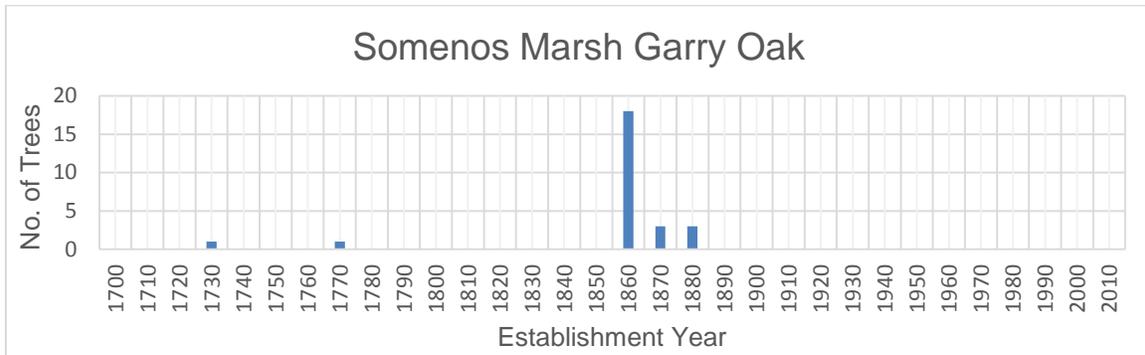
## 2.8. Results

### 2.8.1. Stand Structure

#### *Somenos Marsh*

Twenty-six of the 38 Garry oak trees sampled at Somenos Marsh were intact enough to create a site chronology and determine establishment dates (Figure 2.4). Our

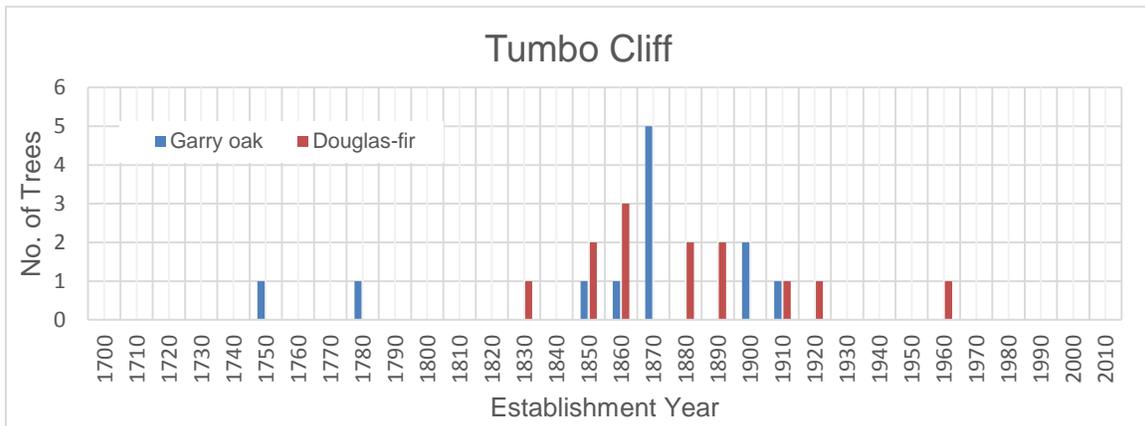
chronology indicates that a small, remnant group of Garry oak established in the 1730s and 1770s and was followed by a larger cohort of oak that established between 1860 and 1890. The majority of Garry oak established in the 1860s. Due to the limited number of Douglas-fir trees in the sample plot (three trees), a chronology was not created. However, the number of rings indicate that these three Douglas-fir trees were all younger than 100 years old.



**Figure 2.4 Establishment distribution of Garry oak at Somenos Marsh**

***Tumbo Cliff***

Thirteen of the 14 Garry oak and 16 of the 24 Douglas-fir trees sampled at Tumbo Cliff were used to create site chronologies. Of these, 12 Garry oak and 13 Douglas-fir trees were intact enough to determine establishment dates (Figure 2.5). Two Garry oak trees established in the 1750s and 1780s, and the largest cohort (n=7) established between 1860 and 1880. A small pulse (n=3) of Garry oak established between 1900 and 1910. Multiple cohorts of Douglas-fir established between 1830 and 1970, but many of the cores that were taken from what appeared to be veteran trees (i.e. the earliest Douglas-fir cohort) were too damaged to determine establishment dates. One tree dated to 1828 (not shown in the establishment distribution) with no visible signs of ring curvature, indicating that this Douglas-fir established prior to 1828.



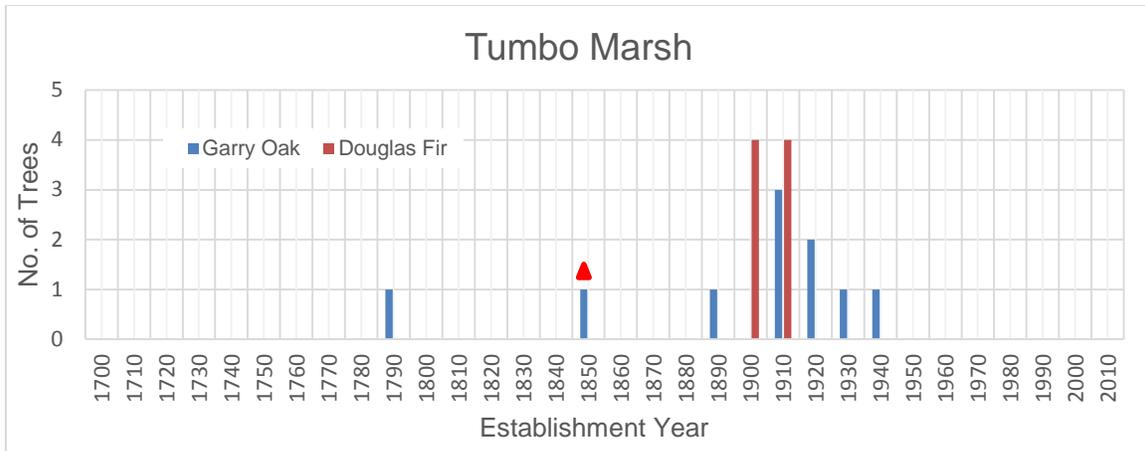
**Figure 2.5 Establishment distribution of Garry oak and Douglas-fir at Tumbo Cliff**

### ***Tumbo Marsh***

All ten Garry oak and eight of the ten Douglas-fir trees sampled at Tumbo Marsh were used to create the establishment distributions (Figure 2.6). Two Garry oak trees established prior to 1850. One increment core sample that dated to 1850 had no pith or evidence of curvature, indicating establishment prior to 1850. Although its age cannot be determined, an establishment prior to 1800 would align with the oldest Garry oak tree from this site chronology. The next Garry oak establishment date is in the 1900s and is followed by repeated establishment until 1960 when regeneration stopped, with 70% of the trees established between 1910 and 1950. In contrast to the Garry oak, only one cohort of Douglas-fir established from 1900 to 1920.

Both Garry oak and Douglas-fir trees grew quickly at the Tumbo Marsh site. The Garry oak had an average growth rate of 4 rings per centimeter, greater than the average rate of 6-8 rings per centimeter (Stein 1990). A second indication of high growth rates is the low series intercorrelation (0.457) for the Garry oak chronology (Table 2.2) and low correlation between increment cores from the same tree (Larsson 2011b). These low correlations both within and between trees may indicate ideal growing conditions, where the lack of limiting growth factors reduced the occurrence of marker rings that occur under suboptimal growing conditions (Speer 2010). Marker rings are identifiable rings present in majority of cores samples in a series and are used to accurately crossdate a series (Speer 2010). While the low series intercorrelation could

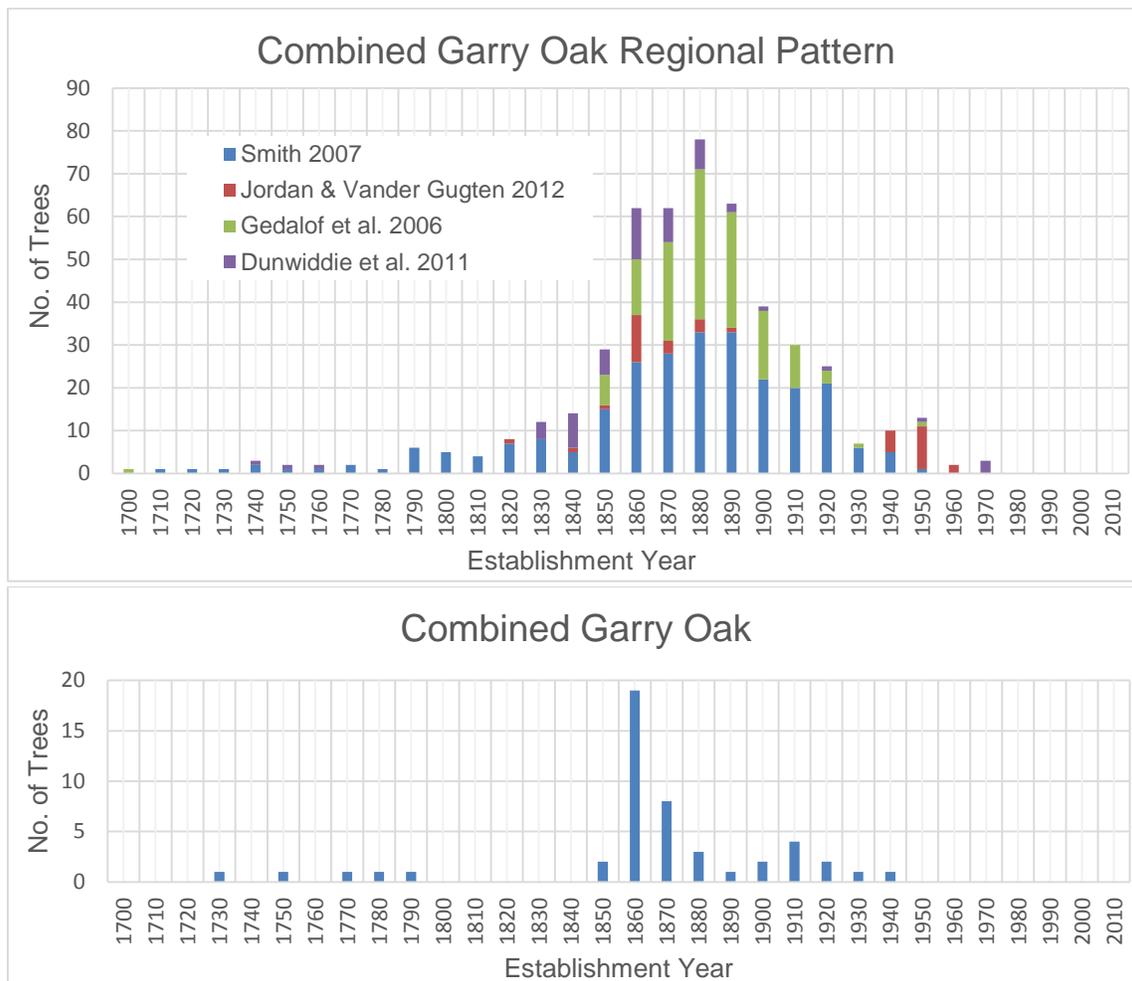
also be due to small sample size, this would not explain the low correlation between increment cores from the same tree.



**Figure 2.6 Establishment distribution of Garry oak and Douglas-fir at Tumbo Marsh**  
 (▲) Increment core sample which did not contain the pith or rings of curvature, indicating establishment prior to 1850.

## 2.9. Discussion

The overall establishment pattern of Garry oak when all sites are combined is generally consistent with other studies in this region (Gedalof et al. 2006; Smith 2007; Dunwiddie et al. 2011; Jordan & Vander Gugten 2012) (Figure 2.7a and b). First, the combined establishment dates show a small, remnant group of Garry oak which established throughout the 1700’s. The establishment of Garry oak ecosystems likely occurred on southern Vancouver Island and surrounding Gulf Islands around 8300 cal yr BP (Pellatt et al. 2001) and thrived during the Medieval Warm Period (MWP) between 1100 and 700 cal yr BP, when the climate was warmer and dryer (Mann et al. 2009). The trees that established in the 1700s either represent the last remaining live Garry oak from a larger population, or the only individuals that were able to establish during this time.



**Figure 2.7 Combined establishment distribution of Garry oak**  
 (a) Combined Garry oak regional pattern (Gedalof et al. 2006; Smith 2007; Dunwiddie et al. 2011; Jordan & Vander Gugten 2012) (b) Combined establishment distribution of Garry oak for Tumbo Cliff, Tumbo Marsh and Somenos Marsh.

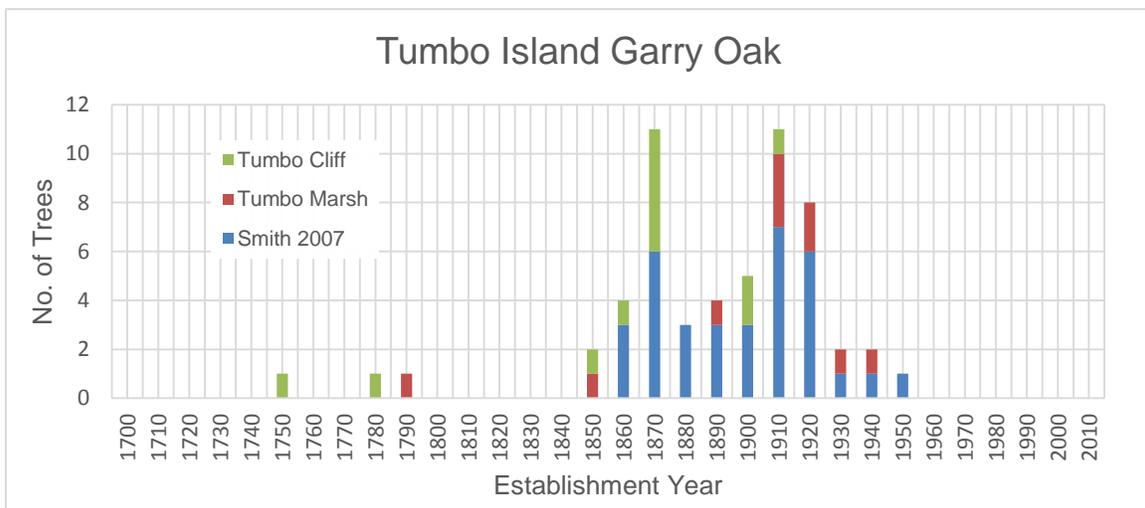
The second distinct feature is the slight increase in recruitment from 1800-1850, followed by a large pulse (and distinct peak) of Garry oak establishment in the mid-1800s that tapered off in the early 1900s. The timing of increased recruitment in the mid 1800s precedes or roughly coincides with European settlement on Vancouver Island (Lothian 1987; McDadi & Hebda 2008). Increased Garry oak recruitment following European settlement has been linked to increases in disturbances and/or land use (e.g. logging and agriculture) (Copes-Gerbit et al. 2017), changes in the fire regime (Boyd 1999; Gedalof et al. 2006; Smith 2007; GOERT 2011; Dunwiddie et al. 2011) and the end of the LIA (Pellatt & Gedalof 2014). The cool conditions of the LIA ended in the mid-1800s and were followed by a warmer drier climate (Pitman & Smith 2013). Established

Garry oak can endure large ranges of temperature and precipitation conditions but are only moderately resistant to cold and will succumb to extreme wind, wet snow, and freezing rain events. In addition, acorns prefer to germinate in warm, moist conditions (Stein 1990). The temperature and precipitation following the LIA, combined with other factors likely facilitated massive Garry oak recruitment. Similar increases in forest corresponding with LIA conditions have been observed in South America and Europe (Nevle et al. 2011; Kaplin 2015).

The extreme peak in Garry oak recruitment from 1850-1900 may also be associated with European settlement. Prior to European settlement, Indigenous peoples had lived on Vancouver Island and surrounding Gulf Islands for at least 5,000 years (Grier et al. 2009; McCune et al. 2015), likely used fire in cultural and agricultural activities (Turner 1999; MacDougall et al. 2004; McCune et al. 2015). Early settlers on eastern Vancouver Island documented many fires between 1843 and 1865, which are believed to have been ignited by Indigenous peoples (Turner 1999; MacDougall et al. 2004). The frequent use of fire helped to maintain open grassland and savannah ecosystems by halting or slowing succession, which allowed establishment of some Garry oak and prevented establishment of conifers (Peter & Harrington 2004). Once burning practices were forcibly stopped after European settlement (Turner 1999; MacDougall et al. 2004), the resulting continuation of succession allowed for the conversion of savannah to woodland through infilling of Garry oak trees and eventual conversion to a closed canopy conifer forest (Pellatt et al. 2001; McCune et al. 2013). This pattern is present in the Somenos Marsh site, and although there were not enough Douglas-fir samples to crossdate the establishment patterns show the rapid infilling of Garry oak in the 1860s followed by establishment of Douglas-fir in the early 1900s.

Although the combined data support a regional pattern of establishment, each site varied slightly in establishment pattern between 1850 and 1900 (Figures 2.7 and 2.8). These site-specific differences could result either from small sample sizes or the influence of local stressors on local establishment patterns. For example, Tumbo Island holds three distinct populations within one km of each other: Tumbo Cliff, Tumbo Marsh, and a third flat, Coastal Bluff Community with shallow soils and some Douglas-fir encroachment (Smith 2007). Both Tumbo Cliff and the Smith (2007) site share similar

site characteristics and have a distinct establishment peak during the 1870s (Figure 2.8). In contrast, Tumbo Marsh has vastly different site characteristics, including slope, soil depth, and moisture, and lacks a distinct establishment peak between 1850 and 1900 (Figure 2.8). Site-specific soil conditions in the Tumbo Marsh site likely prevented Garry oak from establishing. Until these conditions changed to favour Garry oak growth, only a few oak were able to establish prior to 1910. Furthermore, crossdating tree core samples between Tumbo Marsh and Tumbo Cliff was unsuccessful, likely because of major differences in site characteristics and therefore also growing conditions, which affected the timing of Garry oak establishment.



**Figure 2.8 Establishment distribution of Garry oak from Smith 2007, Tumbo Marsh and Tumbo Cliff**

Below we consider the site-specific stressors that may have contributed to the individual structures at Somenos Marsh, Tumbo Cliff, and Tumbo Marsh.

### 2.9.1. Somenos Marsh

The Garry oak ecosystem in Somenos Marsh shifted abruptly from an open grassland/savannah to a mixed Douglas-fir/Garry oak woodland in the mid 1800s, consistent with other sites on southern Vancouver Island and in the Gulf Islands (Figure 2.7; Gedalof et al. 2006; Smith 2007; Jordan & Vander Gugten 2012). The largest establishment pulse of Garry oak indicates rapid recruitment of Garry oak trees during the 1860s. Our tree-ring evidence also suggests subsequent Douglas-fir encroachment

into the established Garry oak woodland. Three young (<100 years old) Douglas-fir trees were found, surrounded by older Garry oak. Furthermore, substantial numbers of Douglas-fir trees border the Somenos Marsh site in a mixed Douglas-fir/Garry oak woodland and Douglas-fir closed canopy forest, further supporting encroachment into the Somenos Marsh site. Finally, phytolith records from soil cores extracted from the adjacent Douglas-fir closed canopy forest confirm that an open grass ecosystem existed in the area prior to Douglas-fir infilling (McCune et al. 2015). The timing of these shifts in the mid-1800s in Somenos Marsh roughly coincides with the broader pattern of European settlement on Vancouver Island. Archeological findings show that Somenos Marsh was located near an ancient village (Brown 1996; McCune et al. 2015). This suggests that the early succession patterns may have been affected by burning until it was halted and encroachment increased, leading to an abrupt change from savannah with a few Garry oak trees, to woodland, to mixed Douglas-fir/Garry oak woodland, and eventually to Douglas-fir closed canopy forest.

### **2.9.2. Tumbo Cliff**

On the Tumbo Cliff site, the peak establishment of Garry oak in 1870 is generally consistent with the regional pattern of Garry oak establishment during the mid-to-late 1800s. However, rather than following the Garry oak establishment pulses, the establishment of Douglas-fir appears to be continuous (Figure 2.5). Furthermore, because our oldest Douglas-fir core had a minimum age of 1828, the oldest Douglas-fir establishment may even surpass the age of the oldest cohort of Garry oak. Thus, the Garry oak ecosystem on Tumbo Cliff may be in a climax successional state, or the final stage of succession (Kimmins 1987).

The first recorded European presence on Tumbo Island occurred in 1886 with the establishment of a coal mine within 200 m of the Tumbo Cliff site (Parks Canada 2004). Fire scars are observed on many of the large veteran Douglas-fir trees, which may have resulted from blasting while digging the mine, but they could also come from other sources such as lightning strikes or Indigenous burning. The largest pulse of Garry oak establishment in the 1870s predates the mining activity, suggesting the arrival of European settlers did not cause the pulse in Garry oak tree establishment. Given that

Garry oak establishment precedes European settlement, establishment on Tumbo Cliff and similar sites (Smith 2007) could be associated with climate warming following the LIA.

Unlike other sites where frequent disturbances maintained Garry oak ecosystems, the persistence of Garry oak at the Tumbo Cliff site could result from harsh drought conditions and shallow soils, which slowed succession rates of Douglas-fir and allow the Garry oak ecosystem to persist here. Both Garry oak and Douglas-fir samples on the Tumbo Cliff site contain massive areas of suppression over multiple decades, consistent with previous observations that Garry oak ecosystems experience slow succession rates on xeric or droughty sites (Johnson et al. 2002). Garry oak can outcompete Douglas-fir in these environments because Douglas-fir are unable to establish in harsh conditions, and thus have a restricted ability to overtop the Garry oak (Hermann & Lavendar 1990). As the soil becomes deeper and the ability for soil to retain moisture increases away from the bluff, Douglas-fir form a closed canopy forest and restrict the ability for the Garry oak to compete. If frequent fires were the cause of the Garry oak distribution on the bluff, they would also have deterred the establishment of Douglas-fir in the deep soils, which does not appear to be the case. Thus, frequent disturbance (such as fire) may never have been an important factor in the persistence of the Garry oak ecosystem. Alternatively, if the current stand is a remnant from a time period when frequent burning occurred, then frequent disturbance has not been present at this site during the lifetime of the established Garry oak and Douglas-fir. Either way, the massive areas of suppression within the tree cores of both species indicate reduced growth rates overall, and combined with relatively harsh conditions of the slope area point to slowed succession rates which may have allowed the Garry oak to persist on the Tumbo Cliff site.

### **2.9.3. Tumbo Marsh**

The largest pulse of Garry oak establishment in Tumbo Marsh does not follow patterns seen in Somenos Marsh, Tumbo Cliff, or other regional studies (Gedalof et al. 2006; Smith 2007; Dunwiddie et al. 2011; Jordan & Vander Gugten 2012). Tumbo Marsh contains some of the largest, youngest and fastest growing Garry oak trees in this study,

70% of which established between 1910 and 1950, which is well after the typical regional Garry oak establishment. In addition, only two cohorts of Douglas-fir were established, in the 1900's and 1910's. These Garry oak and Douglas-fir establishment peaks differ enough from the regional peak to raise questions about what drove establishment and what that implies for restoration.

The large size of the Garry oak trees, relatively smaller size of encroaching Douglas-fir, deep soil and the open meadow landscape seem to suggest that frequent fires or other disturbances kept the Douglas-fir from establishing prior to European settlement. However, the Douglas-fir located in the Garry oak stand are either older than or roughly the same age as most of the Garry oak. Prior to European settlement on Tumbo Island, natural dikes transected the island, creating a salt marsh in the center that linked the north and south sides (Parks Canada, 2004). According to historical records, a causeway was built by European settlers in Tumbo Marsh in the late 1800's to early 1900's, which impeded salt water intrusion into the marsh. The subsequent influx of fresh water from a spring in the middle of Tumbo Marsh allowed the formation of a less saline marsh. The establishment of a fox farm in 1924 likely represented the final stage of converting the salt marsh into a fresh water marsh, due to the need for a large supply of fresh water to operate the farm (Parks Canada, 2004). Prior to European settlement, Tumbo Marsh would have been entirely or partially flooded with salt water, making establishment of Garry oak and Douglas-fir difficult. The duration, timing, saturation depth and drainage of water inundation play a vital role in the regeneration, development, survival and succession of a species (Connor et al. 1998).

Establishment dates and locations of individual trees suggest that the remnant older cohort of Garry oak was most likely located on the periphery of the salt marsh, and Garry oak and Douglas-fir then established in the rest of the marsh once it was inundated with fresh water. The consistently high-water table measured in soil surveys suggests that Tumbo Marsh would have had regular flooding for extended periods of time (Kenney et al. 1988). Coastal oak species genotypes may have relatively high tolerance to saline and saturated soil conditions (Conner et al. 1998). In contrast, Douglas-fir trees and seedlings cannot thrive in consistently saturated soil conditions (Hermann & Lavendar 1990; Heninger et al. 2002). The establishment of Garry oak and

Douglas-fir following the establishment of the fox farm suggests that Douglas-fir was the first to advance into the marsh. Garry oak soon followed and was able to advance further into the marsh due to a higher tolerance to soil saturation levels and slightly saline conditions. The conditions must have been quite favorable for the Garry oak because the individuals closest to the marsh were able to grow at an accelerated rate.

Visual inspection of this site without examining land-use history and establishment patterns might suggest a different story, which could have very large management and restoration implications. The size and location of the Garry oak and Douglas-fir indicate a younger cohort of Douglas-fir is encroaching on a much older cohort of Garry oak. However, given the soil conditions and flood patterns, Douglas-fir are probably not able to establish further into the Garry oak stand. We noted Douglas-fir seedlings encroaching into the stand, but they were all heavily browsed by deer, and half of the needles were brown, further suggesting their inability to advance due to soil conditions or flood patterns. Lodgepole pine encroachment on the southwest corner of the plot is also taking place. The lodgepole pine may not be affected by the current soil conditions, flood patterns or deer browsing impacts and may soon be an added pressure on the ecosystem.

## **2.10. Synthesis**

Two of our study sites show establishment patterns that are broadly consistent with other regional studies. First, Somenos Marsh experienced a large pulse of Garry oak that quickly infilled the open savannah directly following European settlement. This pattern is consistent with Garry oak ecosystems with deep and well-drained soils in an intermediate, or seral successional state (Kimmins 1987; Stein 1990). A likely cause of this successional pattern is the exclusion of frequent fire used by Indigenous peoples or the activities of European settlers (e.g. logging) (Boyd 1999; Gedalof et al. 2006; Smith 2007; GOERT 2011; Dunwiddie et al. 2011; Copes-Gerbit et al. 2017), combined with favourable growing conditions. Second, the Garry oak ecosystem on Tumbo Cliff, which located on rock outcroppings with dry shallow soils, is in a climax successional state. A likely cause of this successional pattern is slow succession, combined with the inability for Douglas-fir to establish in arid, shallow soils. The establishment pattern on Tumbo

Marsh is different from Somenos Marsh and Tumbo Cliff, likely due to the salt flat conditions prior to the early 1900s, which prevented Garry oak recruitment into the marsh area.

These data also indicate that recruitment of Garry oak has ceased at all three sites, which could be related to successional state or specific site conditions. Recruitment ended in the 1880s, 1910s and 1940s at Somenos Marsh, Tumbo Cliff and Tumbo Marsh, respectively. Most other sites also demonstrate little to no recruitment since 1940 (Gedalof et al. 2006; Smith 2007). Interestingly, Garry oak seedlings were present in many study areas, but for unknown reasons were not able to develop into mature trees. Deer browsing or trampling (Gedalof et al. 2006; Smith 2007) and herbivory by small mammals (MacDougall et al. 2010) has been cited as possible causes for low sapling recruitment. No Garry oak seedling or sapling was present at our three sites, but there was an abundance of acorns. Early successional Garry oak ecosystems have been known to contain the best acorn producing Garry oak trees when compared to late successional Garry oak ecosystems (Peter & Harrington 2004). Given that the Somenos Marsh and Tumbo Cliff sites are most likely classified as late-climax successional stage Garry oak ecosystems, they could be less able to recruit young Garry oak trees. The Tumbo Marsh site may be in an earlier successional stage compared to the other two sites, but it may also be restricted in its ability to recruit additional Garry oak trees because of the marsh and adjacent closed canopy conditions.

## **2.11. Management & Restoration Recommendations**

Reintroducing fire as a management and restoration strategy appears to depend on the unique characteristics of each site. Somenos Marsh is a wet, deep soil site with well documented vegetation and site history that is experiencing pressure from conifer encroachment. Areas surrounding Somenos Marsh, including part of the Somenos Marsh study site, have undergone different restoration and management efforts to maintain the Garry oak ecosystem including; pulling woody invasive species, mowing, and planting native species (D. Polster 2015, GOERT 2015 11<sup>th</sup> Research Colloquium Blank Slate Restoration Proceedings). The next recommended restoration step is removing Douglas-fir (>7 years) in the closed canopy portion of Somenos Marsh,

followed by vegetation and site surveys, and prescribed fire to open the landscape and allow the re-establishment of native species. Treatments should follow Douglas-fir removal to specifically target non-native species. Post-burn monitoring and possible restoration should be assessed after the prescribed burn. The recommended burn cycle should occur every 3 to 7 years (Tveten & Fonda 1999; USDI NPS 2010). Burn cycles longer than seven years allow Douglas-fir seedlings and saplings to grow thick enough bark that fire may not kill them (Engber et al. 2010; Cocking et al. 2012; Ryan & Reinhardt 1988; USDI NPS 2010).

An important factor to consider is that fire has likely been absent from Somenos Marsh for more than a century. Thus, although invasive shrubs and herbaceous species are removed under the past management practices, the first burn cycles may still produce an influx of non-native species before native species re-establish (Dunwiddie 2002; USDI NPS 2010). Ideally, after three burn cycles, the distribution of non-native species will decrease because of their sensitivity to fire, thus allowing fire-adapted native species to re-establish (MacDougall & Turkington 2007).

While reintroducing fire may be the most effective restoration strategy, the location of Somenos Marsh near rural development and settlements may restrict the feasibility of burning, especially given that prescribed burns are most effective during periods of high fire risk. Fire surrogates may continue to be the most appropriate alternative to control non-native species and promote native species. However, the use of fire surrogates would depend on the target restoration species, because in some cases fire is not fully replaceable (MacDougall & Turkington 2007). Restoration of ecosystems which target native fire-adapted grasses may require fire to reproduce and if surrogates are used the target grass reproductive yields may be low (MacDougall & Turkington 2007).

Tumbo Cliff is a relatively shallow, xeric site that is also experiencing pressure from well established Douglas-fir and other conifers. The establishment patterns and site history of Tumbo Cliff does not indicate frequent disturbance was required to maintain the existing Garry oak ecosystem. Thus, the Tumbo Cliff site requires a cautious approach to prescribed fire. A detailed understanding of vegetation communities, fuel

characteristics, and well-established fire control methodology will be needed if fire is to be implemented. Removing established Douglas-fir is recommended prior to implementing prescribed fire to release the Garry oak from competition for light and resources and to restore understory microclimate conditions to a warmer and drier state, which would better facilitate prescribed burns and allow the re-establishment of native species. Removing Douglas-fir will also decrease the probability of a crown fire which could potentially impact the Garry oak ecosystem on the bluff. Post treatments should follow Douglas-fir removal and specifically target non-native species.

It is essential to take a cautious approach to prescribed fire in Coastal Bluff/Douglas-fir community because several outcomes can occur. Fire introduced to the Tumbo Cliff site in 2016 killed a large percentage of encroaching Douglas-fir and lodgepole pine saplings and seedlings. However, in the dense, moist patches of the understory fire easily extinguished, and in the dry, dense woody patches fire ignited Douglas-fir trunks. In both cases, fire crews had to be diligent to either restart the burn or extinguish fire which could reach the crown of the trees. These outcomes are consistent with other experimental prescribed fires in Coastal Bluff/Douglas-fir community (e.g. Tveten & Fonda 1999; Engber et al. 2011; Devine et al. 2013).

Tumbo Marsh is a deep soil site experiencing early encroachment pressure from Douglas-fir and lodgepole pine seedlings and saplings. While the well-established Douglas-fir do not appear to impact the Garry oak stand, newly established Douglas-fir and lodgepole pine are advancing further into the marsh and could overtop the oak in time. Even though current vegetation characteristics of Tumbo Marsh appear to have resulted from historical land-use changes in the adjacent marsh, a well-developed Garry oak tree community has developed which presents an opportunity for conservation and restoration. Prescribed fire at Tumbo Marsh would stop the encroachment of Douglas-fir and lodgepole pine, but implementing prescribed fire at Tumbo Marsh requires a cautious approach, and should only be undertaken after a detailed vegetation survey and experimental restoration plan design. Currently, Tumbo Marsh may have a mix of vegetation from different ecosystems, in which Garry oak associated vegetation may only make up a small part, and experimentally reintroducing fire would aid in determining the type of vegetation that would return post-burn.

An additional component to consider prior to implementing controlled fire is the structure of Tumbo Marsh. The site area may be better classified as a Riparian or Wetland Marsh Garry oak ecosystem, which may impact the success of controlled fire. Burning has been found to be effective in removing and controlling woody species and non-native herbaceous species in wetland prairies, but overall produced no change in native herbaceous species cover (Clark & Wilson 2001). This suggests Wetland Garry oak ecosystems may behave differently to the reintroduction of fire than other structural types of Garry oak ecosystems. To better understand the interaction between the tree growth and the marsh conditions in Tumbo Marsh, the pre-burn inspection should also include (1) soil conditions (*e.g.* salinity, compaction, and saturation), (2) yearly flood patterns, and (3) deer browsing pressures.

## Conclusion

Understanding how both regional history and site-specific conditions have influenced ecosystem structure is pivotal when devising a management strategy for a particular site. In this study, we have examined establishment patterns, site classification(s), and site history at three structurally distinct Garry oak ecosystem sites in southern Vancouver and the Gulf Islands. Our results demonstrate the importance of combining regional and local knowledge for making site-specific recommendations for restoration and management.

While Garry oak ecosystems in southern Vancouver and the Gulf Islands represent an assortment of scattered single remnants or patchy stands, a regional pattern is observed when all site establish dates are combined and compared to other sites in the region (Gedalof et al. 2006; Smith 2007; Dunwiddie et al. 2011; Jordan & Vander Gugten 2012). In general, the combined establishment dates show a small remnant group of Garry oak established in the mid-late 1700's, followed by a larger cohort (and distinct peak) of Garry oak that established between 1850 and early 1900s, and little to no recruitment after the mid-1900s. The establishment of Garry oak ecosystems on southern Vancouver Island and surrounding Gulf Islands is the result of a past warmer and dryer climate (i.e. 8300 cal yr BP) (Pellatt et al. 2001), and these ecosystems likely thrived during the MWP (i.e. between 1100 and 700 cal yr BP). The Garry oak that established in the 1700s and early 1800s either represent the last living Garry oak, or the only individuals that could establish during this time. Douglas-fir recruitment at majority of these sites has been continuous since the mid to late 1800s.

The connection between Garry oak ecosystems, Indigenous peoples and fire has been recognized as an important mechanism which maintained the structure and function of these ecosystems during climate periods such as the LIA, which may have favoured conifer dominated ecosystems (Pellatt et al. 2007; Pellatt & Gedalof 2014). The

peak in establishment between 1850 and early 1900s corresponds with the decline of Indigenous populations, the introduction of European settlement and fire suppression, and the end of the LIA (Boyd 1999; Pitman & Smith 2013; Pellatt & Gedalof 2014). The expansion of trees after the LIA is consistent with the general collapse of Indigenous populations in the Americas (Nevle et al. 2011; Kaplin 2015). Massive recruitment of Garry oak and Douglas-fir on southern Vancouver Island and surrounding Gulf Islands appears at some sites to predate European settlement, suggesting an ecological trajectory for Garry oak ecosystems was already set in place prior to European settlement. The over-all combined effects of declining Indigenous populations, fire suppression, increase in European land use practices (e.g. logging, grazing) (Gedalof et al. 2006; Smith 2007), and climatic warming and drying associated with the end of the LIA (Pitman & Smith 2013) likely triggered the massive recruitment from 1850 to the early 1900s.

By comparing and contrasting the establishment patterns, site classification, and site histories of the three sites analyzed in this study, the local conditions or stressors which shaped the development of the individual Garry oak stands are revealed. This information can be integrated into a restoration and management strategy for each site, and used as reference information for similar sites. For example, the Somenos Marsh site is a deep soil site with well documented vegetation and site history. The establishment pattern of Garry oak in the Somenos Marsh site is consistent with the regional pattern, and the site history indicates a clear relationship among Indigenous occupation, subsequent European settlement, and the development of Garry oak woodland suggesting that the current Douglas-fir/Garry oak woodland was preceded by an open grassland/savannah. The timing of this vegetation shift roughly coincides with European settlement and the cessation of Indigenous burning practices on Vancouver Island in the mid-1800s (Turner 1999; MacDougall et al. 2004). These findings support research indicating the importance of Indigenous land management in the development of deep soil Garry oak ecosystems. In contrast, the Tumbo Cliff site is a dry, shallow soil site, and the site history does not indicate frequent fire as an important factor in the persistence of the Garry oak ecosystem. However, the site still contains a peak of Garry oak establishment in the 1870, which is consistent with the regional pattern. Regional climate, soil conditions, and periodic fire likely drive the establishment patterns and site

characteristics observed in Tumbo Cliff and similar shallow soil sites. Finally, the Tumbo Marsh is a deep soil site, which lacks the typical establishment peak observed in the majority of sites between 1850 and 1900. The site history of Tumbo Marsh indicates Garry oak and Douglas-fir were unable to recruit into the Tumbo Marsh site before its conversion to a fresh water marsh in the early 1900s. The uninhabitable soil conditions at Tumbo Marsh superimposed pressures on top of the regional signal and prevented Garry oak and Douglas-fir from establishing during 1850-1900. Once soil conditions became favourable Garry oak established and grew quickly.

Recent work recognizes that there is no silver bullet when devising a restoration and management strategy for these ecosystems (Pellatt et al. 2007; Dunwiddie & Bakker 2011; Dunwiddie et al. 2011; Pellatt & Gedalof 2014). Garry oak ecosystems on southern Vancouver Island and surrounding Gulf Islands are likely the product of climate and site-specific anthropogenic conditions. Active management which emulates some of the components of past conditions within the context of site-specific characteristics will likely be necessary to effectively deter the encroachment of conifer tree species and maintain a site in a seral successional state. Using a multi-proxy approach provides a comprehensive understanding of the structure and function of a site-specific Garry oak ecosystem, which can be used to create a restoration prescription for the site (Copes-Gerbitz et al. 2017). Because of the interplay between past climate, indigenous population and land use, and modern alteration of ecological processes such as fire, each of the sites analyzed within this study will require active management to restore and manage the Garry oak ecosystem. The restoration prescription should be site-specific, taking into consideration both of the regional and local stressors which played a key role in the development of the ecosystem.

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