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ORIGINAL PAPER

Garry oak ecosystem stand history in Southwest British Columbia, Canada: implications of environmental change and indigenous land use for ecological restoration and population recovery

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Abstract

In the Pacific Northwest of North America, endangered Garry oak ecosystems have a complex history that integrates effects of Holocene climate change, Indigenous land management, and colonial settlement during the Anthropocene. In western Canada, Garry oak and Douglas fir recruitment corresponds with the end of the Little Ice Age (LIA; ca. 1870), after the collapse of Indigenous populations but in some cases prior to European settlement. We examined establishment patterns at three sites in southwest British Columbia, each with different edaphic characteristics based on slope, exposure, and drainage. At our Somenos Marsh site on Vancouver Island, we see a clear relationship between Indigenous occupation, subsequent European settlement, and development of an oak woodland, indicating that Indigenous land management was important for development of many Garry oak ecosystems. However, at the Tumbo Cliff site (Tumbo Island, BC), shallow soil xeric conditions, regional climate, and periodic fire were likely drivers of stand and ecosystem development. Finally, at the deep soil Tumbo Marsh site, Garry oak established and grew quickly when conditions were favorable, following the early twentieth century conversion of a saltwater tidal flat into a freshwater marsh. Combining site level historical records, site characteristics, and dendrochronological data provides a greater understanding of the local and regional factors that shape the unique structures of Garry oak ecosystems at each site. This information can be integrated into restoration and fire management strategies for Garry oak ecosystems as well as elucidate the timing of European settler and climate change impacts on these ecosystems.

Keywords Dendroecology · *Quercus garryana* · British Columbia · Ecological restoration · Douglas fir · Indigenous prescribed fire · National Park

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Introduction

Garry oak (*Quercus garryana*) associated ecosystems are home to more than 100 threatened or endangered species (GOERT 2011) and are identified as a critically endangered ecosystem in North America (Noss et al. 1995). Several factors contribute to the decline of these ecosystems, including: (1) fragmentation and habitat loss (e.g., MacDougall et al. 2004; Lea 2006; Bjorkman and Vellend 2010); (2) exotic and invasive species (e.g., Fuchs 2001; MacDougall and Turkington 2005; Devine and Harrington 2006; MacDougall et al. 2010; Bennett et al. 2013); (3) ungulate browsing (e.g., Gonzales and Arcese 2008; MacDougall 2008); (4) changes in historic disturbance regimes (e.g., Agee and Dunwiddie 1984; Gedalof et al. 2006; Pellatt et al. 2007; Smith 2007; McDadi and Hebda 2008; Dunwiddie et al. 2011); and (5) climate change during and after the Little Ice Age (LIA) (e.g., Pellatt et al. 2007). These combined threats have degraded the ecological integrity of Garry oak ecosystems in British Columbia (BC) (Pellatt et al. 2007) and left a mosaic of scattered single remnant trees or patchy stands (Erickson 2000; Fuchs 2001).

Fire is considered an important disturbance mechanism for Garry oak ecosystems (MacDougall et al. 2004; Dunwiddie et al. 2011; Pellatt et al. 2007; Pellatt and Gedalof 2014; Bakker et al 2019). Garry oak ecosystems were established 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 likely 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 and Gedalof 2014). A 378-year fire scar chronology from nearby Waldron Island in Washington, USA, indicates that fires were more frequent in Garry oak ecosystems prior to European settlement (Sprenger and Dunwiddie 2011). This idea is supported by evidence of cyclical burning practices by Indigenous peoples (Boyd 1999) and the dominance of fire adapted vegetation in intact Garry oak ecosystems (MacDougall 2005; Pellatt and Gedalof 2014). Frequent, low-severity 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 and Harrington 2004). European colonization brought disease and pan-American genocide to Indigenous people in North America (Boyd 1999). Some studies hypothesize that the decrease in Indigenous peoples in the Americas resulted in forest expansion due to decreased Indigenous land management, subsequently reducing atmospheric CO_2 levels and cooling the climate (Nevle et al. 2011; Kaplan 2015; Koch et al. 2019). Regardless of what caused late Holocene climate change, the Little Ice Age (LIA), disease, and colonial suppression of Indigenous land management altered the ecological trajectory of Garry oak ecosystems. Combined with the effects of fire exclusion enforced by European settlers, the eventual canopy infilling by Garry oak and encroachment of conifer tree species occurred.

Conservation and recovery actions target remaining Garry oak ecosystems throughout the Pacific Northwest (PNW). In BC, Garry oak ecosystems are primarily found on southern Vancouver Island and in the southern Gulf Islands (Fig. 1; GOERT 2002; Parks Canada Agency 2006). The Gulf Islands National Park Reserve (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 reestablish prescribed fire as a tool to restore Garry oak ecosystems

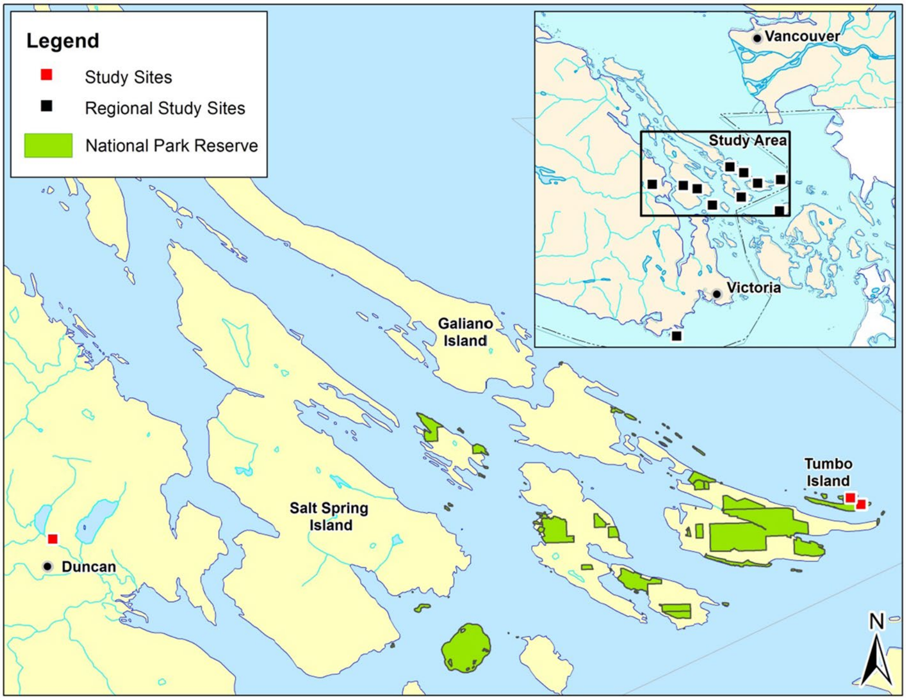

Fig. 1 Study area, showing southern Vancouver Island, southern Gulf Islands and Gulf Islands National Park Reserve, and the three study sites (red squares) including two study sites on Tumbo Island and one study site on Vancouver Island (Somenos Marsh). Inset shows location of the regional study sites (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 and Vander Gugten 2012)

while recognizing past Indigenous land management practices. In 2010, Parks Canada began an experimental restoration project that initiated controlled experimental burns on Tumbo Island (also known as Temosen Island by the W̱SÁNEĆ First Nation) in the GINPR in 2016.

While prescribed fire is one approach to ecosystem management, several other regional and local factors contribute to ecosystem distribution and structure. Understanding historical disturbance, land use, and stand history can aid in recognizing which factors are most important to an effective management strategy. This study investigates the development of Garry oak stands at three structurally different sites by examining the establishment patterns of the dominant tree species using dendroecological (tree ring) analysis, site classification(s), and site history. We assess (1) the timing of stand origins in relation to European colonization, (2) factors at play during the development of each Garry oak ecosystem, and (3) which regional and local factors (i.e., prescribed fire) are important for informing management strategies.

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). British Columbia represents the northernmost extent of the Garry oak range along the Pacific Coast of North America (Stein 1990). In BC, 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 tree species in this zone 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 BC and Washington. Garry oak ecosystems found on Vancouver Island, Gulf Islands, and San Juan Islands are primarily found in small patchy stands that differ in disturbance history, slope gradient and position, and moisture regime (Erickson and Meidinger 2007). As a result, the plant communities in different Garry oak ecosystems vary substantially (Fuchs 2001; GOERT 2011).

Study area

Three study sites were chosen based on their location on public lands and within or near GINPR, lack of existing dendroecological data, and structural characteristics that best represented the range of different Garry oak ecosystems in BC (Fig. 1). The study sites had structural characteristics that encompassed a deep soil woodland community (Somenos Marsh), shallow soil with rocky outcrops (Tumbo Cliff), and a savannah and meadow community (Tumbo Marsh).

Somenos Marsh

The Somenos Marsh site (Fig. 2) is located within an approximately 8.0 ha BC crown land parcel on the south side of Somenos Lake on southern Vancouver Island, BC (lat 48.48°N, long 123.42°W). The Garry oak ecosystem that surrounds Somenos Lake is characterized by wet, deep sandy loam soil. The area is imperfectly drained, and the soil can be saturated for extended periods during the growing season (Christie et al. 1985). The Somenos Marsh site and surrounding area is flat and transitions from a Garry oak dominated community to a Douglas fir dominated community. Depending on the time of year the Garry oak dominated community can be classified as a Deep Soil, Wetter or Average Moisture Garry Oak Community (GOERT 2011).

Tumbo (Temosen) Island

Two sites are located on Tumbo Island, a small (1.1 km^2) uninhabited island acquired by Parks Canada in 1997 and included in GINPR in 2003 (Fig. 1). The two Tumbo Island sites, Tumbo Cliff and Tumbo Marsh, are located approximately 600 m apart (Fig. 3)

Fig. 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

and illustrate the local variation in Garry oak ecosystems based on site factors such as exposure, soil characteristics, and topography.

The Tumbo Cliff site is located on the southeastern side of Tumbo Island (Fig. 3b), is characterized by 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 holding the majority of trees. Garry oak are located within the shallow soil where rapid draining occurs and are small, with an average diameter at breast height (DBH) of less than 30 cm. Upslope from the cliff, the forest develops into a mixed stand of Douglas fir, Arbutus, and lodgepole pine (*Pinus contorta*). This site is classified as a combination of Douglas fir and Coastal Bluff communities (GOERT 2011). 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 Tumbo Marsh site sits on the perimeter of a freshwater *Typha*-dominated marsh on the eastern central part of Tumbo Island (Fig. 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 (Kenney et al. 1988). This study site is a mixed stand dominated by large-diameter (> 1 m) Garry oak, small-diameter Douglas fir, one mature lodgepole pine, and lodgepole pine saplings. The Tumbo Marsh site is best classified as either a Deep Soil, Wetter Garry Oak Community (GOERT 2011) 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).

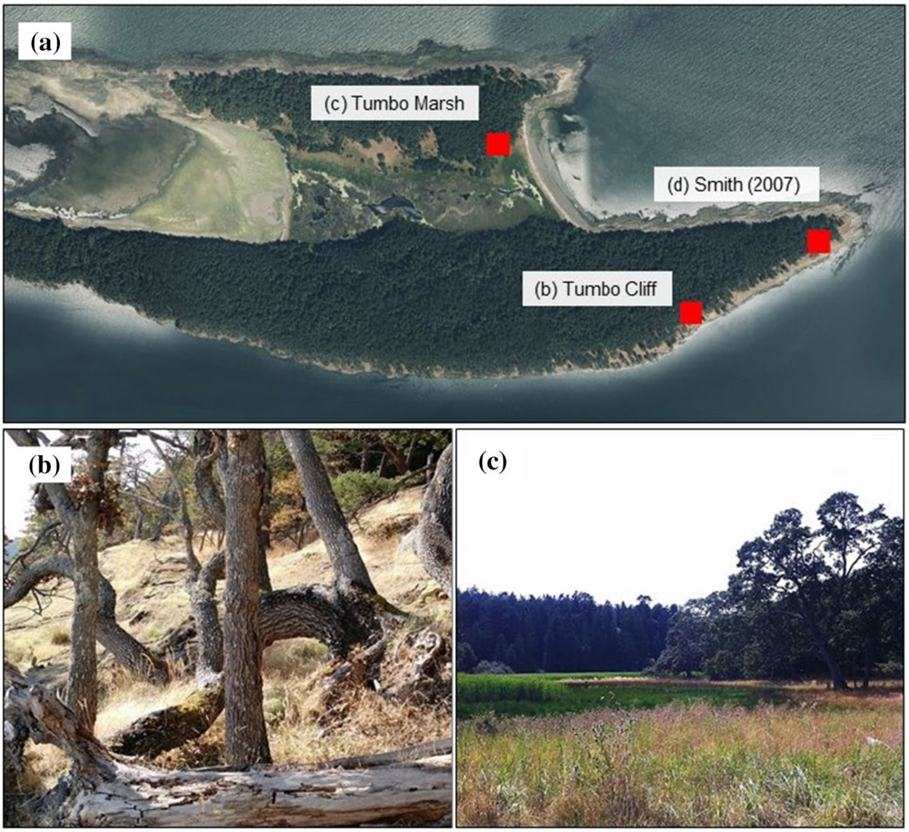

Fig. 3 Tumbo Island study sites. **a** Aerial view of Tumbo Island study area. The red squares signify the locations of **b** Tumbo Cliff, **c** Tumbo Marsh and **d** previous study location of Smith (2007). Bottom panel **b** picture of Tumbo Cliff study site and **c** picture of Tumbo Marsh study site

Methods

Design and sample collection

Dendroecological (tree ring) analysis was used to reconstruct the approximate establishment dates of the three stands. Within each study area, representative plots were set out for sampling structural characteristics. 50 m × 75 m plots were set out at Somenos Marsh and Tumbo Cliff sites, and the entire Garry oak meadow (approximately 50 m × 50 m) was sampled at Tumbo Marsh. 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 cross-date efficiently and accurately and determine establishment dates (Speer 2010). The Tumbo Marsh site is considered a sensitive site due to the limited number of Garry oak trees and therefore, to restrict destructive sampling, only half of the trees had two cores taken from them at DBH. Sample selection strategies were kept consistent within each site but differed slightly at each site because of different site characteristics (described below).

The plot for the Somenos Marsh site was placed to encompass the majority of the Garry oak trees which resulted in only three individual Douglas fir captured in the sampling. Garry oak are known to reproduce by vegetative sprouting (Sugihara and Reed 1987; Hermann and Lavendar 1990; Hanna and Dunn 1996; Fuchs 2001), therefore, if two Garry oak trees were located within one meter of each other and had approximately the same DBH, one tree was randomly selected for sampling. Otherwise, all Garry oak (n = 38) and all Douglas fir (n = 3) were sampled in the plot.

Douglas fir and Garry oak dominated the Tumbo Cliff 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.

The Tumbo Marsh site was dominated by large-diameter Garry oak, small-diameter Douglas fir, and one lodgepole pine. Many of the Garry oak (n = 5) at the Tumbo Marsh 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.

Sample analysis

Seventy-three of the trees sampled (26, 29, 18 from Somenos Marsh, Tumbo Cliff and Tumbo Marsh, respectively) had increment cores that were sound enough to create Garry oak and Douglas fir chronologies (Table 1). Prepared cores were rubbed with white chalk to accentuate ring boundaries and scanned at 2400 dpi resolution using a Microtek ScanMaker 9800XL. Ring widths were analyzed using CooRecorder (Larsson 2011a).

Standard dendrochronology techniques (Speer 2010) and the program CDendro (Larsson 2011b) were 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).

Of the 73 cores used in the master chronologies, five hit the pith and 63 had rings of curvature. The remaining five increment cores (without pith or rings of curvature) were used for crossdating samples within the master chronology but not in the final stand structure analysis. For the 63 cores with rings of curvature, CooRecorder (Larsson 2011a) was

Table 1 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 curvature)	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

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, 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 (Gedalof 2016, University of Guelph, personal communication). Tree ages were binned into 10-year groups to account for uncertainties in age estimates for the cores that were sampled at DBH and included into the chronologies for each site.

Results

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 (Fig. 4). The average number of missing rings at DBH was found to be nine years for the Garry oak trees and applied to six cores. The chronology indicates that one Garry oak established in the 1730s and in the 1770s and was followed by the largest group of oak that established between 1860 and 1890. The majority of Garry oak (n = 18) 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, ring counts indicate that these three Douglas fir trees were all younger than 100 years old.

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. The average number of missing rings at DBH was found to be 12 years for the Garry oak and 17 years for the Douglas fir trees and applied to two cores of Garry oak and two cores of Douglas fir trees. The chronology indicates that two Garry oak trees established in the 1750s and 1780s; the largest number (n = 7) established between 1850 and 1880; and a small pulse (n = 3) of Garry

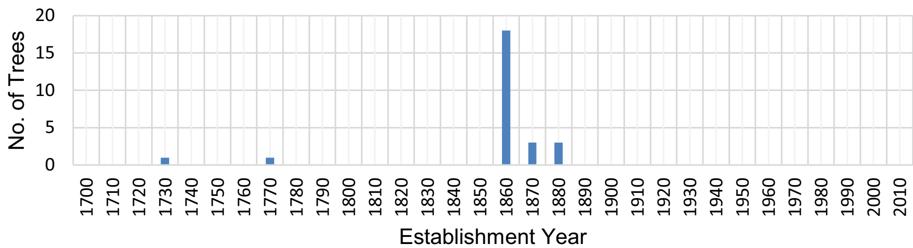

Fig. 4 Establishment distribution of Garry oak at Somenos Marsh

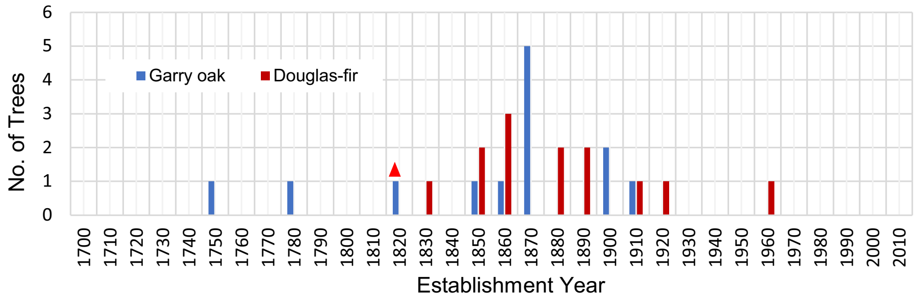

Fig. 5 Establishment distribution of Garry oak and Douglas fir at Tumbo Cliff. (Filled Triangle) Increment core sample which did not contain the pith or rings of curvature, indicating establishment prior to 1820

oak established between 1900 and 1910 (Fig. 5). Multiple Douglas fir established between 1830 and 1970.

Tumbo Marsh

The Tumbo Marsh site establishment distributions are limited by the tree cores being collected only at DBH. As identified above, the average number of missing rings at DBH was nine years at the Somenos Marsh site and 12 years at the Tumbo Cliff site for Garry oak and 17 years at Tumbo Cliff for Douglas fir. These differences suggest that the estimated ages for the trees at Tumbo Marsh are much older than identified in the establishment distribution. However, analysis of both Garry oak and Douglas fir tree core samples show wide annual rings and no areas of suppression, indicating that trees grew quickly at the Tumbo Marsh site. The Garry oak tree core samples had an average growth rate of four rings per centimeter, greater than the average growth rate of six to eight rings per centimeter (Stein 1990). A second indication of high growth rates is the low series intercorrelation for the Garry oak chronology (Table 1) 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).

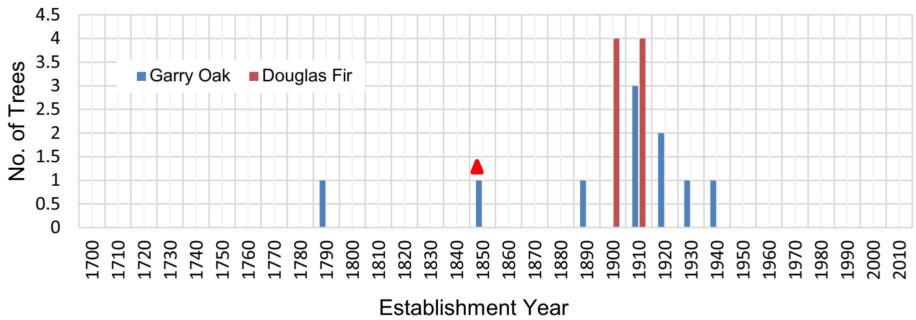

Fig. 6 Establishment distribution of Garry oak and Douglas fir at Tumbo Marsh. (Filled Triangle) Increment core sample which did not contain the pith or rings of curvature, indicating establishment prior to 1850

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. Based on these findings we anticipate the differences between DBH and the base to be less than 10 years for the trees at the Tumbo Marsh site and by binning the establishment distribution into 10-year groups we aim to capture these differences.

All ten Garry oak and eight of the ten Douglas fir trees sampled at Tumbo Marsh were used to create the establishment distributions (Fig. 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. The next Garry oak establishment date is in the 1900s and is followed by continuous establishment until 1950 when regeneration stopped, with 70% of the trees established between 1910 and 1950. In contrast to the Garry oak, only one group of Douglas fir established from 1900 to 1920.

Discussion

We first compare the combined establishment patterns of Garry oak at all three study sites to the broader regional context because of the limited number of Garry oak samples. When data from all sites are combined, the overall establishment pattern of Garry oak is

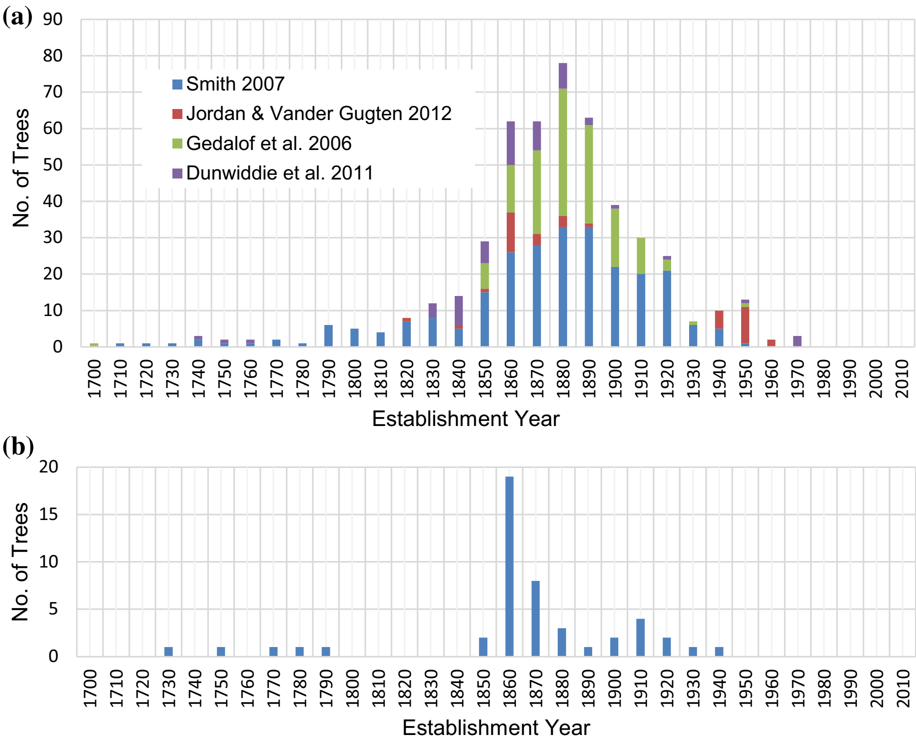

Fig. 7 Combined establishment distribution of Garry oak. **a** Combined Garry oak regional pattern (Gedalof et al. 2006; Smith 2007; Dunwiddie et al. 2011; Jordan and Vander Gugten 2012) **b** Combined establishment distribution of Garry oak for Tumbo Cliff, Tumbo Marsh and Somenos Marsh

consistent with other regional studies (Gedalof et al. 2006; Smith 2007; Dunwiddie et al. 2011; Jordan and Vander Gugten 2012) (Fig. 7a and b).

Although the combined data support a regional pattern of establishment, analysis of individual sites reveals that both Garry oak and Douglas fir vary slightly in their establishment patterns between 1850 and 1900. These site-specific differences could result from small sample sizes, sampling differences at the Tumbo Marsh site, or the influence of local stressors on local establishment patterns. While we acknowledge the small sample sizes and sampling differences at the Tumbo Marsh site, we believe that there is merit in comparing the establishment patterns at a site level to the regional pattern of establishment. 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. 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. 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 oaks 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.

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

Somenos Marsh

The Somenos Marsh site indicates a clear relationship between Indigenous occupation, subsequent European settlement, and the development of surrounding Garry oak woodlands. The Garry oak ecosystem in Somenos Marsh shifted abruptly from an open grassland/savannah to a Garry oak woodland in the mid-1800s, consistent with other sites on southern Vancouver Island and in the Gulf Islands (Gedalof et al. 2006; Smith 2007; Jordan and 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 from the adjacent Douglas fir closed canopy forest confirm that an open grass ecosystem existed prior to Douglas fir infilling (McCune et al. 2015). The timing of these shifts in the mid-1800s 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). Thus, early succession patterns may have been affected by burning until it was halted and encroachment increased, leading to a conversion from savannah with few Garry oak trees, to woodland, to mixed Douglas fir/Garry oak woodland, and eventually to Douglas fir closed canopy forest. These findings support previous conclusions that Indigenous land management was critical to the maintenance of many species in Garry oak ecosystems.

The Somenos Marsh site most closely reflects the regional successional history and development of Garry oak ecosystems on Vancouver Island and the Gulf Islands and will continue to experience encroachment from Douglas fir trees. As such, it seems an obvious candidate for a prescribed burn program that integrates 3–7 year burn cycles with post-burn monitoring for the successful return of native species (USDI NPS 2010; Engber et al. 2011; Cocking et al. 2012). However, many factors affect the success of a prescribed fire including fuelbed load (Engber et al. 2011), season of prescribed fire (Tveten and Fonda 1999), burn frequency (Tveten and Fonda 1999; USDI NPS 2010), species composition (Tveten and Fonda 1999; MacDougall 2005; MacDougall and Turkington 2007; Stanley et al. 2011), soil depth (MacDougall 2005; MacDougall and Turkington 2007), and encroachment from conifer species (Devine et al. 2007; Cocking et al. 2012; Devine et al. 2013).

While reintroducing fire may be an effective strategy, the proximity of Somenos Marsh to human settlements restricts the feasibility of burning, especially given that prescribed burns are most effective during periods of high fire risk (MacDougall and Turkington 2007). Areas surrounding Somenos Marsh, including part of the Somenos Marsh site, have undergone different restoration and management efforts to maintain the Garry oak ecosystem including; pulling woody invasive species, mowing, and planting native species (Polster 2015; GOERT 2015 11th Research Colloquium Blank Slate Restoration Proceedings). Fire surrogates (i.e. pulling woody species, mowing, and planting native species) may continue to be the most appropriate alternative to control non-native and promote native species. However, the successful implementation of prescribed fire and fire surrogates depends on the target restoration species.

Tumbo Cliff

On Tumbo Cliff, 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 Douglas fir appear to have established simultaneous with the Garry oak (Fig. 5). Furthermore, this site was limited by the number of Garry oak trees present and many of the cores taken from what appeared to be veteran trees (i.e. the oldest Douglas fir) were too damaged to determine establishment dates. One tree dated to 1828 with no visible signs of ring curvature, indicating that this Douglas fir and other veteran Douglas fir established prior to 1828 and could possibly surpass the age of the oldest Garry oak trees on the site.

The first recorded European presence on Tumbo Island occurred in 1886 when a coal mine was established within 200 m of the Tumbo Cliff site (Parks Canada 2004). Charring on the bark occurs on many of the large veteran Douglas fir trees, which could have resulted from blasting while digging the mine, lightning strikes, or Indigenous prescribed fire. The largest pulse of Garry oak establishment in the 1870s predates the European settlement and mining activity, suggesting that Garry Oak establishment on Tumbo Cliff and similar sites (Smith 2007) could be associated with changes in climate or natural disturbance regimes following the LIA.

Unlike other sites where frequent disturbance maintained Garry oak ecosystems, the persistence of Garry oak at the Tumbo Cliff site could have resulted from harsh drought conditions, steep slope and shallow soils, which deterred establishment or slowed succession of Douglas fir and allowed the Garry oak ecosystem to persist here. Both Garry oak and Douglas fir samples on the Tumbo Cliff site contain periods of slow growth evidenced by multiple areas of unusually narrow growth rings in the sample cores, consistent with previous observations that Garry oak ecosystems experience slow succession rates on xeric or droughty sites (Johnson et al. 2009). Away from the bluff, where the soil layers are deeper and retain more moisture, Douglas fir form a closed canopy forest and restrict the ability of 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. Alternatively, edaphic characteristics of the site may have prevented low severity fire from impacting conifers on moister sites. It appears that frequent disturbance (such as fire) may not have been an important factor in the persistence of the Garry oak ecosystem. Even if the current stand is a remnant from a time period when frequent burning occurred, frequent disturbance has not been present at this site during the lifetime of the established Garry oak and Douglas fir. Either way, the areas of unusually narrow growth rings within the tree cores of both species indicate reduced growth rates in response to relatively harsh conditions and point to slowed succession rates that allowed the Garry oak to persist.

Establishment patterns and site history of Tumbo Cliff indicate that frequent fire was not required to maintain the existing Garry oak ecosystem. Past fire is evident from fire scars in the study area, but the stand structure suggests that disturbance is likely due to natural rather than repeated anthropogenic ignition. A prescribed fire was undertaken at the site in 2016 and effectively killed a large percentage of encroaching Douglas fir and lodgepole pine saplings and seedlings. Due the number of mature Douglas fir, fire crews had to be diligent. These outcomes are consistent with other experimental prescribed fires in Coastal Bluff/Douglas fir communities similar to Tumbo Cliff (e.g. Tveten and Fonda 1999; Engber et al. 2011; Devine et al. 2013). On these types of sites, 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. This would facilitate prescribed burns and allow reestablishment of native species. Removing Douglas fir will also decrease the probability of crown fires that might impact the Garry oak ecosystem on the bluff.

Tumbo Marsh

Neither Garry oak nor Douglas fir establishment in Tumbo Marsh follows patterns seen in Somenos Marsh, Tumbo Cliff, or other regional studies (Gedalof et al. 2006; Smith 2007; Dunwiddie et al. 2011; Jordan and Vander Gugten 2012). Tumbo Marsh contains some of the largest, youngest, and fastest-growing Garry oak trees in this study. Seventy percent established between 1910 and 1950, well after typical regional Garry oak establishment. Unlike other sites, the Douglas fir established in the 1900s and 1910s are either older than or roughly the same age as the Garry oak. These delayed Garry oak and Douglas fir establishment peaks raise questions about what drove establishment and what that implies for restoration.

Prior to European settlement on Tumbo Island, natural dikes transected the island, creating a salt marsh in the center (Parks Canada 2004). According to historical records, European settlers built a causeway through Tumbo Marsh in the late 1800’s to early 1900’s, which impeded salt water intrusion into the marsh and resulted in fresher marsh conditions. The establishment of a fox farm in 1924 likely represented the final stage of conversion to a freshwater marsh, due to the need for a large supply of fresh water to operate the farm

(Parks Canada 2004). Thus, prior to European settlement, high salinities in Tumbo Marsh would have impeded the establishment of Garry oak and Douglas fir.

The remnant older Garry oak likely established on the periphery of the salt marsh, and Garry oak and Douglas fir established in the rest of the marsh once it was inundated with fresh water. The 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). Establishment patterns suggests that Douglas fir first advanced into the marsh after the fox farm was built. Garry oak soon followed and was able to advance further into the marsh possibly due to its higher tolerance to saturated soils.

Without prior knowledge of land use history and establishment patterns, a simple visual inspection of this site might suggest a different story, with significant management and restoration implications. The large size of the Garry oak, relatively smaller size of encroaching Douglas fir, deep soil, and open meadow landscape all suggest that a younger group of Douglas fir is encroaching on a much older group of Garry oak, and that frequent fires or other disturbances kept Douglas fir from establishing prior to European settlement. However, given the soil conditions and flood patterns, Douglas fir may not have been able to establish further into the Garry oak stand.

While the current vegetation characteristics of Tumbo Marsh likely resulted from recent land use changes (rather than combined pressures of climate, Indigenous burning, and European settlement), the well-developed Garry oak tree community presents an opportunity for conservation and restoration. Tumbo Marsh is a deep soil site experiencing early encroachment pressure from Douglas fir and lodgepole pine that are advancing into the marsh and could overtop the oak in time. Prescribed fire at Tumbo Marsh would stop this encroachment but implementing prescribed fire at Tumbo Marsh should only be undertaken after a detailed vegetation survey and experimental restoration plan design. Currently, Tumbo Marsh may have a mix of vegetation from several ecosystems, of which vegetation associated with Garry oak may only be a small part. Experimental burns would help determine the types of vegetation that would return post-burn.

Another consideration prior to prescribed burning is the structure of Tumbo Marsh. The site could be classified as a Riparian or Wetland Marsh Garry oak ecosystem, which may reduce the success of controlled fire. Burning has been effective in controlling woody and non-native herbaceous species in wetland prairies but produces no change in native herbaceous species (Clark and Wilson 2001). Thus, Wetland Garry oak ecosystems may react differently to the reintroduction of fire than other structural types of Garry oak ecosystems. To understand the interaction between the tree growth and 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

Site specific historical records, site characteristics, and dendrochronological data improve our understanding of local and regional factors that shape the structure of these ecosystems and can be integrated into unique restoration and fire management strategies for each site.

Recent work recognizes that there is no "silver bullet" when devising a restoration and management strategy for these ecosystems (Pellatt et al. 2007; Dunwiddie and Bakker 2011; Dunwiddie et al. 2011; Pellatt and 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 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. A comprehensive understanding of the structure and function of site-specific Garry oak ecosystems can be used to create restoration prescriptions for each 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 here will require active management to restore and manage the Garry oak ecosystem. The restoration prescription should be site-specific, considering both regional and local factors that influenced development of the ecosystem.

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Data availability Data is stored at the Parks Canada Agency, Government of Canada. It is available upon request.

Declarations

Conflict of interest None.

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