Restoring British Columbia's

Garry Oak Ecosystems

PRINCIPLES AND PRACTICES

Chapter 3
Natural Processes and Disturbance

Contents

Chapter 3

Natural Processes and Disturbance

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Figure 3.1 Intact deep soil woodland at Cowichan Garry Oak Preserve. Photo: Shyanne Smith

3.1 Introduction

What is the goal of your site restoration? This should be one of your first questions as you design a restoration project. Given that we cannot predict community change and often do not even know what an ecosystem might have been like prior to human influence (Parks Canada Agency 2000; Samways 2000; Choi 2004), how do we determine what to restore to? Restoration need not attempt to predict what a particular ecosystem would be without human interference, but rather should attempt to restore processes and attributes (Hebda 1999). For example, prescribed[1] burning, livestock grazing, or mowing and native plant seeding may be used as restoration

1 Prescribed fires are fires deliberately set by managers to produce disturbances or conditions that are beneficial to an ecosystem or that achieve management objectives.

surrogates to replace the lighting of frequent fires and bulb digging by First Nations (Anderson and Barbour 2003) that would have historically maintained some Garry Oak (*Quercus garryana*) savannahs. Given the impacts of climate change, land use practices including fire suppression, and introduction of invasive alien species, we are unlikely to be able to restore to a specific historical condition and introduction of such a state is also not likely desirable due to the current stressors and changing climate (Harris et al. 2006). Understanding historical composition, structure, and processes, however, is the first step toward restoring a degraded site to a functional, resilient ecosystem.

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A basic understanding of prairie, savannah, and woodland systems and their maintenance is an important foundation for interpreting site conditions and determining appropriate methods for implementing restoration. This chapter outlines principles of stand dynamics, some of the natural processes (dynamic interactions between living and non-living elements), and historical disturbances to consider when designing a restoration plan for Garry Oak and associated ecosystems.

We first generally discuss ecosystem function and role of disturbance (Section 3.1.1. and Section 3.1.2). We then discuss the concept of stand dynamics (Section 3.2), and apply this to our local systems and explain the roles of fire, alien invasive species, herbivory, plant disease, and climate change in the dynamics of Garry Oak and associated ecosystems (Section 3.3). We conclude (Section 3.4) by summarizing key restoration considerations that relate to natural processes and disturbances.

3.1.1 Ecosystem Function

Four fundamental processes govern ecosystems: water cycling, nutrient cycling, energy flow, and succession. Water cycling involves the capture, storage, and release of water from precipitation, surface flow, and subsurface flow, as well as water uptake and release by organisms. Plans for restoration should consider how each action will affect water cycling. Physical disturbances, such as ditches, irrigation channels, water bars, or even removal of vegetation or trail blazing, may disrupt the supply of water to a site. The loss of wetlands, which serve as sponges, reduces the ability of a site to store and gradually release water. Changes in vegetation structure, such as tree in-growth into a meadow, may increase rainfall interception water uptake from the soil and thus reduce the availability of water to other species. The capacity of soil to absorb and store water may be significantly reduced by even seemingly minor changes, such as the replacement of perennial species by annual grasses or by trampling which reduces soil porosity.

Changes in nutrient cycling may also have profound effects on ecosystem structure and function. For instance, nitrogen[2] often limits plant growth in natural ecosystems in our region. Much of our native flora is well-adapted to nitrogen-poor conditions. An increase in the amount of nitrogen available for plant growth may benefit numerous alien species that are profligate nitrogen users and give them a competitive edge over native plants. Soil nitrogen levels may be

2 The key component of proteins that constitute much of biological tissue.

boosted by inputs from nearby agricultural and urban activities. Some alien invasive species may even increase the availability of nitrogen; for instance, Scotch Broom (*Cytisus scoparius*) has a symbiotic relationship with nitrogen-fixing bacteria that are attached to their roots. The extra boost of nitrogen helps broom plants grow vigorously and may increase the amount of soil nitrogen available to other invasive plants. Micro-organisms and soil fauna (such as earthworms) break down decaying vegetation and release nutrients that are then recycled in the ecosystem. Rainwater could flush many of these nutrients deep into the soil, but plant roots can intercept and recycle many nutrients. Changes in plant community composition may alter the rooting zone structure enough to reduce the recycling of nutrients within the soil.

Energy cycling is driven by the ability of plants to capture energy from sunlight, carbon from the atmosphere, and water from the soil to create sugars which fuel ecosystems. Plants, animals, fungi, and bacteria use these fuels to drive their life processes, and as the fuels are used up, the carbon they contain is released back into the atmosphere in the form of carbon dioxide. Rapid and effective carbon cycling may be blocked in some ecosystems, resulting in a buildup of plant litter, wood, and soil organic matter. An increase in plant litter may reduce the ability of light rainfalls to replenish soil moisture and may prevent some plants from successfully seeding into some areas. Low levels of soil organic matter, on the other hand, tend to reduce the ability of the soil to act as a sponge and store water for plant growth. Herbaceous plants, particularly grasses, "pump" large amounts of carbon into the upper soil as their old roots die and decay. Trees and shrubs, in contrast, release a greater proportion of their dead tissue onto the soil surface as litter.

Ecological succession is an ongoing process that follows a more or less predictable sequence of changes, that at times causes lakes to be overgrown and eventually end up in the current climax forest ecosystem. The successional trajectory is influenced by local circumstances such as weather, stochastic events, and seed sources. This is also a "force" many management objectives aim to keep at bay. For example, Douglas-fir (*Pseudotsuga menziesii*) or Grand Fir (*Abies grandis*) in-growth is driven by natural succession. At times, ecosystems stabilize at intermediate succession stages until circumstances change. The lessons from considering these general processes are:

1) Successful restoration may involve preliminary assessment of more than stand composition and structure
2) Barriers to successful restoration may not be apparent immediately and their detection may require a strategy that considers principles of ecological function such as those described by Harwell et al. (1999) as Essential Ecosystem Characteristics

3.1.2 Role of Disturbance

The current widespread decrease in species diversity in prairies and increasing encroachment of prairies and open savannahs are examples of the need for active management of disturbance-based ecosystems[3]. Such early- to mid-successional ecosystems, such as deep soil Garry Oak communities, depend on disturbance to prevent succession into conifer forest. Ecological disturbance can be defined broadly as "any relatively discrete event in time that disrupts

3 Most ecosystems are "disturbance-based" to some degree, meaning that they are occasionally impacted by disturbance, but savannah or grassland systems like the Garry Oak ecosystems discussed exhibit high levels of disturbance.

Ecological disturbance can be defined broadly as "any relatively discrete event in time that disrupts ecosystem, community or population structure and changes resource, substrate availability, or the physical environment".

ecosystem, community or population structure and changes resource, substrate availability, or the physical environment" (White and Pickett 1985). Thus, disturbance includes processes that historically operated in Garry Oak ecosystems, such as fires and bulb digging, or simulations of such disturbances, such as mowing or weeding.

If the integrity of ecosystems that have historically been maintained by First Nations is to be protected, management must implement actions that simulate First Nations management activities (Anderson and Barbour 2003). Re-introducing disturbance, however, does not necessarily mean that plant communities will respond the same way as they did historically. There are three potential difficulties with re-introducing disturbances:

1) Historical dynamics are not fully understood because they functioned in ways that are not apparent today
2) Historical disturbances do not function as before due to factors such as habitat loss, population decline, and community change due to invasive species
3) There are high costs and risks associated with re-introducing disturbance in the modern (settled) landscape (MacDougall and Turkington 2006, 2007)

Because present conditions and species composition differ from the historical state, the same disturbance will not necessarily have the same effect as it did historically (Hobbs and Huenneke 1992) and our understanding of how plant communities respond to disturbance is still limited due to the complexity of the process. Disturbances interact with other ecosystem-level processes such as production, biomass accumulation, energetics, and nutrient cycling, and change the structure and dynamics of natural communities. Because historical disturbances have largely been suppressed in our natural areas, plant communities have tended to become dominated by a few competitive, often invasive, species (Wilsey and Polley 2006).

In addition, different anthropogenically driven disturbances, such as increased herbivore pressure, eutrophication (i.e., excess nutrients in aquatic systems), and soil disruption have facilitated the establishment of alien invasive species worldwide (Jenkins and Pimm 2003).

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The suppression of historical disturbances may also be maintaining the dominance of alien invasive species in many cases (MacDougall and Turkington 2005). Because disturbance plays an important role in influencing the structure and composition of ecosystems, it is imperative to understand the historical disturbance patterns at a particular restoration site, as well as the current disturbances, and their influence on ecosystem composition and structure and ultimately on restoration goals.

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3.2 Stand Dynamics in Savannah Systems: General Principles

The term “stand dynamics” generally refers to changes in forest stand structure[4] over time, including stand behaviour, during and following disturbances. Stand dynamics, therefore, encompasses natural processes and disturbances that affect the species and structure of an ecosystem that has a tree component.

Savannahs are broadly defined as tree-grass or woody-herbaceous communities and are characterized by the co-dominance of tree and herbaceous layers (Scholes and Archer 1997). These communities typically experience a drought season, which limits tree growth. Savannahs are generally classified as a state between open prairie or meadow and closed-canopy[5] woodland.

Savannahs are not simply prairies with trees. Pavlovic et al. (2006) found that the species composition in oak woodlands in Indiana was most strongly influenced by the amount of canopy cover rather than by other environmental factors, at least at a fine scale (at a broader level, soil productivity was the primary variable). Similar findings were obtained for oak woodlands and savannahs in California: vegetation in the understorey of oak savannahs and woodlands was different and more productive than vegetation in open grasslands. The oak understorey also reacted differently than vegetation in open grasslands to both the presence and removal of grazing pressure (Frost et al. 1997).

Savannahs are not simply prairies with trees.

A number of studies describe the encroachment of trees into savannahs, but the conditions that maintain savannah communities vary and are poorly understood (Sankaran et al. 2004); therefore, questions remain about how savannahs develop, how trees and the ground layer of vegetation interact, and how savannahs are maintained (Scholes and Archer 1997; Jeltsch et al. 2000). Descriptions of savannahs worldwide (including temperate North American savannahs) reveal a general pattern of transition into forest over the last 50–300 years (Archer 1989; Scholes and Archer 1997; Foster and Shaff 2003; Moore and Huffman 2004).

4 Stand structure refers to forest structure in terms of tree species and/or sizes of trees.

5 A closed canopy is created by sufficient shading by trees that have grown enough to fill any gaps that allow light to penetrate to the ground surface.

> It is important to consider disturbance in light of your restoration goals, the current state of your restoration site, and potential effects of disturbance given the changed conditions.

Climatic and soil characteristics, fire, herbivory, biotic interactions, and human activity have all been identified as factors involved in this transitional process. Although there have been many attempts to create comprehensive models of savannah dynamics, the variability among sites means that a careful assessment of site-specific conditions is necessary before beginning restoration.

The process of forest encroachment has become an important management concern for North American savannahs (Arno and Gruell 1986; McPherson 1997). Encroachment can be divided into two categories: clump coalescence and gradual progression. Clump coalescence occurs when individual trees or shrubs establish in patches within openings, leading to further encroachment, whereas gradual progression occurs when woody vegetation slowly expands from the perimeter of openings. These two modes of forest encroachment have been described in field studies but have rarely been related to fire regimes and anthropogenic factors. For example, a study of forest progression in Africa indicates that increased anthropogenic fire frequency produces a shift from more rapid climate-driven clump coalescence to more gradual progression from the edges (Favier et al. 2004).

The configuration of a habitat patch in relation to adjoining habitat patches and the site's grazing history and topography have also been found to affect plant community composition (Foster and Tilman 2003; Hersperger and Forman 2003). Thus, when you look at a given savannah site to decide how stable it is, it may be important to look at the adjacent forested habitats for clues. The successional state of habitat patches and the level of contrast between patches and their surrounding landscape will typically result in unique patch dynamics and life forms, making generalizations difficult and potentially misleading (Watson 2002). When savannahs are fragmented and occur as patches within a matrix of forested and developed land, this increased patchiness may also result in an elevated rate of forest encroachment. Patterns of forest encroachment can also vary between nearby habitats due to local differences, including unique human land use history.

In general, evidence indicates that virtually all savannah ecosystems have had a long history of relatively frequent, low-intensity fires. In the past, many fires were started by lightning, but the landscape management activities of First Nations peoples were responsible for much of the regularity of the fire regime[6] across North America. European settlement has disrupted the fire regime in most locations. The predominant post-settlement pattern has been one of fire suppression[7] or complete fire exclusion. These changes in the disturbance regime have resulted in dramatic changes to the composition, structure, and function of savannah ecosystems. As

6 The term fire regime refers to the pattern of fire that occurs over time (e.g., the average interval between fires and/or fire severity when fires occur).

7 Fire suppression refers to active human intervention to prevent fires from occurring or at least restricting them to small areas through fire fighting activities.

expected, the precise role of fire, and the changes that have accompanied fire exclusion, vary among vegetation types.

Re-introduction of fire or simple introduction of another disturbance is not always an easy or effective solution to restoring savannahs. Savannahs that have historically been maintained by fire or other disturbance may experience increased invasion by alien species if disturbance is returned to the system, creating additional restoration difficulties. Re-introduction of fire in temperate grasslands often benefits many alien species, to the detriment of native ones (Agee 1993; Grace et al. 2001). It is important to remember that fire regimes within a given system may also vary between patches of similar habitat (Wardle 2002), thereby making it necessary to determine site-specific fire prescriptions. It is important to consider disturbance in light of your restoration goals, the current state of your restoration site, and potential effects of disturbance given the changed conditions (see Case Study 1 in Chapter 8).

3.3 Stand Dynamics in Oak Savannahs and Prairies in the Pacific Northwest

Savannah ecosystems are some of the most altered ecosystems worldwide, and much of North America's oak (*Quercus* spp.) savannah ecosystems have been lost to development. The encroachment of woody species into oak savannahs presents additional complications, since a current lack of adult oak recruitment has been observed in a number of different oak savannah and forest types (Russell and Fowler 2002; Brudvig and Asbjornsen 2005; Gedalof et al. 2006). Throughout North America, the observed decline in oak has been attributed to various factors, such as selective logging of oaks, catastrophic fires, fire suppression, poor seed production, seedling damage, shading and competition from other tree species and alien grasses, and chestnut blight in the eastern United States (Abrams 1992; Lorimer et al. 1994; McEwan et al. 2006). However, dendrochronological analyses of Garry Oak and Douglas-fir stand structures in British Columbia indicate that both tree species increased in abundance in coastal savannahs and prairies following European settlement (Gedalof et al. 2006; Smith 2007).

Factors involved in encroachment of conifers into savannahs are not well understood but links have been identified among fire suppression, increased deer browsing, and lack of oak recruitment in many oak forests and savannahs in North America. In some oak savannahs, conifers appear to be recruiting successfully, possibly as a result of increased oak establishment immediately following European settlement and the suppression of fire (Agee and Dunwiddie 1984; Peter and Harrington 2002; Gedalof et al. 2006; Smith 2007). In order to restore an oak savannah effectively, restoration practitioners need to understand both the processes that historically maintained the savannah and the processes and conditions that affect the current stand structure and regeneration.

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Historically, fire was instrumental in inhibiting shrub and tree encroachment (including oak) into open prairies. It also maintained the open vegetation structure of oak savannahs and parklands.

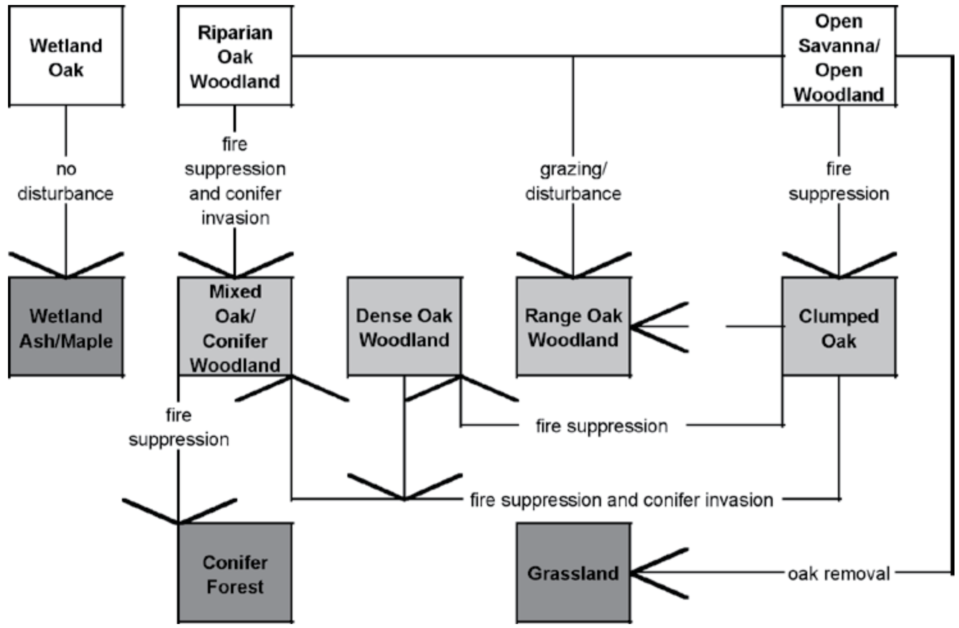

Figure 3.1 Stand development model of the impacts of different disturbance regimes, particularly fire suppression, on different types of Garry Oak woodland in the South Puget Sound area of Washington. Disturbance regimes are representative of those that have dominated the landscape since European settlement. Progression from white to light gray to dark grey boxes indicates a transition from historical oak to altered oak to non-oak habitats. Redrawn with permission from Hanna and Dunn (1996).

McCoy et al. (2006) studied historical Garry Oak ecosystems by examining charcoal and fossil pollen from lake sediments on Pender Island and Vancouver Island. Their work shows low fire activity prior to 1780 AD, increased fires between 1780 and 1860, and little fire activity after about 1940. Hanna and Dunn (1996) proposed a stand-development model that illustrates the impacts of post-European settlement disturbance regimes, particularly fire suppression, on different types of Garry Oak stands in the South Puget Sound area of Washington (Figure 3.1). This model shows changes occurring in many Garry Oak stands throughout the species' range.

Current stem densities within the stands are as much as an order of magnitude higher than they were at the time of European settlement (Hanna and Dunn 1996; Gedalof et al. 2006; Smith 2007). Fire stimulates oak sprouting but causes high seedling mortality; therefore, in the absence of fire, oak (and possibly conifer/maple) density increases, conifers establish in the understorey, and savannahs convert to conifer forests (Sugihara et al. 1987; Smith 2007).

Smith (2007) and Gedalof et al. (2006) studied tree ring chronologies, stand structure and recruitment, and understorey composition at representative Garry Oak ecosystem sites on Vancouver Island and the southern Gulf Islands. One common factor observed at B.C. sites was an increase in stand recruitment at the time of European settlement. This recruitment was most likely related to increased disturbance and/or disruption of land use and fire regimes at that time. Increased site disturbance resulted in increased opportunities for tree seedling establishment, and in the absence of repeated disturbance, these pulses of regeneration established dense woodlands and forests. Rates of forest encroachment varied considerably between sites depending on environmental conditions, land use history, fire history, or other natural disturbances at the site. All sites exhibited a high degree of conifer encroachment as a result of disturbance and land clearing activity concurrent with European settlement (except for those sites where encroachment was environmentally controlled, such as on exposed islets or steep slopes). Grazing/browsing pressure, exposure and/or salt spray, adjacent forest, slope, and soil type/depth influence encroachment patterns and rates in oak savannahs in B.C. For example, on Tumbo Island in the southern Gulf Islands, there is a clump coalescence pattern of encroachment, as well as heavy browsing by deer. Forest progression is slower than at sites with gradual forest progression because browsing pressure restricts conifer establishment. Otherwise, gradual forest progression is the typical form of encroachment that can be expected to occur in these Garry Oak sites, and the rate of encroachment is linked to browsing pressure, site disturbance, adjacent forest cover (and seed source), understorey vegetation type and density, and degree of canopy closure. Fire-maintained savannahs are much more likely to be more mesic, less steep, and have a deeper, more organic soil than environmentally maintained (e.g., shallow soil rocky environment) savannahs which are more likely to have harsher site conditions, and readily show impacts from herbivores (e.g., presence of alien invasive grasses, disturbed soil, and clipped vegetation).

Grazing/browsing pressure, exposure and/or salt spray, adjacent forest, slope, and soil type/depth influence encroachment patterns and rates in oak savannahs in B.C.

3.3.1 Role of Fire and other Environmental Controls and Site Conditions

What do we Know about the Historical Role of Climate, Fire, and First Nations Management?

Burning by aboriginal peoples is widely thought to have had an important influence on the composition and structure of Garry Oak communities (Tveten and Fonda 1999; Thysell and Carey 2001). Fire history, dynamics, and effects within Garry Oak and associated prairie and mixed forest ecosystems have been studied throughout the Pacific Northwest from California to British Columbia. These studies have documented the ubiquitous use of fire by First Nations peoples prior to European settlement.

Charcoal in sediment cores taken on southeastern Vancouver Island indicates that fire activity gradually increased between 11,500 and 10,000 ybp[8], presumably as a result of warming, high-intensity storms and lightning strikes. The sediment cores further indicate that between 10,000 and 7000 ybp, fires were more frequent and not stand-replacing, and were most likely the result of drier conditions at that time. Charcoal levels dropped between 7000 and 4000 ybp at lowland sites as the climate again grew moister. However, at about 2000 ybp, fire activity increased at several sites, even though the climate continued to moisten and cool. This increase in fire activity is attributed to burning by First Nations peoples (Brown and Hebda 2002).

The functions of First Nations management activities varied from place to place, but for the most

8 ypb = years before present.

part were associated with directly enhancing important food resources such as camas, berries, and Bracken Fern (*Pteridium aquilinium*), improving the ease of capture or collection of game or other resources (such as deer), or making travel across land easier (Agee 1993; Anderson 2007). It has also been reported that burning was done to reduce the prevalence of insect pests and disease (Anderson 2007). The precise characteristics of the fires are largely unknown, but historical accounts and tree ring analyses indicate that they were ignited in late summer and fall, burned frequently, perhaps annually in some places, and covered large expanses of the landscape. This regular fire regime prevented the build up of fuels; consequently, fires were generally flashy and of low intensity, and were carried quickly through the landscape by the dry herbaceous understorey. Tree ring analyses at several Garry Oak savannah sites in B.C. indicate that, historically, the landscape had less tree cover and regular low-intensity fires (Smith 2007). Historical descriptions of B.C.'s Garry Oak ecosystems during and after European settlement support these findings and suggest that the landscape was a mosaic of vegetation types, determined mainly by topography, soil depth, and fire (see Chapter 2). This mosaic would have consisted of varying patch sizes from small rocky outcrops to large, deep-soil savannahs (MacDougall et al. 2004). Pollen analysis of soil profiles confirms the mosaic nature of the vegetation (McDadi and Hebda 2008).

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First Nations peoples also introduced other disturbances to savannahs and prairies. In particular, the cultivation of camas and other bulbs is believed to have played an important role in maintaining an abundance of forbs in Garry Oak and associated ecosystems. First Nations peoples actively dug and sowed bulbs and corms, thereby practicing a form of tillage that aerated the soil and encouraged forb growth (Turner 1999; Anderson 2007).

The effects of fire exclusion, which began after European settlement around 1850, are important to consider. Fire exclusion has been described as the most serious ecological problem facing remnant Garry Oak stands that are protected from development (Sugihara and Reed 1987; Agee 1993; Hanna and Dunn 1996). Disturbance by fire allows Garry Oak woodlands to persist in deeper

Fire exclusion has been described as the most serious ecological problem facing remnant Garry Oak stands that are protected from development.

Pellow Islet is an example of a small islet where shallow soils, wind, and salt spray restrict vegetative growth. Photo: Emily Gonzales soil sites that would otherwise succeed to conifer forest. Large-scale conversions of prairie and oak savannah to forest have been documented in California, Oregon, Washington, and British Columbia. Estimates indicate that up to 50% of all Garry Oak woodlands that are suitable for conifer establishment might be lost within 30 years (Agee 1993).

Aboriginal burning, however, may not have been a factor in maintaining all oak savannahs. Agee and Dunwiddie (1984) identified a fire rotation of approximately 80 years on Yellow Island in the San Juan Islands. Shrub and tree invasion on this island is thought to be linked to above-average summer precipitation rather than to a change in the fire regime. Conifer encroachment was also not an issue at some sites in Canada's Gulf Islands, where forest development was restricted by environmental controls such as extremely well-drained or thin soils, steep slopes, and exposure to wind or salt spray (Figure 3.2 and 3.3) (Smith 2007). Soils in Garry Oak ecosystems in B.C. are often shallow or have excessive drainage (Roemer 1972, 1993), and are often nitrogen poor, which reduces competition from other native species. It is important to note that some Garry Oak communities are maintained through a combination of abiotic conditions, such as precipitation and soil characteristics, rather than through disturbance such as fire.

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Effects of Prescribed Fire and Fire Surrogates on Garry Oak Ecosystems

Prescribed fire is in use as a restoration tool in Garry Oak and associated prairie ecosystems at a number of locations in California, Oregon, and Washington. The use of prescribed burning is only at an early, experimental stage in Garry Oak ecosystems in B.C. Most often, prescribed fire requires the prior manual removal of ladder fuels, such as shrubs, and may require the removal of woody debris and thatch, depending on site conditions. Additionally, individual trees may need to be manually removed to achieve the desired stand density. *A Practical Guide to Oak*

Figure 3.2 Krummholtz oaks on an islet in the southern Gulf Islands, subject to salt spray and wind. Photo: Brian Reader

Figure 3.3 Extremely steep slopes can be environmentally maintained as open savannah or prairie. Photos: Shyanne Smith

Release (Harrington and Devine 2006; www.fs.fed.us/pnw/pubs/pnw_gtr666.pdf) provides an introduction to the release of oak stands.

Fire surrogates are also used when the use of fire is not practical or desirable. Surrogates include mowing and raking or other manual removal of vegetation or woody material. A study in a savannah dominated by alien perennial grasses (Kentucky Bluegrass, (*Poa pratensis*) and Orchard-grass, (*Dactylis glomerata*)) in B.C. indicates that annual prescribed fire and fire surrogates were similarly effective in controlling the alien invasive grass species and encouraging perennial forb species over a five year period (MacDougall and Turkington 2007) (See Case Study 2 in Chapter 8). However, assessment of manual disturbance (thinning) of oak woodlands in Oregon after four to seven years found that the single treatment resulted in increased annual species cover, including a doubling of alien annual grass cover, and a decrease in native perennial species (Perchemlides et al 2008). These findings illustrate the need for ongoing management and site-specific research and monitoring.

Once a savannah converts to forest, it becomes increasingly difficult to successfully implement prescribed fire, or otherwise restore the ecosystem to a savannah state. The benefits of using fire as a restoration tool also vary due to complications such as the responses of invasive species to fire and altered species composition (see Section 3.3.2 below, and Chapter 9: Alien Invasive Species). In addition, prescribed fire alone, even over multiple years, can result in increased woody understorey cover due to widespread sprouting from tree bases and stumps (Chiang et al. 2005). Prescribed fire should be considered as a potential restoration tool, to be used in conjunction with other restoration techniques, including invasive species removal, re-introduction or enhancement of native species, litter removal, and stand and/or soil modification.

Once a savannah converts to forest, it becomes increasingly difficult to successfully implement prescribed fire, or otherwise restore the ecosystem to a savannah state.

Experimental prescribed fire at Cowichan Garry Oak Preserve (see Case Study 2 in Chapter 8). Photo: Tim Ennis

Timing

The frequency and timing of burns or surrogate management activities are important considerations for restoration and management. High-frequency burning (three or more times per decade) can prevent development of an oak sapling layer and canopy infilling, while low-frequency burning (less than two fires per decade) can produce stands with dense thickets of saplings (Peterson and Reich 2001); however, the optimal timing and frequency of prescribed burning of Garry Oak stands in B.C. are largely unknown. Given the summer drought period that Garry Oak ecosystems in B.C. experience, fires would likely have historically occurred between July and October, and would have been set after camas harvesting was completed and most vegetation had senesced. Fires likely occurred patchily across the landscape, creating a mosaic of different communities and stand structures.

Timing prescribed burns or similar treatments (cutting and raking or weeding) for mid-summer, when alien invasive grasses are at their reproductive peak, was found to be dramatically more effective in controlling alien invasive grass abundance.

Effects on Plant Species

The effects of fire on herbaceous vegetation are not limited to the inhibition of woody shrubs and trees. Different species of plants respond differently to the changes in temperature, litter, soil moisture, soil chemistry, microclimate, and soil biota that are caused by fire, and they exhibit varying levels of vulnerability to direct damage (Daubenmire 1968). Fire-adapted forbs and grasses that evolved and persisted in these ecosystems possess various structural adaptations (e.g., they are capable of dying back to living tissues near or below the ground surface) and life history strategies (e.g., late summer die-back of above-ground parts) that enable them to tolerate frequent, low-intensity fires. Bulb and rhizome-forming species, and species with fire-adapted seed strategies, tend to be favoured by fire (Sugihara and Reed 1987). Timing prescribed burns or similar treatments (cutting and raking or weeding) for mid-summer, when alien invasive grasses are at their reproductive peak, was found to be dramatically more effective in controlling alien invasive grass abundance, compared to late season burns at the Cowichan Garry Oak Preserve (MacDougall and Turkington (2007).

A study in Oregon found that four to seven years after fuel-reduction thinning treatment (cutting and chipping or cutting and pile-burning), native annual species had expanded more than other functional groups, particularly when a seed source was available (Perchemlides et al. 2008). These native annuals included species of *Clarkia*, *Epilobium*, *Lotus*, and *Plagiobothrys*. Several species in these genera are rare in our B.C. Garry Oak ecosystems. The results of this study demonstrate the need for careful restoration plan design. If your goal is to restore, for instance, a population of a rare annual, you may decide to implement manual fuel-reduction treatments that open the canopy and create soil disturbance. If your goal is to restore native perennials, you would instead likely choose methods which would create less soil disturbance, while still removing canopy or thatch, such as cutting and raking and/or low-intensity prescribed burning during the dormant season of the target perennial.

Effects on Plant Communities

Plant community responses to fire and fire surrogates are complex due to competitive interactions among resident species, and many other factors, including microhabitat, weather, seasonality

SOIL DISTURBANCE AND RARE ANNUALS

Photos: Shyanne Smith

GOERT members discuss the role of disturbance in creating a carpet of a Threatened annual, Macoun's Meadowfoam (*Limnanthes macounii*), that appeared after plowing of a firebreak (Left photo). A surprising find, it is thought that individuals of this species had persisted at low, undetected numbers in a small vernal seep area. When the firebreak was cleared, the disturbance created conditions needed for the population to expand. Soil disturbance has also been observed to be important for several other rare annual forbs. Soil disturbance by feral goats at the site of the largest population of another rare annual, Slender Popcornflower (*Plagiobothrys tenellus*), is also thought to have played a key role in the persistence of the species (Right photo).

and frequency of burning or disturbance, and fire or other disturbance intensity. A compilation of responses of numerous species to fire is available in the Fire Effects Information System (www.fs.fed.us/database/feis). There are also several resources available from the USDA Forest Service that summarize the effects of wildland fire on flora, fauna, soils, water, air, and alien invasive plant species. The effects of re-introducing fire or other disturbance in the presence of alien invasive plants, particularly grasses, is a concern because many of these species are well-adapted to disturbance and are able to establish in disturbed areas more rapidly than native species. See Section 3.3.2 for more information on alien invasive plants. Care must be taken to ensure that fire, or similar disturbance is applied during the reproductive peak of these grasses and after native vegetation has senesced. Fire, or other disturbance, as a restoration tool was found to most effective where native flora was already present (MacDougall and Turkington 2007; Perchemlides et al. 2008). Native seed addition following burning may be beneficial, or even necessary, in more degraded sites.

Effects on Animals

Faunal responses to fire and other disturbance have received considerably less attention than has plant responses. The Fire Effects Information System (2011) provides some information about responses of a number of vertebrate species to fire, including some species found in Garry Oak and associated ecosystems in B.C. The responses of vertebrates to a given frequency of burning depend largely on how fire impacts vegetation structure. For example, animals that are associated with grasslands and other open ecosystems tend to benefit from a frequent fire regime. Many species, in fact, rely on fire or other disturbances for the maintenance of their habitats. However, some grassland species are favoured by conditions that immediately follow a burn, while others do better under conditions that occur a few years later (Clark and Kaufman 1990; Johnson 1997). Fire also creates standing dead and downed wood, which favours species that depend on these habitat elements (e.g., Western Bluebird [*Sialia mexicana*] and Lewis's Woodpecker [*Melanerpes lewis*]). These and other birds that rely on coastal prairie and oak savannahs have declined or become extirpated from the region (Huff et al. 2005; GOERT 2002). Temporal factors, such as the seasonality of burning, are also important in determining the effects of fire on animals. For example, direct mortality or disruption of breeding may occur if burning happens during critical periods in an animal's life cycle (Cavitt 2000).

> A compilation of responses of numerous species to fire is available in the Fire Effects Information System (www.fs.fed.us/database/feis).

Like vertebrates, invertebrate species vary in their response to fire. Some invertebrates are favoured by conditions that immediately follow a burn, whereas others do better a few years later. In contrast to highly mobile vertebrates, invertebrates are more vulnerable to direct fire-caused mortality (Nicolai 1991; Swengel 1996; Siemann et al. 1997). Because fire suppression has caused increased fuel loads in most places, fires tend to burn hotter than they did historically, thus increasing mortality risk. Maintaining populations of invertebrates that are vulnerable to fire-caused mortality but depend on fire-maintained ecosystems requires a staggered burning strategy, such as rotating burns among portions of the site (U.S. Fish and Wildlife Service 1984; Schultz and Crone 1998). Thus, management must incorporate not only the disturbance process itself, but variation in time and space to support a complex of species over time. Habitat patches in fragmented landscapes must be large enough to accommodate such complex disturbance patterns.

Research and Monitoring

Experimental work is currently being undertaken to learn more about fire, including the use of prescribed fire, in Garry Oak and associated ecosystems in B.C. The Nature Conservancy of Canada and Andrew MacDougall of the University of Guelph have led this research at the Cowichan Garry Oak Preserve near Duncan B.C. (see Prescribed Fire case study (2) in Chapter 8). The Fire and Stand Dynamics Steering Committee (www.goert.ca/about_fire_stand_dynamics.php), operating under the Restoration and Management Recovery Implementation Group of GOERT, is also working to design and implement the use of techniques to manage stand structure, promote awareness about woody encroachment and management by land managers, and further fire and stand dynamics research.

In general, the use of prescribed fire has been found to reduce the cover of alien invasive herbs in California (Sugihara and Reed 1987; Hastings and Barry 1997) and to suppress C3 grasses[9] (including native species) and increase growth and reproduction of some native forbs here in B.C. There have been mixed results, however, at Fort Lewis (Tveten 1997; Tveten and Fonda 1999), Mima Mounds (Schuller 1997), and Yellow Island (Dunwiddie 1997) in Washington. These results underscore the need for caution in applying prescribed fire. Potential sites must be carefully assessed, and burning or other disturbance should be used within an adaptive management framework, in which management actions are applied experimentally, results are monitored, and management is refined according to the results obtained. See Chapter 7 (Inventory and Monitoring) for further information on adaptive management methods.

Potential sites must be carefully assessed, and burning or other disturbance should be used within an adaptive management framework, in which management actions are applied experimentally, results are monitored, and management is refined according to the results obtained.

3.3.2 Disturbance and Alien Invasive Species

Controlling Invasive Species with Fire or Other Disturbance

Fire can be effective in controlling some invasive alien species, such as Scotch Broom, if repeated over a number of years (Dunn 1998). However, other invasive species in Garry Oak ecosystems in British Columbia can be favoured by fire. MacDougall has been studying the effects of fire and invasive grasses on plant diversity in a deep-soil Garry Oak savannah for a number of years. His research indicates that most annuals and other species that have rapid seed production and high seedling growth rates, and that quickly colonize disturbed areas, are favoured by disturbance, but some invasive alien grasses (such as some bluegrass species) actually fare best in the absence of disturbance in this system (MacDougall and Turkington 2004). Exotic bluegrass species are able to dominate in undisturbed systems due to their ability to tolerate reduced resource availability under intense competition. MacDougall's research has also demonstrated that native species are recruitment-limited in invaded Garry Oak ecosystems, meaning that their scarcity, compared to non-native species, may be a result of fewer available native plant seeds (MacDougall and Turkington 2006). In addition, available light appears to be the primary limiting factor for native forb growth. Removing biomass (including thatch and leaf litter) before alien grasses set seed has been shown to effectively increase growth of several native perennial forbs (MacDougall and Turkington 2007).

Invasive Plants

Little is known about the relationships among different understorey plant species and communities and the forms and rates of forest encroachment in savannahs. However, alien invasive plants can be considered a disturbance or something that changes the "ecosystem, community or population structure and changes resource, substrate availability, or the physical

9 C3 grasses: Grasses are divided into two groups, C3 and C4, based on their photosynthetic pathways for carbon fixation. C3 grasses are referred to as "cool season grasses" while C4 plants are considered "warm season grasses".

An example of an often-overlooked alien invasive that affects Garry Oak and associated ecosystems is the earthworm.

environment" (White and Pickett 1985). Research has demonstrated that savannahs are not simply "prairies with trees" (Leach and Givnish 1999), and that replacement of dominant native perennial grasses with alien annuals is associated with decreased oak recruitment (D'Antonio and Vitousek 1992; Gordon and Rice 2000). Other studies have shown that alien invasive grasses can alter nitrogen dynamics in the soil (Sperry et al. 2006). Scotch Broom, a nitrogen-fixer, has the potential to change ecosystem-wide resource supply and facilitate the growth of nitrogen-loving plants. It also generates large amounts of woody fuel that can support high-intensity fires, and in this way alters the natural disturbance regime. Gorse (*Ulex europaeus*) has similar characteristics and destructive potential as Scotch Broom, but to date is not as widespread in B.C. (Clements et al. 2001).

A strong link between invasion of alien species and rates and forms of tree recruitment or other ecosystem change has not been established. MacDougall and Turkington (2005) illustrate the importance of considering the presence and removal of alien invasive species in a functional ecosystem context. They examined whether alien invasive grasses could be considered the drivers or passengers of ecosystem change, and found at their study site that invasion by the dominant non-native grasses was likely a side effect of fire suppression rather than a result of superior competitive ability.

Invasive Animals

Plants are not the only invasive species that can affect stand structure and drive ecosystem change. Non-native Eastern Grey Squirrels (*Sciurus carolinensis*)consume acorns, and thus pose a threat as a competitor for this valued resource. Although they may help disperse oaks by caching acorns, they do not tend to transport acorns very far, and their habit of biting out the apical meristem at the tip of the acorn prior to caching it likely limits their role as dispersers (Fox 1982; Pigott et al. 1991; Fuchs 1998). Herbivores can also have a significant impact on stand regeneration and ecosystem composition (see Section 3.3.3).

An example of an often-overlooked alien invasive that affects Garry Oak and associated ecosystems is the earthworm. Most earthworms in B.C. are European introductions and are considered ecosystem engineers (Jouquet et al. 2006). On southeastern Vancouver Island and the Gulf Islands, native earthworms are generally absent (Marshall and Fender 1998); however, it is unknown whether they have always been sparse or absent, or if they have been displaced. Earthworms play an important role in ecosystem function as decomposers and in structuring and aerating soils (Speirs et al. 1986; Koss 1999). Changes in the nature or extent of earthworm activity can affect nutrient regimes, ecosystem productivity, and other ecosystem functions (Fuchs 2001).

3.3.3 Herbivory

Research conducted on the Gulf Islands and San Juan Islands shows that herbivory by deer limited the establishment, growth, survival, and reproduction of both seedlings and transplanted native forbs and shrubs, and that competition from alien plant species had relatively less impact (Gonzales and Arcese 2008; Gonzales and Clements 2010). It should be noted that this research was conducted on shallow soil sites, so the results may not be applicable to deep soil sites. Alien annual grasses were rarely browsed and increased with increasing ungulate density (deer

Exclosures around oak seedlings or other vegetation may be needed to control herbivory by deer. Photo: Shyanne Smith

and sheep). The volume of alien perennial grasses declined with herbivory, but their overall presence was unaffected by ungulate density (despite being preferentially foraged). An important implication from this research is that reducing ungulates, such as deer, which is necessary for the recovery of many native forbs, may also benefit alien perennial grasses (see also Chapter 8, Case Study 1).

Present densities of deer exceed historical levels (Gonzales and Arcese 2008). As a result of increased herbivory, less palatable species (e.g., alien grasses) have a competitive advantage. Reducing deer numbers alone may not result in an increase in native grasses and forbs, since alien perennial grasses may replace the alien annuals. Gonzales and Arcese (2008) found that deer prefer native forbs over most alien annual and perennial grasses, and they suggest that

Figure 3.4 Feral goats in steep open savannah on Saturna Island. Photo: Shyanne Smith

restoration practitioners will improve their success by controlling herbivore density. Where deer are abundant, herbivore pressure can be reduced through fencing, culling, or increasing deer alertness[10]. Fertility control, repellents, and habitat modification are alternatives to hunting in suburban communities, but the success of these approaches as long-term solutions remains uncertain (Gonzales and Arcese 2008).

In addition to the abundant native Columbian Black-tailed Deer (*Odocoileus hemionus columbianus*), introduced mammalian herbivores, such as goats (*Capra hircus*), sheep (*Ovis aries*), Eastern Cottontail rabbits (*Sylvilagus floridanus*), and domestic European rabbits (*Oryctolagus cuniculus*) also occur in Garry Oak and associated ecosystems throughout their range in B.C. Like other perturbations, these abundant herbivores can shift plant communities to new ecosystem states. Research has shown that in general, in the presence of increased herbivory, plant communities become homogenized, and change in structure and composition (Gonzales and Arcese 2008; Gonzales and Clements 2010). In this way, herbivory tends to encourage dominance by alien annual grasses, whereas protection from herbivory favours alien perennial grasses. Their research also suggests that herbivory can be used to reduce cover of alien perennial grasses by fencing restoration sites from fall to spring, when most native forbs are germinating and growing, then opening the sites to grazing during

Herbivory can be used to reduce cover of alien perennial grasses by fencing restoration sites from fall to spring, when most native forbs are germinating and growing, then opening the sites to grazing during summer.

10 Deer alertness is increased by hunting, noise-makers, predator presence, etc. Increased deer alertness results in more sporadic browsing, diluting the impact of deer on the site.

summer, after the native forbs have senesced. Grazing by sheep or goats can not only reduce biomass, but can also create bare soil sites for native annual species establishment (Smith, pers. observ.) (Figure 3.4).

It is important to note that cover of invasive alien flora does not necessarily increase with increased levels of herbivory, and protection from herbivory once alien invasive species have established will not automatically reduce the invasive vegetation. However, herbivory does tend to encourage dominance by alien annual grasses, whereas protection from herbivory favours alien perennial grasses. With the widespread abundance of deer and other herbivores throughout Garry Oak and associated ecosystems, isolated, small islets or other locations with low densities of herbivores may provide important reference sites for historical Garry Oak and associated plant community composition and structure (Gonzales 2008).

Other forms of herbivory that may occur on a site-specific basis should also be considered, such as herbivory by insects or other invertebrates. For example, Winter Moth (*Operophtera brumata*) and particularly Gypsy Moth (*Lymantria dispar*), can seriously defoliate oaks. The introduced European Black Slug (*Arion ater*) can also destroy seedlings, and has been reported to impact a number of rare plant populations, particularly those of Yellow Montane Violet (*Viola praemorsa* ssp. *praemorsa*) and Deltoid Balsamroot (*Balsamorhiza deltoidea*) (Fuchs 2001).

Diseases cause disturbance and facilitate plant succession by debilitating or killing a plant, thereby creating space or favourable conditions for other plant species.

3.3.4 Plant Disease

Plant disease has been defined as any interference with the normal functioning of a plant that results in disturbed or abnormal physiological action or the deterioration of any of its parts (after Hubert 1931). Disease is the result of the interaction of a disease agent, a host, and environmental factors. Diseases cause disturbance and facilitate plant succession by debilitating or killing a plant, thereby creating space or favourable conditions for other plant species. When planning an ecosystem restoration project, it is advisable to know about occurrence and incidence of diseases that are capable of causing major disturbance so that the risk of future damage can be assessed and appropriate measures can be taken to minimize risk.

Fungi, including those that cause disease, are normal components of ecosystems. Information on the classification and biology of fungi is provided on the Tree of Life website (www.tolweb.org/fungi).

The lists of fungi mentioned below (Table 3.1) which occur on native grasses, forbs, shrubs, and trees in Garry Oak ecosystems, were compiled from the Herbarium Collections Database and host-fungus index at the Pacific Forestry Centre (www.pfc.cfs.nrcan.gc.ca/biodiversity/herbarium/index_e.html) and the Pacific Northwest Fungi Database (http://pnwfungi.wsu.edu/programs/aboutDatabase.asp). Many of the native graminoids and shrubs, and most of the native forbs referred to in this publication, lack disease records in the databases. For example, no fungi are recorded on onion (*Allium* spp.) in Garry Oak ecosystems. In contrast, in the Pacific Forestry Centre herbarium there are 91 collections of 49 fungi on Garry Oak trees. Thus, it is evident that a systematic survey of disease has not been conducted in these ecosystems.

Table 3.1 Some frequently recorded or damaging diseases on graminoids, forbs, shrubs, and trees in Garry Oak ecosystems.

DISEASES OF GRAMINOIDS			
Host	**Plant part**	**Fungus**	**Type of damage**
Blue Wildrye (*Elymus glaucus*)	foliage	*Puccinia striiformis*	rust
	foliage	*Puccinia recondita*	rust
Alaska Oniongrass (*Melica subulata*)	foliage	*Erysiphe graminis*	mildew
DISEASES OF FORBS			
Host	**Plant part**	**Fungus**	**Type of damage**
Common Camas (*Camassia quamash*)	foliage	*Urocystis colchici*	smut
White Fawn Lily (*Erythronium oregonum*)	foliage	*Uromyces heterodermus*	rust
	foliage	*Ustilago heufleuri*	smut
DISEASES OF SHRUBS			
Host	**Plant part**	**Fungus**	**Type of damage**
Oceanspray (*Holodiscus discolor*)	stem	*Phellinus ferreus*	decay
	stem	*Hymenochaete tabacina*	decay
Hairy Honeysuckle (*Lonicera hispidula*)	foliage	*Microsphaera penicillata*	mildew
	foliage	*Hyponectria lonicerae*	leaf blight
Tall Oregon-grape (*Mahonia aquifolium*)	foliage	*Microsphaera berberidis*	mildew
Nootka Rose (*Rosa nutkana*)	foliage, fruit	*Phragmidium fusiforme*	rust
	foliage	*Phragmidium rosae-californicae*	rust
Common Snowberry (*Symphoricarpos albus*)	foliage	*Puccinia crandellii*	rust
	foliage	*Puccinia symphoricarpi*	rust
Red Huckleberry (*Vaccinium parvifolium*)	foliage	*Lophodermium cladophylum*	leaf spot
	stem	*Pucciniastrum goeppertianum*	witches broom
DISEASES OF TREES	**Plant part**	**Fungus**	**Type of damage**
Host	foliage	*Pucciniastrum sparsum*	rust
Arbutus (*Arbutus menziesii*)	foliage	*Coccomyces arbutifolius*	leaf spot
	foliage	*Coccomyces quadratus*	leaf spot
	foliage	*Diplodia maculata*	leaf spot
	branch/stem	*Fusicoccum arbuti*	canker
	stem	*Phellinus ferreus*	decay
	branch/stem	*Hymenochaete tabacina*	decay
Oregon ash (*Fraxinus latifolia*)	branch	*Cytospora* sp.	canker on twigs
Garry Oak (*Quercus garryana*)	foliage	*Taphrina caerulescens*	leaf blister
	roots/butt	*Armillaria gallica*	killing of roots, decay
	roots/butt	*Ganoderma* spp.	decay
	roots/butt	*Inonotus dryadeus*	decay
	stem	*Phellinus ferreus*	decay
	stem	*Hericium erinaceus*	decay
	stem	*Laetiporus gilbertsonii*	decay

Not all host-fungus records in the databases have been listed in Table 3.1. For shrubs and trees, host-fungus combinations that were recorded frequently or that are especially damaging are listed. For graminoids and forbs, the host-fungus combinations were the only ones recorded in the databases; they are included in the table to indicate the types of diseases that occur on these plant types.

Pathogens, Parasites, and Saprophytes

A pathogen is a biotic agent that causes disease. A parasite lives its whole life (obligate parasite) or part of its life cycle (facultative parasite) on living tissue, whereas a saprophyte lives on dead organic material. For example, in the Garry Oak ecosystem, rusts are obligate parasites on the foliage of several plants, *Armillaria gallica* is a facultative parasite on the roots of oak, and *Hymenochaete tabacina* is a saprophyte on decaying dead branches.

Detection, Diagnosis, and Assessment of Fungal Disease

DETECTION

Fungal diseases are recognized by the symptoms they cause in their hosts. Symptoms include declining amount of foliage, necrotic spots on leaves, cankers on stems, and decay in woody tissue.

DIAGNOSIS

Mycologists use symptoms and signs to determine the cause of a disease. The reproductive structures of fungi are used to identify the cause of the infestation; these vary from microscopic dots on leaves to mushrooms and large conks on the stem of trees. Knowing the cause helps determine the type and amount of damage that can be expected and the kind of remedial treatment that might be applied.

ASSESSMENT OF DAMAGE

The amount of damage caused by foliage pathogens can be estimated by determining the proportion of leaf area affected, and the proportion of leaves and plants affected. Damage to woody tissue by canker-causing fungi can be similarly estimated. Bole- and root-decaying fungi are difficult to detect unless there are external signs or symptoms. Fungal fruiting bodies

Figure 3.5 Whole tree failure of a 280-year-old Garry Oak caused by decay of its roots by *Armillaria gallica* and *Inonotus dryadeus*. Photo: Duncan Morrison

Figure 3.6 *Armillaria gallica* rhizomorphs on the surface of a Garry Oak root. The rhizomorphs are attached to the bark and are associated with small infections in the bark that will eventually coalesce into a large lesion. Photo: Duncan Morrison

Figure 3.7 A lesion at the soil line on a Garry Oak stem caused by *Armillaria gallica*. Wood behind the lesion was decayed by the fungus. The host has produced callus tissue at the margin of the lesion and a reaction zone (black line) in the wood adjacent to the *A. gallica* decay. Photo: Duncan Morrison

(mushrooms and conks) on the bole or at the soil line, and suspect characteristics, such as lesions and wounds, are indicators of internal decay in the bole or roots. The diameter and length of a decay column in the bole or the proportion of structural roots decayed can be determined with an increment borer or resistograph instrument. Removal of soil by hand or with an air spade by trained personnel permits examination of the major roots for lesions and signs of fungi, such as rhizomorphs or decay.

Diseases of Graminoids

The diseases recorded for the two graminoid species in the Pacific Forestry Centre database were caused by rusts and a mildew (Table 3.1). These fungi require specific environmental conditions for infection to occur. It is unlikely that these conditions will occur every year, so although plants may be stressed, it is unlikely that they will be killed.

Diseases of Forbs

Two smuts and a rust have been recorded on species of Liliaceae (Table 3.1). As with the grasses, the risk of mortality is low.

Diseases of Shrubs

Most of the diseases of important shrub species are caused by rusts and mildews (Table 3.1). The risk of mortality is low.

Diseases of Trees

A number of wood decay fungi have been reported on both Arbutus (*Arbutus menziesii*) and Garry Oak (Table 3.1). Several of these, especially *Armillaria gallica, Inonotus dryadeus* and *Ganoderma* spp. are responsible for whole tree failure (Figure 3.5) and *Laetiporus gilbertsonii* for

Figure 3.8 Mushroom of *Armillaria gallica* attached to the base of a Garry Oak tree. Photo: Duncan Morrison

failure of large branches. It is common to find more than one of these fungi in trees that have failed. Characteristics of the diseases they cause are described below. Fungi that cause brown rot decay preferentially remove cellulose and hemicellulose from wood, leaving a brittle matrix of modified lignin. In contrast, fungi that cause white rot decompose lignin and cellulose. Some of the diseases that cause significant disturbance to Garry Oak and Arbutus are described below.

DISEASES THAT CAUSE SIGNIFICANT DISTURBANCE TO GARRY OAK TREES

Armillaria root disease

Four species of *Armillaria* are known from the range of Garry Oak in southwestern B.C.: *A. ostoyae, A. sinapina, A. nabsnona*, and *A. gallica* (Morrison et al. 1985). All four species could occur in Garry Oak ecosystems, especially in moist ecosystem classification units. *Armillaria ostoyae* is a virulent primary pathogen, mainly of conifers. *Armillaria sinapina* and *A. nabsnona* are pathogens of low virulence that are usually found on stressed, woody angiosperms.

Armillaria gallica has a circumpolar distribution, and in southwestern B.C., *A. gallica* is associated primarily with broad-leaved tree species, including Bigleaf Maple (*Acer macrophyllum*), Garry

Figure 3.9 Sporophore of *Inonotus dryadeus* at the base of a Garry Oak stem. The current year sporophore is above that of the previous year. Photo: Conan Webb, Parks Canada

Figure 3.10 Sporophore of *Ganoderma* sp. at the soil line on a Garry Oak stem. Photo: Chris Paul

Figure 3.11. Sporophores of *Laetiporus gilbertsonii* on a Garry Oak stem. Photo: Dave Gilbert

Figure 3.12. Stem canker caused by *Fusicoccum arbuti* on arbutus. Photo: Brenda Callan, NRCan

Oak, Paper Birch (*Betula papyrifera*), Red Alder (*Alnus rubra*), and hawthorn (*Crataegus* spp.). This fungus is common in Garry Oak ecosystems, especially in moist ecosystem classification units, and is often associated with whole tree failure of oak. The fungus spreads from colonized wood through soil by root-like strands called rhizomorphs (Figure 3.6), or at contacts between a healthy root and colonized wood. The fungus invades, decays and kills bark tissue and root wood (Figure 3.7). Rhizomorphs spread the fungus throughout a root system, and over many years most structural roots can become decayed and can be killed. From mid-October to mid-November, diseased trees can be recognized by the presence of mushrooms at the base of the stem or on the ground around the tree (Figure 3.8).

Inonotus dryadeus

Inonotus dryadeus is found throughout much of North America, primarily on oaks and other hardwoods. This species causes a mottled white rot of the roots and root crown of both living and dead trees. Infections reportedly begin in the roots and spread into the root crown, but decay does not extend much above ground level. Fruiting bodies are annual, but old basidiocarps may persist for several years. They develop near the base of the trunk or from roots below the soil surface (Figure 3.9). Basidiocarps vary in size, but can be large, up to 50 cm wide. Fresh basidiocarps are yellowish to brownish above and may be covered with drops of amber liquid; hence, the common name "weeping conk". The lower surface is buff with fine circular to angular pores (4–6 per mm). Basidiocarps eventually become brown to black and cracked. Trees with *I. dryadeus* fruiting bodies have substantial amounts of root decay and an elevated risk of wind-throw (Swiecki and Bernhardt 2006). This fungus is implicated in whole tree failure of Garry Oak.

Ganoderma spp.

One or more species of *Ganoderma* cause decay of Garry Oak in southwestern B.C. Sporophores occur on the stem at or near the soil surface (Figure 3.10); there is often an old basal wound associated with fruit bodies. Extensive decay in the lower bole and roots of mature trees has resulted in whole tree failure. Work is needed on the taxonomy of the species on Garry Oak, their biology, and the hazard associated with the presence of conks on trees.

Laetiporus gilbertsonii (syn. *L. sulphureus*)

Laetiporus gilbertsonii causes brown cubical decay of *Quercus* spp., including Garry Oak, along the Pacific coast of the United States from California to Washington, and probably into southern B.C. Recently, molecular techniques and mating incompatibility were used to examine collections of *L. sulphureus sensu lato* from North America (Burdsall and Banik 2001). Based on those results, two new species were described from western North American collections: *L. conifericola* from conifers and *L. gilbertsonii* (Figure 3.11) from oak and eucalyptus. The fungus causes brown rot in stems and branches, having entered the tree through pruning wounds or broken branches.

The fungi that cause diseases are native components of the ecosystem.

DISEASES THAT CAUSE SIGNIFICANT DISTURBANCE TO ARBUTUS

Fusicoccum arbuti (syn. *Natrassia mangifera* and *Hendersonula toruloidea*) has a broad geographic and host range and causes stem canker (Figure 3.12), but in B.C. it has only been recorded on Arbutus (Hunt et al. 1992). Weakened or stressed trees, especially those near the ocean, appear to be susceptible to the disease. Infection of Arbutus bark by spores likely occurs through tissue damaged by winter injury, sunscald, or mechanical wounds. The first symptoms are areas of discoloured and killed bark, which become sunken, and later slough off. A perennial canker is formed with callus tissue surrounding the areas of dead bark. Small branches may be killed by girdling.

Cultural Practices and Remedial Measures

Should we consider modifying cultural practices or introducing remedial measures to reduce the effects of diseases on plants in Garry Oak ecosystems? The fungi that cause diseases are native components of the ecosystem, so for most of the diseases listed above, the answer is "no". Foliage diseases caused by rusts, smuts, and mildew have little or no long-term impact on the plants because foliage is deciduous, and incidence of disease varies from year to year. Similarly, saprophytes such as *Hymenochaete tabacina* and *Fuscoporia ferrea*, which decay stems and branches that are dead due to suppression (shading), are of little consequence.

In contrast, fungi that decay the wood of roots, stems, or large branches of Garry Oak rarely kill trees but can predispose branches, stems, or whole trees to failure. Usually, these fungi cause detectable disease and failure in trees older than 100 years, although younger trees can become diseased. Except for *A. gallica*, which can colonize and kill root tissue, most fungi require a wound through which their spores can colonize the wood. Wounds are created by pruning branches and mowing machines, and possibly by ground fires. For sites where protection of existing trees is desirable, managers should avoid creating wounds (wound dressings do not prevent colonization by decay fungi). Diseased trees should be monitored, hazardous ones should be removed, and new trees should be planted if required.

3.3.5 Climate Change and Garry Oak Ecosystems

Ecological restoration must address the effects of climate change. Broadly speaking, we can expect changes in weather patterns, including more extreme climatic events, higher temperatures, and changes in precipitation patterns, along with increases in sea level (Harris et al. 2006).

Restoration practitioners need to consider how species ranges may shift under climate change, what new plant communities may form given the unprecedented changes, and how genetic variability should be incorporated into restoration design.

Given the current fragmented and degraded state of most Garry Oak ecosystems, we need to be aware of the potential for climate change to impact these ecosystems over time.

In the context of Garry Oak ecosystems and their restoration, climate change could be seen as a mixed blessing. On one hand, an ecosystem that is generally favoured by warmer and drier conditions than today would seem to be favoured by predicted changed conditions (many of the Garry Oak and associated ecosystems described in this publication may be favoured by warmer and drier conditions). On the other hand, rapid and dramatic climatic change is intensely disruptive to established ecosystems and will most likely result in extirpation (or extinction) of some species. In addition, atmospheric CO_2 concentrations may have a role in maintaining savannah systems. This may be contributing to in-growth of woody vegetation in savannah openings and can be expected to increase with ongoing climate change (Bond and Midgley 2000).

Looking to the Future—Clues from the Past

Historical conditions should not be regarded as a blueprint for our restoration designs, but rather as a reference or guide to be used to help us set restoration goals or targets (see Section 8.2). Our understanding of historical conditions also highlights the importance of restoring Garry Oak ecosystems in Canada. Two lines of evidence strongly suggest that Garry Oak and associated ecosystems, in general, are likely to expand their range in Canada as the climate warms. Studies of fossil pollen from a Saanich Inlet core (Pellatt et al. 2001) reveal that dry meadow ecosystems in the area (with *Camas* spp. as an element) were much more widespread than today under warm, dry climates about 8000 years ago. Once Garry Oaks arrived in our region 8000-7000 ybp, they became widespread and abundant along the southeast side of Vancouver Island. For example, extensive stands likely occurred in the Cowichan Valley at that time. They seem to have become particularly common about 6000 years ago as the climate remained warm but moisture increased. Cooling and moistening climate reduced the range of the species and associated ecosystems after 4000 ybp, despite the use of burning practices by First Nations peoples (Brown and Hebda 2002).

Restoration efforts must consider the effects of climate change on ecosystem dynamics, and we must consider how our restoration sites fit into the broader regional landscape.

It is notable that some species that are exceedingly uncommon today in our region, such as Oregon Ash (*Fraxinus latifolia*), were much more common under the warmer climates of the past. This suggests that even rare species may have a more positive future as climatic conditions change, provided that they can survive in the region until the climate becomes more favourable to them. Keeping species at risk from extinction in the meantime will be a challenge because ecosystem changes due to climate change can be rapid and catastrophic, allowing little opportunity for migration and dispersal (Hebda 2004). Given the current fragmented and degraded state of most Garry Oak ecosystems, we need to be aware of the potential for climate change to impact these ecosystems over time.

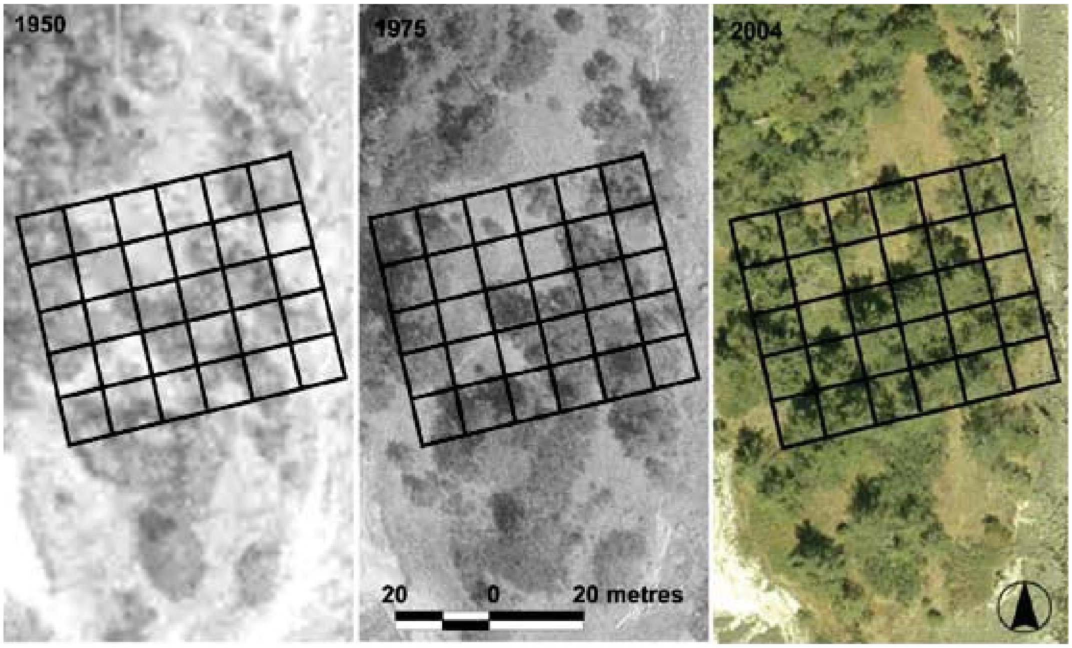

Figure 3.13 Using air photos to understand change in recent history. This series of images show a study plot (60x50 m) superimposed on air photos from 1950, 1975, and 2004 to show change in tree cover over time. Image: Shyanne Smith

Climate models that project the future extent of suitable climate for a species provide a strong second line of evidence that Garry Oaks and their associated species will have an opportunity to expand their range markedly. It has generally been accepted that the range of Garry Oak and associated ecosystems will begin expanding in B.C. under a warmer climate. However, recent bioclimatic modelling, based on a spatial model of climatic suitability for Garry Oak ecosystems and forecasted distribution of climate regions based on global climate models, indicates suitability for the current Garry Oak range will actually decrease in the near future (Bodtker et al. 2009). However, this modelling also indicates that the climate suitability will improve again later in the century. These results reinforce the need for active restoration and management of Garry Oak and associated ecosystems, and the need to take an experimental, adaptive management approach to restoration. Restoration efforts must consider the effects of climate change on ecosystem dynamics, and we must consider how our restoration sites fit into the broader regional landscape. By integrating model results with our understanding of past and current ecosystems, we can assess possible climate change impacts on, and adaptations of, species within Garry Oak and associated ecosystems, and prepare for change.

Collecting site-specific reference information is an important first step in restoration because it helps to define restoration goals and allows restoration efforts to be effectively evaluated.

Figure 3.14 Tree ring cores can be used to assess disturbance and changed conditions at a site over the life of the tree. Cores can be taken with an increment borer, mounted, sanded, and viewed with a microscope. Software that measures each annual tree ring is useful for accurately recording small variations in growth and creating site chronologies. Photo: Shyanne Smith

3.4 Summary of Restoration Considerations

3.4.1 Understanding Site History

Collecting site-specific reference information is an important first step in restoration because it helps to define restoration goals and allows restoration efforts to be effectively evaluated (see Chapter 7: Ecological Inventory and Monitoring). From a practical perspective, an understanding of the historical reference state can result in a restoration that is more likely to be self-sustaining and therefore easier and less costly to maintain (White and Walker 1997). Reference information includes not only baseline current conditions (climate, topography, soil, vegetative composition, and successional trends) but also any available historical data, ranging from historical accounts and photos (Figure 3.13) to legacies remaining on the landscape, such as woody debris and dendrochronological (tree ring) records (White and Walker 1997) and pollen profiles of soils (McDadi and Hebda 2008).

Understanding the ecological history of a site is important to its management and restoration, particularly when little is known about the historical stand structure, typical regeneration patterns, importance of environmental controls, and historical fire regimes. Given the widespread changes to vegetation and disturbance regimes in North American open-land habitats, it is unlikely that many present species assemblages closely resemble those that occurred prior to European settlement (Motzkin and Foster 2002). Using available methods of understanding site history (such as soil cores, tree ring study, weather instrument and historical accounts, photographs, long-term ecological monitoring, air photos, and even packrat middens), historical conditions can be reconstructed and used to provide context to inform management and restoration (Figure 3.13 and 3.14) (Swetnam et al. 1999; Kettle et al. 2000).

RESTORATION DESIGN TIPS

- Consider what impacts your restoration activities might have on the four fundamental processes governing ecosystems: water cycling, nutrient cycling, energy flow, and succession.

- What is the goal of your restoration? Are you restoring for a specific purpose such as for native annual forbs, or for grassland birds? What does current research suggest? For example, soil disturbance has been found to benefit several native annuals but not native perennials. Weigh the costs and benefits of restoration activities and identify specific objectives (see Chapter 5).

- Check into research already done (ask GOERT) and look for clues about your site's history in historical photos, writings or maps, old air photos, or tree rings. Look for cohorts (many trees of similar age), stumps indicating logging, fire scars on trees, or charcoal in the soil. Determine when any cohorts established, and when any logging, fire or other disturbance occurred.

- Check for environmental controls (filters): are shallow or extremely wet soils or exposure to wind or salt maintaining open prairie or savannah conditions? (See also Section 8.3.)

- Consider the three potential problems with re-introducing disturbances: the need to understand historical dynamics, that disturbances will not likely have the same results today as historically, and the high costs and risks of introducing disturbance into the modern landscape.

- Consider the effect of your timing of disturbance activities, as well as the effects on native and invasive plants and animals, and on plant communities.

- Assess deer abundance: is there an evident browse line (trees and shrubs heavily "pruned" within reach of deer)? Deer prefer native forbs over alien grasses—controlling herbivores will increase success toward achieving most restoration goals. Are there other herbivores to be considered?

- Assess plant diseases that may be present at your site. Is there a need to alter your restoration activities because of disease?

- Consider the effects climate change may be having on your site. How might climate affect your site in the next 50 years? 100 years?

- Assess the importance of your site in a regional context. How does it connect to other nearby sites? Are there important services it provides to these other sites? How does your restoration affect this?

3.4.2 Garry Oak Ecosystems Stand Dynamics and Disturbances

Communities constantly change: organisms die and are replaced by others; energy, water, and nutrients pass through ecosystems; and natural succession is always at work. Many of these changes are gradual so it appears that there is little change in community form and function. Other changes establish new conditions, and plant communities may thereby change in significant ways (e.g., succession, invasive species, and disease outbreaks). For instance, shrubs and trees may enter into meadow ecosystems and eventually give rise to thickets or forests. These changes may be limited by environmental factors. For example, wind and salt spray limit the growth of shrubs and trees on many maritime meadows close to the ocean, while shallow soils are so prone to drought that woody species grow poorly. Ecosystem disturbances, such as fires and windstorms, may reverse or stall succession. Many areas of Garry Oak woodland and associated meadows were maintained over long periods by fires that were deliberately used by First Nations to maintain good conditions for growing camas (an important food source) and hunting game. As other peoples settled in the area, fires were suppressed and fire-sensitive trees, shrubs, and herbaceous plants gradually invaded many meadow and woodland areas. The introduction of many alien invasive species into the region means that fire alone is likely to favour dominance by alien invasive plant communities rather than cause a return to the ecosystems that were maintained in the past by First Nations. See Case Study 1 in Chapter 5 for an example of restoration considerations for a site with unusual ecosystem processes.

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