Tree Growth and Foliar Growth and Nutrition Responses to Drought in three North Saanich Parks: potential implications of climate change[1]

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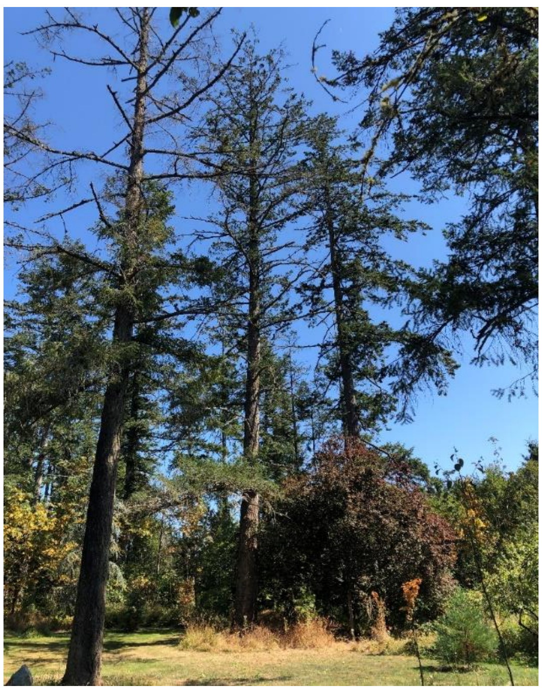

1/ Report prepared for Friends of North Saanich Parks – based on proposal *North Saanich forest soil properties and foliar analyses for several CDFmm vegetation associations and potential stand response to prolonged drought*

Summary

Park users and community stewards have noted a decline in the vigor of mature native trees in some North Saanich parks. Drought is suspected as a cause; hence, there are concerns about the future of these trees and associated ecosystems as climate change progresses.

The objectives of this study were to assess (1) whether drought was affecting the vigor of mature Douglas-fir (*Pseudotsuga menziesii*) in three North Saanich parks and (2) the contributing role of nitrogen (N) deficiency. Douglas-fir is the dominant native tree in the region and the parks studied were felt to be particularly susceptible to drought. Following discussion with the Friends of North Saanich Parks (FNSP), the objectives and data collection were modified from the original FNSP proposal. In the report I first present contextual information on (a) physiography and forest vegetation of North Saanich and the broader region (b) connections between drought and physiological and growth responses of trees to moisture stress and (c) potential effects of climate change on summer drought and then present data collected on crown condition and foliar growth and nutrition in the context of weather data and soils data presented in the companion soils reports (Bonsdorf and Hope 2022; Hope and Bonsdorf 2022).

Key take-home messages:

- Drought stress is difficult to conclusively identify as a cause of tree decline and ideally, requires a variety of measurements of the tree over time. Effects of drought on the tree may be direct (prolonged stomatal closure to failure of water transport to leaves) or indirect (via increased susceptibility to damaging insects and pathogens, induced nutrient deficiencies, etc.). Drought stress, from the tree perspective, is dependent on the amount and continuity of moisture supply (precipitation, subsurface water movement, and soil storage capacity, including depth of rooting zone), moisture demand (temperature, vapor pressure deficit, canopy leaf area) and the ability of the tree to take up and transport water to foliage. Crown assessments repeated over time, analyses of changes in stemwood annual rings, and analyses of foliage, combined with meteorological and timely soil moisture data, can provide different lines of evidence pointing toward drought as a proximate or ultimate cause of tree decline. However, none, by themselves, provide specific proof of drought stress and a connection to tree decline and mortality.

- Weather data collected at Victoria International Airport suggest that growing seasons since 2010 have become warmer and drier compared to the most recent 30-year normal (1981-2010), consistent with longer-term predictions from climate models.

- Soil moisture contents determined in late August 2022 were low in all three parks and may indicate mature Douglas-fir were subject to a soil moisture deficit during the long precipitation-free period of summer 2022. Soil moisture deficits may have been exacerbated in Denham Till which appeared to have a much shallower rooting zone and, potentially, a reduced moisture availability to trees. It is unclear how the low soil moisture contents compare with previous growing seasons (with varied temperature and precipitation). Although soil moisture contents may have approached or been lower than the “permanent wilting point”, it is unclear how they affected tree physiological processes associated with moisture stress. To better understand how drought affects growth of Douglas-fir in North Saanich parks, it would be useful to better document relationships among temperature, precipitation and soil moisture contents over time and integrate those through appropriate growth models such as 3PG.

- Based on visual estimates of crown density, mature Douglas-fir appeared to be declining in Denham Till relative to trees assessed in Gulf View and Nymph Point. However, needle and shoot characteristics were not necessarily consistent with site differences in crown density. For example, shoot elongation was greater in 2021 than in 2022 in all sites and analyses of current-year foliage collected in late summer-fall suggested that trees in all three sites were deficient in N and, possibly, S (sulfur). Lower soil N concentrations at Denham Till were not necessarily associated with lower foliar N concentrations. It is unknown how crown condition has changed over time, how crown condition metrics relate to drought stress and mortality in Douglas-fir, and how it compares with Douglas-fir elsewhere. These relationships should be investigated further.

- Drought may make mature trees more susceptible to disease and insect infestation, leading to tree decline and, potentially, death. *Armillaria* infection was suspected as a possible cause of tree decline at Denham Till, Conclusive evidence was not found. However, continued monitoring for insect and pathogen infestations should be considered.

- Measurements of annual ring widths would provide insight into long-term tree growth responses to past weather conditions and site histories. Cores from only two trees at each of two parks were available to inspect and initial measurements were inconclusive. Analysis of a broader sample of cores within and across parks could provide valuable insight into how tree condition is changing over time. Increment coring is broadly accepted as not impacting tree health.

- This study considered possible effects of drought stress on mature Douglas-fir at only three parks. It would be very useful to have a broader landscape-level assessment of tree condition across North Saanich parks and the District in general. Such an assessment might be possible by combining canopy cover and LIDAR assessments (such as those sponsored by the Capital Regional District) with other District-wide landscape data.

- Climate change is likely to result in hotter droughts and to contribute to growth reductions and increased mortality of mature native tree species, and their associated ecosystems, in North Saanich parks and, more broadly, across the District. Appropriate assessments and monitoring of tree and ecosystem health are needed to develop appropriate land management actions.

Introduction

North Saanich contains 29 designated parks (District of North Saanich 2015). An important reason for parks is to protect natural features, including environmentally sensitive areas and mature native trees and forest (District of North Saanich 2007, 2015). Mature trees are important ecologically, provide aesthetic value, and contribute to public enjoyment and wellness. Ensuring their health helps maintain desired ecological processes and benefits for park users.

In recent years, park users and community stewards have noted a decline in the vigor of mature native trees in several North Saanich parks. Tree decline can have a variety of causes (Harris et al. 2004). Here, decline was suspected to result from drought.

The objective of this study, requested by the Friends of North Saanich Parks (FNSP), was to assess whether drought was affecting the vigor of mature Douglas-fir (*Pseudotsuga menziesii*) in three North Saanich parks and to assess a possible accompanying role of N deficiency. The three parks were felt to represent drier conditions (among North Saanich parks) and, hence, be more prone to drought / moisture stress. The working hypotheses in the original proposal were that moisture stress (1) was related to tree canopy decline in parks in association with (2) reduced soil N availability and foliar N concentrations. Subsequent discussion with FNSP resulted in adjustments to the planned tree assessments and foliar nutritional analyses, the latter to include mineral nutrients other than N and S. The focus of this report is crown condition and foliar nutrition of mature Douglas-fir in the context of recent climate and soils data provided in concurrent studies (Bonsdorf and Hope 2022; Hope and Bonsdorf 2022). To that end, I discuss the regional biophysical setting and native tree occurrence, potential effects of climate change-related drought on growth and nutrition of native trees with emphasis on coastal Douglas-fir, and specific findings from the three studied parks.

Biophysical setting- climate, soils, and dominant tree species

North Saanich and much of low-elevation southeastern Vancouver Island is in the moist maritime Coastal Douglas-fir (CDFmm) subzone of British Columbia's biogeoclimatic ecosystem classification (BEC) system (Green and Klinka 1994). The climate is cool Mediterranean; winters are mild and moist and summers are warm and dry with pronounced soil moisture deficits. Winter precipitation is lessened by the rain shadow influence of the Vancouver Island and Olympic Mountains.

North Saanich and the Saanich Peninsula lie in the Nanaimo Lowland of the Georgia Depression and the topography is undulating and moderately hilly. Elevations in North Saanich ranging from sea level to 157 m asl (Cloake Hill). The topography and surficial deposits result from glaciation and from fluvial, marine, and organic material deposition (Jungen 1985). Textures in surficial deposits range from coarse (e.g., bouldery glacial till in morainal deposits; sandy-sandy gravel in fluvioglacial deposits) to finer textures associated with contemporary streams (gravelly sand to sandy silt), marine deposits (stony sand to clay) and organic deposits.

The chemical and physical characteristics of soils which form over surficial deposits vary with texture of parent materials, organic matter inputs, topography, and types and extent of soil disturbance. Resulting soil characteristics, in turn, affect moisture and nutrient availability to vegetation. Human-caused soil disturbance includes clearing and tilling for agriculture and soil removal or deposition of fill associated with construction. Unless mitigated, these disturbances can deplete soil organic matter, compact soils, and alter soil horizons, further affecting moisture and nutrient availability to vegetation and impacting tree growth and condition.

In the CDFmm, coastal Douglas-fir is relatively common on all site types except the wettest and driest. It is the dominant late-successional species on “zonal” sites, those characterized by soils which are moderately deep to deep, well-drained, and intermediate in soil moisture and nutrient availability (Green and Klinka 1994). Characteristics of Douglas-fir that contribute to its dominance include the ability to photosynthesize and accumulate carbon during mild winter weather, to tolerate and recover from moderate summer drought over a range of sites (Waring and Franklin 1979), and a strong growth response to increased sunlight and nutrient and growing-season moisture availability over normal ranges (Hermann and Lavender 1990; Nigh 2006). Douglas-fir is moderately tolerant of summer drought, but its growth is still typically limited by available growing-season moisture (Coops et al 2007). Other native tree species such as Garry oak (*Quercus garryana*), arbutus (*Arbutus menziesii*), bigleaf maple, (*Acer macrophyllum*), western red cedar (*Thuja plicata*), and black cottonwood (*Populus balsamifera* ssp. *trichocarpa*) may be important locally in the CDFmm depending on site characteristics (e.g., moisture and nutrient availability); type, frequency and magnitude of stand disturbance; availability of propagules; and biotic influences such as competition, plant pathogens, and herbivory by insects and browsing mammals.

Potential effects of climate change on native tree productivity, health, and distribution

Over the next several decades, and compared to recent climate normals, climate change In southwestern British Columbia and the US Pacific Northwest is predicted to increase the amounts and intensities of fall, winter, and spring precipitation with less precipitation falling as snow. Growing seasons will likely be longer; summers will be hotter and drier with higher daily maximum and minimum temperatures, greater vapor pressure deficits, and longer growing-season dry spells (Spittlehouse 2008; Restaino et al 2016; Capital Regional District 2017), so-called “hotter drought” (Allen et al. 2015). Recent local climatic data suggest this is occurring (Figure 1).

Although many native trees of the region are adapted to some summer drought, hotter droughts associated with climate change threaten tree health and survival on some sites. Over the long-term, plant growth and survival require carbon uptake through photosynthesis to exceed that lost through respiration associated with plant growth and maintenance. At the same time, carbon uptake is accompanied by water loss (transpiration) through open stomata. This water loss is a necessary tradeoff with carbon uptake. Drought stress results when plant water losses exceed soil water supply, uptake, and transport to foliage. Depending on the imbalance, damage can be slow and moderate or relatively rapid and severe. Hotter droughts: (1) decrease water supply by reducing precipitation inputs and increasing evaporation from soil and (2) increase demand by increasing transpiration rates from foliage. To survive, plants must maintain sufficient carbon uptake while minimizing moisture losses and maintaining an appropriate balance between water loss and water supply. Trees and other vascular plants can, to a point, compensate for imbalances between water supply and demand by closing stomata at appropriate times (a quick response) and, over the longer-term, by increasing growth of roots (increasing water supply) and by decreasing biomass allocation to branches and leaves (reducing whole-plant water loss). Those adjustments may reduce the potential for water stress, but also may reduce the potential growth of the tree and its ability to accumulate carbon reserves used to support future growth and defense against damaging pests. A severe restriction of water supply from soil relative to water loss from leaves may cause water columns between roots and leaves to cavitate, preventing necessary water flow to leaves, causing lethal dehydration of tissues, and damaging or killing the tree (Broadribb et al. 2019). Tree species differ in their ability to cope with drought.

The effects of higher temperatures and reduced precipitation on water availability (supply) are mediated by site factors, including slope position and aspect, groundwater inputs, soil (rooting) depth, soil texture and rockiness, and organic matter contents (Saxton and Rawls 2006; Anderegg et al 2013). Effects of drought may be exacerbated on a given site if soils are degraded (Hilbert et al. 2019). Drought associated with climate change is predicted to threaten the health and ability of Douglas-fir to tolerate hotter droughts on Vancouver Island (Hamman and Wang 2006; Klassen 2012) especially on marginal sites such as upslope sites with rocky or porous soils (BC Ministry of Forests 2001; Burleigh et al. 2014). There, the amount of spring precipitation may be increasingly important in maintaining Douglas-fir (Coops et al 2010).

Drought effects on tree growth are multi-faceted and vary over time (Table 1; Figure 2) and mortality is difficult to ascribe directly to drought (Trugman 2021). Conclusively identifying drought as a primary cause of tree decline is problematic without timely and specific measurements of water transport and loss from the tree because visible symptoms associated with crown decline (discoloration and loss of foliage, reduced shoot and needle elongation, branch and top death) may have other, albeit related, causes. Drought may reduce the availability and uptake of some essential mineral nutrients; combinations of drought stress, nutrient deficiencies, and warmer spring temperatures may accelerate the spread of pathogens such as *Armillaria* (Kubiak et al. 2017; Teshome et al. 2020) and insect herbivores which contribute to crown decline and, possibly, mortality. Furthermore, drought-related damage to tree crowns may not be apparent until the year following drought (BCMOF 2001). Nonetheless, assessments of crown and foliar condition, combined with estimates of soil moisture availability and compared with appropriate data in the scientific literature, can suggest whether drought is contributing to crown decline and whether more detailed measurements and appropriate tree and site maintenance are warranted. Because the amount of leaf area is strongly related to diameter growth in trees, measurements of annual ring widths from increment cores may also infer how long the tree has been in decline and whether decreased increment is associated with weather patterns or site disturbance. From the perspective of natural areas management, it is worth remembering that tree mortality and changes-to soil moisture and nutrient availability, whether due to climate change or site disturbance, may also change characteristics of other vegetation and associated ecosystems on some sites (Klassen 2012; Allen et al. 2015).

Dieback and mortality of Douglas-fir, attributed to growing-season drought, was reported from western Washington and Oregon as early as 2012 (WSU Forestry Extension 2018; OSU Coop Extension 2018) and premature death of foliage has also been noted on Douglas-fir growing on drier sites on southern Vancouver Island (Gilchrist 2022). Climate change modeling, the predisposition of many forest sites to moisture stress on southern Vancouver Island, and current observations of warm dry growing seasons and crown decline on Douglas-fir suggest that drought stress is currently affecting Douglas-fir in North Saanich parks and is likely to have increasing impacts in future years.

Potential implications of warmer and drier growing seasons on North Saanich parks include:

1. direct and indirect effects on tree growth and survival that vary with site and species
2. changes to site conditions that may be exacerbated or mitigated by soil disturbance and quality
3. damage to or disappearance of ecosystems which a park is intended to protect.

Possible implications for park management include changes to monitoring and management of existing trees, site management to improve the soil moisture regimes for existing mature trees, and ongoing reforestation with more climate and site-appropriate species. If climate change disrupts protects key ecosystems and disconnects them from their current park locations, there may be a need to designate new parks to protect those ecosystems.

Questions

1. Do Douglas-fir trees in selected North Saanich parks appear stressed as evidenced by crown condition, shoot and needle mass and nutrition, and diameter increment?
2. Does stress appear related to recent climatic conditions and/or soil characteristics?

Methods

Budget and time constraints, combined with increases in the chemical analyses required, limited the types of measurements possible and restricted detailed measurements of shoot and foliar characteristics to one or few branch samples from each of two trees on three sites in a single year. In addition, soil samples were from one location per park and varied in distance from sample trees. This greatly restricts what can be inferred about drought, nutrition, and condition of mature Douglas-fir in these (and other) North Saanich parks. However, the data can provide a starting point for increased monitoring of tree condition and growth and possible changes to soil and tree management.

Sites

Tree condition in relation to soil characteristics was examined in three parks (Denham Till, Gulf View, and Nymph Point; occasionally referred to DT, GV and NP, respectively) dominated by Douglas-fir. These parks were thought to be at the drier end of a soil moisture gradient across North Saanich parks and, hence, prone to drought stress. Overstory and understory vegetation was described previously (Adams 2021; Williams 2021).

Soil descriptions

Methods for soil description and interpretation and for soil carbon (C), nitrogen (N) and water content measurements and associated findings are described in the concurrent soil studies (Bonsdorf and Hope 2022; Hope and Bonsdorf 2022). In this report, I include data from those reports which seem most pertinent to assessing soil moisture and nutrient availability.

Tree characterization

Tree characterization consisted of crown and foliage assessments on dominant or co-dominant Douglas-firs thought to be representative of trees in each park. Crowns of five trees were assessed in each site. Assessments required the crowns to be visible in their entirety from the ground and accessible for collecting foliar samples; trees sampled may therefore have not been less representative of the broader stand.

Crown condition assessments included visual estimates of live crown ratio, crown dieback, and crown density (USDA FIA 2011; Table 2). Due to time constraints and greater subjectivity of measurements (e.g., Table 2), crown transparency was not estimated and included in this report. Crown condition was assessed in late August 2022 in the field and trees were photographed to allow reassessments of crown density and possibly, estimates of transparency, if required. Increment cores from four of the trees (NP43, NP50, GV62 and GV63), collected in 2021, were made available by the Friends of North Saanich Parks for inspection and possible measurements. No cores were available for the Denham Till trees (DT 93, DT206).

The USDA FIA crown assessment methodology uses metrics that provide different insights into crown health and possible stressors, potentially allow comparison against a large range-wide database for Douglas-fir and have been evaluated as predictors of tree mortality for some species (e.g., Morin et al 2012). However, the crown metrics are semi-qualitative, require judgement as to the “normal” crown outline of a healthy mature tree of the studied species and do not specifically indicate drought stress.

To provide further recent information on crown condition, shoot elongation in the current (2022) and previous (2021) year was measured; foliar characteristics examined included length and color of freshly-collected needles and needle mass and concentrations of macro- and micronutrients of oven-dried needles. Shoot elongation, needle color, and needle lengths and masses can indicate if, but not necessarily why, the tree is stressed; analyses of foliar nutrient concentrations and contents can indicate which, if any, mineral nutrients are deficient in the tree. Foliar nutrition assessments are generally considered to be a more reliable measure of tree nutritional status than are indices of soil nutrient availability (Mead 1984; Weetman 1990) but also have limitations (Mead 1984; Brown 1999; Brown 2004). Current-year needles collected after the growing season are recommended for diagnosis of nutrient deficiencies in temperate zone conifers because they tend to be less variable at that time and may be better correlated with tree growth (e.g., Mead 1984).

Foliage was sampled in two (of the five trees assessed for crown condition) twice in 2022, once in early-mid May and again in early September (Gulf View and Denham Till) or mid-October (Nymph Point). The May sampling was complicated by the cool wet spring; terminal buds containing the current-year needles had not flushed at the time of collection in four of six trees and were shoots and needles were just beginning to elongate in the other two (Gulf View 62 and Nymph Point 43). A first-order branch was collected from an exposed portion of the upper half to third of the crown and the terminal and first-order lateral shoots from that main branch were excised. Needles originating in the current-year (2022) and previous-year (2021) were then removed and the lengths of corresponding shoots measured. Needle lengths were measured on fresh foliage and color was assessed using Munsell color charts for plant tissues under broad spectrum white LED light. Needles were then oven-dried at 65C for a minimum of 48 hours and average needle mass determined on samples of ca. 100-200 needles. Needle lengths, needle masses and needle colors were determined only on Y1 (2021) needles collected in May 2022, as buds containing 2022 needles had not consistently flushed at the time of sampling. Needle lengths, colors, and dry masses were determined on both the 2021 (previous-year) and 2022 (current-year) cohorts in the late summer- fall 2022 samples.

Oven-dried needles from both cohorts of needles and at both sampling dates were ground and analyzed for N, C, and S concentrations by the BC Ministry of Environment Analytical Lab. Current-year needles sampled in late summer-early fall were also analyzed for other macro- (P, K, Ca, and Mg) and micronutrients (Fe, B, Cu, Mn, Zn).

Results and Discussion

Air temperature and precipitation

Figure 1a shows the difference of monthly mean air temperature maxima (Tmax) and minima (Tmin) from May through August in each year from 2011-2022 with the corresponding norms from the 1981-2010. Both the average Tmax and Tmin over the May-August period have tended to be warmer than the 1981-2010 norms in all years since 2012. Presumably, the higher temperatures are associated with greater vapor pressure deficits, a primary driving force of evaporation from soil and of transpiration from foliage (Restaino et al. 2016). Figure 1b indicates growing season precipitation was > 10% less than the 1981-2010 norms in either 6 or 8 years (depending on the growing season duration chosen) beginning in 2011, with the driest growing seasons in 2015, 2016, and 2021. Although the 2022 was very dry from July into October, the April or May through July precipitation was substantially greater than the 1981-2010 norm. This shift in precipitation is consistent with decreases in soil moisture contents from May to August at all three parks (Table 3).

Soil

Soil characteristics particularly pertinent to soil moisture availability include soil texture, coarse fragment and organic matter content, and soil depth, as indicated by horizon characteristics and presence of roots (Table 3a). A noticeable difference at the Denham Till soil pit, compared to those at Gulf View and Nymph Point, was the shallow rooting zone combined with gleying, suggesting high water tables in winter and perhaps an increased predisposition to drought in summer. All sites were characterized by a thin LFH layer and Ah horizons of similar thickness; however soil carbon (C) (and soil N) concentrations in the Ah horizon were lower at Denham Till. Soil volumetric moisture contents (ϴ) in the A and B horizons of each site decreased in August to levels typically associated with the permanent wilting point (ca. -1.5MPa) (Table 3b; Hope and Bonsdorf 2022). What those soil moisture contents mean for physiology and growth of mature Douglas-fir on these sites is not clear. Cavitation (disruption of the water column leading to tissue death) in Douglas-fir occurs when shoot water potential is much more negative (i.e., the soil is drier) than that of the permanent wilting point (e.g., Bond and Kavanagh 1999; Andrews et al. 2012), but stomata tend to close at higher soil moisture contents (Bond and Kavanagh 1999). This is thought to be a way for evergreen conifers to protect against cavitation and premature tissue death. Given the dead larger branches at trees examined in Denham Till, it is possible that cavitation has occurred, but it is unclear in what years. Likely, the soil moisture contents measured in 2022 were sufficient to increase the amount of time stomata were closed and to reduce carbon uptake compared with moister growing seasons.

Crown condition

Assessed trees were of similar stem diameter and stand position (dominants or co-dominants and adjacent to open areas. Little dieback, as defined in FIA protocols, was observed (Table 4). Live crown ratios were greater in Gulf View, intermediate at Denham Till, and least at Nymph Point. The latter may have been due to past pruning of lower branches on those trees adjacent to the marina parking lot and buildings. Crown density was much lower at Denham Till (Table 4; Figure 3); approximately half of that at Gulf View and Nymph Point (31 versus 61 and 62%). The data suggest considerable foliage loss in Denham Till Douglas-firs over recent years. How the crown densities observed here compare with crown densities on different sites elsewhere in the range of coastal Douglas-fir is unclear but may be possible to determine from online USDA FIA data. Across the range of coastal Douglas-fir in the US, median crown density was mean crown density was 49.5% (Randolph et al. 2010); but was 38% in 2010 and had decreased over time (Randolph 2015). It may be worthwhile to examine crown characteristics of mature trees in more detail over time in North Saanich parks and compare the data with range-wide data for those species.

Shoot elongation, needle growth, and needle color

Shoot lengths were consistently longer in 2021 than in 2022 in all 3 sites. In contrast, needle lengths did not consistently differ between cohorts (Table 5). Needle mass appeared greater in year 1 than in either current-year (year 0) or year 2 needles in the Gulf View and Nymph Point trees. Late summer needle color was similar across sites for the current-year (2022) cohort but needles were more yellowish in the

Y1 (2021) cohort in the Denham Till trees than at Gulf View and Nymph Point (Table 5). The yellowish color of Y1 needles was not associated with decreased foliar N concentrations (Table 6).

Foliar elemental concentrations

In current-year needles collected at the end of the growing season, foliar N and S concentrations appeared to be deficient in all three sites (Table 6). Lower soil N concentrations at Denham Till were not necessarily associated with lower foliar concentrations of N (Table 3). Soil and foliar concentrations of N in Douglas-fir may be correlated (e.g., Slesak et al. 2011) or not (Du et al. 2018) and drought may not reduce the availability (and uptake) of soil mineral N (Hornyak et al. 2017). The concentration of K may have been deficient in tree GV63 at Gulf View. Concentrations of other elements appeared sufficient. It was somewhat surprising that end-of-season foliar N and S concentrations were lower in current-year needles than in the Y1 cohort (Table 6); concentrations of mobile nutrients such as N and S often decrease with needle age as they are mobilized and translocated to adjacent newer tissue (Mead 1984).

Needles collected in May were analyzed only for N and S and current-year needles were only beginning to expand. Foliar concentrations of N and S were greater in current-year needles in May than in September, probably reflecting dilution as needles expanded and biomass increased (e.g., Chapin and Kedrowski 1983).

General Discussion and Conclusions

Recent weather data suggest that the growing season climates in Greater Victoria are getting warmer and drier, a trend predicted to occur with climate change. Mature Douglas-fir trees in and around North Saanich parks appear to be in decline. Hotter droughts associated with climate change may be an underlying cause of decline. The general objectives of this study were to assess the possibility that drought was associated with observed decline of mature Douglas-fir in certain North Saanich parks and to assess possible associations among atmospheric and edaphic drought, soil N availability, foliar nutrition, and tree growth.

The time, budget, and techniques available for the study greatly limit what can be said conclusively about the relations of drought, tree nutrition, and tree growth and condition, future soil and tree conditions under climate change, and ultimately, proactive management approaches to the parks. The data collected here and in associated soils and ecosystem characterization studies provide a good starting point for a more robust and formalized monitoring program of mature trees and associated ecosystems in the parks, perhaps utilizing community science approaches where appropriate.

The limited data collected in this study suggest that some mature Douglas-fir, especially in Denham Till, are, and have been, severely stressed, as indicated by the presence of snags, large dead branches, and low crown density. The crown density assessments come with considerable uncertainty as they are semi-quantitative, not specific to certain stressors, and one-time measurements cannot show how decline has progressed over time. It is unclear at this point how the data compare with coastal Douglas-fir on similar sites elsewhere in its range, but USDA FIA databases are publicly accessible and contain such information. Crown assessments are worth refining, should be applied to a greater number of trees in and around the parks and then related more closely to localized soil conditions. Such standardized condition assessments, repeated over time, could provide a useful record of tree changes over time for the municipality and aid in planning and management; the community could be involved with data collection following appropriate training in the procedure. FIA crown assessment data have been related to subsequent mortality in some tree species but (apparently) not for coastal Douglas-fir. That information may exist and would be useful information for parks staff when planning and implementing appropriate management activities to protect mature native trees.

With respect to the time course of stress and canopy decline, it would be useful to assess diameter growth from increment cores in relation to weather data and any known on-site conditions. Preliminary measurements were made on cores from NP43, NP50, GV62, and GV63 (Appendix 1) but are not conclusive. Cores were collected in 2021 and therefore did not include the period during which soil moisture data were collected. The available cores are from two trees only on two of the three sites and don’t include the site with trees exhibiting clear decline (Denham Till). It would be worthwhile in future work to collect cores from additional trees in each site (and perhaps other parks) and attempt to relate ring widths to weather, longer-term soil moisture data, and perhaps, other aspects of site history.

Historical temperature and precipitation data from the nearby Victoria International Airport, combined with 2022 measurements of soil moisture content in the single soil pits at the three parks, suggest that drought could be contributing to decreased growth of some mature Douglas-fir, particularly at Denham Till. Some uncertainties in linking soil moisture and tree condition include: (1) only one location (but multiple depths in the profile) for soil moisture sampling at each site and that not at the location of the sampled trees (2) a lack of soil moisture data for other years in combination with assessments of tree growth or crown condition (3) uncertainty in how soil moisture content relates to more precise measures of moisture stress in the plant itself. Growth models such as 3PG can be used to relate Douglas-fir growth to moisture availability if soil moisture deficits can be satisfactorily estimated. This is worth investigating. It is unclear how the combination of higher growing season temperatures, changes in vapor pressure deficit, and decreases in growing season precipitation predicted with climate change will affect Douglas-fir growth and mortality in these and other North Saanich parks. For example, growth of Douglas-fir may be more strongly impacted by decreased soil moisture in some sites and by increased temperature in others; Breedlow et al. (2013) showed that drier sites were associated with lower temperature optima for growth. They concluded climate change might increasingly reduce growth more through increased temperatures than through reduced soil moisture contents. As mentioned above, it may be worthwhile to more comprehensively document changes in soil moisture and relate these to tree growth and crown condition. This might provide some guidance toward park management to maximize tree health under conditions likely with climate change. Climate change will not only affect trees in the parks, but also associated ecosystems. Appropriate monitoring of park trees and soils is the key first step toward management of parks under climate change. Subsequent management actions might range from shorter-term actions such as locally improving soil quality (and available moisture) to existing trees to longer-term more drastic proactive actions such as reducing some tree cover (and moisture demand) or facilitating a gradual change of native tree species composition to species more tolerant of drought. However, management actions should be based on appropriate inventory and monitoring data.

The Denham Till site was intriguing. Crown condition was worse there than at Gulf View or Nymph Point. Soil moisture contents were not less than in the other parks, but the rooting zone was much shallower and gleyed. In that site, poor drainage and aeration during winter and spring might restrict root growth and reduce potential water uptake and exacerbate drought stress during summer. There was also concern that branch death and needle loss was associated with the presence of *Armillaria* sp., a root pathogen which can become more infectious in association with drought stress and nutrient deficiencies. Evidence of *Armillaria* was looked for in August 2022, but not found (Joey Tanney, Natural Resources Canada, personal communication. November 2022).

In this study, possible relationships between drought and tree condition were examined in only three North Saanich parks and with extremely small samples for assessment of soil and tree conditions in each. Landscape-level assessments are important to provide a context in which to place data from individual parks. Canopy coverage assessments over time, such as those sponsored by the Capital Regional District, combined with District-level landscape information, could provide a District-wide assessment of potential drought stress effects on forest condition and the contributions of land-use changes.

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Table 1. Some potential direct and indirect effects of “hotter” drought stress on tree growth

Direct/acute effects on growth

- Stomatal closure- reduced carbon uptake
- Reduced current-year shoot elongation (Lavender 1980)
- Reduced end-of-season needle initiation and size of terminal buds (Lavender 1981)
- Reduced accumulation of carbon reserves
- Reduced allocation of carbon to diameter growth and defensive compounds (Trowbridge et al 2021)
- Reduced allocation of biomass to leaves, branches and stems and increased allocation to roots
- Changes in stem anatomy and water transport capacity in stems
- Cavitation in stem and branch water columns, death of foliage and live woody tissue

Indirect effects on growth

- Reduced availability and uptake of some essential mineral nutrients potentially leading to nutrient deficiencies or imbalances (Sardans 2007; Teshome et al. 2020; Boczon et al 2021), reduced carbon uptake, reduced needle, shoot, and stem growth, needle discoloration and senescence
- Increased susceptibility to pathogens and insect herbivores

Table 2. Definitions of crown condition metrics used in crown condition assessment (USDA FIA 2011)

Live crown ratio- represents the length of stem containing live branches as a proportion of the total length of the stem. Live crown ratio provides an indicator of potential long-term future growth.

Crown dieback-refers to death of branches in the upper crown and containing fine twigs* and is considered to indicate the severity of recent stresses to the tree. Dead upper-crown branches no longer containing fine twigs are referred to as snags.

Crown density- refers to the amount of sunlight blocked by all crown biomass and is determined relative to a "normal" crown shape. Crown density estimates crown condition in relation to a typical tree for the site where it is found and may indicate past long-term stress and potential future growth in the near-term.

Crown transparency- refers to the amount of skylight penetrating only the live foliated portion of the crown and relative to a "normal" crown shape. Areas with dieback, large dead branches, and between large branches where foliage is not expected to occur is excluded from estimates (Randolph et al 2010). Hence, density and transparency are not exact inverses of each other, because the former includes both woody tissue and foliage and the latter includes only foliage and excludes areas without live branches. Transparency may vary with stresses during current and preceding years, including current defoliation.

*(where twigs are defined as having secondary branches and < 2.5cm diameter at the point of attachment to the stem or larger branches, beginning at the terminal end of the branch and proceeding toward the stem.)

Table 3. (a) Selected soil profile descriptions (Bonsdorf and Hope 2022) and (b) bulk densities, volumetric moisture contents (Ө) and total C and N concentrations (Hope and Bonsdorf 2022)

(a)

Variable	Denham Till	Gulf View	Nymph Point
Soil type_Assn	Gleyed dystric Brunisol_Fairbridge	Orthic sombric Brunisol_Beddis	Orthic dystric Brunisol_Saanichton
Slope and position	Flat(2%)	Midslope (10%)	Flat(3%)
Rooting depth(cm)	40	56	86
LFH type/thickness(cm)	Mull / 2	Mull / 1.5	Mull / 3
Ah thickness(cm)	15	22	11
Texture, CFC(%) A/B	SiCL 20 / SiCL 15	SL 10 / SL 20	SiCL 5 / SiC 2
Color A_B	10YR4/3_10YR5/4	7.5YR3/2_10YR4/3	5YR3/1_10YR5/4
Mottling?	Y	N	Y

(b)

Site	Hrzn	BD	ӨMay	ӨAug	C	N	C/N
					%	%	
Denham Till	LF	0.06	0.033	0.007	42.5	0.73	58
	Ah	0.91	0.245	0.069	3.3	0.16	21
	Bgi	1.03	0.277	0.071	2.2	0.12	18
Gulf View	LF	0.11	0.047	0.011	36.3	0.99	37
	Ah	1.07	0.482	0.063	5.3	0.26	20
	Bm	1.21	0.278	0.054	1.2	0.08	14
Nymph Point	LF	0.13	0.078	0.018	42.7	0.99	43
	Ah	0.75	0.240	0.059	6.9	0.32	22
	Bg	1.24	0.232	0.065	2.0	0.10	21

Table 4. Crown condition characteristics. Abbreviations: LCR- live crown ratio; CD- crown density

Site	Tree	Dbh (cm)	LCR	Dieback (%)	CD (%)
DenhamTill	95	70	0.70	0	20-25
	206	91	0.75	0	5-15
	210	71	0.60	20-25	25-30
	xx	50.8	0.60	0	45-50
	xx	48.5	0.60	0	35-40
	xx		0.45-0.50	0	40
GulfView	62	61	0.65	0	50-55
	63	89	0.80	0	60-65
	60	90	0.80	0	70
	61	87	0.70	0	60
	xx	64.8	0.75	0	65-70
NymphPoint	43		0.60	0	45-50
	50		0.50	0	60-65
	45	76	0.55	0	55
	46	61.5	0.65	0	70
	xx	93	0.50	0	65

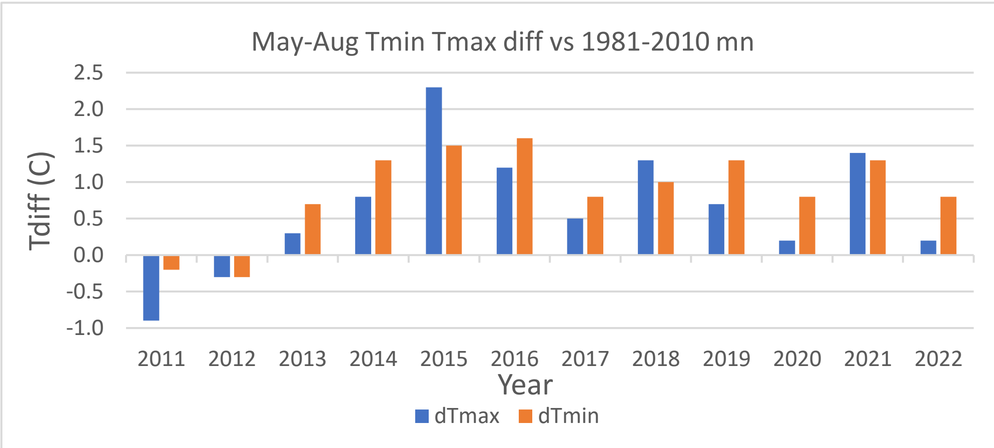
Table 5. Shoot length (SL) and needle length (NL) (mean and s.e.), dry mass (NM_{100}), and color for May and August 2022 sampling at Denham Till (DT) Gulf View (GV) and Nymph Point (NP)

Date	Site	Tree	Cohort	SL	NL	NM_{100}	Color(predom)
			Year	cm	mm	g	
05/2022	DT	95	2022				
			2021		14.7(0.5)	0.358	5GY4/4
			2020		14.7(0.3)	0.328	
		206	2022				
			2021		14.3(0.7)	0.412	5GY 4/4
			2020		16.4(0.5)	0.509	
	GV	62	2022				
			2021		20.7(0.4)	0.977	7.5GY 3/4
			2020		10.3(0.3)	0.269	
		63	2022				
			2021		20.2(0.4)	0.925	7.5GY 3/4
			2020		13.5(0.2)	0.480	
	NP	43	2022				
			2021		23.1(0.4)	1.048	5GY 4/4-7.5GY4/4
			2020		19.1(0.3)	1.100	
		50	2022				
			2021		20.6(0.5)	0.670	7.5GY 4/4-4/6
			2020		21.0(0.5)	0.652	
09/2022	DT	95	2022	4.7(2.4)	21.0(0.5)	0.469	7.5GY 4/6
			2021	7.9(4.0)	15.0(0.6)	0.263	5GY 4/4
		206	2022	2.9(0.4)	17.4(0.4)	0.613	7.5GY 4/4 – 4/6
			2021	4.4(0.5)	15.1(0.3)	0.491	5GY 4/4
	GV	62	2022	3.4(0.5)	17.9(0.7)	0.308	7.5GY 4/4
			2021	7.8(0.5)	19.3(0.5)	0.531	7.5GY 3/4
		63	2022	4.8(2.4	15.5(0.6)	0.371	7.5GY 4/4
			2021	8.1(4.0)	20.8(0.6)	0.720	7.5GY 3/4
10/2022	NP	43	2022	4.1(0.3)	20.4(0.4)	0.528	7.5GY 4/6
			2021	9.2(0.3)	18.9(0.3)	0.567	7.5GY 3/4
		50	2022	3.7(0.4)	15.0(0.4)	0.267	7.5GY4/4
			2021	5.5(0.4)	21.0(0.3)	0.555	7.5GY3/4

Table 6. Foliar nutrient concentrations by needle cohort, May and September/October 2022 samplings at Denham Till (DT), Gulf View (GV) and Nymph Point (NP). Abbreviations: ns- no sample. *<7.5 indicates moderate deficiency. ** Ballard and Carter 1986. 1/Coleman et al. 2014. For ratios (P/N, S/N, and K/N), P, S, and K are a percentage of N (i.e., N=100)

Date	Site	Tree	Cohort	C	N	P	K	Ca	Mg	S	Fe	B	Cu	Mn	Zn	Al	P/N[1]	S/N[1]	K/N[1]
				%	g/kg						mg/kg								
05/2022	DT	95	2022	50.4	26.5					1.5									
			2021	47.1	10.9					0.6									
		206	2022	ns	ns					ns									
			2021	47.3	10.6					0.6									
	GV	62	2022	47.3	23.2					1.3									
			2021	46.9	14.5					0.9									
		63	2022	49.6	25.9					1.5									
			2021	46.7	11.8					0.7									
	NP	43	2022	47.6	21.8					1.1									
			2021	46.9	11.6					0.7									
		50	2022	44.8	19.7					1.3									
			2021	47.9	11.2					0.8									
09/2022	DT	95	2022	50.7	**9.9**	1.7	9.8	2.8	1.3	0.8	93	25	3	169	23	92	17	8.1	99
			2021	51.9	13.7					1.1									
		206	2022	50.3	**9.7**	1.4	9.2	3.3	1.5	0.7	151	24	3	250	23	158	15	7.2	94
			2021	51.1	17.3					1.3									
	GV	62	2022	49.5	**10.5**	2.1	8.8	8.7	2.4	0.8	50	23	3	326	38	88	20	7.6	83
			2021	50.1	19.7					1.4									
		63	2022	49.5	**11.8**	2.3	5.2	5.4	1.8	1.1	186	51	5	314	31	327	19	9.3	44
			2021	49.7	14.3					1.3									
10/2022	NP	43	2022	50.9	**9.5**	1.5	6.8	5.1	2.0	0.8	159	25	4	316	24	231	16	8.4	72
			2021	51.8	12.9					1.1									
		50	2022	50.4	**11.2**	2.3	7.2	6.3	1.8	1.0	136	41	4	269	21	101	21	8.9	65
			2021	50.4	13.7					1.0									
Deficiency**					<12	<1	<4.5*	<3.5	<0.9	<1.2	<25	<10	<1	<15	<10		<6.2	<7.4**	<50

Figure 1 (a). Differences between average daily temperatures (May through August, 2011-2022) with 1981-2010 mean, Victoria International Airport. (Environment Canada). (b) Growing-season precipitation 2011 through 2022, compared to 1981-2010 mean, Victoria International Airport.



(b)

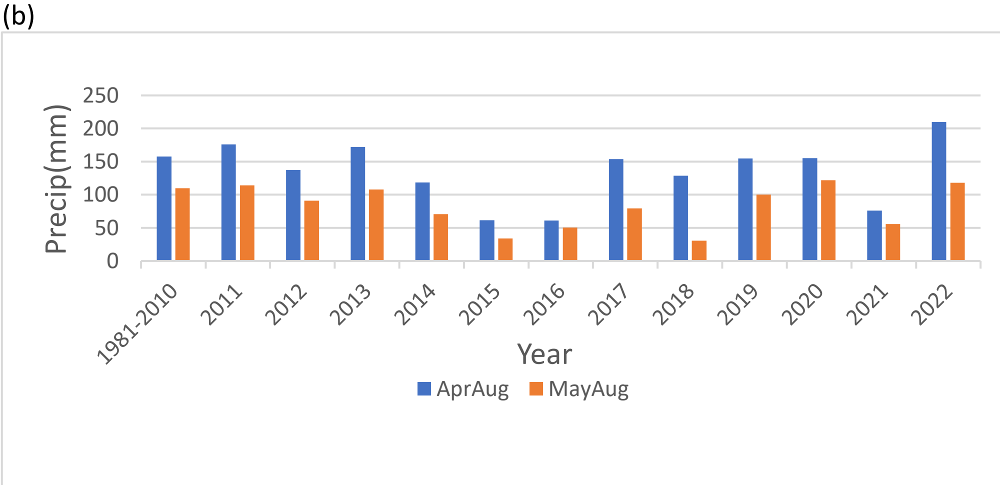


Figure 2. Conceptual framework relating drought stress to tree physiological damage and mortality (Anderegg et al. 2013)

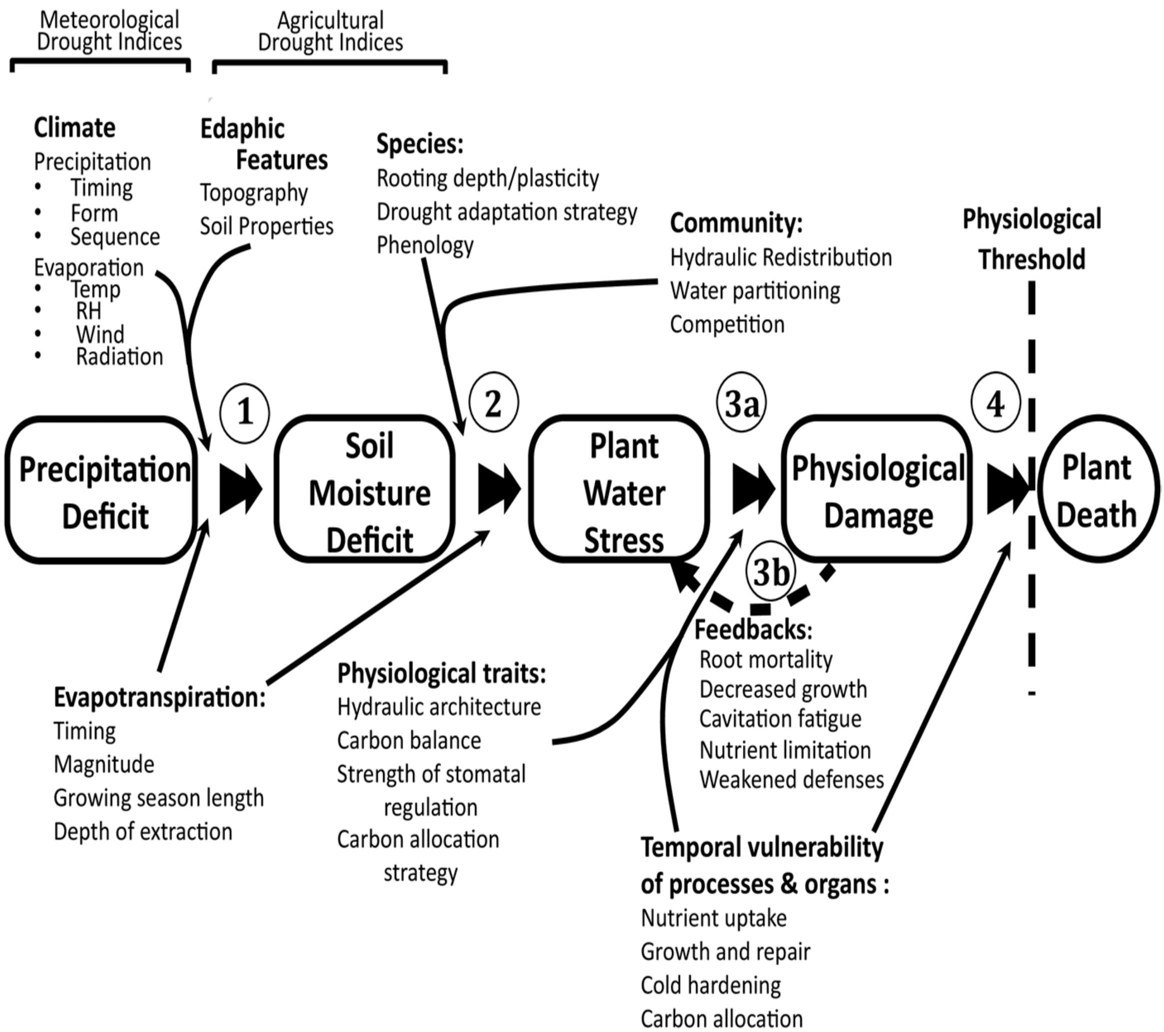


Figure 3. a,b Trees sampled at Denham Till for foliage and canopy characterization

(a) DT 95 (b) DT 206

Figure 3 (continued) c,d. Trees sampled at Gulf View for foliage and canopy assessments

(c) GV62 (d) GV63

Figure 3 (continued) e,f. Trees sampled at Nymph Point for foliage and canopy assessment.

(e_) NP43 (f) NP 50

Appendix 1. Preliminary measurements of annual ring widths 2011 through 2021, expressed relative to the mean annual ring width from 2010 through 2021 (mean = 100). Cores are from trees GV62, GV63, NP43, and NP50. Cores from Denham Till were not available.