APPENDIX 1

Assessing the risk of drought in British Columbia forests using a stand-level water balance approach

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Abstract

We use an annual water balance approach to assess the current and future relative risk of drought-induced stress and mortality for tree species at the stand-level in British Columbia. The aim is to develop a drought risk mapping tool that can be used by forest managers to make harvest and silviculture decisions at the stand level in response to climate change. We use the concept of absolute soil moisture regime and compare estimates based on expert opinion to those calculated by a water balance equation using long term climate data and reference site and soil conditions for different site types. The quantitative estimates of absolute soil moisture regime class generally agreed with those based on expert opinion. In most climatic areas absolute soil moisture regime for certain drier site types was predicted to become drier by one class under projected future climate. We estimate that a number of the tree species examined will be at risk of drought-induced stress and/or mortality for certain climate/site combinations. Under future climate scenarios moist to wet site types were never estimated to be in moisture-deficit situation, suggesting that these sites are the most stable sites from a drought perspective under a changing climate and therefore should warrant extra consideration for forest conservation.

Keywords

drought, British Columbia, forest management, biogeoclimatic ecosystem classification, absolute soil moisture regime, climate change

Introduction

Increased drought, caused by recent regional warming, is believed to be one of the leading causes of tree mortality in forest ecosystems of Western North America (Van Mantgem et al. 2009) and worldwide (McDowell et al. 2008). Drought is difficult to define (McWilliam 1986). Kozlowski et al. (1991) define drought from a forest perspective as a period of below-average precipitation that reduces soil moisture and results in prolonged plant water stress and reduced growth. However, an increase in temperatures can also cause drought-like soil moisture conditions by increasing evapotranspiration (Pike et al. 2008). Drought can therefore be caused by an increase in evaporative demand due to increases in temperature, decrease in water availability, or both (Van Mantgem and Stephenson 2007). The effects of drought vary with site characteristics such as soil texture, exposure, and slope, as well as biological determinants such as forest cover and age (Kozlowski et al. 1991, Gitlin et al. 2006). Seasonal droughts are common in many forested ecosystems (Kozlowski et al. 1991), but drought conditions also occur infrequently as supraseasonal or even decadal events (Lake 2011). Drought frequency and severity are projected to increase in the future in many forested ecosystems in association with temperature increases and complex temperature/precipitation interactions (Pike et al. 2008, Christensen et al. 2007). Drought and drought-induced forest mortality will have substantial socioeconomic and ecological consequences at a global scale, and is therefore an issue of increasing interest (McDowell et al. 2008, Allen et al. 2010).

Drought-caused mortality occurs either directly through hydraulic failure, carbon starvation, or indirectly through increasing susceptibility to attacks by biological agents (e.g., bark beetles) (McDowell et al. 2008, Adams and Kolb 2005, Klos et al. 2009). Van Mantgem and Stephenson (2007)found that an increase in drought-caused mortality was correlated with increases in water deficits. The predicted increase in drought conditions may lead to preferential mortality of species which in turn may lead to shifts in species composition at the stand and landscape-level (McDowell et al. 2008). In the context of forest management, the need to address the potential vulnerability over time and space is critical if current planning decisions and objectives are to be achievable (Turner et al. 2003). Spatial and temporal assessments of climate change impacts can be used to provide and understanding of potential response of species and ecosystems to climatic change which in turn will remove some of the uncertainty on how to manage these systems (Nitschke and Innes 2008a). In the context of increasing drought mortality risk, both the current and future drought risk of species at the stand-level is important for determining relevant management actions that may reduce the potential impacts of drought mortality on stand composition, structure and productivity.

In British Columbia, a Biogeoclimatic Ecosystem Classification (BEC) system is used to classify ecosystems (Pojar et al. 1987). The BEC system breaks the province in to biogeoclimatic units (BGC) using a classification of zonal ecosystems to define areas of similar climate. The zonal ecosystem is a mature vegetation community that occurs on “zonal sites” – areas with average soil and site conditions—which best reflect the regional climate (Pojar et al. 1987). Within each BGC unit an edatopic grid, which has a relative soil moisture regime (RSMR) scale on the y-axis and relative nutrient scale on the x-axis, is used to classify other sites which are drier or wetter/

poorer or richer than the zonal site based on their physiographic position and soil characteristics.. A key component of the BEC system is the concept of actual soil moisture regime (ASMR) (Pojar et al. 1987). ASMR is classifiaction scheme based on the number of months that rooting-zone groundwater is absent during the growing season and defined by the ratio of actual evapotranspiration (AET) over potential evapotranspiration (PET). For each combination of BGC unit a RSMR an ASMR can be estimated. This has been done for all BGC units in B.C. by experienced ecologists (unpublished data).

Recently a tree and climate assessment tool (TACA) for modelling species response to climate variability and change has been developed by Nitschke and Innes (Nitschke and Innes 2008b). This tool makes use of AET/PET ratio to predict drought using an annual water balance approach (Oke 1987). Climate variables of precipitation, minimum and maximum temperature can be inputed in to the model to derive estimates of AET/PET for sites with given soil characteristics (% coarse fragments, soil texture, rooting depth) and slope position (shedding, receiving or neutral). Slope position and soil characteristics are the major determinants of relative soil moisture regime used in the BEC edatopic grid.

The database used to develop the BEC has over 50 000 plots which are mostly assigned a BGC unit and RSMR (British Columbia Ministry of Forests, Range and Natural Resources Management 2011). Using this extensive database and expert knowledge of the ecologists working in the program we can assign current tree species distributions to their extent across the ASMR gradient.

Our aim was to calibrate outputs of ASMR calculated by TACA using an annual water balance approach against experience-based estimates, determine ASMR for current climates in different BGC units throughout BC, determine potential ASMR for a future with lower ASMR and forecast potential impacts on tree species based on their existing ASMR tolerance. The long-term purpose is to develop a tool to predict and map drought risk at the stand-level using existing forest cover and ecosystem maps as input layers.

Methods

TACA (Tree and Climate Assessment) (Nitschke and Innes 2008b) is a mechanistic species distribution model (MSDM) that analyses the response of trees to climate-driven phenological, biophysical, and edaphic variables. It assesses the probability of species to be able to regenerate, grow and survive under a range of climatic and edaphic conditions. The soil moisture function was modified to incorporate the Hargreaves model of evapotranspiration (Hargreaves and Samani 1985) and estimates of daily solar radiation based on equations from Bristow and Campbell (1984) and Duarte et al. (2006). The application of the Hargreaves equation allowed for validation of model outputs as the Hargreaves equation is used across British Columbia to calculate evapotranspiration. In addition, the soil component of TACA was expanded to allow for five different soil types to be run simultaneously allowing for the representation of multiple RSMR's.

We used RSMR keys provided in BEC field guides (e.g., DeLong 2004) to determine a set of soil conditions and slope position that would result in xeric to subhygric RSMR's (Table 1).

With our focus on drought we did not include hygric and subhydric RSMR’s as by definition these sites have saturated soils throughout the growing season. The values in Table 1 were used in TACA for calculating AET/PET values for the different RSMR’s within a BGC unit. Soil texture specific available water storage capacity (AWSC) (mm/m) and field capacity FC (mm/m) parameters provided in TACA (Nitschke and Innes 2008b)were used to calculate available water holding capacity AWHC (mm) and available field capacity (AFC) (mm) based on rooting depth (RD) and % coarse fragment content (CF) using the following equations:

$$AWHC = AWSC * RD * (1 - CF) \qquad \text{[Equ. 1]}$$

and

$$AFC = FC * RD * (1 - CF) \qquad \text{[Equ. 2]}$$

The difference between AFC and AWHC provided the percolation rates (mm/day) for water shedding and receiving positions.

Long-term climate stations, with a minimum 10 year climate record, were selected to represent a particular BGC unit. Where more than one station was available we selected the station that was most completely encompassed by the BGC unit (e.g., closer to the middle of its extent) and/or the one with the longer climate record. Stations were selected to cover the range in climatic conditions across B.C. and are shown in Table 2. Once a climate station was selected the data was screened and years with incomplete records removed (e.g., > 10 missing values for a year for any of the variables) and missing daily records interpolated using surrounding values. Mean values for each year were then calculated and the years ranked based on mean temperature, precipitation, and annual heat index ([Mean Annual Temperature + 10]/ [Annual Precipitation/1000]; Wang et al. 2006). The TACA model runs on a set of 10 years of data so years to include were chosen using the 90th, 75th, 50th, 25th and 10th percentiles for mean temperature and precipitation. If a particular year was chosen more than once then a year which represented an annual heat index not already represented was substituted. These 10 years were used as input as the observed climate record to run TACA.

We assigned the 10 year average AET/PET values output from TACA to Actual Soil Moisture Regime (ASMR) classes described by Pojar et al. (1987)(Table 3) and compared them to estimates provided by experienced ecologists. The estimates of the ecologists were based on their knowledge of the relative length of drought experienced by different BGC unit/RSMR combinations, the plants typifying sites with different RSMR’s within a BGC unit, and any available soil moisture data.

For stations with at least a 25 year record, we also computed ASMR classes using the 10 years from the record with the highest heat index in order to simulate future climate conditions which may result in lower soil moisture availability (ASMR extreme). This allowed us to use daily data which is required to run TACA but not readily available for future climate conditions. TACA allows for the inclusion of climate change predictions through a direct adjustment approach where the monthly predicted change in temperature is applied to the observed climate data by either adding or subtracting the mean monthly difference from each daily value for temperature or by multiplying each daily precipitation value by a modifier based on predicted increase or decrease in precipitation. For all stations, the AET/PET values for ASMR extreme was in the mid range of those computed from three 2020s climate scenarios selected to represent climate change over the next 20 to 30 years . The three climate scenarios were the A2 scenario implemented through the Canadian Global Circulation Model, version 3 (CGCM3), of the Canadian Centre for Climate Modeling and Analysis (Flato et al. 2000), The B1 scenario implemented through the Hadley Centre Coupled Model, version 3 (HadCM3) (Johns et al. 2003), and the A1B scenario implemented through the Hadley Centre Global Environmental Model, version 1 (HadGEM1) (Johns et al. 2006). Future climate data using these scenarios were calculated using the ClimateWNA model (Wang et al. 2006).

We used the vegetation data from the BEC database to examine tree species distribution across BGC/RSMR combinations to determine the ASMR class limits for selected tree species that covered a broad range in drought tolerance.

Results

The selected BGC units cover a wide range of regional climates from grasslands with hot dry climates (e.g., Thompson variant of the Very Hot Dry Bunchgrass subzone) to high elevation forests with wet cold climates (e.g., Cariboo variant of the Wet Cool Englemann Spruce – Subalpine fir subzone) (Table 2). Many of the climate stations had wide ranges in values, over the measurement period, for the selected climatic variables, especially those in wetter climates (Table 2).

There was very strong agreement between the ASMR class values estimated by TACA and those arrived at by expert opinion (Table 4). Of the 50 sites assessed, the TACA model estimate of ASMR was one class drier compared to expert estimate on 13 sites with one case where the expert estimate was one class wetter than the TACA estimate (Table 4). In most of these cases the AET/PET value calculated by TACA was very close to the class break (Tables 3&4).

When the years with the highest annual heat index were assessed within the selected BGC units, 13 out of 35 BGC/RSMR combinations shifted to a drier ASMR class. The BGC units where the most changes occurred were the Kootenay variant of the dry mild Interior Douglas-fir subzone (IDFdm2) where all the RSMR classes shifted one ASMR class except the subhygric and the Okanagan variant of the very dry hot Interior Douglas-fir subzone (IDFxh1) where the subxeric, submesic, and mesic RSMR classes all shifted one ASMR class (Table 5). There were very few shifts within the wetter BGC units and no shifts were estimated on subhygric RSMR sites within any of the BGC units (i.e., no moisture deficit even in the driest predicted climatic conditions for this RSMR class).

Based on a shift to drier soil moisture conditions expected for the future there were a number of tree species that would experience drought stress and /or suffer drought induced mortality resulting in potential range reductions based on their current ASMR tolerance and range:

- For western larch (*Larix occidentalis* Nutt.), stress and/ or mortality may occur on subxeric to submesic sites in the IDFxh1 (Tables 5&6);
- for lodgepole pine (*Pinus contorta* Dougl. ex Loud.var *latifolia* Engelm.), stress and/ or mortality could be expected on submesic to mesic sites in the IDFdm2;
- for western red cedar (*Thuja plicata* Donn.) stress and/ or mortality may occur on xeric to subxeric sites;

- for western hemlock (*Tsuga heterophylla* (Raf.) Sarg.), stress and/ or mortality may occur on submesic to mesic sites, in the Shuswap variant of the moist warm Interior Cedar – Hemlock subzone (ICHmw2);
- for interior spruce (*Picea glauca* (Moench) Voss x engelmanii (Parry) Engelm.), drought induced stress and/ or mortality could be expected on mesic sites in the ICHdm2 and submesic to mesic sites in the dry cool Sub-boreal Spruce subzone (SBSdk); and,
- Douglas fir (*Pseudotsuga menziesii* var. g*lauca* (Beissn.) Franco) and ponderosa pine (*P. ponderosa* Dougl.) will likely not experience any significant drought impacts across the studied ecosystems.

Discussion

Across the range of the tree species investigated in this study mature individuals (>80 yrs) have experienced a wide range of precipitation and temperature conditions. Based on the climate records which represent a wide range of their ecosystems in British Columbia, precipitation can vary in such a manner that drier climatic areas can receive annual precipitation more typical of moister regions, and moist regions (e.g., ICHmw2) can receive annual precipitation similar to that expected in drier areas. Mean annual temperature also is highly variable with warmer BGC units (e.g., ICHmw2) being as cold in some years as colder high elevation BGC units. Trees within British Columbia therefore appear to tolerate a wide range of interannual climatic fluctuations. Within these distinct yet overlapping climatic regimes species occur across edaphic gradients driven in large part by soil moisture availability which suggests that climate effects are mediated through edaphic constraints and/ or extreme climate years. Zimmerman et al. (2009) identified that the distributions of some species are sensitive to the extremes of a regions climate in particular to summer moisture availability (drought) and winter temperatures (frost).

Under projected climate change the climatic regimes for many of the current ecosystems are expected to shift towards the warmer and drier extremes which would lead to long-term changes (reductions) in available soil moisture. Soil moisture appears to be sensitive to even modest changes in average temperatures (Daniels et al. 2011). An increase in average temperature of only one °C over the past century in western North America has been linked to increased tree mortality rates (Van Mantgem et al. 2009, Daniels et al. 2011), possibly through changes in snowpack (Mote et al. 2005, Knowles et al. 2006) and summer drought (Westerling et al. 2006). Van Mantgem et al. (2009) suggest that this phenomenon is already occuring across a wide range of forest types, elevation classes, tree sizes, and genera in western North America leading to increased rates of mature tree mortality. Breshears et al. (2005) attributed regional scale die-off of overstorey trees across southwestern North America woodlands to depleted soil water and suggest even more profound impacts assuming future warmer conditions. Hogg et al. (2008) describe growth declines and substantial mortality in trembling aspen stands in western Canada associated with a severe drought from 2001 to 2002. Increased drought stress can also limit regeneration after disturbance, possibly leading to a semi-permanent conversion of forest to grassland (Hogg and Wein 2005, Johnstone et al. 2010).

Differences in drought tolerance may explain differential species and population mortality after drought (Mueller et al. 2005, Martinez-Meier et al. 2008) as well as species distributions and ranges (Swetnam and Betancourt 1998, Aber et al. 2001). Within a species, drought may initially and most strongly impact populations growing near climatic- (Griesbauer et al. 2011) or edaphic-controlled species distribution limits (McDowell et al. 2008, Gitlin et al. 2006), as plants growing on limiting sites may experience long-term stress that weakens their ability to resist relatively rapid stressors such as drought events (Mueller-Dombois 1987). Understanding species and spatial variation in drought-induced mortality patterns will become increasingly important to natural resource managers (Mueller et al. 2005) for selecting suitable species and genotypes for reforestation (Millar et al. 2007) as well as projecting future forest compositions and species distributions (Tardif et al. 2006). Our model addresses this for BC by providing a tool that can identify which tree species/ populations are likely to be at a high risk to drought caused stress/ mortality under a range of edaphic (as defined by ASMR) conditions.

The corroboration of ASMR estimates using the Hargreaves equation implemented in TACA with those of experienced ecologists provides a strong basis for value belief. The Hargreaves equation has been used successfully to calculate evapotranspiration rates in various climates and generally performs as well as the more complicated Penman Monteith equation particularly where solar radiation data is unavailable (Di Stefano and Ferro 1997); which was the case for this study). The finding of large shifts in ASMR in dry to moist BGC units based on a drier warmer future indicate that these are the areas where climate adaptation plans relating to forest management are most urgently needed. The predictions of future conditions in dry climatic portions of British Columbia consistently indicate drier warmer conditions (Nitschke and Innes 2008a, Hamann and Wang 2006). Even if precipitation increases in some areas the impact of warmer temperatures could still lead to decrease in available soil moisture, especially if the increases in precipitation are not during the summer months (Pike et al. 2008, Christensen et al. 2007). In British Columbia, climate change is predicted to result in an increase in winter precipitation with declines in summer precipitation along with warming temperatures.

Wetter edaphic sites such as those found at higher elevation/ altitude and with riparian and drainage areas have acted as refugia for mesic species during droughts and fires associated with past climatic events (Burke 2002, Rouget et al. 2003) and are hypothesised to play a critical role under future climate change (Stott et al. 1998). The finding of no drought limitations in wetter climate areas and on subhygric sites even in the driest of climates supports this hypothesis and emphasizes the importance of these sites for the future conservation of forest species (Meave et al. 1991). These sites may also represent the best choice for long-term storage of carbon, provision of old forest characteristics for maintenance of faunal species who require them, maintenance of genetic diversity, and other intrinsic value of natural forests.

Our identification of sites and species that may exhibit drought induced mortality on specific sites (i.e., specific BGC RSMR combinations) allows forest managers to focus their efforts on climate change mitigation and adaptation on particular sites rather than across broad regions. Adaptation strategies may include the use of even-aged versus uneven-aged systems on drought risk sites where mid-summer water stress can be reduced by providing multi-aged stands which lower temperatures, raise humidity and reduce evaporative demand (O'Hara and Nagel 2006). Forests that provide higher humidity, cooler temperatures and wetter edaphic conditions are important for maintaining species that cannot tolerate climatic change that brings warmer and drier conditions (Stott et al. 1998, Meave et al. 1991). Enrichment planting could also be used to establish shade tolerant species that are vulnerable to climatic induced drought stress in the understorey of established stands. Likewise, enrichment planting can also be used following artificial or natural regeneration planting to fill in the gaps that result from disturbance or climate-based mortality (Nitschke and Innes 2008b). Planting can be used to facilitate the persistence of species and ecosystems through "human-assisted migration"; and be used to plant new species that are better adapted to the altered climate (Hogg and Bernier 2005). The use of enrichment planting for this latter objective could allow for a gradual and controlled transition of species at risk of climate induced drought to species more tolerant of future soil moisture regimes.

Much of the work to date in British Columbia and other jurisdictions has focused on predictions of future potential tree species distributions at broad regional scales (e.g., Hamann and Wang 2006, McKenney et al. 2007, Rehfeldt et al. 2008, Coops and Waring 2011, Shuman et al. 2011). We feel that our research is providing an important transition from these broad regional predictions to more site-specific predictions that are more useful for directing forest management activities relating to climate change adaptation and mitigation.

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Table 1. **Combinations of slope position and soil conditions for different relative soil moisture regimes (RSMR).**

RSMR	Slope position	Coarse Fragments (%)	Soil texture	Rooting depth (cm)
Xeric	Shedding	55	Sand	25
Subxeric	Shedding	40	Loamy Sand	50
Submesic	Shedding	40	Sandy Loam	50
Mesic	Neutral	40	Loam	50
Subhygric	Receiving	20	Silty Clay Loam	30

Table 2. **Range in key climate data for climate stations selected to represent biogeoclimatic (BGC) units.**

BGC unit	Location Years of Record	Mean Annual Precipitation (mm)	Mean Annual Temperature (°C)	Annual Heat Index
Very Dry Hot Bunchgrass – Thompson variant	Kamloops 1951 - 2006	153 - 389	6.5 - 10.9	44 - 128
Very Dry Hot Ponderosa Pine – Okanagan variant	Kelowna 1951 - 1969	210 - 370	5.7 - 9.3	49 - 82
Very Dry Hot Interior Douglas-fir Okanagan variant	Vernon 1946 - 1996	248 - 608	6.2 – 9.2	28 - 70
Dry Mild Interior Douglas-fir – Kootenay variant	Marysville 1973 - 2003	272 - 657	3.7 – 7.2	21-61
Dry Warm Interior Cedar Hemlock – West Kootenay variant	Crescent Valley 1941 - 1964	651 - 940	4.8 – 8.3	16 – 32
Dry Cool Sub-boreal Spruce	Smithers 1943 - 2008	312 – 761	1.7 – 5.4	18 – 45
Moist Warm Interior Cedar – Hemlock – Thompson variant	Nakusp 1913-1988	494 – 971	4.1 – 8.4	17 - 32
Dry Cold Engelmann Spruce –	Peachland	413 – 753	2.1 – 4.7	17 – 36

Subalpine fir – Cascade variant	Brenda Mines 1969 - 1991			
Wet Cool Sub-boreal Spruce – Willow variant	Aleza Lake 1953 - 1980	709 - 1157	2.0 -4.9	10 – 18
Wet Cool Engelmann Spruce – Subalpine fir – Cariboo variant	Barkerville 1936 - 2006	873 - 1845	-0.7 – 3.5	6 - 15

Table 3. Classification of actual soil moisture regime (ASMR) modified from Pojar et al. (1987).

Differentia	ASMR	AET/PET
Rooting-zone groundwater absent during the growing season Water deficit occurs (soil-stored reserve water is used up and drought begins if current precipitation is insufficient for plant needs)		
Deficit > 5 months	Excessively Dry (ED)	< 0.55
Deficit > 4 months but ≤ 5 months	Very Dry 1 (VD1)	≥ 0.55 < 0.65
Deficit > 3 months but ≤ 4 months	Very Dry 2 (VD2)	≥ 0.65 < 0.75
Deficit > 1.5 months but ≤ 3 months	Moderately Dry (MD)	≥ 0.75 < 0.85
Deficit > 0 months but ≤ 1.5 months	Slightly Dry (SD)	≥ 0.85 < 0.95
Deficit occurs rarely. Utilization and recharge occurs. Current need for water exceeds supply and soil-stored water is used.	Fresh (F)	≥ 0.95 < 1.0
No water deficit occurs. Current need for water does not exceed supply, temporary groundwater may be present. Drought does not occur even in driest years.	Moist (M)	≥ 1.0
Rooting-zone groundwater present during the growing season. Water supply exceeds demand.	Very Moist – Very Wet	> 1.0

Table 4. Estimates of Actual Soil Moisture Regime (ASMR) class by biogeoclimatic unit and Relative Soil Moisture Regime class. Where TACA model and expert estimate disagreed the expert estimate is in brackets. Actual AET/PET values computed by TACA are below the class. ASMR classes described in Table 3.

BGC unit	Relative Soil Moisture Regime				
	Xeric	Subxeric	Submesic	Mesic	Subhygric
Very Dry Hot Bunchgrass – Thompson variant	ED 0.43	ED 0.47	ED 0.51	VD1 (ED) 0.56	F 0.99
Very Dry Hot Ponderosa Pine – Okanagan variant	ED 0.50	VD1 (ED) 0.56	VD1 (ED) 0.60	VD2 0.65	F 0.99
Very Dry Hot Interior Douglas-fir Okanagan variant	VD1 (ED) 0.64	VD2 0.70	VD2 0.73	MD 0.77	F 0.99
Dry Mild Interior Douglas-fir – Kootenay variant	VD2 0.68	VD2 0.72	MD (VD) 0.75	MD 0.79	F 0.99
Dry Warm Interior Cedar Hemlock – West Kootenay variant	MD (VD) 0.76	MD (VD) 0.83	SD (MD) 0.85	SD 0.90	F 0.98
Dry Cool Sub-boreal Spruce	MD 0.76	MD 0.82	SD 0.85	SD 0.90	M[1] 1.0

BGC unit	Relative Soil Moisture Regime				
	Xeric	Subxeric	Submesic	Mesic	Subhygric
Moist Warm Interior Cedar Hemlock – Shuswap variant	MD 0.77	MD 0.82	SD 0.85	SD (F) 0.89	M 1.0
Dry Cold Engelmann Spruce – Subalpine fir – Cascade variant	SD (MD) 0.86	SD (MD) 0.90	SD 0.92	F 0.96	M 1.0
Wet Cool Sub-boreal Spruce – Willow variant	SD (MD) 0.89	SD 0.94	F 0.96	F 0.99	M 1.0
Wet Cool Engelmann Spruce – Subalpine fir – Cariboo variant	F (MD) 0.97	F (SD) 0.99	F 0.99	M 1.0	M 1.0

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[1] TACA model only provides values to 1.0 which indicates that a site does not suffer a water deficit as is therefore moist or wetter. The model is unable to calculate the amount of moisture present on moist to very wet sites. Assignments are based on both the expert estimates and the TACA score.

Table 5. **Estimates of Actual Soil Moisture Regime (ASMR) class by biogeoclimatic unit and Relative Soil Moisture Regime class when the 10 most extreme values of annual heat index were used. AET/PET values show below ASMR class. Where class changed from those generated using values spread out through the range the original value is shown in brackets. ASMR classes described in Table 3.**

BGC unit	Relative Soil Moisture Regime				
	Xeric	Subxeric	Submesic	Mesic	Subhygric
Very Dry Hot Bunchgrass – Thompson variant	ED 0.38	ED 0.44	ED 0.47	ED (VD1) 0.52	F 0.98
Very Dry Hot Interior Douglas-fir Okanagan variant	VD1 0.55	VD1 (VD2) 0.60	VD1 (VD2) 0.63	VD2 (MD) 0.68	F 0.98
Dry Mild Interior Douglas-fir – Kootenay variant	VD1 (VD2) 0.60	VD1 (VD2) 0.64	VD2 (MD) 0.67	VD2 (MD) 0.72	F 0.99
Dry Cool Sub-boreal Spruce	VD2 (MD) 0.70	MD 0.76	MD (SD) 0.80	SD 0.85	M 1.0[1]
Moist Warm Interior Cedar Hemlock – Thompson variant	VD2 (MD) 0.74	MD 0.79	MD (SD) 0.81	SD 0.85	M 1.0
Wet Cool Sub-boreal Spruce – Willow variant	SD 0.88	SD 0.92	F 0.95	F 0.98	M 1.0
Wet Cool Engelmann Spruce –	SD (F) 0.92	F 0.96	F 0.98	M 1.0	M 1.0

Subalpine fir –

Cariboo variant

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[1] TACA model only provides values to 1.0 so Moist assignments are based on both TACA and expert estimates.

Table 6. Current tree species distribution in British Columbia over actual soil moisture regime classes for selected species across a range of ASMR limits.

Tree species	**Actual Soil Moisture**					
	ED (1)	**VD1 (2)**	**VD2 (3)**	**MD (4)**	**SD (5)**	**F (6)**
Pinus ponderosa	■	■	■	■	■	■
Pseudotsuga menziesii		■	■	■	■	■
Larix occidentalis			■	■	■	■
Pinus contorta var. latifolia				■	■	■
Thuja plicata				■	■	■
Picea glauca x *engelmanii*					■	■
Tsuga heterophylla					■	■