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A Stand-Level Drought Risk Assessment Tool for Considering Climate Change in Forest Management

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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 and Stephenson 2007) and worldwide (McDowell et al. 2008; Allen et al. 2010). Changes in tree species distributions as a response to climate change have been examined at a broad level in British Columbia (e.g., Hamann and Wang 2006), but the varied response of individual tree species at the stand level to differing site properties, such as soil moisture regime, is needed to inform stand-level management. From 2009 to 2013, a Drought Risk Analysis and Decision Support Tool was developed by B.C. Ministry of Forests, Lands and Natural Resource Operations (FLNRO) researchers and was funded by the Future Forest Ecosystem Science Council, Project B5 (www2.gov.bc.ca/gov/content/environment/natural-resource-stewardship/natural-resources-climate-change/natural-resources-climate-change-applied-science). The project focussed on predicting soil moisture availability at the site level in response to climate change, and resulted in the development of the Stand-Level Drought Risk Assessment Tool. Since that time, the tool has been further developed and used for projecting drought-related effects of climate change on tree species across British Columbia. This Extension Note highlights the Stand-Level Drought Risk Assessment Tool methods, field validation, some of the current applications, and how the tool could be used in the future.

Description

The Stand-Level Drought Risk Assessment Tool uses a water balance approach first described by Pojar et al. (1987), referred to as actual soil moisture regime (ASMR). Actual soil moisture regime is a classification scheme used to quantify soil moisture regime based on the number of months that rooting-zone groundwater is absent during the growing season, and is defined by the ratio of actual evapotranspiration (AET) to potential evapotranspiration (PET). Potential evapotranspiration is a measure of the ability of the atmosphere to remove water from a surface through the processes of evaporation and transpiration, assuming no control on water supply (Pidwirny 2006). Actual evapotranspiration is the quantity of water that is actually removed from a surface due to the processes of evaporation and transpiration (Pidwirny 2006). The climatic component for determining ASMR was derived using long-term daily climate data from Environment Canada weather stations that were associated with biogeoclimatic (BGC) units, while the site component was derived using site and soil conditions that represented a relative soil moisture regime (RSMR). For each combination of BGC unit and RSMR, an ASMR value (i.e., AET/PET) can be estimated. To estimate the ASMR value, a subcomponent of a tree and climate assessment tool (TACA) was used (Nitschke and Innes 2008). The TACA tool uses the AET/PET ratio to predict drought based on an annual water balance approach (Oke 1987). Estimates of AET/PET for sites were derived from climate variables (precipitation, minimum and maximum temperature), soil characteristics (percent coarse fragments, soil texture, rooting depth), and slope position (shedding, receiving, or neutral). Soil characteristics and slope position are the major determinants of RSMR used in the Biogeoclimatic Ecosystem Classification (BEC) edatopic grid.

Once a BGC unit/RSMR combination was assigned to an ASMR value, the FLNRO BEC database of more than 50 000 data entries from field plots was searched for situations where a tree species occurred in plots assigned a particular BGC unit/RSMR but not in plots in the next driest RSMR. If a tree species was not present in plots that represent the drier RSMR in a general area where that species is common, then it was assumed the species was not on the drier sites because its drought tolerance had been exceeded. Thus, the ASMR for this next driest RSMR was used as a drought or soil moisture threshold. If there was more than one of these situations, the average of the ASMR threshold values was used. Through this process, tree species distributions have been assigned to their extent across the ASMR gradient (i.e., from AET/PET values for the driest to wettest sites that a tree species occupies). The ASMR gradient was then divided into risk categories (Table 1). Very high risk was considered to occur when the ASMR (i.e., AET/PET) value was lower than the tree species threshold. In the absence of any information by which to assign values to the lower risk categories, increments of +0.05 were used (Table 1). Table 2 illustrates situations where a particular tree species was at its ASMR threshold (limit) during past climatic conditions and is now exceeded in current climate as well as further into the future. Future climate projections used in the tool were from ClimateWNA for a selection of models and emission scenarios (Wang et al. 2006). Figure 1 summarizes the process of obtaining the risk category value.

TABLE 1 *Actual soil moisture regime (ASMR) values for drought risk categories for some common tree species in British Columbia*

Tree species	ASMR value by risk category: Very high	High	Moderate	Low
Douglas fir	< 0.6	0.60–0.65	0.66–0.71	> 0.71
Lodgepole pine	< 0.76	0.76–0.81	0.82–0.87	> 0.87
Western redcedar	< 0.77	0.77–0.82	0.83–0.88	> 0.88
Hybrid spruce	< 0.8	0.80–0.85	0.85–0.90	> 0.90

TABLE 2 *Actual soil moisture regime (ASMR) values for future climatic periods where past conditions were near the soil moisture threshold of a particular tree species*

BGC unit/RSMR[a]	ASMR value by climatic period: Past (1961–1990)	2020s (2010–2039)	2050s (2040–2069)	2080s (2070–2099)
PPdh2/xeric (Fd)	0.61	0.57	0.53	0.50
ICHdw1/subxeric (Pl)	0.76	0.73	0.70	0.68
ICHwk2/xeric (Cw)	0.78	0.75	0.70	0.65
SBSdk/subxeric (Sx)	0.81	0.77	0.74	0.72

a BGC: biogeoclimatic; PPdh2: Ponderosa Pine Kootenay Dry Hot (Fd: Douglas-fir); ICHdw1: Interior Cedar–Hemlock West Kootenay Dry Warm (Pl: lodgepole pine); ICHwk2: Interior Cedar–Hemlock Boundary Dry Warm (Cw: western redcedar) SBSdk: Sub-Boreal Spruce Dry Cool (Sx: hybrid spruce); RSMR: relative soil moisture regime.

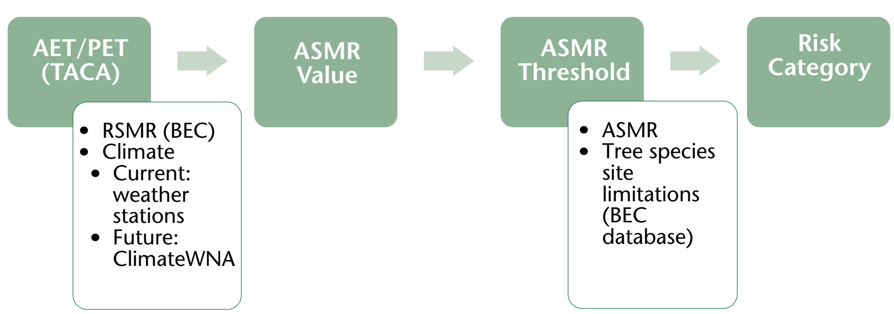

FIGURE 1 *Steps involved in creating a drought risk category by tree species using actual soil moisture regime (ASMR) values (AET/PET: actual evapotranspiration/potential evapotranspiration; TACA: tree and climate assessment tool; RSMR: relative soil moisture regime; BEC: Biogeoclimatic Ecosystem Classification).*

Testing and Field Validation

Field testing conducted in 2011 in the Sub-Boreal Spruce (SBS) zone of central British Columbia examined the response of hybrid spruce and Douglas-fir over a range of ASMR values. Hybrid spruce is a dominant but drought-intolerant species and is predicted to decline over much of its range with future climate change, while Douglas-fir is more drought-tolerant and is expected to expand its range in the SBS (Hamann and Wang 2006). The four field sites represented a xeric and mesic site within each of two geographic locations (areas of Fort St. James and Bear Lake in central British Columbia), which represented a dry/warm climate and a moist/cool climate. Actual soil moisture regime modelled projections from the Stand-Level Drought Risk Assessment Tool across all four field sites indicated that hybrid spruce was at moderate to high drought risk, while Douglas-fir was at low risk. Recent trends in tree growth, represented by average ring width (RW), and recent trends in drought stress, represented by analysis of stable carbon isotope ratio (δ13C) and root non-structural carbohydrates (NSC), were examined across the range of ASMR values.

During the growing seasons (May–September) of 1961–2010, at Environment Canada's weather station in Fort St. James, mean temperature increased significantly (0.2°C/decade), but there was no trend in precipitation. Results from Wiley et al.[1] indicated increasing drought stress and slower growth for hybrid spruce during this period, but there was little effect on Douglas-fir. Average ring width declined for spruce at all sites except the moist/cool–mesic site, with the greatest decline occurring at the dry/warm–mesic site, while average RW for Douglas-fir declined only at the moist/cool sites. Root NSC and average RW were lowest at the dry/warm–xeric site for both species. Stable carbon isotope ratio (δ13C) was also least negative for spruce at the dry/warm–xeric site, which indicated greater water stress. Between sites, average RW declined with increasing δ13C in spruce but not in Douglas-fir. These results support the projections from the Stand-Level Drought Risk Assessment Tool.

Additional field sampling was conducted in 2016 by running the tool for the 2020s (climate modelling period spanning 2010–2039) and projecting areas of very high and low drought risk to direct the selection of field sites. The focus was on capturing information in the SBS Dry Warm Blackwater variant (SBSdw2) and SBS Dry Warm Stuart variant (SBSdw3) BEC site units in the Prince George Timber Supply Area (TSA) to examine any potential effect of the growing-season droughts of 2012–2015 on mature spruce stands in light of the recent spruce beetle outbreak (Westfall and Ebata 2016). At Environment Canada's weather station at the Prince George airport, growing-season precipitation in 2012–2015 was 20–50% lower and mean temperature was 0.6–1.7°C warmer than the averages calculated over the period of record (1942–2016). Furthermore, Prince George had 7 consecutive years of below-average growing-season precipitation between 2009 and 2015, most significantly in 2014, which was the driest growing season on record: 50 mm less rain fell that year compared with the previous record. Field sampling included the collection of ecological variables, tree cores (for average ring width, stable carbon isotope ratio analysis, and root samples for non-structural carbohydrates analysis), and a visual forest health assessment at 24 field sites (12 at high risk for drought and 12 at low risk). Results from the tree core analysis were not available at the time of publication; however, when they become available, they will provide information on potential current stress and growing conditions over time. Field validation work for upcoming field seasons will be directed at assessing additional tree species in British Columbia.

Current Applications

Mapping of drought risk is the most common application of the tool. A site-specific (BGC unit by RSMR) and tree species–specific assignment of drought risk class given current and future climatic conditions is assigned to polygons generated from overlaying Predictive Ecosystem Mapping (PEM) and Vegetation Resources Inventory (VRI) data. A risk rating is based on the PEM site series assignment (the most limiting RSMR is used where a site series crosses multiple RSMRs) and tree species from VRI. This type of mapping has been done for the Prince George, Cranbrook, and Williams Lake TSAs and for the City of Prince George. Figure 2 shows different drought risk levels for hybrid spruce in the Prince George TSA. A Microsoft Excel© version of the tool is available online to allow users to calculate the relative risk of drought-induced mortality in the current climate and in projected climates of the 2020s, 2050s, and 2080s within BEC units of the Prince George and Cranbrook TSAs (www.for.gov.bc.ca/hfp/silviculture/TSS/D rought_Risk.html). Information from the tool, once validation and any necessary updates have been completed, can be used to inform timber supply modelling and indicate areas at risk of forest health concerns or increased fire severity.

1 Wiley, E., B.J. Rogers, H. Griesbauer, and S.M. Landhausser. Recent effects of warming on hybrid spruce and Douglas-fir growth on sites with contrasting soil moisture regime in both dry and moist ecosystems in central British Columbia. Unpubl. rep.

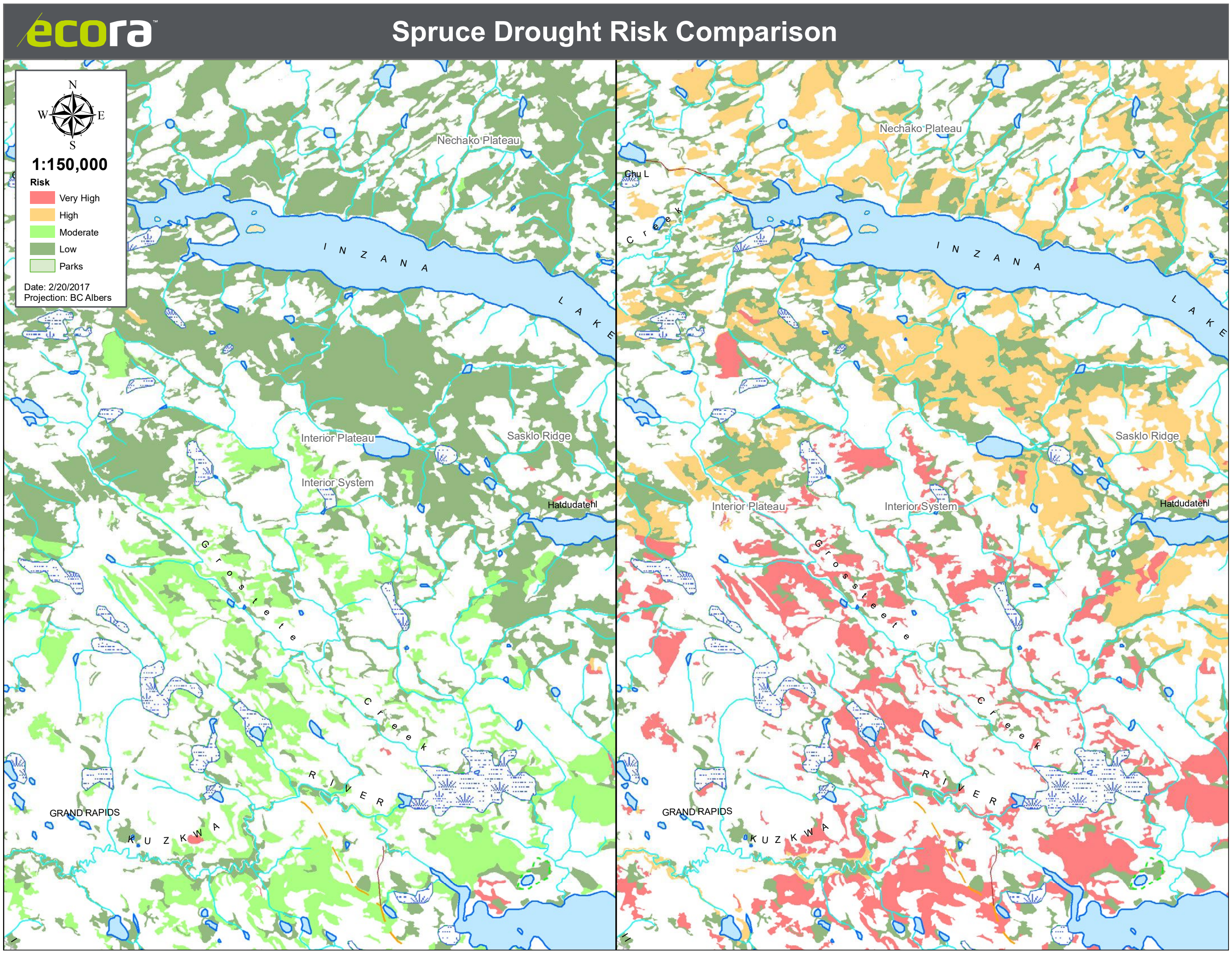

FIGURE 2 *Example of Stand-Level Drought Risk Assessment Tool mapping for risk of mortality from drought for mature hybrid spruce in the Stuart-Nechako Natural Resource District (Inzana Lake area) for current climate (left) and 2080s climate projection (right).*

Summary

Preliminary field testing results indicate the actual soil moisture regime risk category produced by the Stand-Level Drought Risk Assessment Tool correlated well with indicators of tree stress in the Sub-Boreal Spruce zone of central British Columbia. Further field testing was conducted on spruce in the Prince George TSA in 2016; results were not available at the time of publication but will be available in the future. The field assessment will be extended to additional tree species to complete the validation of the tool. Preliminary mapping results of stand-level drought risk for the Prince George, Cranbrook, and Williams Lake TSAs are available by contacting the authors. The authors welcome feedback from users on how well the Microsoft Excel© online version of the tool represents current drought risk for the BEC units available.

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Literature Cited

Allen, C.D., A.K. Macalady, H. Chenchouni, D. Bachelet, N. McDowell, M. Vennetier, T. Kitzberger, A. Rigling, D.D. Breshears, and E.H. Hogg. 2010. A global overview of drought and heat-induced tree mortality reveals emerging climate change risks for forests. For. Ecol. Manag. 259:660–684.

Hamann, A. and T. Wang. 2006. Potential effects of climate change on ecosystem and tree species distribution in British Columbia. Ecology 87:2773–2786.

McDowell, N., W.T. Pockman, C.D. Allen, D.D. Breshears, N. Cobb, T. Kolb, J. Plaut, J. Sperry, A. West, and D.G. Williams. 2008. Mechanisms of plant survival and mortality during drought: why do some plants survive while others succumb to drought? New Phytologist 178:719–739.

Nitschke, C.R. and J.L. Innes. 2008. A tree and climate assessment tool for modelling ecosystem response to climate change. Ecol. Modelling 210:263–277.

Oke, T.R. 1987. Boundary layer climates. Routledge, Cambridge, U.K.

Pidwirny, M. 2006. Actual and potential evapotranspiration. Fundamentals of physical geography. 2nd ed. www.physicalgeography.net/fundamentals/8j.html

Pojar, J., K. Klinka, and D.V. Meidinger. 1987. Biogeoclimatic ecosystem classification in British Columbia. For. Ecol. Manag. 22:119–154.

Van Mantgem, P.J. and N.L. Stephenson. 2007. Apparent climatically induced increase of tree mortality rates in a temperate forest. Ecol. Letters 10:909–916.

Wang, T., A. Hamann, D.L. Spittlehouse, and S.N. Aitken. 2006. Development of scale-free climate data for western Canada for use in resource management. Int. J. Climatol. 26:383–397.

Westfall, J. and T. Ebata. 2016. 2015 summary of forest health conditions in British Columbia. B.C. Min. For., Lands Nat. Resource Ops., Resource Pract. Br., Victoria, B.C. www2.gov.bc.ca/assets/gov/environment/research-monitoring-and-reporting/monitoring/aerial-overview-survey-documents/2015-fh-bc-overview.pdf

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