Mapping of stress on native tree species across the western United States and Canada: interpretation of climatically-induced changes using a physiologically-based approach

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Executive Summary

Using a process-based forest growth model, we calculated realistic monthly water balances across western North America to predict the occurrence of large fires in the years 2001, 2004, and 2007 with 70% accuracy. By constructing a series of decision-tree models based on species' tolerance to drought, frost, high evaporative demand and suboptimal temperatures, we predicted where 20 coniferous species are currently present or absent with an average accuracy of 84%. Using the same models, we identified areas unlikely to be suitable for each of the species throughout the 21st century depending on different rates that CO_2 are emitted from the burning of fossil fuels and changes in carbon stored in vegetation and soil. The rates of projected climatic change are so rapid that many forests are likely to be severely stressed and unable to migrate to more favorable habitat without assistance. In a series of review papers we discuss ways to apply remote sensing to improve model accuracy to better meet the needs of policy makers and managers. Fifteen publications were supported by this grant.

Project Objectives*:* to refine species distribution models to predict where climatic conditions have become more, and less favorable for 20 native conifers of western North America. A secondary goal was to predict where and when conditions change that result in tree mortality and create barriers to species migration.

Results

Although we found it possible to recognize (and predict) those sub- regions in western North America experiencing major outbreaks of fire, insects, and disease (1), managers and decision makers require more precise assessments of vulnerable areas, and how conditions may change. Decadal averaging of climatic conditions proved inadequate to predict drought (2,3,4). Also the effects of drought on species distribution (5), growth (6,7), and mortality (2,3) cannot be assessed accurately without good estimates of the amount of water that can be stored in the rooting zone. Passive satellite-derived-estimates of leaf area index (LAI) provide a basis for estimating seasonal and inter-annual variation in the availability of water (4,8), but are imprecise compared to those that can be derived with airborne LiDAR (9).

With improved estimates of seasonal soil water deficits across the entire study area (Fig.1), we were able to predict where fires > 10 km^2 occurred with 70% accuracy for individual years (Fig. 2). While not all of western North America is getting drier, all is getting warmer (6). The warming of a few degrees during the spring and summer is sufficient to favor outbreaks of insects and disease. Bark beetles are causing extensive tree mortality in many areas (11). In places where thinning is possible to reduce competition for resources, we established that reduction in stocking to reduce risk need to be made in reference to the maximum leaf area index or related measures such as maximum basal area per hectare (12). With continued warming, bark beetles native to western species have the potential to spread eastward on related hosts (13).

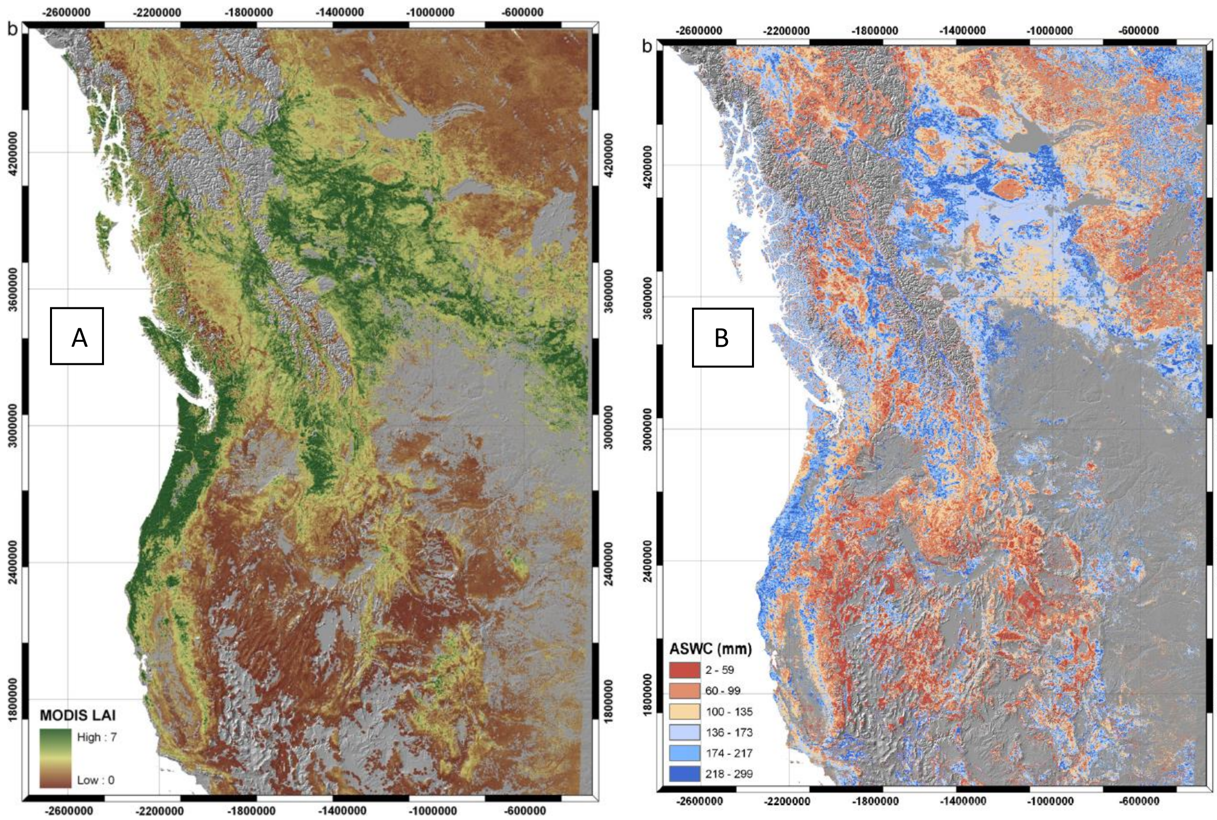

Fig. 1. (A) Process-based models are constrained by using MODIS satellite-derived estimates of maximum leaf area index (LAI). (B) Knowledge of maximum LAI provides a benchmark for models to calculate water use and derive estimates of available soil water capacity (ASWC) across western North America (8).

Adding information on soil water storage capacity (Fig. 1B) allowed us to estimate drought stress on deeply rooted trees, and thereby predict fuel conditions and outbreaks of fire (Fig. 2) recorded by MODIS across western North America with 70% accuracy between 2000 and 2010 (10) Research continues where wetter conditions rather than drought favor outbreaks of needle-cast diseases.

Conditions where native tree species can compete with other vegetation and not be threatened by insects and disease are not always those where tree growth is optimum. For example, less frost combined with warmer and wetter growing conditions are conductive to major outbreaks of leaf-needle cast diseases on Douglas-fir in Oregon and lodgepole pine forests in British Columbia. Our research, as well as that of others, indicates that the rates of climate change under low, as well as high carbon-emission scenarios is likely to create large areas of forests vulnerable to attack from insects and disease (Fig. 3). Although new areas are projected to become available, they are often far beyond the distance (2 km a decade) that seeds are

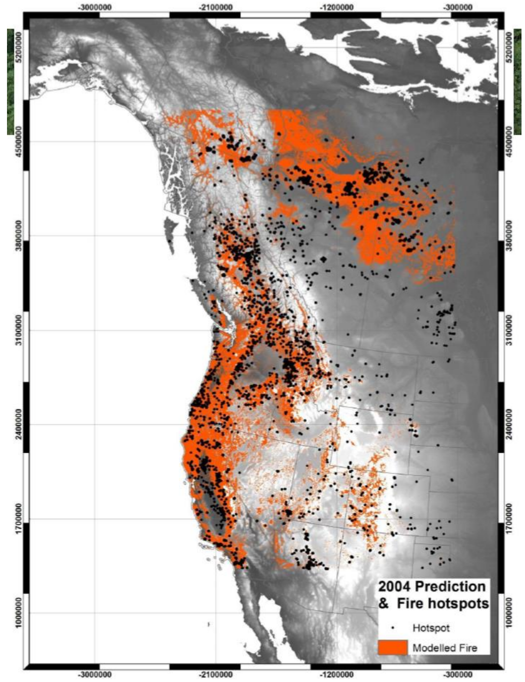

Fig.2. By calculating monthly soil water balances, our models predict soil water deficits and related conditions that raise the probability of fire (area shown in red) which compare well with those areas burnt (areas shown in black (10).

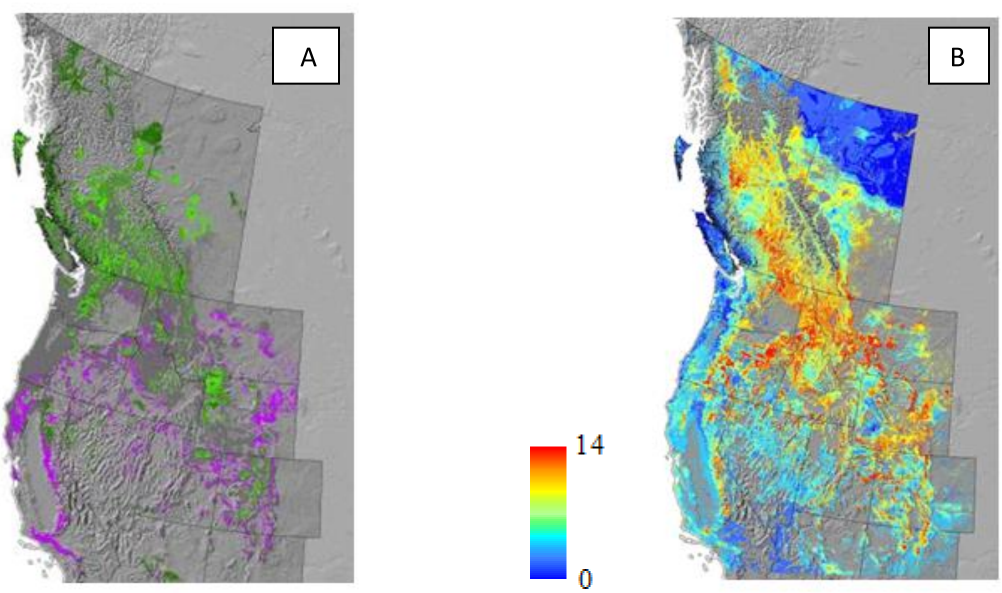

Fig.3 A. Depending on when CO_2 emissions peak in the 21^{st} century, environments favorable for Douglas-fir become more available to the north while stress is predicted to increase on populations at the southern and eastern parts of its range. B. Fourteen out of twenty coniferous tree species are predicted to be stressed in the areas shown in red between 2075-2100 under a moderate CO_2 emission scenario (peak reached by 2050). (12)

likely to be dispersed naturally (11). We recognized areas where corridors might be beneficial to establish and maintain, as well as places where assisted migration would be a necessity in the near future (11).

A series of review articles were published under support from this grant that include sections on the application of remote sensing in forestry and related disciplines (14 -16). One paper broke new ground in the field of dendrochronology by demonstrating how interannual variation in the growth of tree-rings can be interpreted more mechanistically using process-based growth models (17) and another used sophisticated remote sensing combined with ground-based surveys of grazing animals to determine the cause for recent degradation of grasslands on the steppes of Mongolia (18).

Acknowledgment

We appreciative NASA's policy that encourages research that extends beyond the bounders of the United States. This policy has led to global-scale analyses and collaboration that other countries appreciate and emulate. In addition, we applaud the opportunities provided at team meetings where joint programs engage in discussions that advance and integrate research on the land, oceans, and atmospheres.

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* Total publications supported from this NASA grant to date is 15 including two written for more general audiences (listed below)

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