Modeling and Monitoring Ecosystem Performance of Boreal Forests in the Yukon River Basin

Bruce K. Wylie[1], Norman Bliss[1], Lei Ji[1], Li Zhang[2], Larry Tieszen[3], W.M. Jolly[4]

[1]ASRC Research and Technology Solutions, contractor to the U.S. Geological Survey (USGS) Earth Resources Observation and Science (EROS) Center. Work performed under USGS contract 08HQCN0007.
[2]SAIC, contractor to USGS EROS, Sioux Falls, SD. Work performed under USGS contract 03CRCN0001. [3]USGS EROS, Sioux Falls, SD. [4]U.S. Department of Agriculture Forest Service, Fire Sciences Laboratory, Missoula, Montana.

Introduction

We emphasize the ability to quantify ecosystem processes, not simply changes in land cover, across the Yukon River Basin in Alaska (Wylie et al., 2008 figure 1) (Wylie et al., 2008). The method builds upon remotely sensed measurements of vegetation greenness for each growing season. However, a time series of greenness often reflects annual climate variations in temperature and precipitation. Our method seeks to remove the influence of climate so that changes in underlying ecological conditions are identified and quantified. We define an "expected ecosystem performance" to represent the greenness response expected in a particular year given that year's climate. We distinguish "performance anomalies" as cases where the ecosystem response is significantly different from the expected ecosystem performance. Performance anomaly maps produced at 1-km resolution and associated anomaly trends provide valuable information on the ecosystem for land managers and policy makers. The results of their application to date offer a prototype to assess the entire Yukon River Basin, a task slated for completion with our Canadian counterparts for the entire archival period (1984 to current) at 1-km and at 250-m (2000 to current).

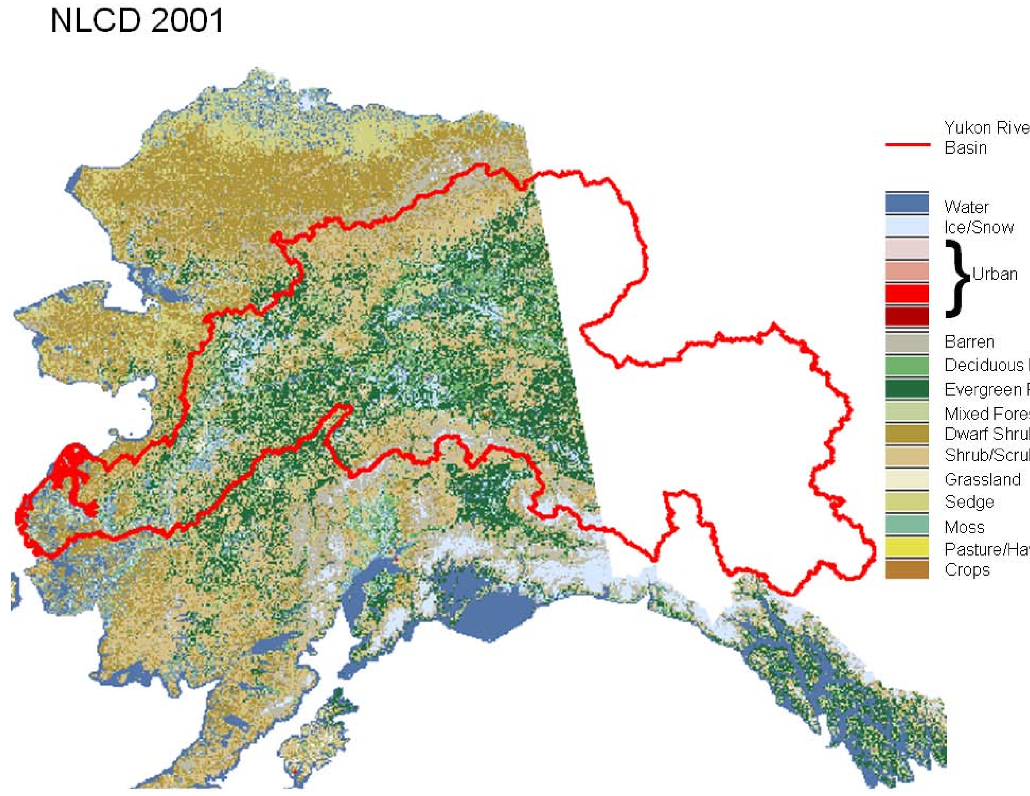

Figure 1. The Yukon River Basin and National Land Cover Database 2001.

Methods

A regression tree model was developed to predict growing season Normalized Difference Vegetation Index (NDVI) and numerous site conditions. We used 1-km Advanced Very High Resolution Radiometer NDVI 7-day composites integrated from April through the first week of October as a proxy for ecosystem performance. Using spatial climatic data and site potential information, annual maps of expected growing season NDVI from 1996 to 2004 were constructed from this model.

GSN = f(site potential , climate)

Growing Season Integrated NDVI (GSN) — *Modeled Long-term AVHRR GSN* — *Precipitation, maximum and minimum temperature for seasonal periods*

Winter, Spring, Summer

Site potential is the historical performance related to elevation, slope, aspect, soils, and other factors. Dry years have lower expected ecosystem performance and wet years have higher expected ecosystem performance. Areas that do not perform within a normal range determined by the regression tree model's expected error were identified as ecosystem performance anomalies. These anomalies are areas that responded to climatic conditions differently from areas with similar expected ecosystem performance.

The anomalies were validated using Composite Burn Index data from selected fires and Landsat spectral indices across a burned to unburned gradient. Linear time series trends in performance anomaly were mapped based on the significance and sign (positive or negative) of the slope.

Results

Expected Ecosystem Performance

Regression tree models predicted expected performance from site potential, climate data, and land cover (R^2 = 0.84) and showed little bias (figure 2). Withheld test locations had similar mean standard error of regression values as those of the model development dataset. Regression tree committee models were used, wherein each regression tree model possessed five different regression trees, each trying to improve predictions made by the previous regression tree model. This resulted in over 500 different piecewise multiple regressions being employed.

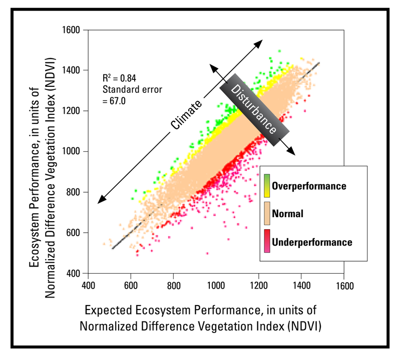

Figure 2. Anomalies defined by the ecosystem performance model's confidence limits.

Ecosystem Performance Anomaly

Significant ecosystem performance anomalies were determined at 90-percent confidence intervals of the expected ecosystem performance model (figure 2). Underperforming anomalies correlated with recent fires (figure 3).

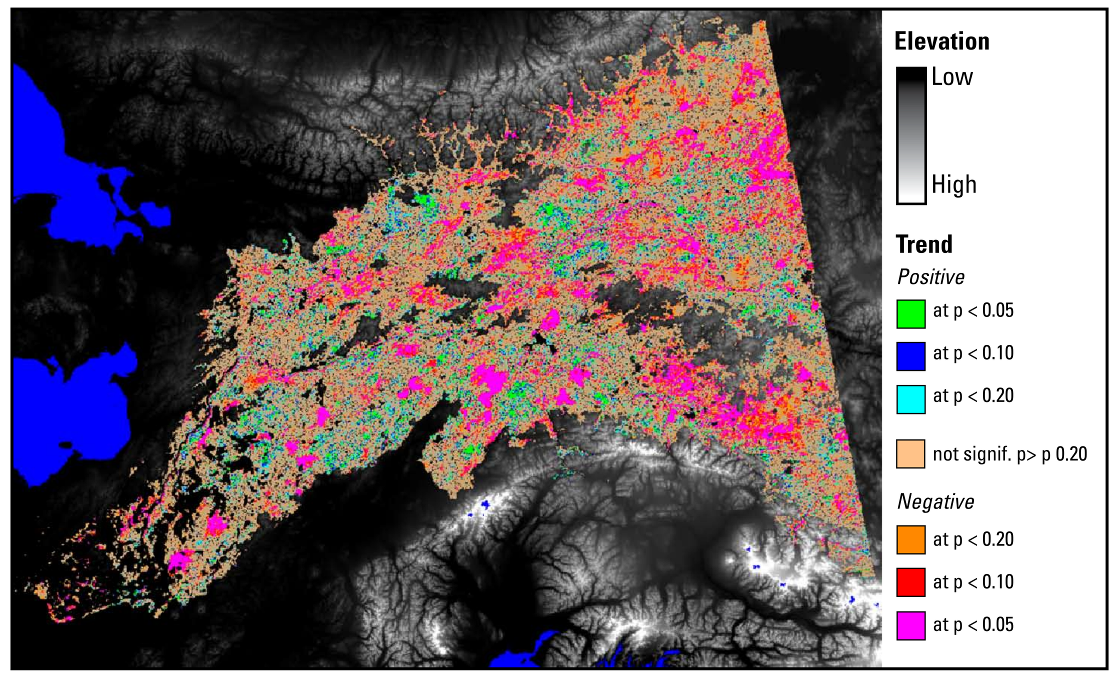

Figure 3. Ecosystem performance anomaly for 2004, with post-1997 fire perimeters. The colored portion of the image represents the Alaskan boreal forest areas within the Yukon River Basin.

Composite burn index (Epting et al., 2005) from selected fires validated the ecosystem performance results (Table 1).

Table 1. Agreement between the difference of pre- and post-fire ecosystem performance anomalies and the Composite Burn Index.

Fire (n)	Statistic	Years 2001	2002	2003	2004
242 (11) Witch fire	R^2	0.66	0.75	0.70	0.75
	MSE	0.40	0.29	0.35	0.29
260 (13) Jessica fire	R^2	0.55	0.43	0.68	0.68
	MSE	0.30	0.38	0.21	0.21
288 (14) Otter Creek	R^2	*	0.57	0.58	0.54
	MSE	*	0.24	0.24	0.26

* Burned 2001

Landsat spectral indices also agreed with performance anomalies across a burned to unburned gradient (figure 4).

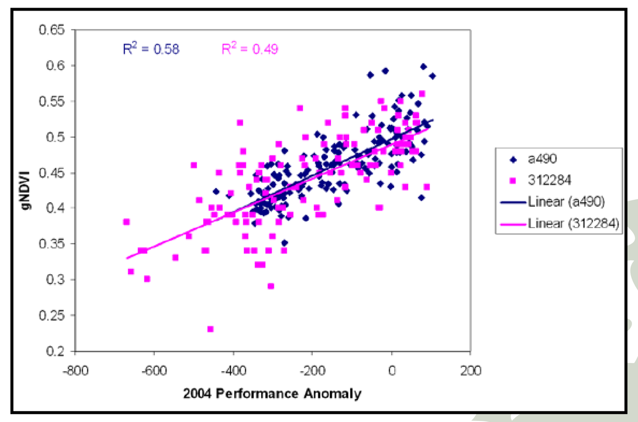

Figure 4. Agreement between 2006 Landsat green NDVI (Landsat bands (4-2)/(4+2)) and 2004 performance anomaly for burn a490 and 312284.

We investigated trends in post-fire performance anomalies and found that ecosystem performance in burned areas showed varying rates of recovery when compared to climatically predicted expected ecosystem performance (figure 5). This indicates that this approach identifies and quantifies post-fire vegetation succession, although ground validation of vegetation and surface cover are needed for further interpretation.

Areas with significant consistent performance anomalies over multiple years are likely boreal forests under environmental stress. Frequency and trend maps of performance anomalies emphasize areas, which perhaps experience degrading permafrost, marked by dryness, insect infestations, or disease (figure 6).

Areas with burn dates prior to the beginning of the study often exhibited positive trends during the study.

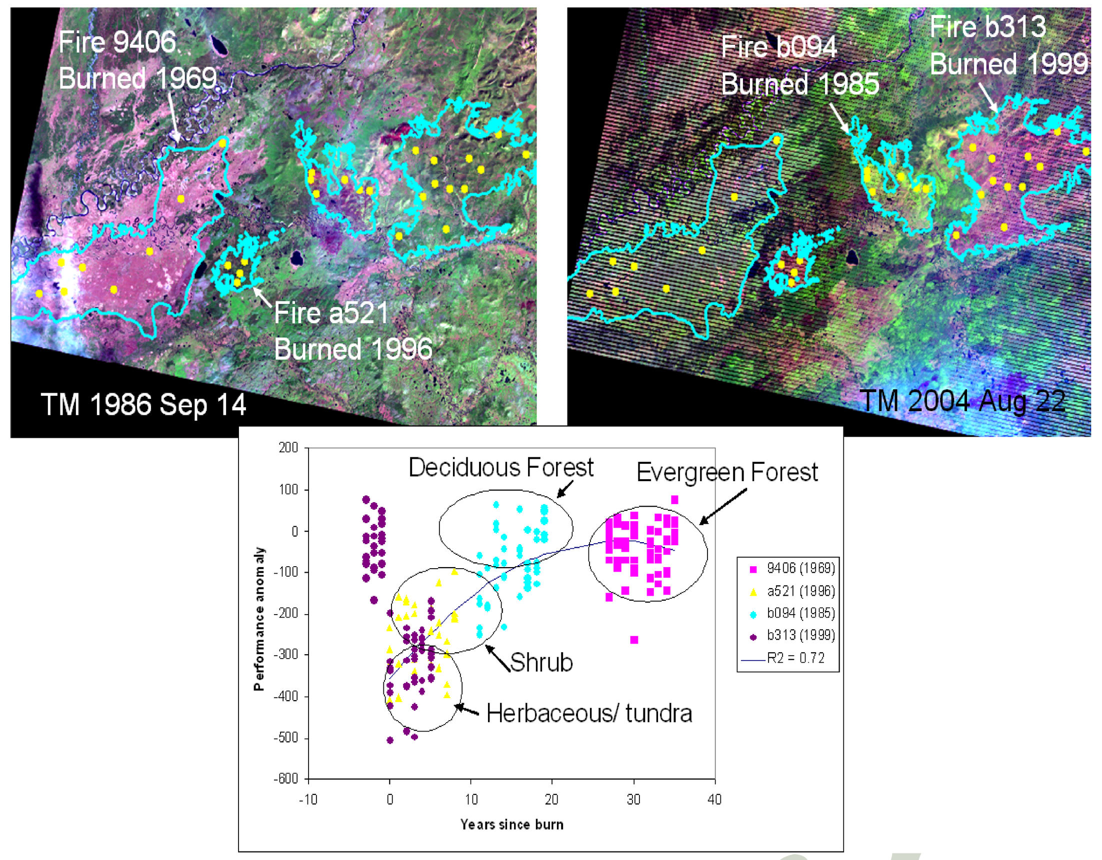

Figure 5. Temporally variant performance anomalies since burn. This may indicate post-fire vegetation types.

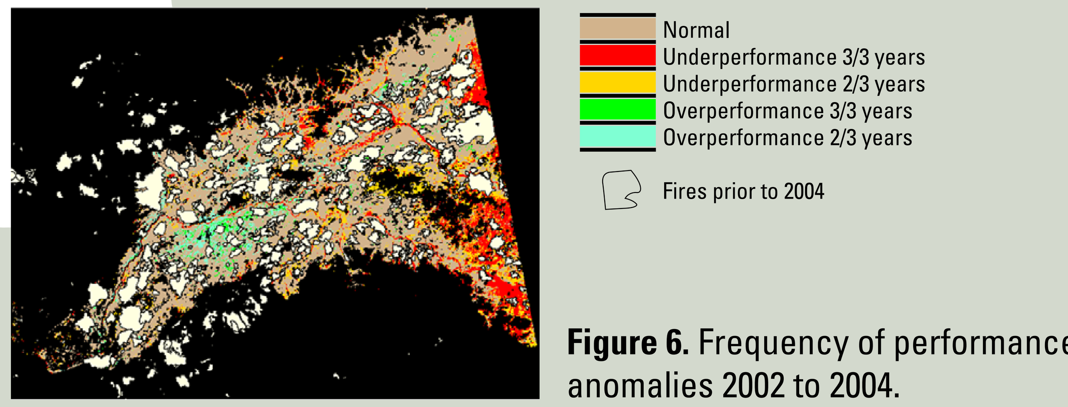

Figure 6. Frequency of performance anomalies 2002 to 2004.

Conclusions

Our approach uses climate data to account for interannual variations in ecosystem performance. The ecosystem performance anomalies reflect ecological changes that are caused by factors other than climate or site potential. The underperforming areas documented in this study were strongly associated with burn disturbances. Based on climate, portions of the study reveal boreal forest's performance is declining, and the trend appears more severe with time.

Acknowledgments

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References

Epting, J., Verbyla, D., and Sorbel, B. 2005. Evaluation of remotely sensed indices for assessing burn severity in interior Alaska using Landsat TM and ETM+. Remote Sensing of Environment 96: 328 – 339.

Saxon, E., Baker, B., Hargrove, W., Hoffman, F., and Zganjar, C. 2005. Mapping environments at risk under different global climate change scenarios. Ecological Letters, 8, 53 – 60.

Wylie, B.K., Zhang, L., Bliss, N., Ji, L., Tieszen, L., and Jolly, M. 2008. Integrating modeling and remote sensing to identify ecosystem performance anomalies in the boreal forest, Yukon River Basin, Alaska. Int. J. Digital Earth 1–2: 196-220.