ASSESSING THE IMPACT OF CLIMATIC STRESS ON FOREST PRODUCTION

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ABSTRACT

An extreme range in forest productivity occurs along a 300 km transect at 45 degrees N latitude in the Pacific Northwest region of the United States. Associated with this transect is a wide array of climates. Measurements made across the transect are serving to test principles on how climate constrains forest productivity. Previous research has demonstrated a linear relationship between intercepted photosynthetically active radiation and the production of dry matter by vegetation. This relationship did not hold for the variety of forest stand types found along the transect. It was hypothesized that three major climatic variables were constraining productivity: (1) freezing temperatures; (2) vapor pressure deficits; and (3) drought. These variables were incorporated into a simple model that effectively reduces annual intercepted photosynthetically active radiation to account for the environmental constraints. With this information we gauge the relative importance of each variable and their integrated effect upon forest productivity.

INTRODUCTION

To accurately predict future rates of carbon flux in the face of uncertain global change requires that we understand controls on primary production. This paper explores a method to explain differences in above-ground net primary production (ANPP) across diverse landscapes by applying simple relationships between plant physiology and climate.

The research reported here is from Oregon Transect Ecosystem Research Project (OTTER). The project is a joint Oregon State University-NASA study emphasizing remote sensing of ecosystem parameters. In support of the remote sensing, the project encompasses a large ground component involving the measurement of a variety of environmental variables including above-ground biomass, production and meteorological values.

STUDY SITES

Oregon provides an ideal location for testing principles of forest ecosystem function. The OTTER project focuses on six sites arrayed on a 300 Km transect across Oregon. This transect encompasses a wide range of climates and forest types (Figure 1). The forest stands along the transect display almost the complete range of forest net primary production found in North America (Gholz, 1982; Jarvis and Leverenz, 1984). The coastal site consists of two stands: an old-growth forest stand of sitka spruce and western hemlock (site 1), and a deciduous red alder stand (site 1A). Moving inland along the transect, the climate becomes increasingly more continental. Site 4, at an altitude of about 1500 meters, is probably most analogous to the Boreal biome. It is characterized by very cold winters, large amounts of snow, low annual mean temperatures and abundant moisture

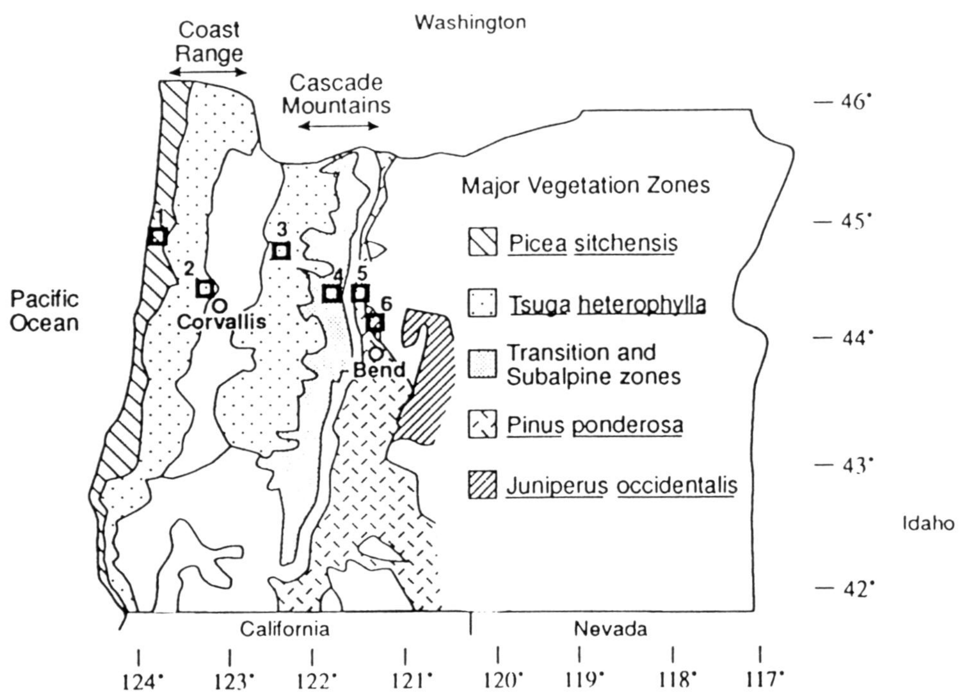

Figure 1. Map of the study area in Oregon showing the location of the study sites and the major vegetation zones.

during the growing season. The sites at the east end of the transect (sites 5 and 6) are characterized by cold winters and hot, dry summers.

METHODS

To accurately gauge the environment along the transect, each of the sites was equipped with a meteorological station. Beginning in the summer of 1989, the stations provided hourly measurements of temperature, precipitation, relative humidity and incoming short wave radiation. Forest surveys of tree numbers and diameters allowed us to compare biomass across the transect. In addition, for each stand across the transect, we measured both dry matter production (woody biomass and foliage) and the intercepted fraction of photosynthetically active radiation (IPAR). To determine ANPP, diameter growth was measured on increment cores from a random selection of trees at each site. Percent IPAR was measured using an integrating ceptometer under the forest canopy. Annual IPAR was determined by using the stand fraction of intercepted photosynthetically active radiation (PAR) multiplied by the total annual incident PAR.

RESULTS AND MODEL DEVELOPMENT

An extreme range of biomass is evident across the transect: from 471 Mg/ha in the moist coastal old-growth stand (site 1) to a low of about 10 Mg/ha in a juniper stand at the dry east end of the transect. Annual IPAR and ANPP also varied widely across the transect (Figure 2).

Monteith (1977) has observed a nearly linear relationship between dry matter production in well-watered agricultural crops and the amount of sunlight intercepted by the canopy. However, for the forest stands along the transect, the relationship between ANPP and annual IPAR is not linear (Figure 3). Obviously, annual IPAR does not account for all of the variability

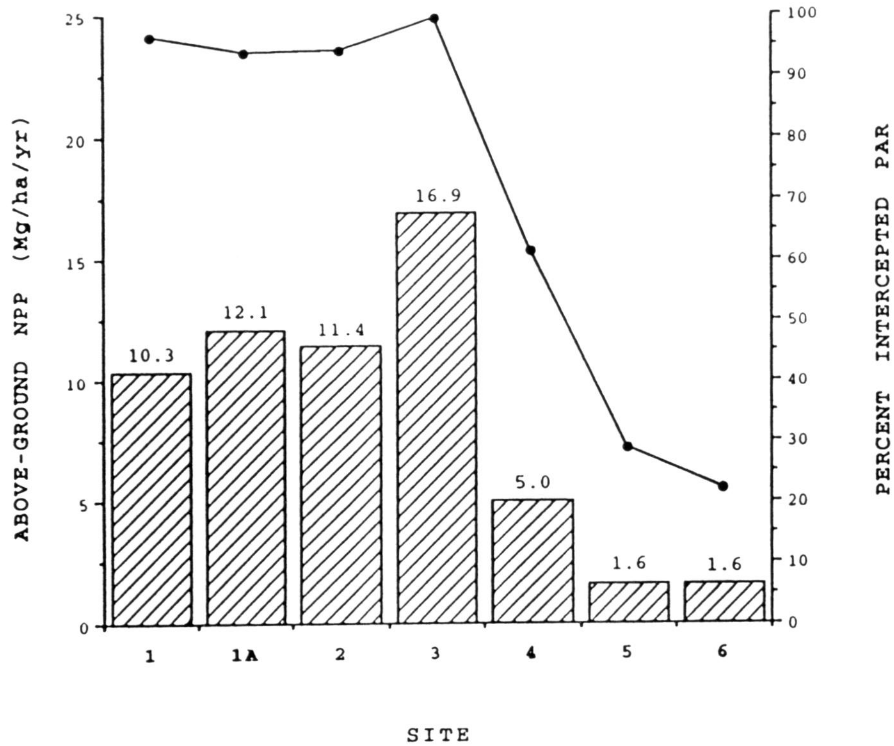

Figure 2. Trends of above-ground net primary production (left axis) and percent intercepted photosynthetically active radiation (IPAR) (right axis) across the Oregon transect.

in ANPP observed across the transect. This finding suggests that, in natural ecosystems, the efficiency of converting solar energy into dry matter production is a function of both the amount of intercepted light and the environmental constraints on photosynthesis.

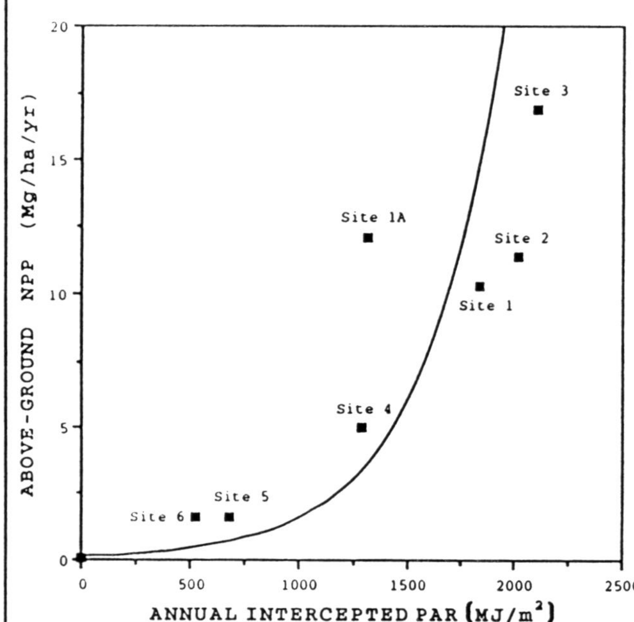

Figure 3. Estimates of annual intercepted radiation (IPAR) were not linearly related to above-ground net primary production across the Oregon transect.

To help explain the range of ANPP values found along the transect, we examined the major constraints on the utilization of photosynthetically active radiation. The term photosynthetically active radiation is somewhat a misnomer. It is not the radiation that is active, but rather it is green photosynthetic biomass. Green biomass has widely variable rates of photosynthesis, depending, largely, on environmental conditions. Previous research has demonstrated a relationship between patterns of ecosystem production and climate (Lieth, 1975). For this study, we hypothesized that the relationship between IPAR and dry matter production would primarily be affected by climate controls over tree-level physiological processes.

Table 1. Criteria for reducing intercepted photosynthetically active radiation (IPAR) based on physiological thresholds applicable to all major tree species in Oregon.

Freezing temperatures:
· If less than -2° C, assume no radiation utilized for 24-hr period
Soil drought:
· If predawn water potential is less than -1.5 MPa, assume no radiation utilized
· If predawn water potential is between -1.0 to -1.5 MPa, assume half radiation utilized
Vapor pressure deficits (VPD):
· If VPD exceeds 25 mb, assume no radiation utilized
· If VPD is between 15 to 25 mb, assume half radiation utilized

To predict yearly ANPP rates in relation to IPAR for the variety of forest stands and climates represented along the transect, we attempted to identify conservative environmental factors that are independent of ecosystem type and do not change from season to season. Based on established physiological principles, we defined the major constraints on photosynthesis across the transect. Three environmental parameters were identified to have primary control over production: freezing temperatures, soil drought and vapor pressure deficits. Much of the radiation intercepted during periods of frost, drought or high humidity deficits cannot be utilized due to stomatal closure (Waring and Schlesinger, 1985).

To account for these environmental controls on production, we developed some simple algorithms to calculate the amount of radiation intercepted by the canopy actually used each day (Table 1). We purposely defined broad thresholds that are more likely to apply to the wide range of species found across Oregon (Running and Couglan, 1988). Soil drought was assessed by measuring predawn water potentials of trees periodically through the dry season. Freezing temperatures and vapor pressure deficits were derived from the data collected by the meteorological stations.

The difference between annual IPAR and utilized PAR represent the restrictions that the climatic variables place on photosynthesis throughout the year. This measure of utilized PAR correlated closely with measurements of above-ground net primary production (Figure 4). One site, the old-growth sitka spruce/ western hemlock forest, showed demonstrably less growth than predicted. The reduced growth may be the result of increased maintenance costs associated with older, massive trees (Ryan, 1991). Our analysis did not account for reductions in net production resulting from high maintenance respiration.

The integrated effect of the climatic constraints in reducing annual IPAR ranged from less than 10% for the coastal forest to greater than 75% for the dry juniper woodland (Figure 5). In addition, this analysis provides an accounting of the relative contributions of the various environmental constraints in reducing annual IPAR. As expected, drought and freezing conditions were the primary climatic constraints on production for the sites at the east end of the transect.

CONCLUSION

Freezing temperatures, drought and vapor pressure deficits are major climatic limitations on forest production. The analysis of climatic constraints on annual IPAR offers a means of gauging the relative contributions of the various environmental components in reducing the effective amount of PAR utilized by a forest canopy. Monitored over time, application of this kind of analysis can offer insights into the role of climate in controlling net primary production.

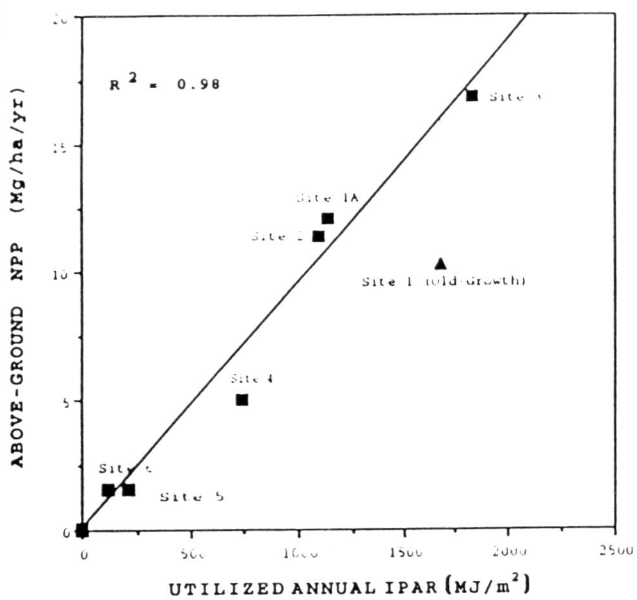

Figure 4. After accounting for physiological constraints to photosynthesis, the estimated utilized annual IPAR was closely related to observed above-ground net primary production (ANPP). An old-growth forest (site 1) was omitted from the regression.

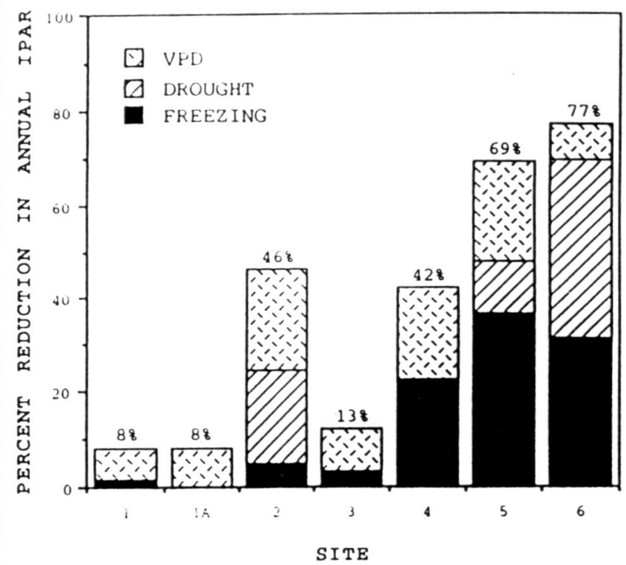

Figure 5. The fraction of intercepted radiation that could not be utilized by the various forest types because of freezing temperatures, drought, or excessive vapor pressure deficits (VPD) ranged from less than 10% at the moist western hemlock/sitka spruce forest to as much as 77% at the dry juniper woodland.

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