Wind and Ecosystem Response at the GLEES[1]

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Abstract.—Research was conducted to determine wind patterns and snow deposition at a high elevation alpine/subalpine ecotone site using deformation response of trees to prevailing winds. The research has provided detailed maps of wind speed, wind direction, and snow depth as determined from tree deformation. The effects of prevailing wind on tree blowdown at the site have also been described. This research is an example of interaction of biological and physical scientists working together to provide detailed description of an ecosystem response to the atmospheric environment.

Introduction

High elevation ecosystems are particularly vulnerable to atmospheric deposition and climatic change. These ecosystems are already highly stressed, and they experience environmental extremes which make plant survival difficult. They commonly experience extremely low temperature, with frosts likely to occur anytime during the growing season. They also experience moisture stress, particularly after snowmelt, because of the low moisture holding capacity of the relatively young and shallow soils. Soils are also low in CEC, and nutrient supply for growth is low. Nevertheless, many plants species have adapted to these harsh environments, and survive from year to year. Most of the vascular plant species occurring at these sites are perennial and rely on root reserves to survive especially difficult years.

The research described here was conducted at the Glacier Lakes Ecosystem Experiments Site (GLEES) in the Snowy Range of SE Wyoming (Musselman 1994). The site is a 600 ha alpine/subalpine ecotone watershed where research is conducted on atmospheric deposition effects on terrestrial and aquatic components of the ecosystem. The research site is located on the SE side of the Snowy Range Ridge. It is located at about 3400 m elevation, and is subject to strong, westerly, prevailing winds (Musselman 1994). Tree asymmetric deformation from wind is common at the site (Wooldridge *et al.* 1995a). Tree deformation occurs when blowing surface ice crystals erode tree needle epidermal tissue so that they are subject to desiccation and death. The result is survival of tree needles only on the downwind, lee side of the trees, and subsequent asymmetric growth of tree foliage and branches. Tree blowdown is common in certain areas of the GLEES, particularly in the eastern portion of the watershed. There is a definite directional pattern in the orientation of the downed trees.

Methods

We examined the degree of tree deformation from wind, and the direction of the deformation, to construct detailed maps of climatic wind speed, wind direction, and snow depth for the research site (Wooldridge *et al.* 1995a). A 300 ha portion of the watershed was divided in 100 m grids, with trees assayed at each grid corner. A smaller portion of the watershed (30 ha) was surveyed at a 50 m grid scale. Wind direction was measured by compass direction of the tree deformation of an Engelmann spruce (*Picea engelmannii*) or subalpine fir (*Abies lasiocarpa*) tree sampled at each grid corner. Wind speed was determined from the empirical relationship between amount of the tree deformation and the mean wind speed. Tree deformation was determined by two methods. The first classified deformation visually on a scale of 0-8, with 0 indicating no deformation and 8 indicating a full krummholz mat. The second method calculated deformation from photographs taken at right angles to the bending, with angle of bending used to determine the wind speed. Empirical equations were used calculate wind speed

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based on the deformation (Hewson *et al.* 1979; Wade and Hewson 1979). Wind speed was mapped on a 100 m grid or smaller map scale for the research site. The wind speed, wind direction, and snow depth maps were verified by long-term meteorological measurements taken at the site.

Snow depth was mapped based on 1) lack of deformation indicating snow cover protection from wind damage, or 2) presence of brown felt blight (*Herpotrichia juniperi*) damage indicating long-term snow cover. The height that deformation began on the trees, and the height that brown felt blight ended, was recorded at each grid point. Isopleths of wind speed and snow depth and wind speed were drawn from the map grid data.

A separate study examined direction of tree blowndown in relation to wind direction (Wooldridge *et al.* 1995b). Tree blowdown direction was determined by measuring compass bearing of downed trees on the ground, or orientation of downed trees on aerial photos. This information was related to wind speed and direction data. Prevailing wind direction was determined from the tree deformation study and from snowdrift patterns on aerial photos.

Results

These measurements demonstrated that in the local upper treeline landscape, spatial information on climatic wind speed, wind direction, and snow depth can be determined from tree deformation. Detailed climatic maps have been constructed from the data (Wooldridge *et al.* 1995a). The research also demonstrated that windthrow of trees at the site can be explained by the downslope high speed winds from the northwest or prevailing winds from the west (Wooldridge et al 1995b).

Wind speed and wind direction varied at the site, dependent on terrain features. The climatic mean wind speed at the study site was 7.4 m s-1 as determined from tree deformation. Mean annual wind speed from the meteorological tower at the site, using a standard anemometer, was 7.8 m s-1. The tower is at a location indicating an 8.0 m s-1 annual mean wind speed from tree deformation data. The two methods of determining wind speed (Hewson *et al.* 1979; Wade and Hewson 1979) provided estimates that were not significantly different. This study provided data for construction of a wind speed map for the site at a surface grid scale of 100 m or less resolution.

Wind direction is primarily westerly at the site, as indicated from the tree deformation and the meteorological tower wind vane. The tree deformation indicators located small scale terrain channelling, and some upwind divergence and downwind convergence around terrain obstacles.

Snow drift orientation was also useful to corroborate prevailing wind directions, and were consistent from year to year as determined from aerial photographs. They indicated a channeling of wind along the SE side of the Snowy Range Ridge, moving in a NE direction. In addition, winds moved from the NW over the crest of the ridge. NW to SE drifting was evident on the top of the ridge, and further SE of the GLEES research site. Drifting within the lee of the ridge indicated SW to NE channelling. A detailed map of wind direction at a scale of less than 100 m surface area was constructed for the GLEES from tree deformation data and from snow drifting patterns.

Isopleths of snow depth constructed from biotic indicators of tree deformation and brown felt blight showed a wide variation in depth, depending upon terrain features and exposure. Snow depth ranged from less than 0.2 m to 5.3 m as estimated from tree symmetry and brown felt blight. Shallow accumulations were found on exposed ridge tops and hills, and over the lakes where wind speeds are high. Mean snow depth for the East Glacier catchment portion of the site was 2.0 m as determined from the biotic indicators (Wooldridge *et al.* 1995a). A snow survey at the site indicated a mean snow depth of 2.6 m for 1991 (Sommerfeld *et al.* 1991). Lower snow depth obtained from biotic indicators than that obtained from the systematic snow survey occurred as predicted. Thus, to obtain accurate estimates of snow depth, biotic indicators of snow depth must be adjusted up by about 20-25%.

Tree blowdown indicated a bimodal direction for windthrown. The bimodal peaks of approximately 265 and 310 degrees, correspond to (1) the prevailing westerly winds and (2) gusts > 20 m s-1 from over the main southwest to northeast quartzite ridge of the Snowy Range. Most blowdown appeared to be from the downslope gusts, with slightly lesser amounts of blowdown from the prevailing winds. Fewer than 10% of the trees were downed in directions outside of 220 to 360 degrees.

Discussion and Conclusions

This study provided for the construction of detailed wind speed, wind direction, and snow depth maps of the research site. The maps provide information at a surface area scale of 100 m or less. The data provide a cost effective and accurate measure of long-term wind patterns at the site, and provided important information to explain ecosystem response to these meteorological patterns. The study provided detailed microsite wind speed data and prevailing wind information for the research area not possible from the one meteorological station located at the site. The maps help describe microclimatic conditions and resulting vegetative habitat at a small scale at the site. They have been used to model tree invasions into meadows at the upper treeline ecotone (Moir and Lee 1990).

The direction of the tree deformation is an indication of the prevailing winds, particularly those which occur in winter when the trees are most subject to desiccation. Meteorological tower data at the site indicate that winds speeds are higher in the winter, although prevailing winds are WNW year round. The study demonstrated the important influence of terrain on wind direction and local channelling from small terrain features.

The tree deformation indicator of wind speed provided an estimate of mean annual wind speed at the site. The tree indicators will integrate effects of desiccation, with desiccation in years of high wind speeds, but regrowth upwind in years with lower wind speeds. The Griggs-Putnam index (Hewson *et al.* 1979) and the Wade and Hewson (1979) methods provided similar estimates of wind speed. Since the Griggs-Putnam method is quicker and easier to use, it can be used directly in the field, and provides estimates of wind speed at a scale not possible from weather stations. Data from a meteorological station at the GLEES indicated that the method provides reasonable estimates of mean annual wind speed. It is the method of choice for estimation of wind speed in the absence of meteorological data.

The snow depth indicator by tree deformation is an estimate of the annual snow accumulation in low snowfall years. Thus, it will underestimate mean annual snow accumulation. The height that deformation begins is at the snow surface. The highest concentration of wind blown ice crystals occur a few cm above the snow surface, causing desiccation and death in this surface layer. In low snowfall years, this desiccation will be lower on the tree. Since growth does not reoccur on these lower portions of the tree, the height of the deformation is an indication of the low snowfall year snowdepths.

Brownfelt blight causes death of coniferous foliage when the foliage is under snowcover for a long period of time. Thus, brown felt blight would be an indicator of high snowfall years when snowdepth is deep and long lasting. However, brown felt blight was less useful as an indicator, since its occurrence was infrequent throughout the site.

The research indicates that topography has a major effect on wind speed, wind direction, and snow depth at the site. Snow depth is a good indicator of amount of atmospheric deposition. Areas of deeper snow accumulation will have higher chemical deposition, since snow has an associated chemical component. In addition, physical and micro-environmental factors which favor snow accumulation, such as areas of low turbulence causing settling, will also favor deposition of the larger particulate portion of dry deposition. Thus, areas where there is more snow deposition are areas with larger amounts of wet and dry chemical deposition.

The areas with the deepest snow accumulation often have snow cover lasting longer into the growing season. Examination of habitat characteristics at the research site studied here indicate that wind, through its effect on tree deformation and tree blowdown, has an important effect on these ecosystems. Wind, in association with terrain features, also has a major influence on snow accumulation. The snow accumulation and associated chemical deposition and snowmelt duration, in turn, have a major influence on the adaptation and survival of plants, the distribution of plant communities, and the resultant vegetative habitats which occur in each area of the study site.

The bimodal pattern of tree blowdown at the site was explained by the direction of the prevailing winds and wind gusts. The blowdown has implications for tree survival in this ecosystem, and the vegetative habitats which occur at these sites.

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