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Effect of Root Strength and Soil Saturation on Hillslope Stability in Forests with Natural Cedar Decline in Headwater Regions of SE Alaska

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ABSTRACT

A natural decline in the population of yellow-cedar (*Chamaecyparis nootkatensis*) is occurring in pristine southeast Alaska forests and may be the most significant forest decline in the western United States. The frequency of landslides in cedar decline areas is three times larger than in areas of healthy forest. Three regions are investigated in order to determine the influence of yellow-cedar decline on root strength, soil saturation, and consequently, slope stability. Nearly complete deterioration is observed in roots up to 25 mm thick on cedar trees that have been dead for approximately 14 years. Soil saturation is quantified with piezometers installed in 120 wells located in steep (25 to 45 degree) hillsides with forests of cedar decline, healthy cedar, and spruce/hemlock. Piezometric measurements indicate that the frequency of soil saturation is not demonstrably greater in areas of cedar decline, suggesting that the increased slide frequency in these areas is due to loss of soil strength through root deterioration. This conclusion is supported by the observation that complete soil saturation occurs regularly in slide-prone areas of both healthy and dead cedar.

Keywords: Landslides, cedar forest (*Chamaecyparis nootkatensis*) decline, soil moisture, root strength.

INTRODUCTION

Forest composition and structure is changing in southeast Alaska due to a large-scale mortality of yellow-cedar (*Chamaecyparis nootkatensis*). Yellow-cedar decline occurs in approximately 200,000 ha of forest in SE Alaska and is the most severe decline known of any forest vegetation in western North America (Mathews *et al*. 1977; Fig. 1). Although the majority of cedar decline occurs on slopes under 25° cedar decline occurs on

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slopes as steep as 45°, which are susceptible to hillslope failure. A composite overlay of a landslide survey of the entire Tongass National Forest

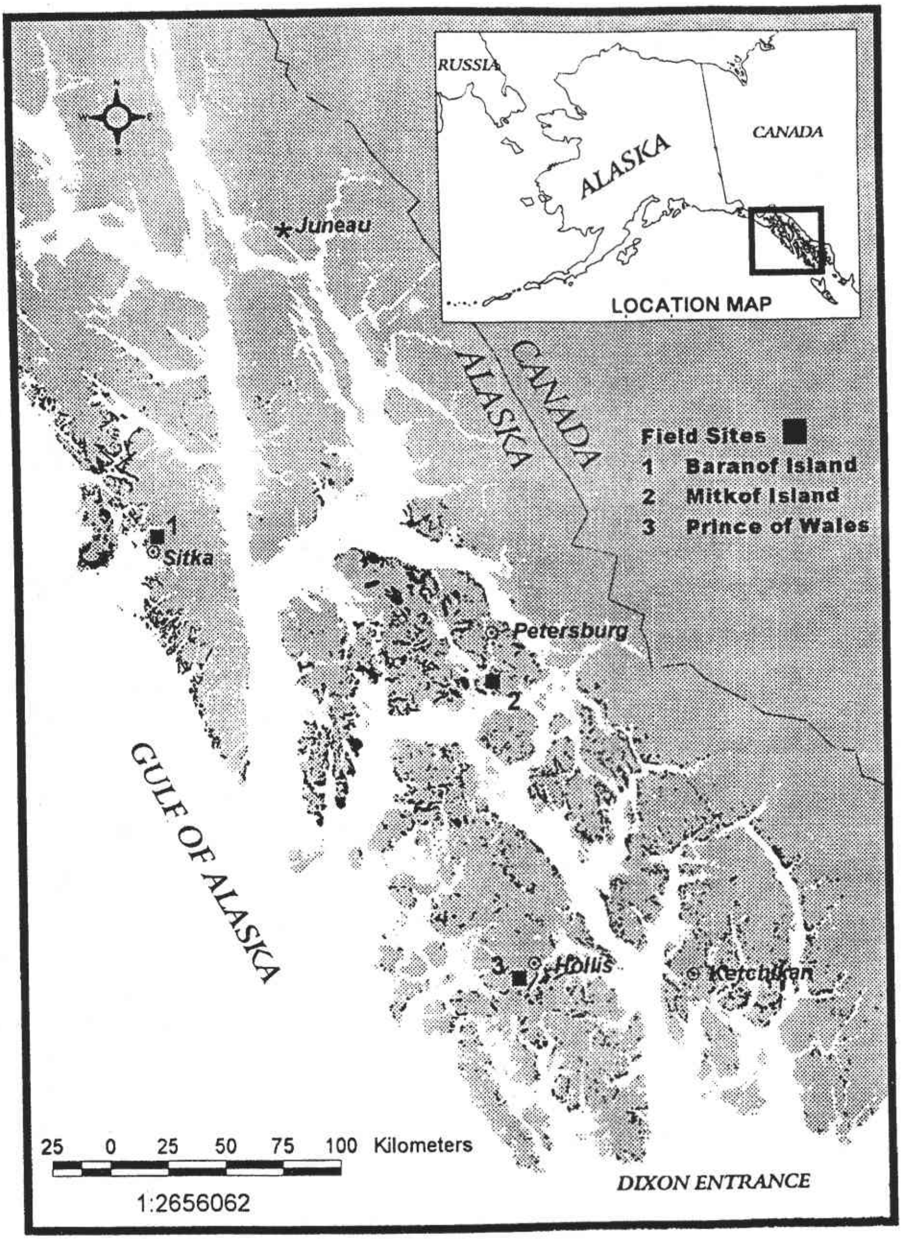

Fig. 1: Location of cedar decline in SE Alaska. Regions of cedar decline are indicated by black patches.

and an inventory of cedar decline indicates that steep cedar-decline slopes have three times as many landslides as steep slopes in adjacent "healthy" forest (Johnson 1993).

Yellow-cedar decline appears to be associated with a change in temperature, chemistry, or hydrology, rather than pests, pathogens, or air pollution (Hennon *et al.* 1994). Yellow-cedar decline may be associated with soil saturation, as sites of decline are typically located in areas of low gradient and topographic convergence. Time series of aerial photographs taken from 1926 to 1976 at several sites on Chichigof Island in SE Alaska indicate a progressive expansion of cedar decline from wetland sites to the adjacent slopes (Hennon *et al.* 1990).

In this study, factors influencing hillslope stability in areas of cedar decline were investigated. Patterns of soil saturation and root deterioration in three regions of cedar decline and "healthy" forests of cedar and spruce/hemlock, were compared to determine if cedar decline is associated with the frequency or extent of soil saturation or the loss of root strength. Soil saturation was measured using 120 peizometers distributed among ridges and hollows. An estimate of root cohesion was developed from observation of root deterioration patterns on seven dying trees. Results of saturation measurements and estimations of root deterioration were combined in a slope stability model to evaluate their potential effect on hillslope stability.

RESULTS AND DISCUSSION

Saturation

Field measurements taken in the 1995 and 1996 fall rainy seasons indicate that total saturation of forest soils in steep regions of SE Alaska is quite common. Forty of the 120 piezometers showed complete soil saturation or artesian pressures at least once during the two field seasons. A box-and-whisker plot (Fig. 2) summarizes the values of the maximum observed soil saturation over the two-year period. These results are separated by forest type and topographic position. Overall, the degree of saturation in areas of cedar decline was not found to be greater than the saturation found in healthy cedar or spruce/hemlock forests. When analyzed separately, the Baranof site had a slight, but significant difference in the average maximum soil saturation between cedar-decline and healthy cedar forests.

Root Deterioration

The extent and distribution of root decay was observed for seven yellow-cedar trees in different states of decay. Both the proportion of decayed

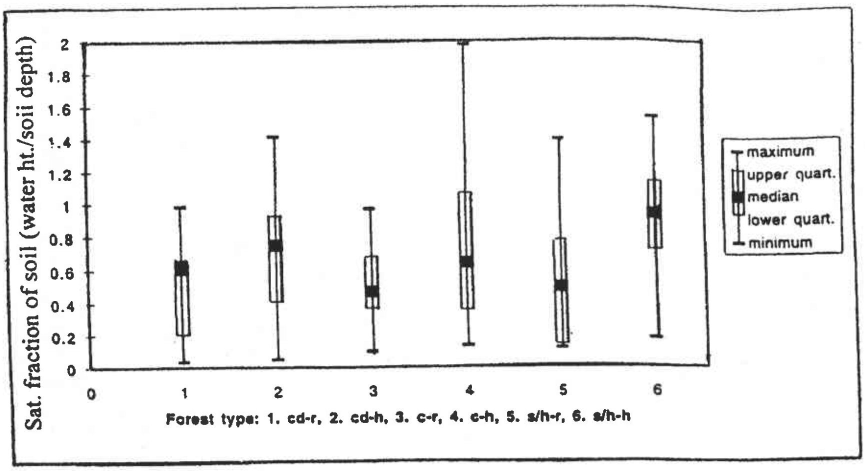

Fig. 2: Maximum observed soil saturation (water table height/soil thickness) over two rainy seasons for 120 piezometers on steep forested slopes in SE Alaska. Data organized by forest type (cedar decline, cd; healthy cedar, c; spruce/hemlock, s/h) and by topographic position (hollow, h; ridge, r).

roots and the size of the largest decayed root increased systematically with the age of tree death. For trees that have been dead for 14–51 years 70–90% of roots with diameters ranging from 1.0 up to 30 mm were decayed (Johnson 1997). The range of reported soil cohesive strength due to root strength varies from 1.0 to 17.5 kPa in forested hillsides (Swanston 1975; Wu *et al.* 1979, Burroughs and Thomas 1977, Sidle and Swanston 1982). A mean cohesion of 4.6 kPa was used in the stability estimations. If this cohesion is reduced by 80%, which is the total reduction in root cohesion found by O'Loughlin and Zeimer (1982) in their observations of clearcut forests, which also corresponds to the observed loss of fine roots in cedar-decline, then the cohesion is 0.9 kPa.

Hillslope Stability

An infinite slope model was used to evaluate the relative influence of the estimated changes in soil saturation and root strength on slope stability. Stability calculations were made for each of the 34 piezometer sites in cedar-decline areas using observed values of soil depth, saturated fraction of soil, and slope angle. Constant values of soil cohesive strength (8 to 12 kPa) and soil friction angle (33° to 39°) were used within each site based upon published measurements (Schroeder 1983). Strength due to roots was assumed to be 4.6 kPa for healthy forest and 0.9 kPa for cedar-decline.

The relative importance of roots and saturation in the stability of hillslopes in the three study areas were compared by conducting two tests. In the first test, the pore pressure at each piezometer location was changed from zero to the maximum observed pore pressure, while root cohesion was kept constant at 0.9 kPa. In the second test, the root cohesion varied from that of assumed healthy forest conditions at 4.6 kPa to assumed cedar decline conditions at 0.9 kPa, while the pore pressure was kept constant at the maximum observed amount. The influence on slope stability is shown using the reduction in factor of safety (available strength divided by applied shear stress) produced by the parametric changes (Fig. 3).

At the Prince of Wales site, a change of root strength from 4.6 to 0.9 kPa reduced the factor of safety by 0.6 to 1.8. A change in the pore pressure from zero to the maximum observed value resulted in a reduction of the factor of safety by 0.1 to 0.7 (Fig. 3a). Root cohesion was more

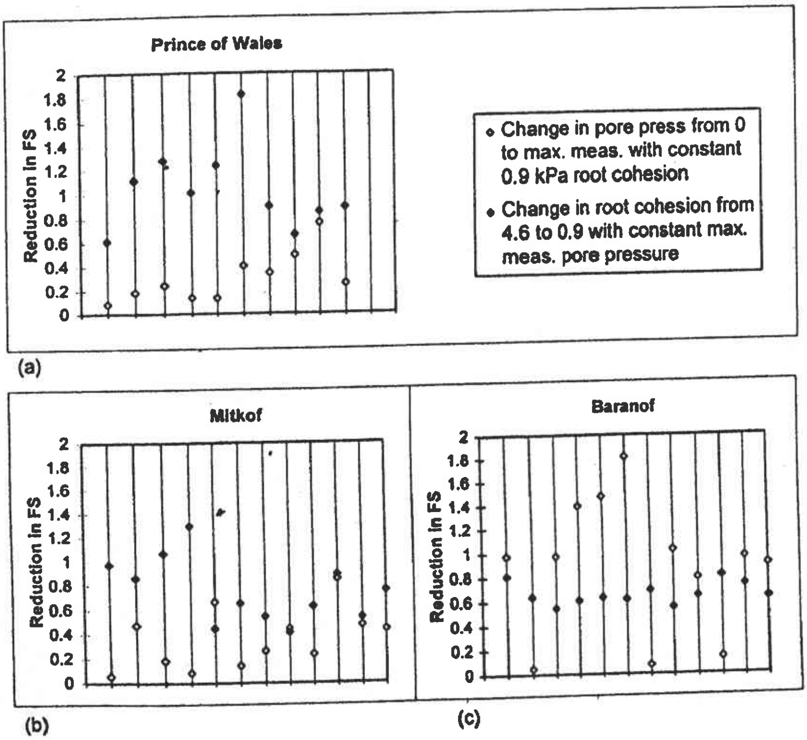

Fig. 3: Reduction in calculated factor of safety produced by increasing pore pressure (holding soil cohesive strength constant) and by decreasing soil cohesive strength (holding pore pressure constant).

important than pore pressure to the hillslope stability in this region. This conclusion is also true at the Mitkof field site where a change in root cohesion accounted for a 0.3 to 1.3 drop in the factor of safety and an increase in pore pressure accounted for a 0.05 to a 0.8 drop in the factor of safety (Fig 3b).

At the Baranof field site, changes in pore pressure had a larger influence on Factor of Safety compared reduction in root cohesion (Fig. 3c). Here, the factor of safety was reduced by 0.5 to 0.8 through the reduction of root cohesion and the factor of safety was reduced by 0.05 to 1.8 by the increase in pore pressure. The prevalence of deep saturated soils make the role of pore pressure override the control that cohesion due to root strength has on the stability of hillslopes.

CONCLUSION

On steep forested slopes in SE Alaska, the frequency of complete soil saturation does not appear to vary between slopes with cedar decline and slopes with healthy cedar or spruce/hemlock forests. This suggests that cedar decline does not produce major changes in shallow subsurface hydrology over time periods of decades related to cedar decay. An explanation other than elevated pore pressures is needed for the increased landslide frequency observed on cedar-decline slopes. A likely candidate is a decrease in the apparent soil-cohesive strength due to root decay. Estimates of the decrease in slope stability from changes in soil cohesive strength demonstrate that the loss of root strength can dominate, particularly on slopes with shallow soils.

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