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Spruce beetle outbreaks on the Kenai Peninsula, Alaska, and Kluane National Park and Reserve, Yukon Territory: Relationship to summer temperatures and regional differences in disturbance regimes

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Abstract

When spruce beetles (*Dendroctonus rufipennis*) thin a forest canopy, surviving trees grow more rapidly for decades until the canopy closes and growth is suppressed through competition. We used measurements of tree rings to detect such growth releases and reconstruct the history of spruce beetle outbreaks at 23 mature spruce (*Picea* spp.) forests on and near the Kenai Peninsula, Alaska and four mature white spruce (*Picea glauca*) forests in Kluane National Park and Reserve, Yukon Territory. On the Kenai Peninsula, all stands showed evidence of 1–5 thinning events with thinning occurring across several stands during the 1810s, 1850s, 1870–1880s, 1910s, and 1970–1980s, which we interpreted as regional spruce beetle outbreaks. However, in the Kluane region we only found evidence of substantial thinning in one stand from 1934 to 1942 and thinning was only detected across stands during this same time period. Over the last 250 years, spruce beetle outbreaks therefore occurred commonly among spruce forests on the Kenai Peninsula, at a mean return interval of 52 years, and rarely among spruce forests in the Kluane region where cold winter temperatures and fire appear to more strongly regulate spruce beetle population size. The massive 1990s outbreaks witnessed in both regions appeared to be related to extremely high summer temperatures. Recent outbreaks on the Kenai Peninsula (1971–1996) were positively associated with the 5-year backwards running average of summer temperature. We suggest that warm temperature influences spruce beetle population size through a combination of increased overwinter survival, a doubling of the maturation rate from 2 years to 1 year, and regional drought-induced stress of mature host trees. However, this relationship decoupled after 1996, presumably because spruce beetles had killed most of the susceptible mature spruce in the region. Thus sufficient numbers of mature spruce are needed in order for warm summer temperatures to trigger outbreaks on a regional scale. Following the sequential and large outbreaks of the 1850s, 1870–1880s, and 1910s, spruce beetle outbreaks did not occur widely again until the 1970s. This suggests that it may take decades before spruce forests on the Kenai Peninsula mature following the 1990s outbreak and again become susceptible to another large spruce beetle outbreak. However, if the recent warming trend continues, endemic levels of spruce beetles will likely be high enough to perennially thin the forests as soon as the trees reach susceptible size.

Keywords: Alaska; Climate warming; *Dendroctonus rufipennis*; Growth release; Forest disturbance; Spruce beetle; Yukon Territory

1. Introduction

The 1990s witnessed massive outbreaks of bark beetles (*Dendroctonus* spp.) in conifer forests across western North America; ranging from Alaska and the Yukon Territory to the southwestern United States (Holsten et al., 1999; Nijhuis, 2004; Logan and Powell, 2005). The regional synchrony of these outbreaks led investigators to examine the relationship between their occurrence and the unusually warm worldwide temperatures of the 1990s. Models based on such examinations and climate warming scenarios predicted declines among conifer forests across North America as insect pests expand their ranges, the tree species they infest, and the aggressiveness of their attacks (Harrington et al., 2001; Logan et al., 2003; Juday et al., 2005; Logan and Powell, 2005).

Recent outbreaks of spruce beetles have caused extensive mortality of spruce across more than 1.2 million ha of forest in

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south-central Alaska from 1989 to 2004 (U.S. Forest Service, 2005) and more than 350,000 ha of forest in the southwestern Yukon Territory from 1990 to 2004 (R. Garbutt, Canadian Forest Service, unpublished data). Advance warning of these massive outbreaks would have helped forest managers in these regions respond more effectively to the rapid changes in forest condition (Ross et al., 2001). However, a poor understanding of the factors that contributed to these outbreaks has made forecasting such events difficult. Previously, spruce beetle populations erupted to outbreak levels when forests were mature and a triggering disturbance, such as windthrow, fire, or harvest, created sufficient numbers of injured and dying spruce which were favorable for beetle reproduction (Schmid and Frye, 1977; Werner et al., 1977; Holsten, 1990; Safranyik et al., 1990). However, the recent outbreaks were different from previous regional events in that they did not result from a clearly identifiable disturbance. Furthermore, it is unclear whether the recent outbreaks were within the normal historical range of outbreak sizes (Ross et al., 2001) because records of outbreaks in the region date back only to 1920 (Holsten, 1990); less than the mean interval of 116 years between outbreaks in Colorado (Veblen et al., 1994).

Evidence for past outbreaks of spruce beetles can be found in growth pulses of trees that survived previous outbreaks (Veblen et al., 1991a,b). Spruce beetles selectively attack mature spruce, because large, slow-growing spruce are less able to resist the establishment of adult spruce beetles in the inner bark or phloem layer (Hard et al., 1983; Hard, 1987). After the overstory spruce are killed by spruce beetles, the smaller surviving spruce have less competition for light, soil moisture, and nutrients, and often increase their growth abruptly (Veblen et al., 1991a,b). In this paper, we used the dendrochronology techniques developed by Veblen et al. (1991a,b) and reconstructed spruce beetle outbreak histories among mature spruce forests in the Kenai Peninsula and Cook Inlet region of south-central Alaska and the Kluane National Park and Reserve in the southwestern Yukon Territory. Specifically, we reconstructed outbreak histories back to the mid-1700s in these two regions using measurements of annual growth rings among mature white (*Picea glauca*), Sitka (*P. sitchensis*), and Lutz spruce (*P.* x *luztii*) in order to (1) estimate the timing, magnitude, and extent of previous spruce beetle outbreaks; (2) estimate the return interval of beetle outbreaks; (3) compare spruce beetle disturbance regimes between the more maritime forests of south-central Alaska and arid interior forests of the southwestern Yukon Territory. We then used data from aerial surveys of forest area infested by spruce beetles from the Kenai Peninsula from 1971 to 2003 to test the hypothesis that the occurrence of regional outbreaks of spruce beetles was related to warm summer temperatures.

2. Materials and methods

2.1. Study area

The Kenai Peninsula–Cook Inlet region (Kenai Peninsula hereinafter) lies in south-central Alaska west of Prince William Sound (Fig. 1). The topography of the area is variable with the Kenai Mountains forming a rugged spine of peaks, icefields, and glaciers along the eastern side of the Peninsula, with elevations rising to 2000 m. The Kenai Lowland forms a broad plateau 15–100 m in elevation, extending to Cook Inlet. On the

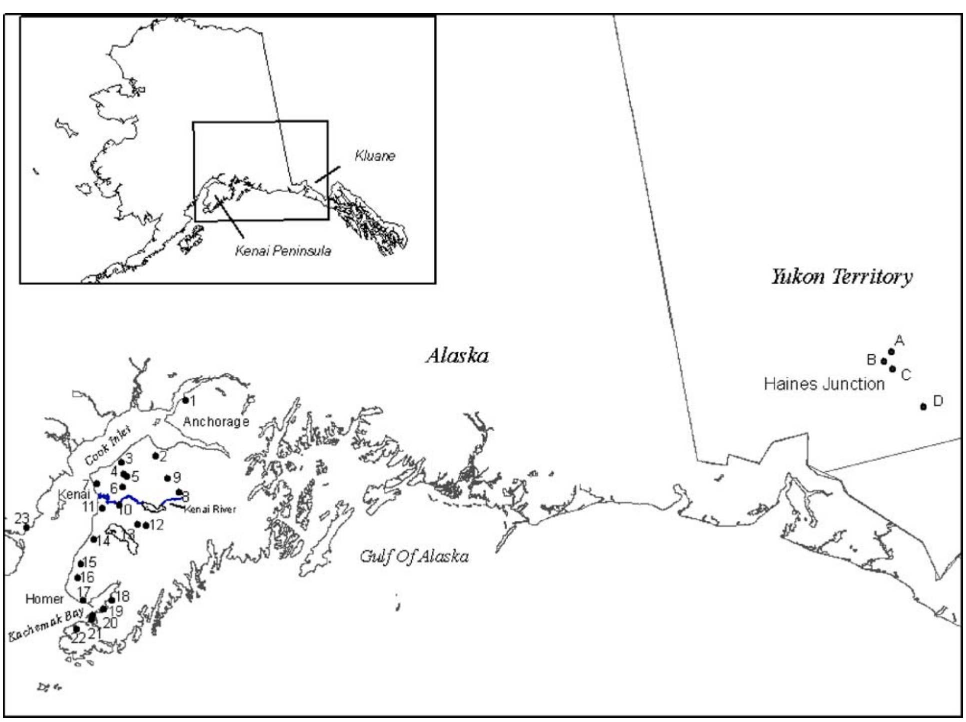

Fig. 1. Locations of mature spruce forests sampled in the Kenai Peninsula—Cook Inlet region, Alaska, USA, and Kluane National Park and Reserve, Yukon Territory, Canada. Site names are shown in Fig. 3.