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Do bark beetle remains in lake sediments correspond to severe outbreaks? A review of published and ongoing research

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ABSTRACT

The recent continental-scale outbreak of native bark beetles in western North America is unprecedented at least since Euro-American settlement. Observational and modeling evidence suggest that warm temperatures observed during the late 20th century altered beetle population dynamics by accelerating beetle reproductive cycles leading to exponential population growth. The linkage between beetle outbreaks and climate warming has motivated efforts to reconstruct these disturbances using long-term environmental records using lake sediments. Here, we present data from across western North America in an effort to understand how beetle remains retrieved from lake sediments may be used as a proxy for reconstructing severe outbreaks and ecosystem response over centennial to millennial timescales. We (1) review existing literature related to beetle taphonomy; (2) present previously unpublished data of beetle remains in lake sediments; (3) comment on the development of a methodology to retrieve terrestrial beetle remains from lake sediments; (4) discuss potential controls on beetle carcass taphonomy into the sediment matrix; and lastly (5) speculate on the use of primary and secondary attack beetle remains as indicators of past outbreak episodes. Our synthesis suggests that the remains of primary attack beetles are rarely preserved in lake sediments, at least using small-diameter piston devices common in multi-proxy studies. Alternatively, remains of secondary attach beetles may be common but further work is required to understand how these insects can be used to aid in interpreting past forest disturbances, including bark beetle outbreaks and wildfire. A number of factors may influence whether or not bark beetle remains become entrained in the area of sediment focusing including lake water chemistry, fish predation and scavenging, and weather conditions during peak beetle emergence.

1. Introduction

The recent continental-scale epidemics of native bark beetles in western North America has reorganized ecosystem nitrogen pools (Morris et al., 2013a; Rhoades et al., 2013), altered terrestrial carbon fluxes (Pfeifer et al., 2011; Hicke et al., 2012a), changed forest structure and composition (DeRose and Long, 2012), generally reduced landscape flammability and rearranged fuel structure (Jenkins et al., 2008; Hicke et al., 2012b; Harvey et al., 2013), while also diminishing air and water quality (Amin et al., 2012; Mikkelson et al., 2013), devaluing real estate (Hanson and Naughton, 2013), increasing winter and spring surface albedo (Vanderhoof et al., 2013), and reducing the duration of snow cover (Biederman et al., 2014). In recent decades, the cumulative economic and aesthetic losses from bark beetle outbreaks (i.e. *Dendroctonus* spp.) exceed those of wildfire and other forest disturbances (Logan et al., 2003). Anthropogenic climate warming is widely acknowledged as the primary driver promoting the irruptive populations of bark beetles (Raffa et al., 2008). Observational and modelling evidence

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demonstrate that increasing temperatures in the lower atmosphere alter beetle population dynamics in two primary ways: (1) temperature-induced acceleration of bark beetle fecundity increases the likelihood of exponential population growth (Hansen et al., 2001a,b; Cudmore et al., 2010; Mitton and Ferrenberg, 2012); and (2) reductions in cold-induced mortality allow greater survival of over-wintering bark beetles, which is particularly pronounced at high-elevations and high-latitudes locales (Reid, 1963; Reid and Gates, 1970; Bentz et al., 2010).

Affecting 47,000,000 ha during the past two decades, the scale and severity of the current outbreak, is unprecedented at least since the arrival of Euro-American settlers in the 19th century (Taylor and Carroll, 2004; Raffa et al., 2008). During outbreaks, primary attack beetles (*Dendroctonus* spp.) first infest the boles of downed and/or stressed trees (Fig. 1). As the outbreak progresses, even healthy host trees succumb to attack. As host trees die, they become susceptible to infestation from secondary bark beetles (e.g. *Pityophthorus* spp., *Ips* spp.), which may attack both the bole and branches of dead host

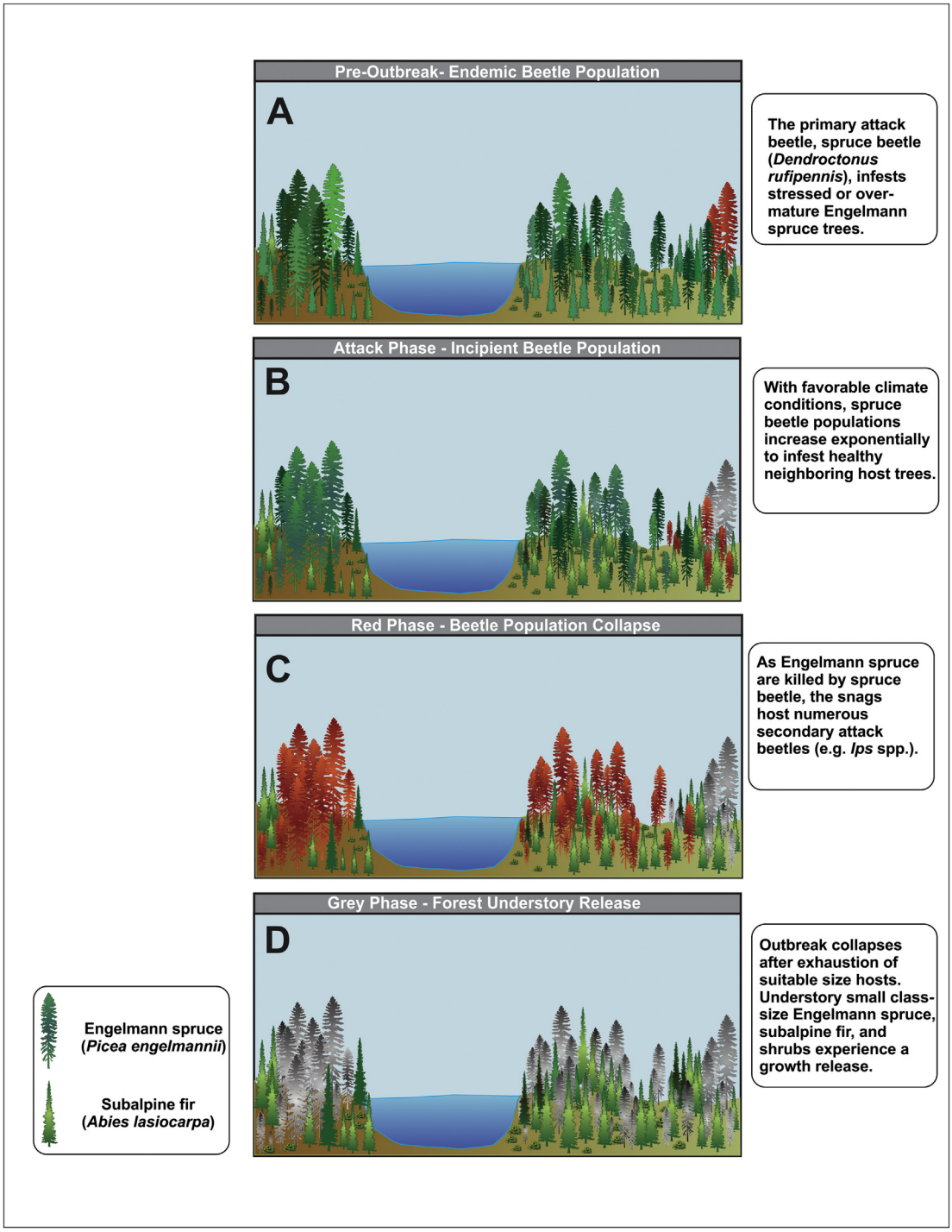

Fig. 1. Conceptual diagram of the progression of a spruce beetle (*Dendroctonus rufipennis*) disturbance through endemic (A), incipient or attack phase (B), red or epidemic phase (C), and grey or collapse phase (Panel D). Secondary attack beetles generally appear during red (C) and/or grey phase (D). Reproduced from Morris (2013). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)