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Bark beetle pests in an altitudinal gradient of a Mexican managed forest

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ABSTRACT

Global climate change is having multiple effects upon plant populations. In recent years, conifers in the northern hemisphere have experienced increased bark beetle damage, particularly at the limits of their distribution. In this project, we investigated bark beetle populations and insect damage in *Pinus* trees along an altitudinal gradient in order to obtain an overview of damage at regional level, and also to analyze the consequences of rising temperatures on insect damage in trees. The study was conducted in the communal pine forests of Nuevo San Juan Parangaricutiro in the state of Michoacán, Mexico. In September 2011, 32 Lindgren traps were hung along an altitudinal gradient from 2200 to 2750 m a.s.l., with traps set at 150–200 m intervals of altitudinal difference. In each trap, α-Pinene and turpentine were added as bark beetle attractants. Every three weeks over a study period of one year, the captured insects were collected and identified in the laboratory. Abiotic site conditions (temperature and humidity) were also measured at each altitude hourly. During the dry season, phytosanitary characterization was conducted at each site. Throughout the study, 19 Scolytinae bark beetle species were recorded, all of which were considered to be non-aggressive pests. Bark beetles showed higher species richness and abundance at the lowest altitude (2200 m a.s.l.), particularly on the early collection dates, compared to other altitudes (2400, 2600 and 2750 m a.s.l.; $p < 0.05$). Maximum temperature, minimum temperature, and lowest humidity were higher at low altitudes while maximum humidity was higher at high altitudes. There was a significant positive relationship between maximum temperature and bark beetle abundance. Pines with bark beetles damage were more abundant at 2200 m a.s.l. with *Pinus pseudostrobus* identified as the most damaged tree species. Higher temperatures at lower elevations and projected temperature rise appear to be related to higher damage by the bark beetles on susceptible tree species in these communal forests. Possible management strategies are discussed.

1. Introduction

The direct effects of climate change on vegetation are observed worldwide (Parmesan and Yohe, 2003): timberlines in temperate forests are advancing towards the poles (Grace et al., 2002), scrublands and semi-deserts are expanding in area (Archer et al., 1995) and vegetation types and individual species are also shifting upward in altitude (Grace et al., 2002; Lenoir et al., 2008). Some tree species are experiencing severe dieback due to increased drought in recent times (Allen et al., 2010; Worral et al., 2013), while some animal populations are increasing their latitudinal and altitudinal range, e.g., *Dendroctonus* spp. in boreal forests (Ungerer et al., 1999; Cudmore et al., 2010). Other recent changes in ecosystems have been linked to a synergy between climate change and anthropogenic activities; in particular, the suppression of fires in conjunction with prolonged dry periods has been associated with an increase in forest pest outbreaks in North America (Raffa et al., 2008). In British Columbia, bark beetle infestations have increased 10-fold in magnitude over the last 50 years (Safranyik et al., 2010).

Pest outbreaks have been recorded since the introduction of modern forestry and agriculture (Lugo, 1997) and millions of

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dollars are invested annually in control measures. It has been calculated that insect pests affect 30 million hectares of forest annually (FAO, 2010). In addition to the consequences of inappropriate intensive management, climate change also influences pest outbreaks, especially those related to insects, because of their dependence on temperature for development (Raffa et al., 2008). Precipitation patterns also play a significant role in plant growth and vigor, in terms of the ability to defend against herbivores and disease (i.e. production of secondary metabolites and, in many conifers, resin; Raffa et al., 2005; Wermelinger, 2004). The climatic conditions that favor the persistence of insect pests in temperate regions are: higher seasonal temperatures and longer vegetation period that allow a synchronous adult emergence, and swarming for mass attack, and the successful development of several generations per year (Bentz et al., 2014; Jönsson et al., 2009), reduced extremes in winter that favor winter survival (Safranyik and Linton, 1998; Faccoli, 2002), and decreased moisture during the growing season that hampers plant resistance to herbivores (Safranyik et al., 2010).

Temperate forests in Mexico originally covered 27% of the country; however, today 40% of these are degraded and the remainder present variable levels of conservation (CONABIO, 2009). In addition to land-use change and ecosystem degradation as a result of anthropogenic activities, it has been predicted that global warming will have devastating effects in Mexican temperate forests, particularly those at lower altitudinal ranges (Villers-Ruiz and Trejo-Vazquez, 1998). The species located at the rear edge of the biome will therefore be affected because their environmental stress tolerance limits will be surpassed (Gonzalez et al., 2010; Mátyás, 2010) and they will become more susceptible to pests and diseases (FAO, 2010).

Bark beetle incidence and damage has increased in recent years throughout the world in temperate forests (FAO, 2010; Marini et al., 2012; Salinas-Moreno et al., 2010). Northern countries in America (Bentz et al., 2010; Creeden et al., 2014; FAO, 2010; Weed et al., 2013) and Eurasia (Schelhaas et al., 2003) are experiencing severe damage every year in locations where bark beetles were previously scarce or even non-existent. In Mexico, recent bark beetle outbreaks have also been reported although detailed documentation is scarce (González-Medina et al., 2010; Moreno et al., 2008; Reyes, 2005).

Already apparent, observed changes of the climate of central Mexico showed an increase of temperature and drought periods were more frequent in recent years. Sáenz-Romero et al. (2010, 2012) modeled climate conditions for Mexico and for Michoacán state using outputs from three general circulation models (GCMs: Canadian, Hadley and Geophysical Fluid Dynamics) from two emission scenarios (A "pessimistic" and B "optimistic") throughout the current century. These authors found that, irrespective of the model used, the increase in temperature will continue and that the magnitude of this increase will be between 3 and 4 °C by the year 2090 with a mean decrease in precipitation of 7.8% for the state of Michoacán. Given this information, it is important to document and to monitor actual levels of bark beetle infestation in economically as well as ecologically important productive temperate forests in Mexico. Particularly, bark beetle damage has recently increased in some community forests of western Michoacán (Dirección Técnica Forestal, CINSJP pers. comm.); however, no formal beetle identification has been carried out and therefore there is a lack of accurate information regarding the specific causal agents.

The objective of this study was to investigate bark beetle species richness and abundance, as well as insect damage in several *Pinus* trees species. The study focused on an altitudinal gradient in the communal pine forests of Nuevo San Juan Parangaricutiro, Michoacán, in central-western Mexico. We related insect presence and damage to climatic variables along the environmental gradient, aiming to obtain an overview of altitudinal effects on insect damage in forest trees.

2. Materials and methods

2.1. Study site

The study was conducted in the indigenous community of Nuevo San Juan Parangaricutiro (ICNSJP) situated in the west-central State of Michoacán, Mexico (19° 21′ 00″ – 19° 34′ 45″ N and 102° 08′ 15″ – 102° 17′ 30″ W; Fig. 1). The forest (11,694 ha) is owned by the community and is managed for timber and resin extraction using sustainable forestry practices (Blanco-García and Lindig-Cisneros, 2005). The forest is composed of pine trees (*Pinus montezumae*, *Pinus pseudostrobus*, *Pinus leiophylla* and *Pinus devoniana*) as well as several oak species. *P. montezumae* is the most abundant species ranging from 35% to 75% across altitudes, *P. pseudostrobus* contributes with 20% of individuals throughout altitudes (17–29%), *P. leiophylla* occurs from 2200 to 2600 m asl and has its abundance peak at 2400 m asl while *P. devoniana* only occurs at low altitudes (2200 m asl; Appendix 1). Forest products constitute the main income for the community.

2.2. Sampling

In order to sample the beetle communities along the altitudinal forest gradient, 32 Lindgren traps of 12 units each were hung at 2200, 2400, 2600 and 2750 m a.s.l. We selected two independent sites per altitude and four Lindgren traps were hung in a 20 × 20 m plot in each of the total of eight sites, which were located at least 5 km apart to avoid spatial autocorrelation. In every trap, α-Pinene (racemat mixture, purity 98%, Aldrich chemistry Lot#79496PMV and Lot#55796LMV) and turpentine were added as bark beetle attractants in the sixth unit, lures were contained in eppedorf tubes with an outgrowing cotton wick, and lures were replaced every three weeks (Domínguez-Sánchez et al., 2008; Gandhi et al., 2010). At the bottom of each trap, a container with 50% antifreeze solution was placed in order to preserve the beetles captured, as suggested by Zylstra et al. (2010). Every three weeks over the course of one year (September 2011–August 2012; 16 samplings in total), the captured insects were collected and identified in the laboratory and the antifreeze solution was replaced. Scolytinae were separated and identified to species using taxonomic keys (Arnett et al., 1980; Arnett et al., 2002; Cibrián-Tovar et al., 1995).

2.3. Tree damage

At the same beetle sampling sites, air temperature and humidity were recorded hourly with data loggers (H01-001-01; Onset Computer Corporation, Pocasset, MA, U.S.A.). At the same sites tree damage was determined using phytosanitary conditions following the methodology proposed by the United Nations and the European Union in 1993 (Del Río and Petrovich, 2011). This was conducted during the dry season when the trees are more stressed. In the center of the plot at each site, two perpendicular 25 m transects were traced; at the two cardinal extremes of each transect, a circular quadrant of 25 m diameter was established and all trees of DBH > 15 cm within the quadrant were considered. Each tree was visually assessed for evidence of bark beetle attack and phytosanitary condition (Del Río and Petrovich, 2011). We then calculated the density of damaged trees per species per site by assessing the total number of damaged trees of *X* species in each site divided by the total number of individuals of *X* tree species at the same site.