Forest Ecology and Management 260 (2010) 52–61

Contents lists available at ScienceDirect

Forest Ecology and Management

journal homepage: www.elsevier.com/locate/foreco

Determining the vulnerability of Mexican pine forests to bark beetles of the genus *Dendroctonus* Erichson (Coleoptera: Curculionidae: Scolytinae)

Y. Salinas-Moreno[a,*], A. Ager[b], C.F. Vargas[a], J.L. Hayes[c], G. Zúñiga[a]

[a] Escuela Nacional de Ciencias Biológicas-IPN, Prol. de Carpio Esq. Plan de Ayala s/n, Casco de Sto. Tomás, México D.F., C.P. 11340, Mexico
[b] USDA Forest Service, Pacific Northwest Research Station, Western Wildlands Environmental Threat Assessment Center, 3160 NE 3rd Street, Prineville, OR 97754, United States
[c] USDA Forest Service, Pacific Northwest Research Station, Forestry and Range Sciences Laboratory, 1401 Gekeler Lane, LaGrande, OR 97850, United States

ARTICLE INFO

Article history:
Received 22 January 2010
Received in revised form 30 March 2010
Accepted 31 March 2010

Keywords:
Bark beetles
Pine
Vulnerability
México
Distribution
Richness

ABSTRACT

Bark beetles of the genus *Dendroctonus* are natural inhabitants of forests; under particular conditions some species of this genus can cause large-scale tree mortality. However, only in recent decades has priority been given to the comprehensive study of these insects in México. México possesses high ecological diversity in *Dendroctonus–Pinus* associations. The geographic coexistence of 12 *Dendroctonus* species suggests greater vulnerability or threat of tree mortality relative to other areas. We use a biogeographic strategy to identify and rank the areas most vulnerable to tree mortality caused by bark beetles in México. We aim to define the areas that might experience high impact by these insects and also to provide a geographic database useful to forest resource management and conservation policies in México. Using collection records of bark beetles and pines, we develop a quantitative estimate of the threat of beetle infestation of forest areas based on factors including pine and beetle species density, host preference and level of mortality caused by beetle species. A quantitative estimate of forest area vulnerability, the Bark Beetle Threat Index (BBTI) was calculated. Despite the vast area of geographic coincidence of *Pinus* and *Dendroctonus* in México, the regions of highest bark beetle pressure are restricted to small zones within some mountain systems. The region that has been most affected by this insect group during the past hundred years is the Transverse Volcanic Belt, followed by the Sierra Madre Occidental and Sierra Madre del Sur. Pine diversity is the major determining factor of BBTI at the regional level, while disturbances from extensive logging and ecosystem change are the key factors behind high BBTIs at the local level.

1. Introduction

Species of the genus *Dendroctonus* are natural inhabitants of coniferous forests in North America (Wood, 1982). Under certain forest conditions (Malmström and Raffa, 2000) and particular climatic events, such as extreme drought (Raffa et al., 2005), some species of this genus can cause large-scale mortality of trees in the *Pinus*, *Picea*, *Pseudotsuga* and *Larix* genera (Wood, 1982). The extensive mortality caused by bark beetle outbreaks has both economic and ecological impacts and affects forest resource management strategies (Malmström and Raffa, 2000; McFarlane and Witson, 2008).

In recent decades, priority has been given to the comprehensive study of bark beetles in México for forest conservation and restoration. Nevertheless, present-day management tends to be limited to local, small scale, direct control methods consisting primarily of sanitation treatments used thirty years ago (Malmström and Raffa, 2000). Only recently have forestry practices been directed to alternatives such as semichemical-based tactics commonly used in Canada and the US (Díaz-Núñez et al., 2006; Macías-Sámano et al., 2004).

Forest health assessments aided by bark beetle risk models or rating systems have been conducted in Canada, the US and Europe for several decades (Beukema et al., 1997; Lewis, 2002; Malmström and Raffa, 2000; Robertson et al., 2008). These risk models attempt to predict the susceptibility of forests to bark beetle attack and mortality at the landscape and regional scales. Prediction models developed in the US and Canada are based on abundant information about site conditions and vegetation characteristics at different scales, as well as on bark beetle biology and ecology (Beukema et al., 1997). In México these data are often scarce, lack necessary precision, and are maintained by different government agencies. This situation has prevented the development of predictive models for basic decision-making to prevent or mitigate adverse impacts of these insects.

Nevertheless, México has abundant fine-scale (presence/absence data) on both pines and *Dendroctonus* beetles (Salinas-Moreno et al., 2004; www.conabio.gob.mx) from the past hundred years, which can be aggregated at the mesoscale level to identify

* Corresponding author.
E-mail addresses: erfran_1960@hotmail.com, yosamo17@yahoo.com.mx (Y. Salinas-Moreno).

0378-1127/$ – see front matter © 2010 Elsevier B.V. All rights reserved.
doi:10.1016/j.foreco.2010.03.029

geographic areas where bark beetles pose the greatest risk to coniferous forests. Although this approach does not lead directly to risk analyses, it can identify geographic regions that should be monitored continuously (Malmström and Raffa, 2000).

1.1. Conditions in México

Temperate coniferous forests cover 13% of Mexico's land area (Challenger, 1998). The vast majority of these forests are composed of trees in the genus *Pinus*, with the remainder in *Pseudotsuga* and *Picea* (Rzedowski, 1981; Styles, 1998). México is a center of pine diversification and one of the top three areas worldwide for *Pinus* species diversity (42 species and 18 infraspecific taxa) (Farjon and Styles, 1997). High ecological diversity is characteristic of pine communities in México. Geographic relief is pronounced in the various mountain systems, affecting mesoclimate (Ferrusquía-Villafranca, 1998) and biotic species diversity. In addition, pine forest composition varies due to the substantial diversity of pine and associated vegetation (Richardson and Rundel, 1998; Styles, 1998). In México, pines are found primarily in three types of communities: pure pine forests and, depending on dominance, pine-oak and oak-pine forests, which occur at different elevations, climates and exposure conditions (Rzedowski, 1981).

Pine-dominated plant communities are present in the major mountain systems of México and regularly sustain disturbance from insect pests and diseases, fire, drought, logging, grazing and extensive land-use change (Challenger, 1998; Perry et al., 1998). Such stress factors, whether natural or anthropogenic, favor recurrent outbreaks of *Dendroctonus*; population levels can build-up in clusters of weakened host trees (Cibrián et al., 1995; SEMARNAT, 2006). There are 12 species of *Dendroctonus* bark beetles in México, six of which are considered primary tree-killing, and they have broad, often overlapping geographic distributions (Salinas-Moreno et al., 2004). In the US and Canada, *Dendroctonus* colonize four genera of Pinaceae, whereas in México, *Pinus* and *Pseudotsuga* species are colonized (Cibrián et al., 1995; Salinas-Moreno et al., 2004). Pine forests of México sustain constant pressure by these beetles.

Some *Dendroctonus* species in México are characterized by high polyphagy, colonizing over 20 species of pine, while others appear to be monophagous (Salinas-Moreno et al., 2004). The polyphagous species differ in relative occurrence on their hosts, suggesting that certain pine species are preferred by particular insect species and that such preference may vary by geographic area (Salinas-Moreno et al., 2004). High polyphagy and broad host distribution favors the geographic coexistence of *Dendroctonus* species. As elsewhere, secondary beetle bark species (those that do not initially colonize susceptible trees) commonly follow primary beetle species in México and it is also common for more than one primary species to occur in the same tree with secondary species (Zúñiga et al., 1995). In addition to within tree niche partitioning, polyphagy and the availability of alternate hosts may avert detrimental effects of direct competition in those areas of geographic coexistence (e.g., Macías-Sámano and Borden, 2000; Poland and Borden, 1998). Areas of *Dendroctonus* species sympatry have been documented mainly in the northwest (Sierra Madre Occidental) and central (Transverse Volcanic Belt) regions of México (Zúñiga et al., 1999).

The geographic coexistence of primary *Dendroctonus* species suggests an increased vulnerability to tree mortality in these areas. Similarly, areas of high pine diversity are likely at greater risk of experiencing mortality from at least one, if not more bark beetle species. In the absence of the detailed attribute data that are needed for local risk or hazard rating systems or more broad-based prediction models, information on occurrence and sympatry in this insect–host system can be used to identify forest regions that are potentially the most susceptible to bark beetle attack.

Table 1
Number and source of collection records for each *Dendroctonus* species considered in this study.

Species	No. of records	Collection[a]
Dendroctonus adjunctus	211	1,2,3,4,5,6,7,8,9,10
D. approximatus	106	1,3,4,5,7,8,9,10
D. brevicomis	18	4,7,8,10
D. frontalis	177	3,4,5,7,8,10,11
D. jeffreyi	6	1,4,10
D. mexicanus	566	1,2,3,4,5,6,7,8,9,10,11
D. parallelocollis	87	1,2,3,4,5,7,8,10
D. ponderosae	2	7,10
D. pseudotsugae	31	3,4,5,7,10
D. rhizophagus	104	1,3,4,5,7,8,10
D. valens	366	1,2,3,4,5,6,7,8,9,10
D. vitei	1	1
Total	1675	

[a] Collection: (1) Colegio de Posgraduados, México, MEX; (2) Centro de Investigaciones Biológicas, Universidad Autónoma del Estado de Morelos, Morelos, MEX; (3) Colección Nacional de Insectos, Ottawa, CAN; (4) División de Bosques. Universidad Autónoma de Chapingo, México, MEX; (5) Escuela Nacional de Ciencias Biológicas, Instituto Politécnico Nacional, D.F., MEX; (6) Instituto de Biología, Universidad Nacional Autónoma de México, D.F., MEX; (7) Instituto Nacional de Investigaciones Forestales Agrícolas y Pecuarias, Secretaría de Agricultura, Ganadería, Desarrollo Rural, Pesca y Alimentación, D.F., MEX; (8) Instituto de Silvicultura, Universidad Autónoma de Nuevo León, Nuevo León, MEX; (9) Museo Historia Natural, D.F., MEX; (10) Sanidad Forestal, Secretaría del Medio Ambiente y Recursos Naturales, D.F., MEX; (11) Sanidad Vegetal, Secretaria de Agricultura, Ganadería, Desarrollo Rural, Pesca y Alimentación, D.F., MEX.

In this study, we use a biogeographic strategy to identify and rank the areas most vulnerable to bark beetle outbreaks in México. Using collection records of bark beetles and pines, we develop a spatially explicit, quantitative estimate of the threat of beetle infestation based on factors such as pine and beetle species density, host preference and level of mortality caused by beetle species.

2. Materials and methods

2.1. Data on bark beetle locations

A database of point locations based on 1530 collection records, over one hundred years, was constructed for the six most widely distributed species of *Dendroctonus* in México: *D. adjunctus*, *D. approximatus*, *D. frontalis*, *D. mexicanus*, *D. rhizophagus* and *D. valens*. Species with highly restricted distributions or few records ($\leq$100) were not included in the study (Salinas-Moreno et al., 2004) (Table 1). *D. pseudotsugae* was omitted because we focused on pine bark beetle species only. The database was initially built using location records previously published in Salinas-Moreno et al. (2004) and was subsequently expanded with data from 11 entomological collections (Table 1) and 42 locations identified during fieldwork from 1986 to 2007. Each location record included the bark beetle species, municipality, state, latitude, longitude, elevation, the host species, collecting date and the collection or bibliographical reference associated with the record. Unique records were those differing in any of the above features or in location data. Insects were collected during both endemic and outbreak population conditions. We recognize the limitation of relying on collection records, which may be incomplete and not represent the entire distribution of any given species; thus, our findings should be considered conservative.

2.2. Data on pine species distribution

A database of point locations based on 4561 collection records was created for the 25 pine species that are susceptible to bark beetles in México (Salinas-Moreno et al., 2004). This database followed the taxonomic classification system of Mexican pines proposed by Farjon and Styles (1997), which recognizes the species listed in