Forest Ecology and Management 384 (2017) 132–136

Contents lists available at ScienceDirect

Forest Ecology and Management

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

Effects of elevation and aspect on the flight activity of two alien pine bark beetles (Coleoptera: Curculionidae, Scolytinae) in recently-harvested pine forests

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ARTICLE INFO

Article history:
Received 26 July 2016
Received in revised form 17 October 2016
Accepted 19 October 2016
Available online 26 October 2016

Keywords:
Alien species
Biological invasions
Climate change
Microclimate
Hylastes ater
Hylurgus ligniperda

ABSTRACT

Climate is an important driver of the establishment and impact of invasive alien species. Species transported to new regions can only invade those with a climate that meets their thermal requirements, but climate change is likely to alter the invasibility of recipient environments. Likewise, species are unlikely to reach pest status where climatic conditions are suboptimal. Here our objectives were to determine the relationship between climatic conditions and flight activity of two alien pine bark beetles (*Hylastes ater* and *Hylurgus ligniperda*) and to anticipate how climate change may affect the future distribution of these species. We used elevational gradients and slope aspect (north versus south-facing slopes), which are known to affect microclimates, to assess the effects on beetle flight across 18 locations in pine forests in the South Island, New Zealand. Using panel traps baited with alpha-pinene and ethanol we caught a total of 45,363 *H. ligniperda* and 6676 *H. ater*. Catches of both species decreased significantly and substantially with increasing elevation. Significantly more beetles were caught at north-facing than at south-facing sites towards the end of the flight season in autumn, leading to an extended flight period at northerly aspects. These results are important for pest management and the identification of 'areas of low pest prevalence' as a measure to reduce post-harvest infestations of logs destined for export. For example, during risk periods, logs could be harvested preferentially from stands with reduced flight activity (i.e., southerly aspects and higher elevations). Furthermore, such sites could be chosen to reduce post-harvest infestation risks during periods of temporary log storage at skid sites in the forest. Our findings are also important because climate change can be an important factor contributing to population expansion of bark beetles, and warmer temperatures could lead to increased flight activity and abundance, as well as enhanced suitability of sites that are currently less favourable.

1. Introduction

Biological invasions are a major environmental and economic concern worldwide (Mack et al., 2000; Aukema et al., 2010, 2011). Globalisation and, in particular, the increase in international trade are the main drivers of the spread of potential pest species by providing new and better dispersal pathways (e.g., Leung et al., 2014; Wingfield et al., 2015). This is facilitated further by the widespread use of exotic plants including trees that are used as ornamentals and in planted forests (FAO, 2015) which resulted in the presence of potential host plants in areas where they did not occur naturally. Climatic suitability is a key factor that determines whether or not arrivals of alien species can lead to successful invasions (e.g., Kriticos, 2012). The climate of recipient regions strongly influences which alien species can successfully establish, according to their thermal range. In Europe, the number and frequency of successful invasions are strongly related to latitude, decreasing towards the colder north (Roques et al., 2009). A warming climate is expected to reduce the thermal limitations that were previously hampering the establishment in cooler regions of species arriving from warmer Mediterranean and subtropical regions (Roques, 2010b). Likewise, organisms from warmer subtropical and tropical regions are predicted to encounter an increasingly favourable climate in the mostly temperate climate of New

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http://dx.doi.org/10.1016/j.foreco.2016.10.046
0378-1127/

Zealand, increasing the likelihood of establishment of such species (Kriticos, 2012). Although responses of bark- and wood-boring beetles to climate change can be complex, it is emerging as a key factor driving – directly or indirectly – at least some of the current infestations of bark beetles occurring worldwide (Bentz et al., 2010; Marini et al., 2012). For instance, global warming may induce tree stress, making forests more suitable to infestation by pests (Bentz et al., 2010; Kolb et al., 2016).

Apart from effects on invasions, climatic conditions can strongly influence pest damage and population outbreaks. Warming can reduce winter mortality, increase breeding success and survival, and may increase voltinism of both native and invasive species (Marini et al., 2012; Bentz et al., 2014; Creeden et al., 2014). In addition, warming can facilitate range expansions of pests to higher latitudes and elevations (Battisti et al., 2005; Robinet et al., 2012; Marini et al., 2012). Irrespective of climate change, climatic conditions may affect the level of infestation of forests and forest products due to direct and indirect effects on population levels and the phenology of insects such as bark beetles. The resulting variation in occurrence, abundance and phenology among locations has implications for phytosanitary risk of international trade and for the need to apply phytosanitary measures (Robinet et al., 2012). Therefore, knowledge of relationships between climatic conditions and bark- and wood-boring beetle populations is of crucial importance.

Bark- and wood-boring beetles (especially Scolytinae, Cerambycidae and Buprestidae) are among the most successful and damaging invaders, causing significant economic and ecological damage to forests (Brockerhoff et al., 2006a, 2014; Haack, 2006; Leung et al., 2014). These insects are easily transported in almost all types of woody material – such as timber and wood packaging material (crating, dunnage and pallets) as well as woody plants for planting – where they can hide from detection and survive long intercontinental voyages (Brockerhoff et al., 2006a; Liebhold et al., 2012; Rassati et al., 2015). Despite the efforts to mitigate pathways responsible for new introductions, the rate of new invasions is increasing or at least steady (Ricciardi, 2007; Kirkendall and Faccoli, 2010; Roques, 2010a).

The pine bark beetles *Hylastes ater* (Paykull) and *Hylurgus ligniperda* (F.) (Coleoptera: Scolytinae), native to Eurasia and the Mediterranean region, respectively (Pfeffer, 1995), are successful invaders that became established in many temperate southern hemisphere countries (Wood and Bright, 1992; Brockerhoff et al., 2006a), probably through international trade (Haack, 2001, 2006; Brockerhoff et al., 2006a). *Hylurgus ligniperda* also became established in the United States. In New Zealand, *Hylastes ater* and *H. ligniperda* were detected in 1929 (Clark, 1932) and 1974 (Bain, 1977), respectively, and they are now found throughout most areas where pine forests occur. Both beetle species are not considered pests as they do not attack live trees. Instead, they breed and develop in fresh phloem of trees that died recently, mainly in pine stumps and roots, as well as logging waste (Chararas, 1962). Nevertheless, *H. ater* may cause some damage due to the maturation feeding carried out by callow adults (during ovarian maturation) on the root collars and tap roots of pine seedlings (Sopow et al., 2015). In addition, both species may act as vectors of sapstain fungi to felled logs (e.g., McCarthy et al., 2010, 2013).

Plantation forestry and the export of pine logs are important contributors to New Zealand's economy (MPI, 2015). To meet the phytosanitary requirements of trading partners, logs are fumigated with methyl bromide or phosphine, or debarked (Pawson et al., 2014); however, these treatments are applied without any a priori assessment of the potential phytosanitary risk (IPPC, 2013) posed by the potential presence of bark beetles on any given shipment. Because both *Hylastes ater* and *H. ligniperda* breed in the fresh phloem of recently dead trees, logs can only be attacked once trees have died or been felled (i.e., post-harvest). As felled logs are temporarily stored at or very close to harvesting areas, there is a window of opportunity where the beetles may infest logs. Therefore, the period of flight activity and how this varies among locations are important to assess phytosanitary risks.

In New Zealand, the main adult flight activity of *H. ligniperda* and *H. ater* occurs from late August to late May and from January to May, respectively, with lower levels of flight activity occurring from late August to December (Unpublished data, Scion). However, the flight activity period varies among regions (Brockerhoff et al., 2006b), and will be affected also by local climatic variation related to elevation and aspect. Therefore, to determine the post-harvest infestation risk throughout the landscape requires an understanding of how elevation and aspect affect probability and intensity of adult flight activity.

Here, we report the results of a study using sites along elevational gradients and at different aspects to determine the effects of local climatic and site factors on the flight activity of *H. ater* and *H. ligniperda*. This information will be used to inform models of phytosanitary risk and to assess potential effects of climate change on beetle distribution. We hypothesised that increasing elevation will reduce the flight activity of both species and that during the cooler months flight activity will be longer at warmer northerly aspects than southerly aspects (in the southern hemisphere).

2. Materials and methods

2.1. Study sites and insect trapping

The experiment was conducted in Ashley Forest, Canterbury, New Zealand (43.15 S, 172.57 E) in the foothills of the Southern Alps. A total of 36 traps were installed along four transects established in each of three recently clear-cut *P. radiata* stands (Marshall Rd., Mt. Grey Rd., Berridale Rd.). Each stand had two pairs of parallel transects, two N-exposed and two S-exposed. All transects were positioned on elevation gradients from 435 m (minimum elevation) to 607 m (maximum elevation) to obtain climatically-different sites. The three traps of each transect were separated from each other by approximately 40 m of elevation, providing 'low', 'mid' and 'high' trap locations, with about 30 m between parallel transects (Table 1, Supplementary Table S1).

Temperature was monitored using ibutton temperature loggers (DS1922L-F5# Thermochron iButton, Maximm San Jose, CA, US) placed on the south-facing (shaded) side of traps. Mean temperatures and their standard errors at the study sites were calculated as the overall average of mean hourly temperature readings between 9:00 am and 8:00 pm from 18 February to 3 April 2013. iButton sensors were suspended from the traps and not placed inside Stevenson screens, hence they are subject to the effects of precipitation and direct radiant heat. As all ibuttons were placed in the same place on the trap they do provide a measure of

Table 1
Mean elevation and temperature (± standard error) at sites of differing elevation and aspect.

Site	Aspect	N	Elevation		
			Low	Mid	High
Elevation (m)	N	18	495	533	571
	S	18	500	541	577
Mean temperature (°C)	N	18	20.8 (±0.34)	20.7 (±0.31)	20.0 (±0.29)
	S	18	19.9 (±0.30)	19.1 (±0.28)	18.7 (±0.29)