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Different role of host and habitat features in determining spatial distribution of mistletoe infection

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A B S T R A C T

Tree mortality and forest decline have been attributed to the several factors including mistletoe infection in Oak Zagros forest, western Iran. As a result of climate change and fragmentation *Loranthus europaeus* has the potential to be more abundant and distributed in these forests. However, little attention has been given to the need for an ecosystem approach to their management. To manage it, scientific understanding of its ecology including recognition of mistletoe spatial pattern and its shaping mechanisms are essential. Using spatial analysis, we examined the spatial distribution pattern of mistletoes in terms of life stages and vertical and horizontal host crown classification in relation to its controlling mechanisms, including host and habitat features. The results showed that twenty-three percent of the trees were infected, infected trees having an average of 4.08 mistletoes. Mistletoes were higher in the middle, lower and inner portion of the infected trees crown, corroborating that mistletoes were aggregated in these parts of the crown. The small scale pattern (451 m) of adult mistletoe distribution was observed, whereas juvenile and medium-aged mistletoes were spread at larger distances of 5110 and 4537 m. Mistletoe prevalence spatially autocorrelated up to about 2 km while plot intensity distributed at small range of 316 m. The results suggest that mistletoes first establish in the middle crown part then develop downward into lower crown. The spatial patterns of plot intensity, adult and lower crown mistletoes with smaller ranges were spatially correlated to host size (crown diameter and area). Whereas habitat features were the predictors of the large ranges of prevalence and juvenile mistletoe. To manage mistletoes, considering their roles as keystone species, a focus on reducing the intensity of infection would be of management value at large distances considering spatial relationship between mistletoe and host and habitat features.

1. Introduction

Mistletoes are a group of plants which have been determined as one of the increasing agents of forest decline worldwide (Sangüesa-Barreda et al., 2012). They adversely affect diameter (Sangüesa-Barreda et al., 2012), height, foliage growth, reproduction (Ward, 2005) and reduce the vigor and fitness of the infected trees (Sterba et al., 1993; Watson, 2001; Press and Phoenix, 2005; Kolodziejek and Kolodziejek, 2013; Aparecida Messias et al., 2014). In addition, severely infected trees are often vulnerable to attack by other pathogenic agents, which often result in the death of infected trees (Sterba et al., 1993; Kumbasli et al., 2011; Kolodziejek and Kolodziejek, 2013). Therefore, mistletoes increase infected tree mortality (Sterba et al., 1993; Ward, 2005; Kumbasli et al., 2011; Kolodziejek and Kolodziejek, 2013; Matula et al., 2015) and causes population decline (Rist et al., 2011). Although mistletoes are important drivers of tree mortality, they also play important role as keystone species in forest worldwide. Mistletoes (*Loranthaceae*) provide structural and nutritional resources within canopies, and their influence on diversity led to their designation as keystone resources (Watson, 2001, 2009b; Watson and Herring, 2012).

Loranthus europaeus Jacq is a hemiparasite of several native trees in Zagros Oak forests in western Iran. In these forests, trees infected with mistletoe had a significantly higher mortality rate than uninfected trees (Naseri et al., 2011). Mistletoes rely on the xylem sap of their host to provide water and mineral nutrients to produce their own photosynthetic products (Ward, 2005; Gairola et al., 2013) thus increasing the drought stress and compromising the carbon balance of the host tree, particularly in areas with pronounced water deficit (Sangüesa-Barreda et al., 2012). In Zagros forests region that has a semiarid climate, with climate change, droughts are expected to turn more extreme. Warming-induced drought stress could make host trees more vulnerable to the negative effects of mistletoes (Sangüesa-Barreda et al., 2012), whereas mistletoes as a result of having no contact with the soil could

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withstand these drought stress and nutrient shortages in their hosts (Watson, 2009a). Therefore, *Loranthus europaeus* are becoming one of the main reasons of forest decline in this region. On the other hand, forest fragmentation has been suggested as the main force explaining the increase in the number of parasitic plants (Lopez de Buen et al., 2002). In disturbed landscapes, mistletoes can become super abundant and lead to premature host death (Watson, 2009b). If so, in future we should observe an increase in mistletoe abundance and distribution in Zagros forests and thus health decrease, as the Zagros forests continue been disturbed and fragmented.

As mistletoes are drivers of tree mortality but simultaneously they play important roles in maintaining biodiversity, their appropriate management is a challenge (Norton and Reid, 1997). Removing mistletoes by pruning of infected branches revealed promising results in cases where mistletoes required management. Successful control of mistletoe infection using this method depends on having enough information about the spatial scale at which should be used (Rist et al., 2011). Management of mistletoes depends on scientific understanding of the ecology of them in the context of the forest conditions (Ramon et al., 2016). Therefore, specific account of mistletoe ecology, including the spatial distribution of infection, related controlling mechanisms, and the processes by which the spread of infection occurs are needed (Rist et al., 2011). Using methods of spatial analysis, it is possible to describe variation in the spatial distribution and the scales at which these patterns occur (Overton, 1994; Aukema, 2004).

Different spatial scales of mistletoe distributions have been observed by scientists (Aukema, 2004; Rist et al., 2011; Wilson et al., 2014). Some studies have shown that spatial distributions of mistletoes were aggregated within individual trees (Ward and Paton, 2007) and that infected trees receive more seeds than uninfected trees (Aukema and Martínez del Río, 2002a). Overton (1994) showed that mistletoes were not spatially autocorrelated at small scales, but Aukema (2004) found spatial correlation of mistletoes infections at large distances (Aukema, 2004). Therefore, sound understanding of spatial scale of mistletoes distribution is not available. On the other hand, although the age classes of mistletoes were studied in the infected tree crown (Ward, 2005; Sangüesa-Barreda et al., 2012) but we are not aware of their spatial distribution. As life stages of the same plant species are different in their resource allocation patterns and their response to herbivores and abiotic factors (Bach et al., 2005) their spatial pattern should be considered in research that really help us to attain more knowledge of spatial dynamics of mistletoes. The distribution of mistletoes within infected tree crowns provides a description of their invasion patterns (Sangüesa-Barreda et al., 2012). The mistletoe position within tree crown helps us to understand how mistletoe infestation occurs. Although vertical and horizontal distribution of mistletoes within crown of host trees have been studied (Norton et al., 1997; Ward, 2005; Sangüesa-Barreda et al., 2012), we do not know to what extent the mistletoe position within crown is under the influence of host distribution.

Mistletoes are mutualists of their avian vectors (Aukema and Martínez del Rio, 2002b). The birds that disperse mistletoe seeds are divided to specialists and generalists. Dietary generalists often take a significant proportion of all mistletoe fruits and, even during peak mistletoe fruiting, these birds often forage on other food sources, thereby regularly transporting mistletoe seeds beyond existing infections. Whereas, specialized diet of specialists restricts them to area with high mistletoes densities, resulting in contagious dispersal patterns (Watson and Rawsthorne, 2013; Mellado and Zamora, 2016).

However, mistletoe distributions are regulated by various abiotic and biotic factors (Gairola et al., 2013), which act at different spatial scales (Ward, 2005; Aukema, 2004). To manage mistletoes, the knowledge of the factors that regulate their distribution and abundance is essential. Without understanding this regulator, it is not possible to identify the ecosystem processes that are essential for mistletoe management (Norton and Reid, 1997). The spatial pattern of habitat within the landscape has an important influence on distribution and abundance of plant species (Bowen et al., 2009; Roura-Pascual et al., 2012; Magrach et al., 2015). Along with other pathogenic agents, mistletoe distributions are controlled by habitat (the environmental conditions under which the hosts are growing) (Kolodziejek and Kolodziejek, 2013; Rahmad et al., 2014). The habitat condition such as canopy cover of the overstorey had an effect on mistletoe abundance (MacRaild et al., 2010; Kumbasli et al., 2011). Most scientists found higher abundance of mistletoe in less dense stands (Sterba et al., 1993; Donohue, 1995; Kumbasli et al., 2011). On the other hand on a local scale, most studies have determined that mistletoe infection is positively related to host tree size (tree height, diameter and basal area), water and nutrient status, canopy light regimes and previous infection of a tree or a site (Ward, 2005; Okubamichael et al., 2011; Matula et al., 2015). Previous studies showed that spatial distribution of mistletoe is influenced considerably by host distribution (Rist et al., 2011; Gairola et al., 2013; Ramon et al., 2016). Therefore, host quality as a critical factor determining which potential host trees are susceptible to infection, should be considered at the stand scale (Watson, 2009a). Norton and Reid (1997) have also suggested that further researches on mistletoe-host relationship is required. Sound understanding of these factors, that affect distribution and spatial ecology of mistletoe, is necessary to develop their management strategies (Rist et al., 2011; Watson, 2009a). Hence both host and habitat quality are important drivers of mistletoe abundance and distribution (Lopez de Buen et al., 2002; Ward, 2005; Kumbasli et al., 2011; Kolodziejek and Kolodziejek, 2013; Rahmad et al., 2014). So far, we are not aware of any research that studied the distribution and spatial ecology of mistletoe in relation to measures of host and habitat quality. Ramon et al. (2016) have also mentioned that further investigation is needed to identify the mechanisms underlying the infection pattern seen.

We consider three questions in this research: (1) what is the spatial distribution pattern of mistletoes? (2) What are the mechanisms controlling the mistletoes distribution, host or habitat? (3) What are the mistletoe spatial distribution patterns in terms of life stages and vertical and horizontal host crown classification?

2. Materials and methods

2.1. Study area

This study was conducted at the Gahvareh forests of the western Iran (43°31′–43°33′N and 64°10′–64°12′E). Average annual rainfall is 490–550 mm with mean temperature of 11–13 °C. This area ranges in altitude from 1844 to 2128 m.

The main hosts of *Loranthus europaeus* Jacq in this area is *Quercus brantii* Lindl, as well as *Amygdalus orientalis* Duh., *Q. infectoria* Boissieri and *Acer monspessulanum* Boiss. although the latter three hosts are much less abundant. *Quercus brantii* or Persian oak (covering more than 50% of the Zagros forest region) is the most important tree species of the Zagros in Iran. They are big sized trees with a height of 15–20 m and a big spherical crown (Sabeti, 2002).

2.2. Mistletoe infection measures

To investigate the presence and abundance of mistletoe and its distribution, 86 plots (1600 m^2) in a 200 m × 200 m sampling grid were established in Gahvareh forests, Kermanshah. For each plot