Journal of Asia-Pacific Biodiversity xxx (2017) 1–7

Contents lists available at ScienceDirect

Journal of Asia-Pacific Biodiversity

journal homepage: http://www.elsevier.com/locate/japb

Original article

Model-based prediction of potential distribution of the invasive insect pest, spotted lanternfly *Lycorma delicatula* (Hemiptera: Fulgoridae), by using CLIMEX

Jae-Min Jung [a,†], Sunghoon Jung [b,†], Dae-hyeon Byeon [a], Wang-Hee Lee [a,*]

[a] *Department of Biosystems Machinery Engineering, Chungnam National University, Daejeon 305-764, South Korea*
[b] *Department of Applied Biology, Chungnam National University, Daejeon 305-764, South Korea*

ARTICLE INFO

Article history:
Received 11 April 2017
Received in revised form
29 June 2017
Accepted 7 July 2017
Available online xxx

Keywords:
CLIMEX software
invasive pest
Lycorma delicatula
potential distribution

ABSTRACT

Lycorma delicatula is one of the major invasive pests of Korea. Careful monitoring is required to protect domestic agriculture as this pest causes severe damage to agricultural crops, such as wilting and sooty mold. This study was designed to confirm the potential distribution of *L. delicatula* using the modeling software CLIMEX and to suggest fundamental data for preventing agricultural damage by *L. delicatula*. Our results show that Korean weather seems to be adequate for *L. delicatula* habitation, indicating that approximately 60% of areas examined have a very high possibility of potential distribution. Particularly, we showed that Gyeongsang-do and Jeonla-do, which have not yet been invaded by *L. delicatula*, were very suitable locations for its growth. Therefore, although it is necessary to set up feasible strategies for preventing further *L. delicatula* invasions, subsequent studies are needed for assessing other invasive species considering the impact of future climate change.

Introduction

Lycorma delicatula is a plant hopper native to China, India, and Vietnam, countries with relatively hot climates. After the initial report of *L. delicatula* in 2006, its population has been increasing all over South Korea, including Seoul, Gyeonggi, Chungbuk, Chungnam, Jeonbuk, and Gyeongbuk (KFRI 2007; Han et al 2008; Choi et al 2012). *L. delicatula* uses its sucking mouthparts to feed on the sap of fruit trees, causing severe damage, such as wilting and sooty mold (Han et al 2008; Lee et al 2009; Park et al 2009; Shin et al 2010). Between 2008 and 2009, this pest was responsible for widespread agricultural-sector damage caused by its excreta leading to sooty mold. In particular, *L. delicatula* is expected to cause significant damage to the vineyards in Korea, as its eggs are able to survive the increasingly warm winters brought about by global warming.

Recently, numerous research studies have been performed in South Korea, demonstrating that *L. delicatula* causes harmful effects. One study, which conducted a morphometric analysis of *L. delicatula*, showed that it was found in 10 localities in Korea, China, and Japan; in addition, 14 morphometric characteristics of the forewing were analyzed (Kim et al 2013). This study showed that in Korea, *L. delicatula* morphology was similar within the northern area of the Yangtze River, but in Seoul and Buan, it was very similar to that of *L. delicatula* in Shanghai. In terms of its biological characteristics, *L. delicatula* has four instars (Park et al 2009). This study showed that the body color of the first to third instar nymphs was black, but the upper body became red. In addition, the adult forewings were brownish with black spots, whereas the hindwings were red. In addition to morphological studies of *L. delicatula*, its survival rate has also been investigated. The occurrence pattern of *L. delicatula* in the Gyeonggi area and the effect of winter temperature on the survival of *L. delicatula* eggs from 2010 to 2013 have been reported (Lee et al 2014). In Jeonnam Province, Choi et al (2012) predicted the hatching time of *L. delicatula* eggs by using an effective environmentally friendly agricultural material, suggesting that a low temperature threshold and thermal constant were required for eggs to mature to the larval stage. In addition, other studies have focused on the effect of specific types of insecticides for the control of *L. delicatula* (Lee et al 2011; Park et al 2009).

* Corresponding author.
E-mail address: wanghee@cnu.ac.kr (W.-H. Lee).
† J.-M. Jung and S. Jung contributed equally to this work.
Peer review under responsibility of National Science Museum of Korea (NSMK) and Korea National Arboretum (KNA).

http://dx.doi.org/10.1016/j.japb.2017.07.001

Please cite this article in press as: Jung J-M, et al., Model-based prediction of potential distribution of the invasive insect pest, spotted lanternfly *Lycorma delicatula* (Hemiptera: Fulgoridae), by using CLIMEX, Journal of Asia-Pacific Biodiversity (2017), http://dx.doi.org/10.1016/j.japb.2017.07.001

Factors such as habitation, dispersion, and reduction of species according to global warming may result in the invasion of alien species. Advanced countries, including America, Australia, and Europe, have used predictive modeling to forecast the potential distribution of pests in order to prevent them from invading domestic ecology. CLIMEX (Hearne software, South Yarra, Victoria, Australia) is a software that has been used for model-based predictions of the distribution and dispersion of species by integrating information regarding the habitat of target species and climate of the target area (Sutherst et al 2000, 2007). In other words, CLIMEX emulates the mechanisms that limit geographical distribution of species, identifies their phenology, and predicts the potential geographical distribution and seasonal abundance in response to climate change (Sutherst et al 2007).

Although there are many studies of *L. delicatula* regarding its morphology, physiology, and population control, to our knowledge, a study for predicting its potential distribution has not yet been conducted. The objective of this study was to investigate the potential distribution of *L. delicatula* in South Korea by using CLIMEX, and to assess high-risk areas for the invasion of *L. delicatula* based on the simulation. Because *L. delicatula* has been considered a major invasive pest and has caused widespread damage in Korea, the results of this study are expected to provide a basic information for monitoring species distribution and preventing its dispersion in advance.

Materials and methods

CLIMEX software

The CLIMEX Model (version 3.0) has mainly two applications: "Compare Locations" and "Compare Years" (Sutherst et al 2007). The "Compare Locations" application can predict the potential geographical distribution of a species according to climate preference, whereas the "Compare Years" application is used to show the response of a species to consecutive years of monthly climate in the same location (Hughes and Maywald 1990; Worner 1988; McKenney et al 2003; Sutherst and Maywald 2005; Sutherst et al 2007). The results of CLIMEX Model are represented by the eco-climatic index (EI), which indicates the survival and growth of a species in many different locations. The EI is a number between 0 and 100, calculated by multiplying the growth index (GI), stress index (SI), and interaction stress index (SX). The GI describes the potential population growth during a favorable season, whereas the SI addresses the extent in population reduction during an unfavorable season. The GI contains seven indices (temperature, moisture, radiation, substrate, diapause, light, and biotic index). The SI is defined by four stresses: cold stress (CS), heat stress (HS), dry stress (DS), and wet stress (WS) (Sutherst et al 2007). In the present study, "Compare Location (1 species)" was applied among eight different applications as we are only evaluating one species (*L. delicatula*) in response to climate in South Korea.

Known distribution of L. delicatula

The distribution of *L. delicatula* was determined by data on the occurrence of *L. delicatula* eggs reported by the Korea Forest Service in 2013 (KFS 2016) and by Han et al (2008) (Figure 1). The report showed that *L. delicatula* had spread throughout the country with particularly high concentrations in Gyeonggi-do ("do" is the equivalent of province, the largest administrative district in Korea), whereas it had not been reported in Geongsangnam-do. Specifically, from 2006 when *L. delicatula* was first introduced to Korea, its population had increased in various parts of the country (KFRI 2007; Han et al 2008; Choi et al 2012). This information was used to calibrate parameters of CLIMEX so that it could correctly simulate the current distribution of *L. delicatula* in Korea, as well as in China.

Climate data

Meteorological data for predicting the potential distribution of *L. delicatula* consisted of five factors: minimum temperature, maximum temperature, precipitation, and relative humidity at 9 A.M. and 3 P.M. Meteorological data were modified based on the monthly data of the Climatological Standard Normal (1981–2010) provided by the Korea Meteorological Administration (KMA) and entered into CLIMEX software. Then, we selected 74 representative locations where CLIMEX applied meteorological datasets and predicted the suitability of habitation by *L. delicatula* (KMA 2016) (Table 1 and Figure 2).

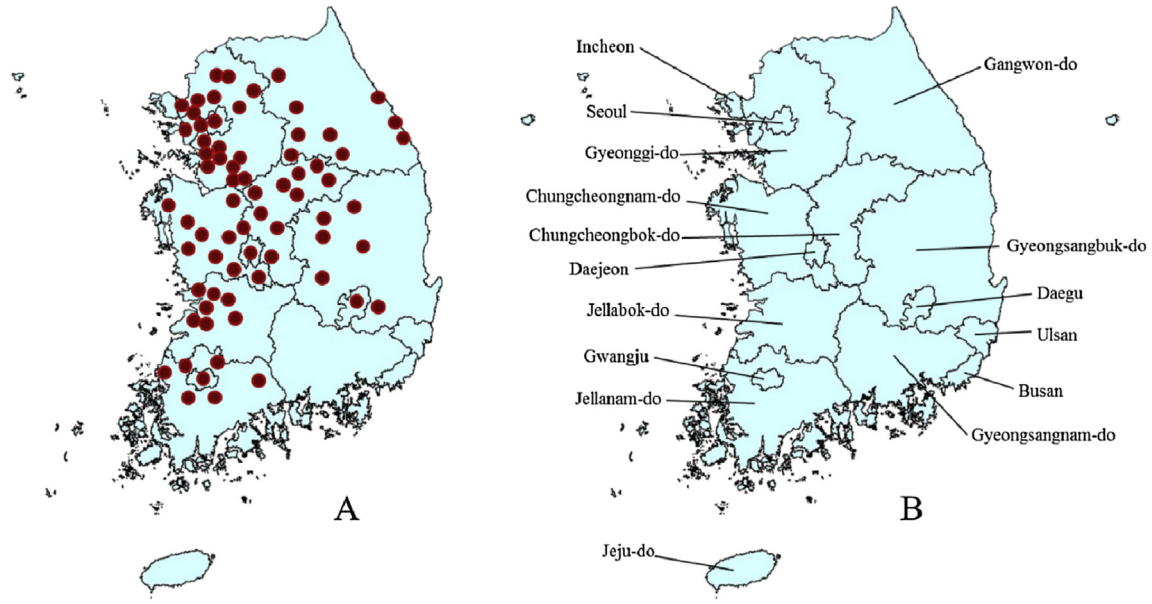

Figure 1. A, Distribution map of *Lycorma delicatula* consulted to KFS 2013; B, administrative districts in Korea including eight provinces and seven major cities. KFS = Korea Forest Service.

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