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The effect of data sources and quality on the predictive capacity of CLIMEX models: An assessment of *Teleonemia scrupulosa* and *Octotoma scabripennis* for the biocontrol of *Lantana camara* in Australia

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ABSTRACT

Understanding the effects of different types and quality of data on bioclimatic modeling predictions is vital to ascertaining the value of existing models, and to improving future models. Bioclimatic models were constructed using the CLIMEX program, using different data types – seasonal dynamics, geographic (overseas) distribution, and a combination of the two – for two biological control agents for the major weed *Lantana camara* L. in Australia. The models for one agent, *Teleonemia scrupulosa* Stål (Hemiptera: Tingidae) were based on a higher quality and quantity of data than the models for the other agent, *Octotoma scabripennis* Guérin-Méneville (Coleoptera: Chrysomelidae). Predictions of the geographic distribution for Australia showed that *T. scrupulosa* models exhibited greater accuracy with a progressive improvement from seasonal dynamics data, to the model based on overseas distribution, and finally the model combining the two data types. In contrast, *O. scabripennis* models were of low accuracy, and showed no clear trends across the various model types. These case studies demonstrate the importance of high quality data for developing models, and of supplementing distributional data with species seasonal dynamics data wherever possible. Seasonal dynamics data allows the modeller to focus on the species response to climatic trends, while distributional data enables easier fitting of stress parameters by restricting the species envelope to the described distribution. It is apparent that CLIMEX models based on low quality seasonal dynamics data, together with a small quantity of distributional data, are of minimal value in predicting the spatial extent of species distribution.

1. Introduction

Bioclimatic models are frequently used in predicting the potential distributions of introduced species (Pearson and Dawson, 2003; Elith et al., 2006; van Klinken et al., 2009). In classical biological control, bioclimatic models of natural enemies are useful when prioritising potential biocontrol agents, designing release programs to maximize establishment rates and when evaluating biological control agents following their release (van Klinken et al., 2003; Zalucki and van Klinken, 2006). However, confidence in predictions is required, especially when prioritising potential biocontrol agents on the basis of the predicted climatic suitability of the target environment. The quality and quantity of data used to build bioclimatic models is an important factor in their reliability (e.g., Lozier et al., 2009) and is the focus of this paper.

The physiologically based bioclimatic modeling approach, CLIMEX, provides a useful tool to assess the likelihood of an introduced species establishing in a particular country or region and its potential distribution. The approach differs from most other models in that it attempts to model the population level consequences of a species' physiological responses to climate variables of temperature and moisture (Sutherst et al., 2004). CLIMEX allows the climatic requirements of a species to be inferred from a range of data sources, including geographic distribution (e.g., Kriticos et al., 2000), abundance data, seasonal dynamics information (e.g., Yonow and Sutherst, 1998), and laboratory data (e.g., rearing temperature, developmental times; see Kriticos et al. (2000) and Zalucki and van Klinken (2006). These species models can be validated using a similar range of data types but from a region that is independent to that from which the data used in developing the model were sourced (Sutherst et al., 2004). This modeling approach contrasts with most other bioclimatic models which use only species distribution data (Pearson and Dawson, 2003; Elith et al., 2006).

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CLIMEX has been used extensively in weed biological control programs to: assess the potential distribution of new biocontrol agents introduced to Australia (e.g., Palmer et al., 1996, 2000); advise on the selection of regions suitable for the release of biocontrol agents (e.g., Senaratne et al., 2006); advise on the best season for their release (e.g., Scott and Yeoh, 1999); and help to determine possible reasons why potential biocontrol agents failed to establish (e.g., Day and McAndrew, 2003). The information from which these models can be derived varies, ranging from quantitative data on biological processes or states, through to qualitative observations and expert opinion (Sutherst et al., 2000). Sutherst and Maywald (2005) highlight the need for ''pragmatic and parsimonious approaches to make the most use of the global climatic data and field observations that are available''.

A particular challenge for biocontrol practitioners is that the field of biological control typically involves working with potential agents for which there may be minimal data (Zalucki and van Klinken, 2006). Consequently, CLIMEX models are usually constructed from a variety of data that vary both in quantity and quality (Sutherst et al., 2000). It is therefore essential that we understand the effects of these data on CLIMEX models used to inform decision making for biological control and other purposes. Here, we assess the effects of different data types and data qualities on the predictions of CLIMEX models to answer the question: can models based upon limited distributional, experimental and/or seasonal dynamics data provide a reasonable prediction of species' range in a new region?

To achieve this, we assess the relative contribution of different data sources – species' 'seasonal dynamics', 'overseas distribution' and a combination of the two, on CLIMEX models. As a case study, we use two long and widely established biological control agents for lantana, *Teleonemia scrupulosa* Stål (Hemiptera: Tingidae) and *Octotoma scabripennis* Guérin-Méneville (Coleoptera: Chrysomelidae), and compare model predictions to known distributions and seasonal dynamics of the two agents in Australia. The impact of data quality is examined through the comparison of the results of the models for the two agents, the *T. scrupulosa* models being based on a higher quantity and quality of available data than the *O. scabripennis* models. The long period of establishment in Australia of both agents (*T. scrupulosa* since 1936 and *O. scabripennis* since 1966), and their subsequent well-known Australian range (Day et al., 2003a), suggest that these are appropriate case studies for such an assessment.

2. Materials and methods

2.1. The weed and agents

Lantana is a weed of tropical American origin now found in over 70 tropical and subtropical countries or regions worldwide (Day et al., 2003b). In Australia, lantana occurs in coastal and subcoastal regions of eastern Australia from Cooktown (15.47°S 145.25°E) in north Queensland to Eden (37.07°S 149.09°E) in southern NSW, with small infestations in the Northern Territory and in south-west Western Australia (Day et al., 2003a). Thirty-one biological agents, of which eighteen have established, have been introduced into Australia in an effort to control lantana. Of these, *T. scrupulosa* and *O. scabripennis* can seasonally cause substantial, widespread damage to lantana plants (Day et al., 2003a), although the weed is not under biological control (Zalucki et al., 2007).

Teleonemia scrupulosa is a sap sucking bug. Adults and nymphs feed on the underside of leaves and occasionally on leaf tips and flowers (Fyfe, 1937). The feeding causes the formation of chlorotic and necrotic lesions and leaf malformation, curling and defoliation (Simmonds, 1929). The life cycle is typically completed within 3–4 weeks (Simmonds, 1929; Fyfe, 1937), with adults surviving for up to 5 months (Khan, 1945). Adult *O. scabripennis* feed and oviposit on the upper surface of leaves. The emerging larvae mine the leaves, causing blotches to occur. The development of egg through to adult takes between 34 and 45 days, with a pre-oviposition period of 3–4 weeks. To avoid seasonally unfavorable conditions, adults can enter a facultative diapause stage (Harley, 1969).

2.2. Model development

Predictive models of the potential distribution of *T. scrupulosa* and *O. scabripennis* in Australia were developed using CLIMEX Version 2.0 (Sutherst et al., 2004) using seasonal dynamics only, distribution only, and all available data (combined model). The distribution of both species in their native and introduced ranges, their ecology and their seasonal dynamics were determined from literature searches and collection records by biocontrol researchers. To ensure the independence of models, the seasonal dynamics model for each species was developed first, followed by a hiatus of several weeks before commencing the model based on overseas distribution, and the developer of the model (BL) was kept unaware of the actual Australian distribution of both agents (sourced from MD). A complete list of data on which the models were based is available from the corresponding author.

2.2.1. Modeling approach 1: seasonal dynamics

The seasonal dynamics model parameters for both species were derived from the qualitative descriptions of the species' seasonal population trends at specific locations. The climatic information of the corresponding grid cells of standard CLIMEX 50 × 50 km world grid coverage, in conjunction with these qualitative seasonal dynamics descriptions, was used to iteratively determine parameters of these models, as described below. A concise description of the CLIMEX parameter set can be found in Zalucki and van Klinken (2006).

The model for *T. scrupulosa* was based on seasonal dynamics data obtained from Dehra Dun in northern India (30.20°N 78.02°E) (Khan, 1945), with cold dry winters and hot monsoonal summers, and Suva, Fiji (18.05°S 178.25°E) (Fyfe, 1937) with a wet tropical climate. Temperature parameters were fitted to maximize species populations during the warm summer months at Dehra Dun and all year round at Suva. The lower temperature threshold (DV0) followed the observation of heavy *T. scrupulosa* mortality at temperatures below 14 °C (Harley and Kassulke, 1971). Locating the lower optimum temperature (DV1) at 25 °C is consistent with Fyfe's (1937) records of shorter nymphal development times above this temperature.

Lower threshold (SM0) and lower optimum (SM1) moisture parameters were fitted to improve species growth during the dry season at Dehra Dun, particularly between February and May, when the population was recorded as increasing after heavy winter mortality. Upper optimum (SM2) and upper threshold (SM3) moisture values were adjusted to maximize growth in Suva, while limiting growth at Dehra Dun, where Khan (1945) recorded high mortality of *T. scrupulosa* during the monsoon season as rain deluges dislodged and/or drowned the insects.

Threshold cold stress (TTCS/THCS) was determined from the temperature threshold recorded by Harley and Kassulke (1971) and replicated the low species numbers during December–January in Dehra Dun (Khan, 1945). Wet stress parameters were fitted to minimize stress in Suva where the population was recorded as growing strongly in a high rainfall environment (2977 mm average annual rain) (Simmonds, 1929; Fyfe, 1935). Heat and dry stress parameters could not be fitted from available data and so were omitted.