HITCHIKERS ON INTERNATIONAL TRADE ROUTES: ESTIMATING THE PROBABILITIES OF INTRODUCTION AND ESTABLISHMENT OF ASIAN GYPSY MOTH WITH *GLS-2D*

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ABSTRACT

As global trade rises so too does the probability of introduction of alien species to new locations. Estimating the probability of an alien species introduction ($p(I)$), and establishment following introduction ($p(E|I)$), is a necessary step in estimating risk (probability of an event times the consequences, in the currency of choice, of the event should it occur); and risk estimation is a valuable tool for reducing the risk of biological invasion with limited resources. The Gypsy Moth Life Stage (aka the Gray-Logan-Sheehan) model (*GLS*) is an accurate and geographically robust model of insect phenology that has been used to estimate $p(E|I)$ of the gypsy moth in western Canada (Régnière and Nealis 2002), Utah (Logan et al. 2006), North America (Gray 2004), and New Zealand (Pitt et al. 2007).

Despite the importance of long-range trade routes in the introduction of gypsy moth, the spatio-temporal variability in weather and its effect on gypsy moth phenology has never been a consideration in estimating either $p(I)$ or $p(E|I)$. That is to say: the degree to which pre-departure phenological development at the source, plus phenological development en route, plus post-arrival development at the destination, influence $p(I)$ and/or $p(E|I)$ has not been considered in the invasion risk calculations. *GLS-2d* is a two-dimensional phenology model that intersects ship arrival/departure with simulated phenological development at the source and then simulates subsequent development on the route to the destination. *GLS-2d* estimates: (1) the probability of introduction from the proportion of the source population that would achieve the next developmental stage at the destination, and (2) the probability of establishment from the proportion of the introduced population that survives until a stable life cycle is reached at the destination.

GLS-2d was demonstrated using three common marine trade routes (to Auckland, New Zealand from Kobe, Japan and to Vancouver, Canada from Kobe and from Vladivostok, Russia). The effect of shipping schedule on the probabilities of introduction and establishment was examined by varying the departure date from January 1 to December 25 by weekly increments.

For the work described here, *GLS-2d* ran 25 independent simulations with randomly chosen years for each weekly departure date. For each simulation, *GLS-2d* estimated oviposition at the port of origin using its “stabilization” option wherein the model determines the location-specific oviposition pattern that is most likely (see Gray 2010 for a complete description). The simulated oviposition pattern of this F_0 generation was intersected temporally with the arrival/departure of a target ship by *GLS-2d* to estimate the infection level of the departing ship and its containers. Daily phenological development was simulated during transit using the weather records of the location in the *GLS-2d* database nearest the estimated location on the prescribed route and thereafter using the weather records from the destination. The proportion of the F_0 eggs oviposited at the origin that subsequently hatched at the destination was calculated for each of the 25 simulations, and $p(I)$ for the departure date was calculated as the average of the 25 proportions.

When egg hatch was successful at the destination, the simulation continued for seven additional generations (hatching eggs to hatching eggs), and the geometric average of inter-generational survival ($\left(\prod_{i=1}^{7}\frac{y_i}{y_{i-1}}\right)^{1/7}$) was calculated for each simulation. The $p(E|I)$ for the departure date was calculated as the average of the 25 geometric averages. Seven generations were used for the calculation of $p(E|I)$ because a stabilized life-cycle pattern is usually achieved within seven generations (Gray 2004).

Successful introduction of Asian gypsy moth requires two things. First, containers and/or ships must be present at the port of origin during egg oviposition. The $p(I)$ increases as the temporal intersection between oviposition period and presence of containers and ship increases—ships depart with a greater abundance of egg masses. Second, the combined weather conditions of the origin, route, and destination must satisfy life-cycle requirements—eggs must hatch at the destination. *GLS-2d* is able to estimate these factors. Introduction to Vancouver from Vladivostok is less likely than from Kobe in part because the more prolonged oviposition period in Vladivostok means fewer egg masses are laid per day there, which results in a generally lower infestation on containers and ships that spend a short time in port. The $p(E|I)$ depends on transit route, departure date, and the climate at the destination. *GLS-2d* simulations indicate that the large latitudinal difference between Kobe and Auckland, and the reversal of the seasons that occurs en route, will partially disrupt phenological development and reduce inter-generational survival until stable seasonality is achieved.

Literature Cited

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