Predicting Invasiveness of Plant Species Based on Biological Information

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Abstract: *Previous studies suggest that, within particular groups of plant species, biological attributes can be used to predict the potential invasiveness of species that are intentionally introduced for horticultural or agricultural purposes. We examined the broad question of whether commonly available biological information can predict the invasiveness of a wide range of intentionally and accidentally introduced species. We collected information from published floras on 165 pairs of plant species. In each pair, one species originated in Europe and successfully invaded New Brunswick, Canada, and the other was a congeneric species that has not invaded North America. Only three biological characters—lifeform, stem height, and flowering period—and European geographic range were known for all species. We conducted multiple logistic regression analyses using two-thirds (110) of the species pairs and tested the predictive ability of resulting models using the remaining 55 pairs. Although a significant logistic regression model was obtained using the biological attributes, the model could not predict invasiveness of the test species pairs. In contrast, a model using only European range successfully predicted invasiveness in 70% of the test species. The importance of geographic range suggests that prediction of invasiveness on a species-by-species basis is not likely to help stem the flow of accidentally introduced invasive species. Species that are inadvertently picked up and moved to a new location due to their wide distribution are the same species that are likely to succeed in a new environment due to their wide environmental tolerances.*

Predicción de la Invasividad de Especies en Base a Información Biológica

Resumen: *Estudios previos sugieren que dentro de grupos particulares de especies de plantas, los atributos biológicos pueden ser usados para predecir el potencial de invasión de especies que son introducidas intencionalmente con propósitos horticulturales o agriculturales. Examinamos una pregunta muy amplia: ¿Puede la información biológica disponible predecir la invasividad de un amplio rango de especies intencional o accidentalmente introducidas? Colectamos información de flora publicada sobre 165 pares de especies de plantas. En cada par, una especie es originaria de Europa y exitosamente invadió New Brunswick, Canadá, y la otra fué una especie congénere que no ha invadido Norteamérica. Sólo tres características biológicas (forma de vida, altura del tallo y periodo de floración) y el rango geográfico europeo estuvieron disponibles para todas las especies. Condugimos múltiples análisis de regresión logística utilizando dos tercios (110) de los pares de especies y probamos la habilidad predictiva de los modelos resultantes utilizando los pares de especies restantes. A pesar de que se obtuvo un modelo de regresión logística significativo utilizando todos los atributos biológicos, el modelo no pudo predecir la invasividad de los pares de especies probados. En contraste, un modelo que empleó únicamente el rango geográfico europeo predijo exitosamente la invasividad en un 70% de las especies analizadas. La importancia del rango geográfico sugiere que la predicción de la invasividad basada en un análisis especie por especie no prodrá ayudar a detener el flujo de especies invasivas introducidas accidentalmente. Las especies que son seleccionadas inadvertidamente y movidas a una nueva localidad en base a su amplia distribución, son las mismas especies que son más probables de tener éxito en un nuevo ambiente debido a su amplio rango de tolerancias ambientales.*

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Introduction

Invasive species have become an increasingly important conservation issue (di Castri 1990). Invasive species enter various habitats (Baker 1986; Fox & Adamson 1986; Gray 1986; Mooney et al. 1986; Mack 1989) and may alter ecosystem properties and processes (Vitousek 1986; Le Maitre et al. 1996) as well as native community structure (Simberloff 1981). An invasive plant may threaten the protected plant species in a reserve (Usher 1988; Macdonald et al. 1989) or change habitat suitability for animals (Trammell & Butler 1995).

Several authors have suggested that it is important to understand what biological characteristics make a species a good invader so that species that are likely to be invasive can be screened and the costs of invasion can be reduced by preventing the initial introductions. Studies have considered either a set of successfully invasive species (Newsome & Noble 1986; Reichard & Hamilton 1997) or have compared species characteristics of native and invasive species (Baker 1965; Caldwell et al. 1981, 1983; Baruch et al. 1985; Roy 1990; Pyšek et al. 1995; Thompson et al. 1995). Characteristics identified as important determinants of invasiveness are small, short-lived seeds that can germinate without pretreatment (e.g., freezing), short juvenile periods and short intervals between large seed crops, large size, long flowering period, vegetative reproduction, and perfect flowers (Crawley 1987, 1989; Perrins et al. 1992, Richardson et al. 1994; Thompson et al. 1995, Rejmánek & Richardson 1996; Reichard & Hamilton 1997).

The usefulness of such characteristics for predicting which species will be invasive differs for intentional versus accidental introductions. In the case of plants that are intentionally introduced for horticultural or agricultural purposes, potential invasiveness can be assessed on a case-by-case basis when application is made for importation of the plant. Biological attributes that predict invasiveness in such a group could be used to decide whether to grant a permit to introduce a species (e.g., Reichard & Hamilton 1997).

If biological attributes of invasiveness apply to both intentionally and accidentally introduced species, then it should be possible to use this information to develop protocols for transportation and shipping that will reduce the probability of accidental introductions of invasive species. A potential difficulty, however, is that many of the attributes used to predict invasiveness of intentionally introduced species are not available for the majority of species. To predict invasiveness of all potentially invasive species, both intentionally and accidentally introduced, we must limit the biological attributes to those that are available for most or all species. The first objective of this study therefore was to determine whether invasiveness can be predicted from commonly available biological information.

In addition to biological information, the geographical range of a species in its area of origin should be related to the probability of its moving and persisting elsewhere (invading) for two reasons. First, wider-ranging species are more likely to come into contact and be carried with international transport of goods. Second, species with larger original ranges are more likely to be pre-adapted to conditions in a new area (Groves 1986; Holdgate 1986; Roy 1990). Thus, our second objective was to determine whether invasiveness can be predicted more successfully using biological attributes or geographic range.

Methods

We compared attributes of plant species that originated in Europe and have successfully invaded New Brunswick, Canada, to congeneric species in Europe that have not invaded North America. We included woody and herbaceous plants and species that were introduced intentionally and accidentally. We used congeneric pairs of species to minimize the potentially confounding effects of phylogeny (Clutton-Brock & Harvey 1991). We compared invasive to noninvasive species from the same source area because simple identification of attributes of a set of invasive species does not imply that these attributes are important for invasiveness; they may simply be attributes of the source flora (Perrins et al. 1992).

Using the *Flora of New Brunswick* (Hinds 1986), we identified all the flowering plants that have successfully invaded New Brunswick from Europe. To have successfully invaded, a plant had to be (1) persisting in New Brunswick, (2) from Europe or Eurasia, (3) a non-native species in North America, and (4) associated with human-disturbed habitat. We paired each invasive species with a randomly selected, noninvasive, congeneric species in Europe according to Tutin et al. (1964). To be considered for pairing, a noninvasive species had to be (1) native to Europe, (2) non-native to North America, (3) associated with a human-disturbed habitat, and (4) in the same genus as the invasive species. We imposed the criterion of being associated with human-disturbed habitats on both the invasive and noninvasive species to control for the degree of disturbance at the invaded site, which has a large effect on the success of invasion (Ewel 1986; Mack 1986; Mooney et al. 1986; Crawley 1986, 1987; Orians 1986; Hobbs 1989; Roy 1990).

We found only three biological characters—lifeform (life), stem height (height), and flowering period (flower)—that could be gathered for a wide range of species from published floras. Lifeform was coded as 1, annual or biennial; 2, herbaceous perennial; or 3, woody. If a range was reported for stem height or flowering period, we used the mid-point of the range.

The *Flora Europea* divides Europe into 39 geographical regions, which we used to determine European geographic range (range) by counting the regions of Europe for which presence of the species was reported. For all of the species characteristics, we used only European values. For a plant pairing to be included in the analysis we had to have a value for all four characteristics for both types of species, invasive and noninvasive.

We held back a third of the invasive-noninvasive pairs, chosen randomly, to later test the predictive ability of models constructed. To address our two objectives, the remaining two-thirds of the data were analyzed in two stepwise multiple logistic regression analyses (SAS Institute 1990). In the first, we included only the three biological attributes (lifeform, stem height, and flowering period), and in the second we included the biological attributes and geographic range.

The predictive abilities of the logistic models were tested by applying them to the reserved third of the data. Using the models, we calculated probabilities of invasiveness that were then compared to the actual status of the species, invasive or noninvasive. The model was presumed to predict invasiveness if the probability of invasiveness was greater than 0.5. We then compared the proportion of species successfully predicted against a null hypothesis of random selection (i.e., proportion correct equals 0.5) using a difference of proportions test (Zar 1996).

Results

Of 391 European invaders in the *Flora of New Brunswick* (Hinds 1986), 165 species (and their noninvasive paired congeneric species) met all the criteria for inclusion in the data set. The 110 pairs randomly chosen to test for differences between invasive and noninvasive species represented 29 families. Asteraceae, Scrophulariaceae, and Fabaceae each accounted for approximately 11% of the pairs, whereas the remaining families ranged between 1% and 7% of the pairs.

The first logistic regression analysis, using the biological variables only, produced a model containing ln(flower) and ln(height) (Table 1). There was no effect of lifeform on invasiveness. Invasive species were significantly taller, 16 cm on average, than congeneric noninvasive species, and the European flowering period of invasive species was significantly longer, 0.75 months on average, than that of congeneric noninvasive species. When this model was applied to the reserved data, predictions for both invasive and noninvasive species were not significantly better than random (Table 1).

The second multiple logistic regression, with the same variables as the first plus geographic range, produced a model containing only range (Table 1; Fig. 1), which fit the data better than did the first model (88.2% versus 68.3% of pairs concordant; Table 1). The second model correctly predicted 70.9% of the reserved invasive plants to be invasive and 72.7% of the reserved noninvasive plants to be noninvasive, which was significantly better than random (Table 1).

Discussion

Although the biological attributes of stem height and flowering period differed significantly between invasive and noninvasive plants, they were poor predictors of invasiveness. Only about 60% of the invasive and noninvasive species could be predicted correctly based on stem height and flowering period, which was not significantly better than what would be predicted by chance. We found no detectable difference in the lifeform of invasive versus noninvasive species, even though lifeform is often suggested as important to invasiveness (Roy 1990; Lodge 1993*a*).

In contrast, the original range of the species was an effective predictor of invasiveness: 88.2% of plant pairs were concordant in the logistic regression model using range alone, and this model successfully predicted invasiveness in over 70% of species that were not included in the model. The European range of invasive species, on average, contained 14.3 more regions than noninvasive species' ranges. Other researchers have noted the importance of range (Roy et al. 1991; Scott & Panetta 1993; Rejmánek 1995). Our study, however, is the first to compare the predictive value of geographic range versus that of commonly available biological attributes.

Table 1. Results of multiple logistic regression of probability of a species invading, *P(I)*, on species attributes, and validation tests.[a]

Variables included[b]	life, ln(height), ln(flower)		life, ln(height), ln(flower), range	
Equation	$p(I) = \frac{e^{-3.917 + 1.621\ \ln(\text{flower}) + 0.508\ \ln(\text{height})}}{1 + e^{-3.917 + 1.621\ \ln(\text{flower}) + 0.508\ln(\text{height})}}$		$p(I) = \frac{e^{-5.177 + 0.21(\text{range})}}{1 + e^{-5.177 + 0.21(\text{range})}}$	
Fit (concordant pairs)	68.3%		88.2%	
Validation[c]	% correct	$p\ (n = 55)$	% correct	$p\ (n = 55)$
	I: 61.8	0.2146	*I*: 70.9	0.0270
	N: 61.8	0.2146	*N*: 72.7	0.0161

[a] *Logistic regression models were based on 110 pairs of invaders and noninvaders.*
[b] *Life, lifeform; height, stem height; flower, flowering period; range, European geographic range.*
[c] *Validations were conducted on 55 pairs of invasive and noninvasive plants not used to build the models;* P(I) > *0.5 predicts an invader. The percent correct is divided into invasive* (I) *and noninvasive species* (N) *for each appraoch. These proportions were tested against a null hypothesis of 0.50.*

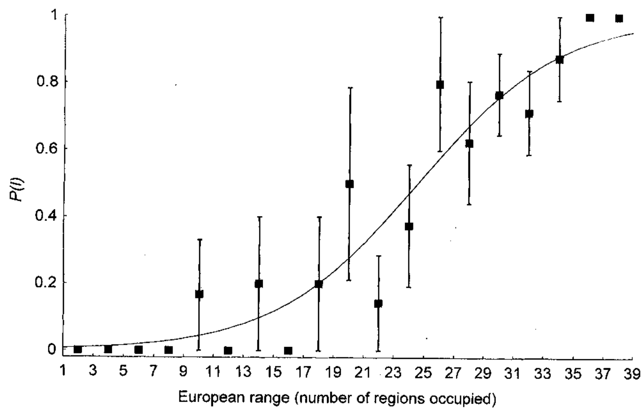

Figure 1. The probability of plant species being invasive (P(I)) against European geographic range (see Methods for a description of how range was measured). The data for the 110 pairs of invaders (P(I) = 1) and non-invaders (P(I) = 0) are plotted as means (boxes) and standard errors (vertical lines) for each range interval. The equation from the second logistic model (involving only range, Table 1) is also plotted (curve).

Geographic range is probably correlated with several biological attributes of species because, presumably, biological attributes permit a species to occupy a large range (Crawley 1987). We found a significant, positive correlation between range and flowering period ($r = 0.29, p = 0.0001$) but no significant correlation between range and the other characteristics. There are probably other, less commonly available biological attributes that are correlated with range.

It has been argued (Daehler & Strong 1993; Lodge 1993*b*) that inexpensive, easily conducted research be used to predict invasiveness in order to prioritize more costly research upon invading species. Previous models or systems for determining invasiveness require data that are restricted to more intensively studied species or genera (Smallwood & Salmon 1992; Tucker & Richardson 1995; Rejmánek & Richardson 1996) and that may be useful for predicting the invasiveness of intentionally introduced species within those groups (e.g., Perrins et al. 1992; Reichard & Hamilton 1997). Because such information is not available for many species, however, it is not useful for predicting the invasiveness of accidentally introduced species.

The importance of geographic range in predicting invasiveness suggests that prediction of invasiveness on a species-by-species basis is not likely to help stem the flow of accidentally introduced invasive species. The species that are likely to be inadvertently picked up and moved to a new location due to their wide distribution are the same species that are likely to succeed in a new environment due to their wide environmental tolerances. Stringent, universally applied measures will be required to curtail these invasions.

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