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# The invasiveness of an introduced species does not predict its impact

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**Abstract** Inconsistent use of terminology plagues the study and management of biological invasions. The term ''invasive'' has been used to describe *inter alia* (1) any introduced non-indigenous species; (2) introduced species that spread rapidly in a new region; and (3) introduced species that have harmful environmental impacts, particularly on native species. The second definition in various forms is more commonly used by ecologists, while the third definition is pervasive in policy papers and legislation. We tested the relationship between the invasiveness of an introduced species and its impact on native biodiversity. We quantified a species' invasiveness by both its rate of establishment and its rate of spread, while its impact was assigned a categorical ranking based on the documented effects of the invader on native species populations. We found no correlations between these variables for introduced plants, mammals, fishes, invertebrates, amphibians and reptiles, suggesting that the mechanisms of invasion and impact are not strongly linked. Our results support the view that the term ''invasive'' should not be used to connote negative environmental impact.

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## Introduction

The emergence of invasion biology as a subdiscipline of ecology has led to ''a surfeit of terms, liable to misapplication and error'' (Occhipinti-Ambrogi and Galil 2004). Although the terms *alien, exotic, non-indigenous, naturalized* and *non-native* generally refer to organisms introduced into a region outside of their historic range, more emotive adjectives such as *nuisance, noxious*, and *invasive* have also been used to describe introduced species that are known, or believed, to threaten resources valuable to humans. Inconsistent use of terms by scientists, stakeholders and policy-makers can confuse policy debates and undermine management efforts (Colautti and MacIsaac 2004; Falk-Petersen et al. 2006). Some have even argued that it has slowed the development of invasion biology as a predictive science (Davis and Thompson 2001). The most widely and inconsistently applied term—*invasive*—is particularly problematic because to many people (especially policy-makers and stakeholders) it implies a species that causes environmental or socio-economic impacts, while to others (including many scientists) it refers only to a species that can rapidly colonize and spread (Richardson et al. 2000; Colautti and MacIsaac 2004; Occhipinti-Ambrogi and Galil 2004).

For example, an Executive Order by the US President defines an *invasive species* as non-native to the ecosystem under consideration and whose introduction is likely to cause economic or environmental harm (Clinton 1999); this definition is also used in the US National Aquatic Invasive Species Act (NAISA 2003). Likewise, the Canadian government considers invasive species as ''harmful alien organisms whose introduction or spread threatens the environment'' (Environment Canada 2004). Several other governmental and international agencies and institutions including the US Environmental Protection Agency, the US Geological Survey, the US Department of Agriculture, the World Conservation Union, and the Convention on Biological Diversity define invasive species as having harmful environmental impacts, particularly on native biodiversity (Huette and Bella 2003; Occhipinti-Ambrogi and Galil 2004; CBD 2006). This definition has also been used by some scientists (Cronk and Fuller 2001; Boudouresque and Verlaque 2002; UCS 2006). However, others recommend that the term *invasive* should have a strict biological definition without any inference to an organism's impact (Richardson et al. 2000; Colautti et al. 2004; Falk-Petersen et al. 2006). In this regard, *invasiveness* refers to the organism's potential to rapidly colonize a large area and thus implicitly considers both its establishment success and its rate of spread. Indeed, identifying the biological attributes that predict invasiveness has become a focus of study with strong applications to risk assessment and management (e.g. Rejmanek and Richardson 1996; Goodwin et al. 1999; Kolar and Lodge 2001, 2002).

Most introduced species do not spread widely, nor do they cause substantial environmental change within the invaded region (Williamson and Fitter 1996; Parker et al. 1999). But are those that become invasive more likely to be harmful to native biodiversity? Apart from the potential cumulative effects of a widespread invader, there are logical reasons why the invasiveness of an introduced species may be correlated with its impact. Introduced species that can rapidly achieve high densities may have greater establishment success (Kolar and Lodge 2001) and dominate invaded communities to the exclusion of native species (Ricciardi et al. 1996; Ortega and Pearson 2005). An introduced species that spreads widely is more likely to affect multiple native species over large fractions of their respective ranges and drive some of them to extinction. However, the relationship between invasiveness and impact has never been quantified. Here, we test the hypothesis that an invasive species (defined in terms of its establishment and spreading rates) is more likely to reduce native species populations.

## Methods

We considered a broad variety of introduced plants, invertebrates, fishes, mammals, amphibians and reptiles that have invasion histories spanning at least a decade. For each introduced species, we reviewed the scientific literature for data on invasiveness that could be coupled with quantitative evidence of impact on native species populations. We used two measures of invasiveness: the establishment success rate (proportion of successful introductions) of the species and its post-establishment rate of spread (km $yr^{-1}$) within the invaded range. Data on establishment rates were obtained for fish (Lever 1996), mammals (Long 2003) and amphibians and reptiles (Lever 2003); we only included species for which there were at least five documented introduction attempts, in order to reduce the bias caused by low sample sizes. Mean and maximum rates of spread (km $yr^{-1}$) were obtained from review articles (Andow et al. 1990; Grosholz 1996; Shanks et al. 2003) and from the primary literature located using electronic databases (e.g. BIOSIS Previews; Cambridge Scientific Abstracts). The final dataset contained rates of spread for 33 invertebrates, 14 vertebrates, 14 plants and six macroalgae.

There is no standard way of comparing the effects of different introduced taxa (Parker et al. 1999), but the categorical ranking of impact potential is a simple, intuitive and robust method of risk assessment suited to data of heterogeneous quality (Kohler 1992; Kolar and Lodge 2002; Hayes et al. 2002). Therefore, we ranked impact on an ordinal scale, with the highest rank reserved for invaders that have caused (either solely or in concert with other stressors) near total extirpations of multiple native species in multiple regions (Table 1). Where experimental evidence was lacking, as was often the case, impact was evaluated by determining whether one or more native species declined following the introduction of the invader and whether this decline was correlated with an increase in the invader's population, with consideration given to potential confounding variables. Our rankings were assigned based on the maximum impact documented at any site within the invaded range. We tested our hypothesis by (1) relating both measures of invasiveness to impact using Spearman correlations, and (2) comparing the mean invasiveness of low-impact (ranking $< 3$) and high-impact (ranking $> 4$) species using the Wilcoxon–Mann–Whitney test (SAS Institute 1999).

## Results

The ranked level of impact of an invader was not correlated with its mean rate of spread (Fig. 1; Spearman $r = -0.04$, $P = 0.76$) nor with its maximum rate of spread (Spearman $r = 0.02$, $P = 0.84$). Similar results were obtained when testing individual taxonomic groups (plants, invertebrates and vertebrates). Low- and high-impact invaders did not differ in either their mean or maximum rates of spread (Wilcoxon $P = 0.96$, 0.74, respectively) (Fig. 2). A general relationship between impact and establishment success rate was similarly lacking (Figs. 3, 4). No significant correlations between ranked impact and mean establishment success were found for mammals ($r = 0.06$, $P = 0.74$), fishes ($r = 0.003$, $P = 0.98$), amphibians and reptiles ($r = 0.37$, $P = 0.14$), or all taxa combined ($r = 0.10$, $P = 0.39$) (Fig. 3). The mean establishment success rate did not differ between low- and high-impact invaders for mammals (Wilcoxon $P = 0.76$), fishes ($P = 0.79$), or combined taxa ($P = 0.26$). Among amphibians and reptiles, high-impact invaders had a weak tendency to have higher establishment success rates ($P = 0.06$), but this may have been biased by their small sample size.

## Discussion

We found no evidence that species capable of rapid colonization are, in general, more likely to have negative impacts on biodiversity. Although the same traits that allow a species to successfully invade a broad range of communities could also magnify their impact (Callaway and Ridenour 2003), it is estimated that as few as 50% of invasive species of plants in general can be classified as ecologically harmful, based on their actual impacts (Richardson et al. 2000). Similarly, a study of California grasses suggests that most invasive genera are not considered noxious environmental weeds (Strauss et al. 2006). Many

**Table 1** Impact ranking criteria for introduced species in this analysis

| Ranking | Qualification |
|---|---|
| 7 | Caused severe ( > 80%) declines in the populations of at least two native species in multiple regions |
| 6 | Caused severe ( > 80%) declines in the populations of at least two native species at one site, or one native species in multiple regions |
| 5 | Caused a severe ( > 80%) decline in the population of a single native species at one site |
| 4 | Caused a significant (but < 80%) decline in at least two native species at one site, or of one native species in multiple regions |
| 3 | Caused a significant (but < 80%) decline in one native species at one site |
| 2 | Had a negative effect on the fitness or survival of multiple native species in one or more geographically-distinct regions |
| 1 | Had a negative effect (e.g. through competition) on the fitness or survival of individuals of one native species at one site |
| 0 | No demonstrable negative impact on native species |

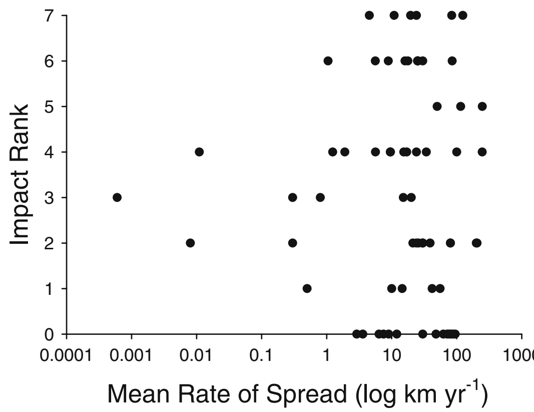



**Fig. 1** Impact rank versus mean rate of spread for invaders (67 species of animals and plants)

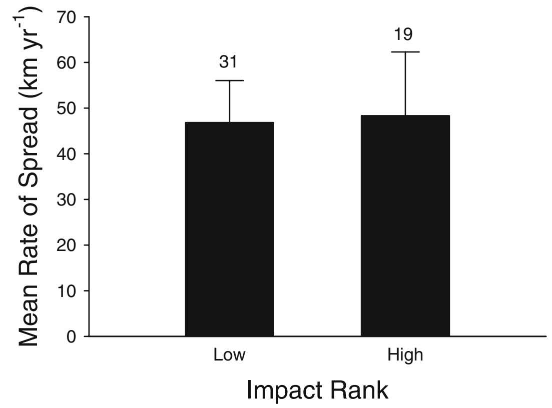



**Fig. 2** Mean ( ± 1 standard error) rate of spread for 'Low'-impact and 'High'-impact invaders. Numbers above the bars are samples sizes

species that have spread widely have not caused substantial ecological impacts in their invaded range (e.g. goldfish *Carassius auratus* and the freshwater jellyfish *Craspedacusta sowerbyi*, which have achieved global distributions; Spadinger and Meier 1999; Fuller 2006), while others that have hardly spread, despite ample opportunity to do so, have exerted strong impacts (e.g. the Asiatic clam *Potamocorbula amurensis* in San Francisco Bay; Kimmerer et al. 1994).

Our study has a number of potential sources of error and biases. We assigned rankings based on the largest impacts recorded throughout the species' invaded range. However, both invasion success and impacts are context dependent and thus can vary broadly across regions (Ricciardi 2003). One factor contributing to context dependence is the relatedness of the invader and members of the recipient community, which may determine both

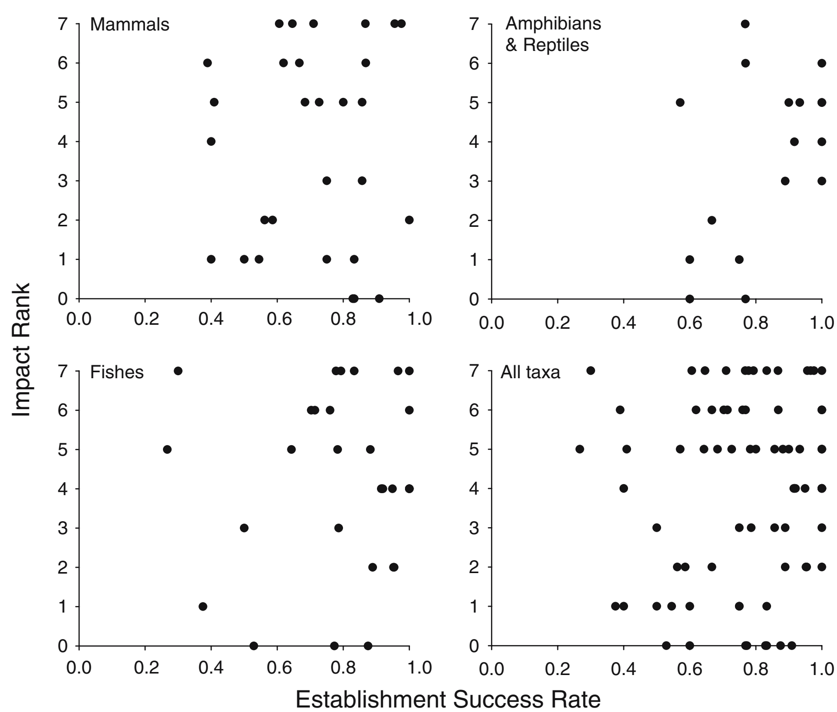


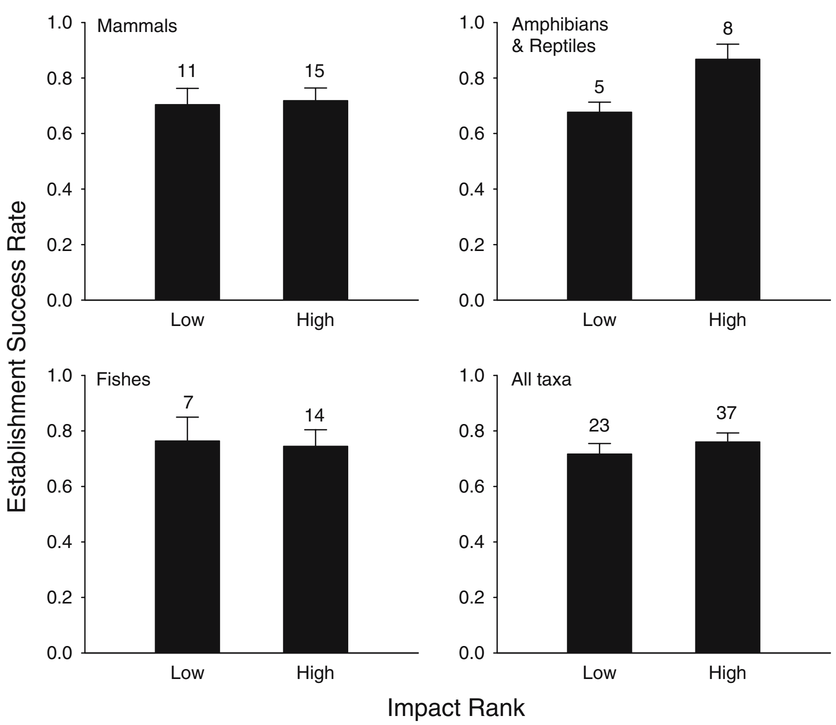

**Fig. 3** Impact rank versus establishment success rate (proportion of successful introductions) for mammals, amphibians & reptiles, fishes, and all taxa combined

invasion success and impact (Ricciardi and Atkinson 2004; Strauss et al. 2006), and so the invasiveness of a species might be correlated with impact only on a local scale. We were not able to couple data for the rate of spread of a species and its impact within a given region; but if such a relationship existed, we would expect to find a correlation between the largest ranked impact and the maximum rate of spread.

Experimental and correlational data are not available for many invaders. Many species that have not spread rapidly or widely are less conspicuous and perhaps less studied. Even the impacts of species with potentially strong effects (e.g. mussels *Limnoperna fortunei* and *Perna perna*; the African clawed frog *Xenopus laevis*) are poorly quantified and thus may have been underestimated. Furthermore, because lag times between the introduction of a species and its maximum impact can span years to decades (e.g. Potvin et al. 2003; Rilov et al. 2004), data provided by studies done in the early stages of an invasion might also underestimate impact, although we attempted to deal with this by excluding species with invasion histories of less than a decade. Finally, our narrow definition of impact excludes many measurable changes to physical habitat, food webs, and ecosystem function (which are relatively poorly studied; Parker et al. 1999; Levine et al. 2003), as well as the local economic effects of introduced species. It is possible that impacts in these categories may be correlated with invasiveness, although we are aware of no theoretical reason why this should be so.

Do different attributes determine the invasiveness and impact of a species? Such a result might be surprising, given that an invader's impacts are correlated with its abundance (Parker et al. 1999; Ricciardi 2003) and rapid population growth is a trait often associated with invasiveness (Kolar and Lodge 2001). Moreover, introduced plants can alter soil chemistry and soil biota in ways that favor the invader and that are harmful to resident species, including native competitors (Tally and Levin 2001; Klironomos 2002; Callaway and Ridenour 2003; Callaway et al. 2004). Some invaders exert ecosystem-level impacts (e.g. changes to nutrient cycling, fire regimes and hydrology) that ultimately promote their spread (Mack and D'Antonio 1998; Levine

**Fig. 4** Mean (±1 standard error) establishment success rate (proportion of successful introductions) for low- and high-impact invaders, including mammals, amphibians & reptiles, fishes, and all taxa combined. Numbers above the bars are samples sizes



et al. 2003). However, invasion success is largely governed by dispersal opportunity and propagule pressure (Kolar and Lodge 2001), and these variables are under the dominant influence of human transport mechanisms (MacIsaac et al. 2001). Ecological impacts are similarly modified by anthropogenic stressors (Byers 2002). Thus, even if there are natural processes linking invasiveness and impact, they may be obscured or overwhelmed by human activities (e.g. Von Holle and Simberloff 2005). In any case, our results suggest that invaders that spread and establish rapidly are not, on average, also those with large local impacts on native species populations. Therefore, the term *invasive* should not be used to connote particular species that threaten biodiversity.

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## References

Andow DA, Kareiva PM, Levin SA, Okubo A (1990) Spread of invading organisms. Landscape Ecol 4:177–188
Boudouresque CF, Verlaque M (2002) Biological pollution in the Mediterranean Sea: invasive versus introduced macrophytes. Mar Pollut Bull 44: 32–38
Byers JE (2002) Impact of non-indigenous species on natives enhanced by anthropogenic alteration of selection regimes. Oikos 97:449–458
Callaway RM, Ridenour WM (2003) Novel weapons: invasive success and the evolution of increased competitive ability. Front Ecol Environ 2:436–443
Callaway RM, Thelen GC, Rodriguez A, Holben WE (2004) Soil biota and exotic plant invasion. Nature 427:731–733
CBD (2006) Invasive Alien Species. Convention on biological diversity. Retrieved from http://www.biodiv.org/programmes/cross-cutting/alien/ on 10 May 2006
Clinton WJ (1999) Executive order 13112. Invasive species. The White House, Washington, DC
Colautti RI, MacIsaac HJ (2004) A neutral terminology to define 'invasive' species. Divers Distribut 10:135–141
Cronk QCB, Fuller JL (2001) Plant invaders: the threat to natural ecosystems. Chapman and Hall, London
Davis MA, Thompson K (2001) Eight ways to be a colonizer, two ways to be an invader: a proposed nomenclature scheme for invasion ecology. Bull Ecol Soc Am 81:226–230
Environment Canada (2004) An invasive alien species strategy for Canada. Government of Canada, Ottawa
Falk-Petersen J, Bohn T, Sandlund OT (2006) On the numerous concepts in invasion biology. Biol Invasions 8 (in press)
Fuller P (2006) Non-indigenous Aquatic Species (NAS) Database. Retrieved from http://nas.er.usgs.gov/ on 10 May 2006
Goodwin BJ, McAllister AJ, Fahrig L (1999) Predicting invasiveness of plant species based on biological information. Conserv Biol 13:422–426
Grosholz ED (1996) Contrasting rates of spread for introduced species in terrestrial and marine systems. Ecology 77:1680–1686
Hayes KR, McEnnulty FR, Sliwa C (2002) Identifying potential marine pests – an inductive approach. Final report for Environment Australia, June 2002. Center for Research on Introduced Marine Pests, CSIRO Marine Research
Heutte T, Bella E (2003) Invasive plants and exotic weeds of Southeast Alaska. USDA Forest Service, Anchorage, Alaska. Retrieved from http://akweeds.uaa. alaska.edu/pdfs/literature/se_inv_plnt_guide.pdf on 10 May 2006
Kimmerer WJ, Gartside E, Orsi JJ (1994) Predation by an introduced clam as the likely cause of substantial declines in zooplankton of San Francisco Bay. Mar Ecol Prog Ser 113:81–93
Klironomos J (2002) Feedback with soil biota contributes to plant rarity and invasiveness in communities. Nature 417:67–70
Kohler CC (1992) Environmental risk management of introduced aquatic organisms in aquaculture. ICES Mar Sci Symposia 194:15–20
Kolar CS, Lodge DM (2001) Progress in invasion biology: predicting invaders. Trends Ecol Evol 16:199–204
Kolar CS, Lodge DM (2002) Ecological predictions and risk assessment for alien fishes in North America. Science 298:1233–1236
Lever C (1996) Naturalized fishes of the world. Academic Press, San Diego
Lever C (2003) Naturalized amphibians and reptiles of the world. Longman, London
Levine JM, Vilà M, D'Antonio CM, Dukes JS, Grigulis K, Lavorel S (2003) Mechanisms underlying the impacts of exotic plant invasions. Proc R Soc London B 270:775–781
Long JL (2003) Introduced mammals of the world. CSIRO Publishers, Collingwood
MacIsaac HJ, Grigorovich IA, Ricciardi A (2001) Reassessment of species invasions concepts: the Great Lakes basin as a model. Biol Invasions 3:405–416
Mack RN, D'Antonio CM (1998) Impacts of biological invasions on disturbance regimes. Trends Ecol Evol 13:195–198
NAISA (2003) National Aquatic Invasive Species Act. 109th U.S. Congress. Retrieved from http://www.theorator.com/bills109/hr1591.html on 10 May 2006
Occhipinti-Ambrogi A, Galil BS (2004) A uniform terminology on bioinvasions: a chimera or an operative tool? Mar Pollut Bull 49:688–694
Ortega YK, Pearson DE (2005) Weak vs. strong invaders of natural plant communities: assessing invasibility and impact. Ecol Appl 15:651–661

Parker IM, Simberloff D, Lonsdale WM, Goodell K, Wonham M, Kareiva PM, Williamson MH, Von Holle B, Moyle PB, Byers JE, Goldwasser L (1999) Impact: toward a framework for understanding the ecological effects of invaders. Biol Invasions 1:3–19

Potvin F, Beaupré P, Laprise G (2003) The eradication of balsam fir stands by white-tailed deer on Anticosti Island, Quebec: a 150-year process. Ecoscience 10:487–495

Rejmanek M, Richardson DM (1996) What attributes make some plant species more invasive? Ecology 77:1655–1661

Ricciardi A (2003) Predicting the impacts of an introduced species from its invasion history: an empirical approach applied to zebra mussel invasions. Freshw Biol 48:972–981

Ricciardi A, Atkinson SK (2004) Distinctiveness magnifies the impact of biological invaders in aquatic ecosystems. Ecol Lett 7:781–784

Ricciardi A, Whoriskey FG, Rasmussen JB (1996) Impact of the *Dreissena* invasion on native unionid bivalves in the upper St. Lawrence River. Can J Fish Aquatic Sci 53:1434–1444

Richardson DM, Pyšek P, Rejmánek M, Barbour MG, Panetta FD, West CJ (2000) Naturalization and invasion of alien plants: concepts and definitions. Divers Distributions 6:93–107

Rilov G, Benayahu Y, Gasith A (2004) Prolonged lag in population outbreak of an invasive mussel: a shifting-habitat model. Biol Invasions 6:347–364

SAS Institute (1999) SAS/STAT user's guide, release 8 edn. SAS Institute Inc., Cary, NC

Shanks AL, Grantham BA, Carr MH (2003) Propagule dispersal distance and the size and spacing of marine reserves. Ecol Appl 13:S159–S169

Spadinger R, Maier G (1999) Prey selection and diel feeding of the freshwater jellyfish, *Craspedacusta sowerbyi*. Freshw Biol 41:567–573

Strauss SY, Webb CO, Salamin N (2006) Exotic taxa less related to native species are more invasive. Proc Natl Acad Sci USA 103:5841–5845

Talley TS, Levin LA (2001) Modification of sediments and macrofauna by an invasive marsh plant. Biol Invasions 3:51–68

UCS (2006) Invasive Species. Union of Concerned Scientists of the USA. Retrieved from http://www.ucsusa.org/invasive_species/invasive-species-index.html on 10 May 2006

Von Holle B, Simberloff D (2005) Ecological resistance to biological invasion overwhelmed by propagule pressure. Ecology 86:3212–3218

Williamson M, Fitter A (1996) The varying success of invaders. Ecology 77:1661–1666