Assessment and control of biological invasion risks

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INTRODUCTION

Biological invasion is usually an irreversible process. Contaminated chemicals in the environment will be decomposed after several years. Invasive alien species, however, reproduce themselves and persist. New invading alien species will change the nature of forests, rivers and lakes in the future. Biological invasion by alien species has recently been recognised as an environmental issue, and standardised procedures (technical as well as legal) to assess and control invasion risks have not yet been established. New ideas and basic studies are urgently required to deal with this new environmental issue.

CURRENT STATUS OF INVASION

The Earth's history of continental drift has created the large scale distribution pattern of species (Frodin 1984, Cox and Moore 1993). Earthworms have very limited ability of dispersal, and the present distribution of earthworm families are partly determined by past plate tectonics (Blakemore *et al.* 2006 - this volume). In addition to such global pattern, recent speciation also occurred at smaller geographical scale. The geographical range of most species is significantly smaller than the circumference of the Earth. It is close to 1000km in woody plants and about 10,000km in ferns (Fig.1). This spatial scale is similar to the geographical range of animals (Shoener 1987, Gaston 1994). Human mediated transports of 100km can cause biological invasion by some species that have a small distribution range; and those of 1000 km may cause invasion by many woody species.

Although natural migration often occurs, the distance over which human mediated transport occurs is three or four orders of magnitude larger than natural dispersal ability (Fig. 2). Japan imports grains and hay cubes for livestock, mainly from North America, and these contain viable weed seeds. 21.6kg of corn imported from the USA contained seeds of 545 weed species and for 21 of those species there were more than 100 seeds (Kurokawa 2001). Such mass transfers beyond 10,000km occur every year.

Human activities, that transport alien species, mainly occur in towns and villages. Alien species that grow in disturbed areas will easily be naturalised, because many seeds of such species are transported unintentionally and many suitable habitats are spread around the place of arrival (Fig.3). However, alien

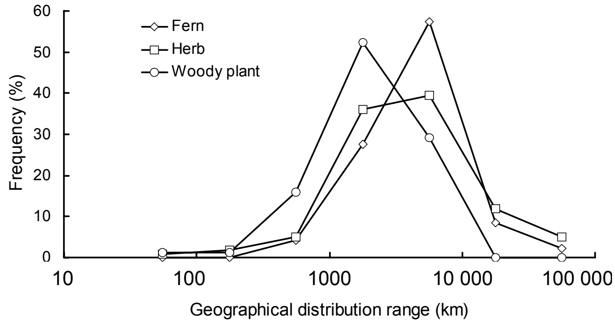

Figure 1 Distribution range (west-east width) of native plants in Kanagawa Prefecture, Japan. Species were randomly sampled at the probability of 20% from a flora list (Flora-Kanagawa Association 2001). Lower taxon such as subspecies was not considered. Geographical range was calculated from longitudinal distribution range and circumference at the latitude of 35º.

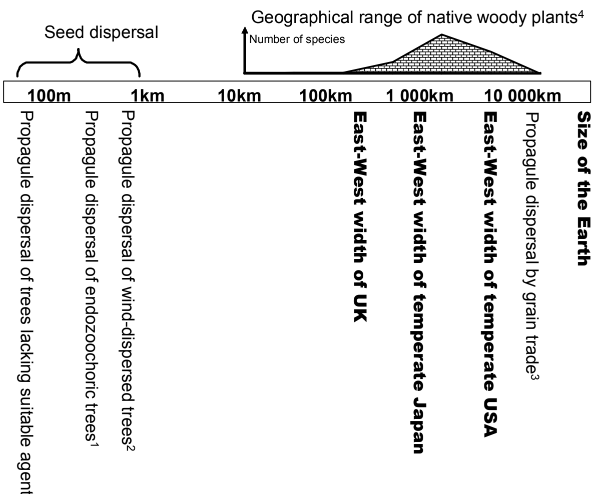

Figure 2 Spatial scale of propagule (seeds, fruits, detached bulbs, etc.) transfer by humans and natural agents. Dispersal distance: 1ha of area receives at least one seed at the probability of 0.5. [1]Komuro and Koike 2005, [2] Clark *et al.* 1999, [3] Kurokawa 2001, [4] East-west geographical range of woody plants native in Kanagawa Prefecture, Japan (Fig. 1)

Pages 4-12. In Koike, F., Clout, M.N., Kawamichi, M., De Poorter, M. and Iwatsuki, K. (eds), *Assessment and Control of Biological Invasion Risks*. Shoukadoh Book Sellers, Kyoto, Japan and IUCN, Gland, Switzerland, 2006.

forest plants have difficulties in spreading in urban and rural landscapes with highly fragmented habitats (Fig.4). Such species may not spread continuously, but eruptive (spasmodic) spread may occur due to stochastic colonisation of the metapopulation (Fig.5). Forest species will quickly spread after the population arrived at continuous forest, as is the case with the alien *Impatience* in Europe (Kornaś 1990, Williamson 1996).

This phenomenon might be one reason that spreading alien species are usually r-strategists (Ehrlich 1989, Rejmánek and Richardson 1996, Pheloung *et al.* 1999, Grtokopp *et al.* 2002, Crooks 2006 - this volume) and are adapted to disturbed habitats. Another reason for the dominance of r-strategists may be the lack of time to spread for K-strategists. Beech is sometimes invasive (Healey *et al.* 2002); however, the life span of Japanese beech (*Fagus crenata*) is about 200 years (Nakashizuka and Numata 1982). It is only 160 years ago that the first steamship crossed the ocean and this is less than one generation for long lived woody plants. A shade tolerant climax forest tree with limited dispersal ability, *Podocarpus nagi*, was introduced to the ancient capital of Japan 1200 years ago (Suganuma 1975), and the species spread gradually to an approximately 1 km by 1km area in the Kasugayama Forest Reserve, a World Heritage site of the ancient capital Nara (Maesako *et al.* 2003). Many species living in stable environment may not have had sufficient time yet to establish and/or spread in the wild. In the next century, however, the number of alien species that are established and/or spreading in stable environments may continue to increase and they might become an important issue.

A global list of all alien species does not exist, and the number of alien species worldwide is not clear, but numbers are known for several countries.

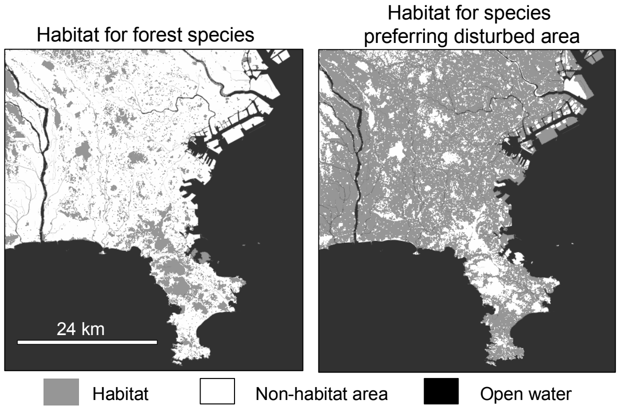

Figure 3 Habitats for disturbed site species and those for forest area in Kanagawa Prefecture (suburb).

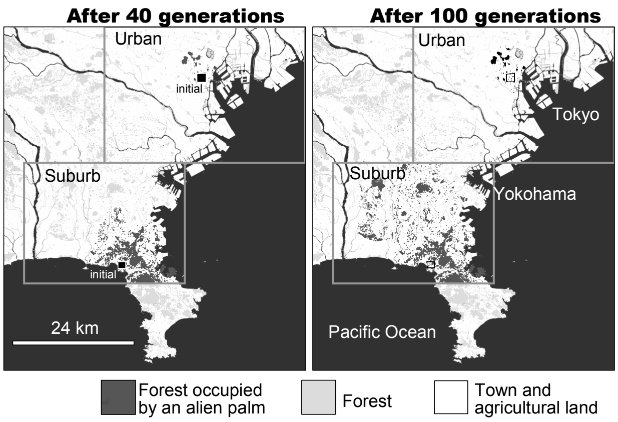

Figure 4 Hypothetical simulation of range expansion of an alien palm (*Trachycarpus fortunei*) in urban and suburban landscapes. The effect of landscape on range expansion was evaluated based on this hypothetical simulation, although the palm has already distributed everywhere.

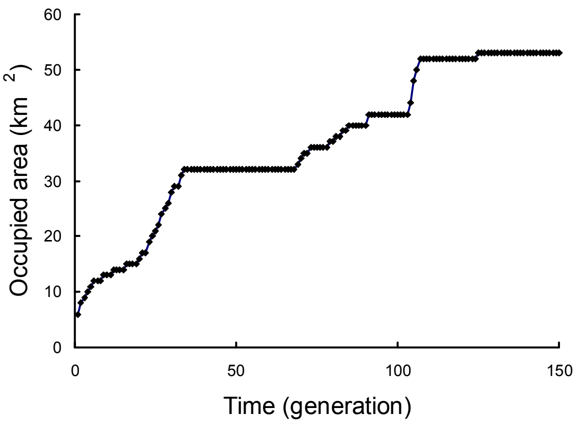

Figure 5 Simulated range expansion of an alien palm (*Trachycarpus fortunei*) in the urban landscape based on the same simulation as in Fig. 4.

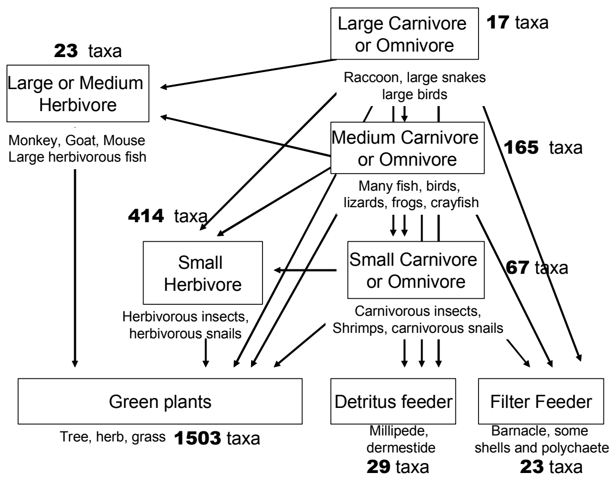

Figure 6 Number of taxa (species and sub-species) established in Japan after 1868, when Japan opened its ports to the World. Information was based on Ecological Society of Japan (2002). The number of taxa is tentative due to lack of information on food habit in some species.

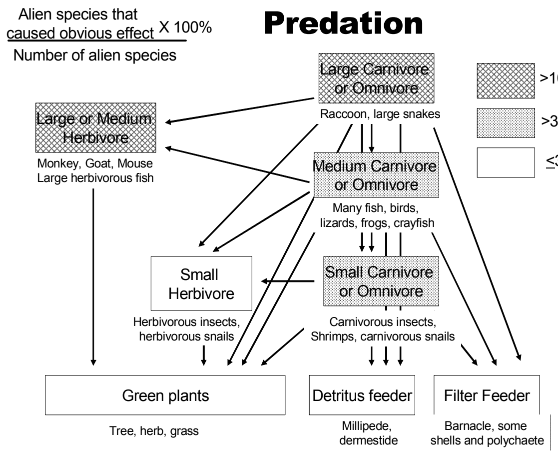

Figure 7 The fraction of species causing serious effects on native species through predation. Figures are tentative due to lack of information.

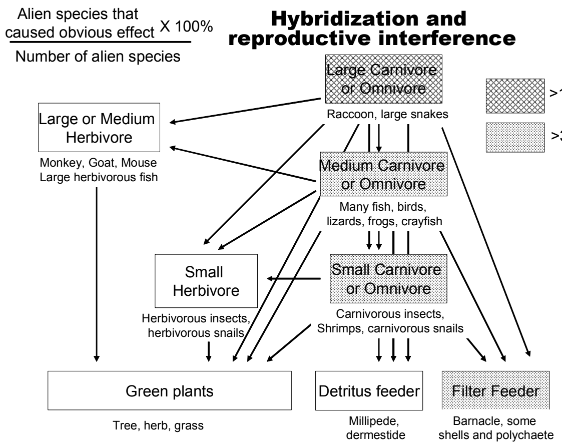

Figure 9 The fraction of species causing serious effect on native species through hybridization and reproductive interference. Figures are tentative due to lack of information especially for plants and small animals.

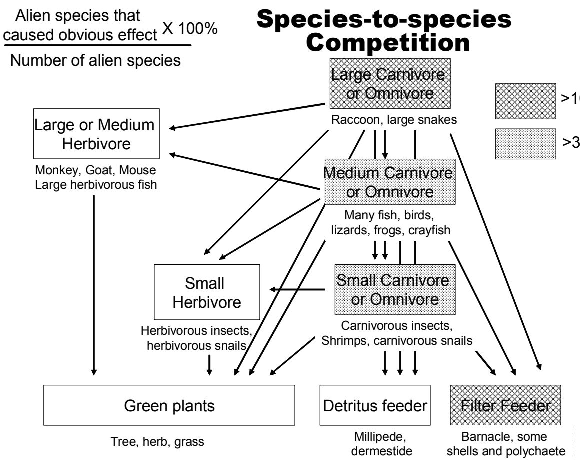

Figure 8 The fraction of species causing serious effect on native species through species-to-species competition. Weak competition working among various species in communities (diffused competition) was not included. Figures are tentative due to lack of information especially for plants and small animals.

Based on the data from Japan, the number of alien species greatly differs in the different trophic levels (Fig. 6). There were about 1500 taxa (species and lower taxon such as subspecies) of alien green plants established in Japan. Large carnivores or omnivores (raccoon, large snakes, etc.), large or medium size herbivores (goat, mouse, etc.), filter feeders (barnacle, shellfish, etc.), and detritus feeders (millipede, dermestide, etc.) had 2 order of magnitude fewer alien species than green plants. Small herbivores (herbivorous insects, herbivorous snails, etc.), medium size carnivores or omnivores (fish, birds, crayfish, etc.), and small size carnivores or omnivores (carnivorous insects, shrimps, carnivorous snails, etc.) had an intermediate number of alien taxa.

Some alien species reduce the abundance of native species through predation or parasitism. Large sized species tend to cause serious effects (Fig. 7). Feral goats (*Capra hircus*) wiped out the vegetation on small islands (Shimizu 1993) and ship rats (*Rattus rattus*) predate the seeds of endemic plants in Ogasawara (Bonin) Islands (Watanabe *et al.* 2002). Large carnivorous fish (*Micropterus salmoides*) feed on shrimp and native fish species (Yonekura *et al.* 2004), and the distribution range of the endemic Amami rabbit (*Pentalagus furnessi*) is decreasing due to predation by the Indian mongoose (*Herpestes javanicus*) (Sugimura 2002). Predation by alien species does not only reduce the prey species, but causes indirect increases in species on the next lower trophic level (Maezono and Miyashita 2003). The Indian mongoose (*Herpestes javanicus*) causes the increase of insects through the decrease of frogs (Watari *et al.* 2006 - this volume).

Another ecological mechanism to reduce native organisms is competition. The land use by native raccoon dog (*Nyctereutes procyonoides*) around farmland can be eliminated by the feral raccoon (*Procyon lotor*) (G. Abe *et al.* 2006 - this volume). The alien barnacle (*Balanus glandula*) may be a competitor to native barnacle on rocky shore (Kado and Nanba 2006 - this volume). Although the introduced canopy tree (*Bischofia javanica*) decreased the dominance of native plants significantly in Ogasawara Islands, reports on serious species-to-species competition between green plants, and between herbivorous animals are less frequent than in the case of large carnivorous animals (Fig. 8). As there are more than one thousand alien plant species, it is possible that their effect might not have been realised yet in many cases. It may also be difficult to determine significant effects on native flora caused by alien plants due to the diffused nature of competition (Hubble 2001). Such effects require further study.

"Ecosystem engineers" are species that change

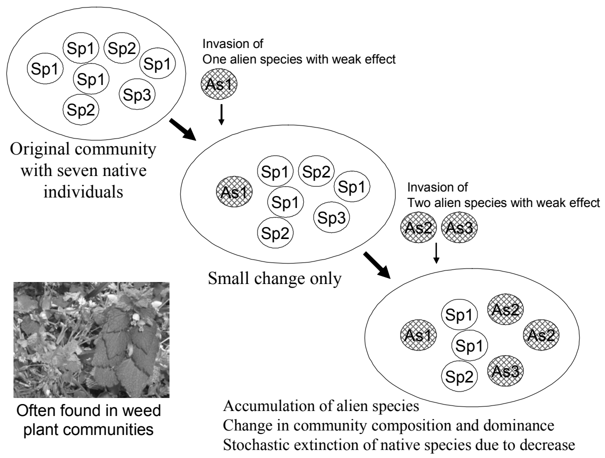

Figure 10 Hypothetical diagram of community change caused by alien species with weak competition effects. Sp_n represents individuals of *n*-th native species, and As_m of *m*-th alien species. Such phenomenon often occurs in weed communities.

physical and chemical environments. These species are similar to resource competitors except that their effects are not limited to native species of the same niche, but extend to a much wider range of species. Earthworms can change soil environments and have an impact on plants (Blakemore *et al.* 2006 - this volume); in the soft-sediment habitats of sea and brackish water a mussel (*Musculista senhousia*) turns the bottom into a dense mat of shells and this affects many types of organisms (clams, eelgrass, etc.) either negatively or positively (Crooks 2006 - this volume).

Records of hybridization and reproductive interference are also frequently found in large carnivorous or omnivorous animals (Fig. 9). Reproductive interference between native and alien salmonoid fish (native *Salvelinus leucomaenis* and alien *Salvelinus fontinalis*) through asymmetrical reproductive behaviour was reported (Kitano 2002). Such interference can usually only be determined after in depth research, and this has not been carried out for most species. This should be remedied, and such research should cover all alien species.

Due to the development of legislation to eliminate the import of invasive alien species and due to the publicity around alien species issues, new intentional releases of large alien animals are likely to be reduced in future. However, the introduction of alien species that have a weaker effect on native ecosystems (e.g. many alien plants) will continue, and the cumulative effect of such weaker effects of alien species will nevertheless cause a significant reduction of native species through neutral replacement (Hubble 2001, Fig. 10). Such alien species with weaker effects and alien species living in stable environments (as discussed before) will increase gradually in the future. As a result, biological invasion issues will increase even more in importance in the next century.

RISK MANAGEMENT

Most countries have a quarantine system to deal with alien species that are detrimental to humans or to economically important species (Tanaka and Larson 2006 -this volume). Some countries have extended their quarantine system to deal with alien species that are harmful to ecosystems. However, no ideal legal and social system has so far been put in place anywhere, as discussed in this volume (Ikeda 2006, Courtney 2006 and Takahashi 2006 -this volume).

The prohibition of introduction of invasive alien species is an important management approach, but it is not sufficient on its own. Due to the volume of imports quarantine systems can not check all the imported commodities and instead they usually check selected samples. Unfortunately, even if only a few individuals are introduced into a natural habitat this can result in their establishment, and severe damage can result.

As another approach to management, risk feedback to importers and carriers may be a possible (Fig. 11). In many cases, the people obtaining benefits are different from the people exposed to risks. For example: carriers, importers, and growers of new crops benefit from the introduction but other citizens, such as traditional farmers and fishermen, and the government carry the risk of naturalised alien species. Possible impacts from alien species include those to cultural values, economic damage to farmers and fishermen, and financial costs to the government who must pay for control and eradication programmes. Tort liability, a mechanism of risk feed back, could be an effective approach for invasion risk management (Courtney 2006 -this volume).

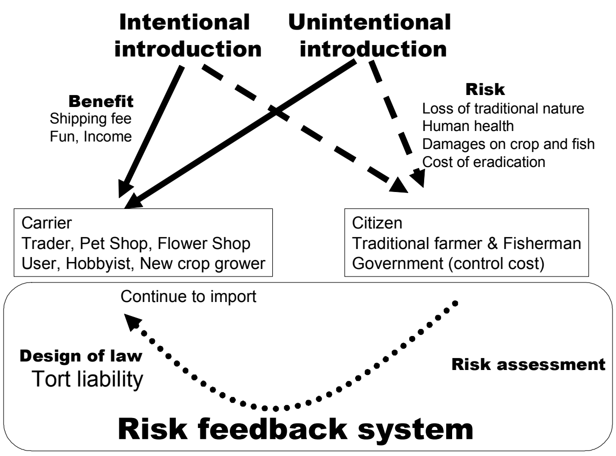

Figure 11 Risk feed back from the people exposed to risks to the people obtaining benefits from the introduction of alien species.

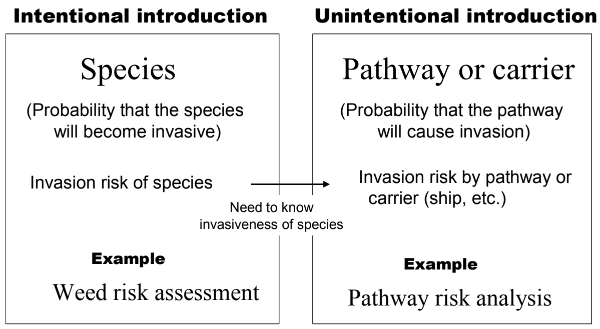

Figure 12 Two types of risk assessment for intentional and unintentional introduction.

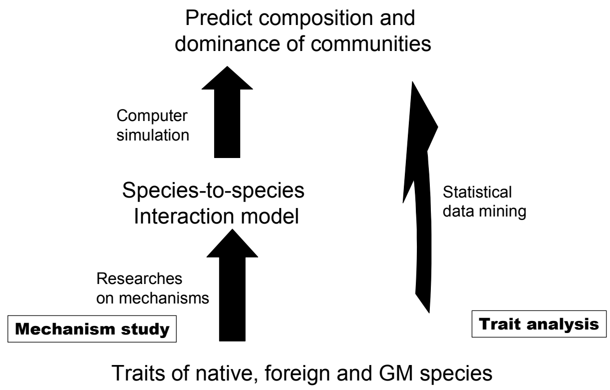

Figure 13 Two approaches to predict community species composition and dominance from biological traits of the species pool.

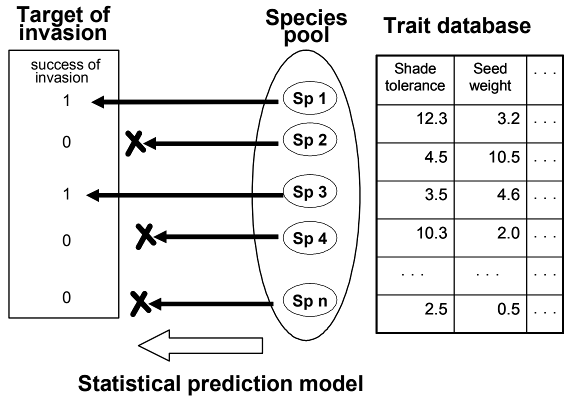

Figure 14 Hypothetical diagram of statistical modeling of invasion risk assessment. The target of invasion (country, island or biological community) is the area used to judge success or failure of invasion (1=success, 0=failure). The species pool is the set of species (sp 1 to sp n) having the chance to invade the target area. The statistical prediction model is obtained based on the trait database and the record of success or failure of invasion.

In Japan, the illegal release of a carnivorous alien fish (large-mouth bass, *Micropterus salmoides*) for game fishing continues. It is quite difficult to identify who released the fish, because it is usually done secretly. The legal system on its own is not effective and other approaches, such as education and raising awareness need to be considered.

RISK ASSESSMENT

Risk management should be based on reliable risk assessment. For intentional introduction, risk assessment is to evaluate the probability that the species will become invasive (Fig. 12). Weed risk assessment (Pheloung *et al.* 1999, Kato *et al.* 2006 - this volume) is widely used for intentional introductions. For unintentional introduction, the aim of risk assessment is to evaluate the probability that the pathway (e.g. importing the specific commodities from the specific foreign country, ballast water from a specific region) will result in invasion.

Research on how to predict invasiveness of a species based on biological traits is in progress, but it has had limited success so far (Williamson 1996, Goodwin *et al.* 1999, Gollasch 2006 - this volume). Although weed risk assessment is successfully used in Australia, New Zealand and Hawaii (Pheloung *et al.* 1999, Daehler *et al.* 2004, etc.), its success is due to the use, as a variable, of history of invasion elsewhere in the world (Koike and Kato 2006 - this volume). Biological traits are also considered in weed risk assessment, but their effectiveness for prediction is low. Many biological traits are specific to a given taxonomical group and ecological guild. The traits for terrestrial plants are quite different from those of aquatic fish. However, history of invasion elsewhere in the world can be used for various species. A risk assessment system based solely on such historical records will be possible for all species, and applicable as the first stage of risk assessment.

In spite of the associated difficulties, biological traits must be used in risk assessment for species that are not known as invasive yet. The palm *Arenga engleri* is considered a major pest in Ogasawara Islands, but invasion in other regions has not been reported at this stage (Kato *et al.* 2006 - this volume). If we can predict species composition and dominance in a community based on biological traits, we can predict invasion by new species. There are two approaches to predict community composition and dominance based on traits of species (Fig. 13). One is a mechanistic approach, studying mechanisms in the community and using computer simulation for prediction; and another is through statistical data mining. Most invasion risk assessment is done using the latter because the simulation technique is not well enough developed yet.

In statistical invasion risk assessments the target of invasion (country, island or biological community) and the species pool, which include the species that have the chance to invade to the target area, are defined first (Fig. 14). Success of invasion for each species is examined, and traits of the species are obtained from literatures and field research. The statistical prediction model is usually obtained assuming success of invasion as the dependent variable, and various traits as independent variables. Grotkopp *et al.* (2002) assumed their target area as whole Southern Hemisphere, and the species pool as introduced alien pine species (Table 1). In Koike (2001) the climax forest community was the target, and local flora was assumed as the species pool.

The selection of the target and the species pool will influence the success of the prediction model. If we consider a wide area with a mixture of various communities as the target, prediction using biological traits becomes difficult (Table 1). If we consider a given biological community as the target, prediction will become easier. Since the same trait in an alien species can influence invasion probability positively or negatively, depending on the target "receiving" community, risk assessment should be done separately for each target community. For instance, for climax forests key traits that were effective in prediction were shade tolerance and tall maximum tree height (Koike 2001, Fig. 15). Alien trees with such traits became extremely hazardous pest (such as *Bischofia javanica* in Ogasawara Islands). However, these same traits will prevent invasion into arable weed communities. This illustrates that if we specify the target community, prediction of invasion based on biological traits of an alien species will become possible.

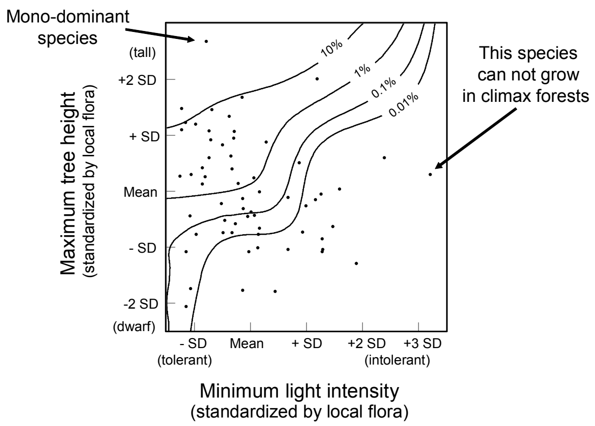

Figure 15 The dominance of woody species in climax forests can be predicted by shade tolerance and maximum height (redrawn from Koike 2001). Each plot represents a species. Data of four forests (boreal mixed, cool-temperate deciduous, warm-temperate evergreen broad-leaved, and subtropical evergreen broad-leaved forests) were plotted on the same axes. Contours show percentage dominance in basal area.

The science of community ecology has made rapid progress in recent years. Traditionally, ecologist had assumed that alien species compete with the native species in same niche, and that the alien species will invade if it wins the competition. However in plant communities, instead of such species-to-species competition, an alien species often causes weak effects on many surrounding species (Hubble 2001), decreasing the abundances of many native species, but only by a little bit. In the case of alien and native turtles in freshwater (Chen 2006 - this volume), species-to-species competition was also not obvious. We are not able to predict invasion by a simple competitive experiment between alien and native species of the same niche; instead estimating the range of ecological traits (envelope) which allow invasion into the target biological community may be a more suitable approach (Weiher and Keddy 1999, Koike 2001, Fig. 15).

Nevertheless, competitive exclusion between two species is often found in vertebrate communities that have few (or sometimes only one) species. Feral raccoons can exclude native raccoon dogs from the forest edge adjacent to farmland and residential areas in Japan (G. Abe *et al.* 2006 - this volume). In the case of vertebrates, behaviour excluding other individuals from the home range and feeding sites can cause competitive exclusion of native species. A clear hierarchy of winner and loser individuals will be established, and the winner will access resources. In plants, such asymmetrical resource competition typically occurs in fertile soil, where the closed canopy of taller species accesses most of the light energy (Tilman 1993, Wilson and Tilman 2002). The relation between animal behaviour excluding other individuals and the number of co-existing species in

Table 1 Target of invasion and species pool in invasion risk assessment models. The target of invasion is the area used to judge success or failure of invasion (country, island or biological community), and the species pool is the set of species considered that have the chance to invade the target area (Fig. 14). References are classified into four groups based on the target and species pool used.

Target	Species pool: Wide range of species	Species pool: Congener
Community	Koike 2001	Tofts and Silvertown 2002*
Mixture of community	Biological part of WRA (Pheloung *et al.* 1999)	Goodwin *et al.* 1992 Grtokopp *et al.* 2002

*Performances in juvenile stage only

the community needs to be studied, in order to assist with the prediction of impacts on native species from competitive exclusion by alien species.

CONTROL AND ERADICATION

Management techniques are rapidly developing. Future range expansion is now not so difficult to predict (Koike 2006 - this volume). In an area of 10 x 10km eradication for large animals can be successful (Clout and Russell 2006 - this volume). There are three types of successful eradications: (1) in a very early stage of invasion with a very small distribution range, (2) in a very intensively managed environment such as a greenhouse or in human health (e.g. smallpox), and (3) where there is a geographical limit such as in islands or when the species has special habitat requirements. Control or eradication of actively spreading populations in natural habitats is very difficult, and techniques to halt spatial spread and to eradicate whole populations should be further developed.

Alien species often have a dense population at the centre of the distribution range, and low density in marginal areas. Such distribution can be caused by two completely different mechanisms (Fig. 16). One is a source-sink structure with high population growth rate at the central core habitat (source population) and the marginal population (sink population) supported by migrants from the core area. In this case there is no geographical range expansion. The other case is that of an actively spreading population, with high population growth rate at the marginal (low density) area. Density dependent population growth is commonly found in alien animals (S. Abe *et al.* 2006 - this volume). In this case the geographical distribution range is expanding.

In a population with source-sink structure, intensive catch at the central source population will be effective as a management programme (Baker 2006 - this volume); however, in an actively spreading population, removal of marginal isolated populations is important and effective to slow down range expansion (Koike 2006 - this volume).

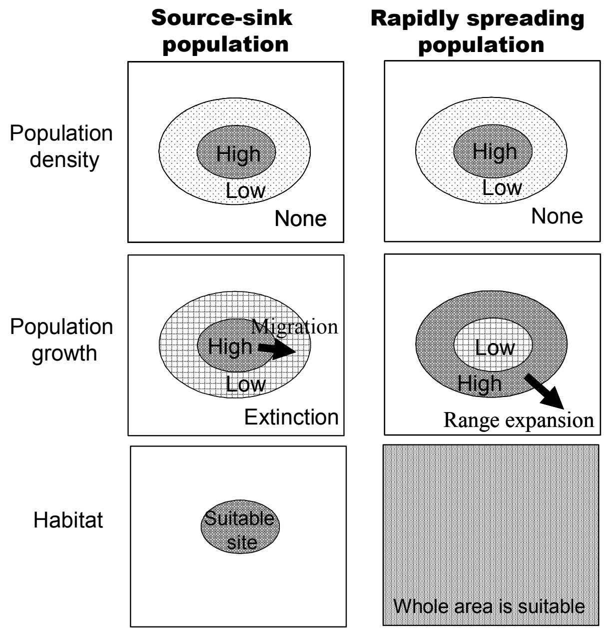

Figure 16 Spatial structure of populations with source-sink structure (left) and of rapidly spreading population (right).

DATABASE

Alien species databases are required for assessment and management of invasion risks. In risk assessment, information on native geographical range including climate information, current distribution outside its native range, and damage to the ecosystem and economy, is critical to assess the invasion risk for the focal species (Goodwin *et al.* 1999, Koike and Kato 2006 - this volume). However, there is no standardised measure yet to evaluate the impact on native ecosystem. Key biological traits for use in invasion risk assessment are also not known except in the case of forest plants and herbaceous weeds in disturbed land (Pheloung *et al.* 1999, Koike 2001). Research on key traits in various habitats should be done immediately to determine what information should be included in databases. In addition, information on ecological traits of native species (at least randomly selected species from the local flora) is also necessary for more accurate prediction, because they also play a role in the success of alien species invasions (Koike 2001).

For eradication and other management, databases need to include effective management methods and techniques (trapping technique, herbicide information, etc.) for each species. Databases with reports of successful and failed eradication projects (Rejmánek and Pitcairn 2002, Clout and Russell 2006 - this volume) and their fiscal costs may be helpful to evaluate the feasibility of planned eradication programmes.

THIS VOLUME

This volume is the compilation of papers presented at the conference “Assessment and control of biological invasion risks” held in 2004 at Yokohama National University. Organization of this book is objective oriented. Papers were not classified by habitats or taxonomical criteria, but by objectives such as risk assessment, risk management and eradication. We tried to extract aspects common to various species instead of accumulating species specific information. This volume also includes contributions reporting on the current status of invasion and on properties of alien species in East Asia.

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