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Biological invasions as a cause of irreversible change

Fumito Koike
Yokohama National University
koikef@ynu.ac.jp

Land cover change, global warming by CO_2, chemical contamination, and introduction of non-indigenous organisms, are threats for original ecosystems on the Earth. Ecological succession usually erases footprints of human land use. Contaminated chemicals in the environment will be decomposed after several years. Invasive non-indigenous species, however, reproduce themselves and persist. New invading species will change the nature of forests, rivers and lakes in the future.

Intentional introduction of non-indigenous species (for erosion control, horticulture, zoo, etc.), often cause invasion into wilderness areas. International commodity trade causes unintentional introduction of weedy species and oceanic species. The naturalized organisms disperse themselves. In the case of green crabs from Europe (*Carcinus aestuarii*), we detected natural dispersal and secondary transport by coastal shipping, but transport by international ocean-going shipping was not statistically significant, suggesting quite a small immigration probability of the crab by long voyages.

Japanese people thought only wilderness areas as valuable ecosystem to conserve before 1980s, however; people began to consider traditionally managed rural landscape (satoyama) as valuable after 1980s. Some of traditional flora in rural landscapes is considered as an ancient no-indigenous species from China. We consider newly introduced species after the end of long seclusion (Meiji Restoration) as the species to control.

1. History of landscape and the value of ecosystems in Japan

1.1. History of rural landscape in Japan

Historically, forests covered wide areas in Japan, but human activity started to change the vegetation at least 2000 years ago (Tsukada 1982). Primary forests were cleared, and secondary grasslands and shrubs covered large areas in 500 AC (Fig. 1). Before the 19th century, grasses and shrubs were important sources of fodder and fertilizer before industrialization (Ohtani and Koike 2005).

Seclusion of Japan ceased in 1868. Industrialization began and spread to remote areas in the early 20th century, when a nationwide railway was built. Silk was transported by rail and exported abroad, causing economic development in remote areas. Farmers grew mulberry trees (*Morus* spp.) to feed silkworms, and grasslands became less important as more farmers purchased fertilizer with the money obtained from sericulture (Okayama Prefecture Government 1980). After the grasslands were abandoned, secondary forests developed as a result of natural succession and conifers were planted in several areas for timber production. The next significant land-use change was about 50 years after the first wave of industrialization: due to rapid economic growth in the 1960s, the use of labor animals and the production of fuel woods disappeared.

Many non-indigenous species arrived at Japan with crops before industrialization, but historical record was limited (old-alien-species). Naturalized new non-indigenous species increased greatly after the end of seclusion, and they can easily distinguished from native species (new-alien-species), due to development of taxonomical knowledge in 18th and 19th century.

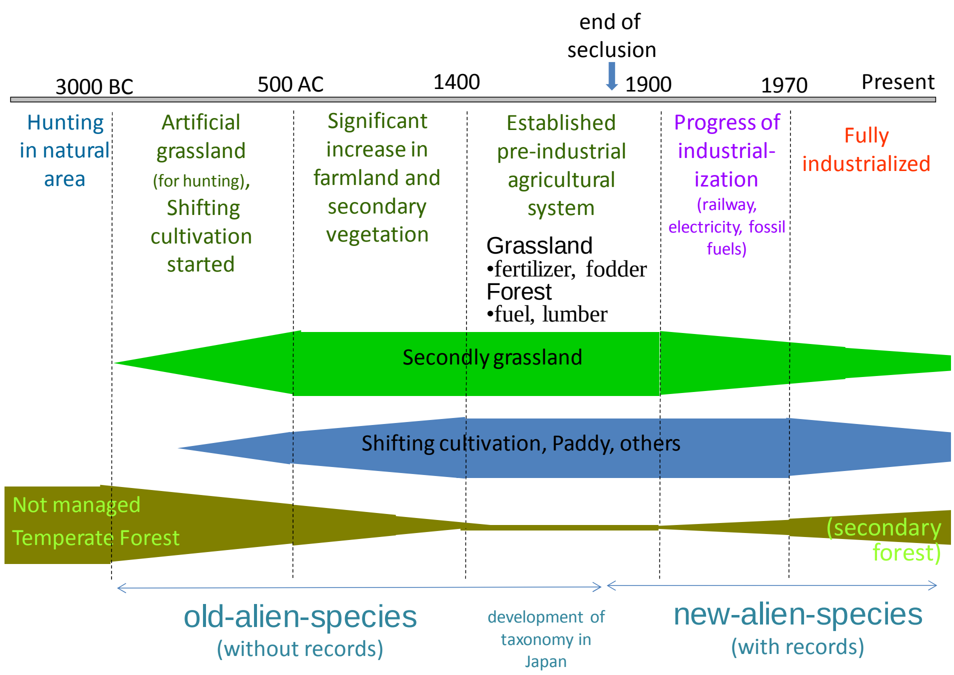

Fig. 1. History of rural landscape in Japan.

1.2. History of the value of “nature”

Importance of wilderness areas (alpine heather land, primary forests, etc.) was realized since 1900s, and the loss of such system became social issues in 1970s, probably corresponding to industrialization and rapid development of deep forest areas.

Importance of secondary ecosystems (traditional rural landscape) was realized in 1990s, about 20 years after completion of industrialization, and by the progress of natural vegetation succession.

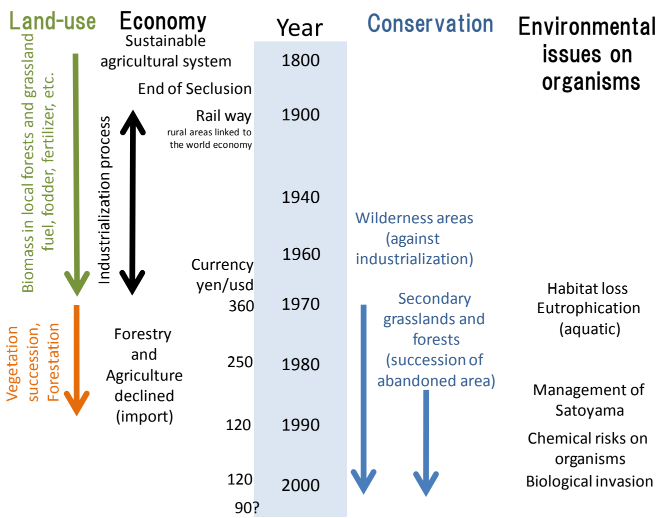

Fig. 2 History of nature conservation.

1.3. History of the meaning of “diversity”

Biodiversity was considered as a number of species in a region or that in an ecosystem. Larger number was the better, and even non-indigenous species could be considered as positive contribution to local biodiversity.

Now almost young ecologists has the consensus that only native or traditionally important species should be counted for biodiversity. New non-indigenous species is usually not included to the local diversity. There are old non-indigenous species introduced before industrialization, and some of these species are counted for “biodiversity”, because they are important member in Japanese traditional landscape.

1.4. History of environmental issues

At the final stage of industrialization in 1970s, development and deforestation of wilderness area, eutrophication of aquatic systems, land development in suburb became important environmental issues.

Species-loss in traditional rural landscapes due to natural vegetation succession and artificial forestation became important issue in 1990s, it was about 20 years after the final stage of industrialization.

Biological invasion became social concern in the late 1990s. It is the time of globalization after the cold-war, but it might not be the direct relation, because the socially concerned species (raccoon from North America, etc.) have already introduced into Japan in 1980s, and they spread and caused damages in 1990s and 2000s.

Releasing animals and plants to wild habitats, and feeding wild animals were considered as a “good human behavior” before 2000s, but it became to be considered as “not good behavior” among young ecologists, to prevent biological invasion and to reduce human effects on the native ecosystems, although they are still “good behavior” in news papers and TVs.

2. Biological invasion

2.1. Difference from other environmental issues

Land cover change, global warming by CO_2, chemical contamination, and introduction of non-indigenous organisms, are threats for original ecosystems on the Earth. Ecological succession usually erases footprints of human land use. Contaminated chemicals in the environment will be decomposed after several years. Invasive non-indigenous species, however, reproduce themselves and persist. New invading species will change the nature of forests, rivers and lakes in the future. We can eradicate invasive species only in small area (< 1 ha for plants), so that biological invasion is an irreversible process.

Although most of non-indigenous species caused only limited damages, some of species cause drastic damage. Pine wilt nematode caused local extinction of pine trees, weeping-lovegrass changed origotrophic gravelous area to dense grassland, *Boschofia* tree became shade-tolerant climax dominants in oceanic Bonin Islands.

2.2. Definition and the nature of non-indigenous species

Some species were introduced several hundreds of years ago, and we do not have reliable information about its introduction (old-alien-species). Some of these pre-historically introduced species are important members of Japanese traditional rural landscape, and they are not considered as noxious species. In legislative context, newly introduced species after the end of long seclusion (Meiji Restoration) are considered as non-indigenous.

Table 1. Definitions of non-indigenous species in Japan.

Type of definition	Geographical range from	Historical range	Pathway
Scientific	Out of native range	Old-alien-species and New-alien-species	Human-mediated (excluding climate change)
Commonsense	Out of native range	New-alien-species	Human-mediated (excluding climate change)
Legislative	Out of national border	New-alien-species	Human-mediated (excluding climate change)

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). 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.3). 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. 3). 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.

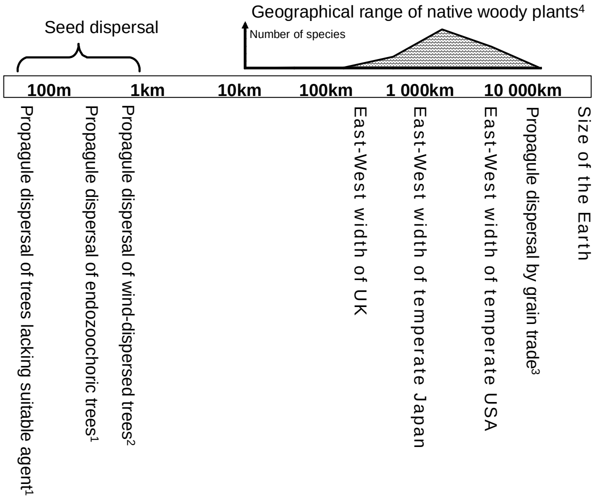

Fig. 3 Spatial scale of biogeographical range and human activities (Koike 2006a).

3. Range expansion - the key process for non-indigenous species

Expansion of geographical distribution range is the key process for non-indigenous species. The raccoon and the European green crab are good examples for range expansion, and the mode and rate of range expansion was estimated using statistical models based on distribution maps.

3.1. Raccoon (Koike unpublished)

A TV animation programme with a raccoon (*Procyon lotor*) character was broadcasted in Japan in the 1970s, and many raccoons were imported from North America as pets. Since then naturalized raccoons have been found in several regions in Japan where land cover is a mixture of urban and forest areas (Table 2).

Table 2. Factors determining initial naturalization of feral raccoons in 47 prefectures in Japan. Number of feral raccoon observations in prefectures (Wildlife Research Center 1998) was predicted from human population (potential owners of pets) and forest cover (potential habitat of raccoons), using Poison regression. AIC (Akaike 1974) represent a goodness of fit (smaller is the better).

Model variables	AIC
Human population	65.4
Forest area	109.1
Human population x Forest cover	60.9

In Kanagawa Prefecture, the raccoon was naturalized in Kamakura City, around 1988 and several female raccoons with young were found in 1990 (Nakamura 1991). Five isolated subpopulations were found in Kanagawa Prefecture in 2004, although only one sub-population around Kamakura City was clearly in 2001.

Dispersal kernel of natural range expansion was determined excluding outlier observations, and raccoons scarcely moved over a habitat-to-habitat distance longer than 10km in three years (half decrease distance of about 7 km, Koike 2006b). Kamakura City was at the centre of the largest subpopulation, and our simulation successfully predicted range expansion of this sub-population (Koike 2006b).

In order to know origins of other new subpopulations, unknown long-distance dispersal kernel was introduced and determined statistically, fixing short-distance kernel of natural range expansion (Koike 2006b), and assuming constant rate of new naturalization (Table 2), based on all distribution data in Kanagawa Prefecture at 2001 and 2004 reported by the early version of Hayama et al (2006).

The half decrease distance of the obtained long-distance kernel was about 100 km (Fig. 4). This distance suggests artificial raccoon transport by cars. Release of captured raccoons after transport by car had been known at least before 2004 in Kamakura area, and the long-distance dispersal might be the human-mediated secondary dispersal.

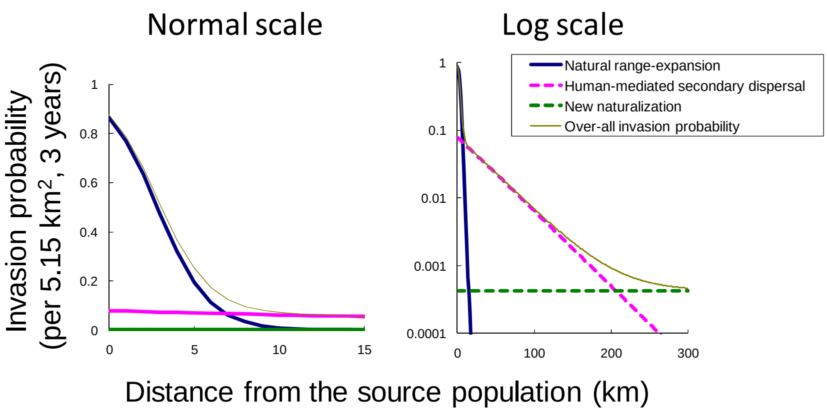

Fig. 4. Composite range-expansion kernel of short-distance natural dispersal (Koike 2006b), unknown long-distance dispersal, and the fixed rate of new naturalization (Table 2) in Kanagawa Prefecture. Unknown long-distance dispersal was determined by a maximum likelihood method fixing other pathways. Logistic models were used for both short- and long- distance dispersal. Log-scale panel is to show long-distant and low-probability invasions.

3.2. European green crab (Koike and Iwasaki unpublished)

Two types of shipping, namely, primary transport to Japan via long-distance ocean-going shipping and secondary transport within Japan via short-distance coastal shipping, were considered for the range-expansion of the European green crab (*Carcinus aestuarii*). The presence and absence of the crab in 50-km shoreline segments were obtained at five year intervals from 1985 to 2005, based on observation records by professional and amateur naturalists.

Natural dispersal was the most significant factor, in spite of its low expansion rate: secondary transport by coastal shipping was the second. Transport by international ocean-going shipping was not statistically significant, suggesting quite a small immigration probability of the crab by long voyages.

Stochastic simulations forecasted that the crab will invade most of the coasts of western Japan along the Pacific Ocean and Seto Inland Sea by 2055, and will become widespread all over the country by 2205. Quarantine scenarios to eliminate transport by vessels revealed that preventing crab transport by domestic coastal vessels may delay the arrival of crabs in Hokkaido and the northern Japan area by 700 years at maximum.

4. Designing future system

Biological invasion is irreversible process, and we cannot stop natural range expansion in almost cases. However human-mediated secondary dispersal is significant, and we can diminish range expansion by stopping such secondary dispersals by car (raccoons) and by coastal shipping (green crabs).

Risk feedback to importers and carriers may be possible to prevent unconsidered new introduction. 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 naturalized non-indigenous species. Possible impacts from non-indigenous 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).

However, we might need to develop new legislative system to shape risk feed-back mechanism accounting for negative externalities, because (1) natural range expansion will take several hundreds of years, and we need to ask remediation to the people lived hundreds of years ago. (2) Some non-indigenous species are economically valuable for several decades, but will soon become useless and noxious species. For example in Japan, fur animals as the American mink and the masked palm civet were useful in early 20th century, but now naturalized populations are quite noxious. No one can predict changes in future economical value. (3) It is quite difficult to identify the criminals who released the non-indigenous organisms. A few individuals are enough for naturalization in some species, and the released animals escape easily. (4) Good standard is needed for accounting damages. Many non-indigenous species caused only weak damages, but we need enormous cost for complete remediation (i.e. eradication). Level of remediation (complete or partial) affects total remediation cost in some orders of magnitude.

A fund to recover damages paid by importers and users might solve such difficulties. It might be similar to superfund in soil remediation in USA.

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