Invasive Alien Species Problems in Japan: an Introductory Ecological Essay

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Abstract

Status of invasive alien species problems in Japan is briefly summarized, with special emphasis on invasions during the period from the 1960s to today, one of the two eras characterizing the modern history of the biological invasion into Japan. A number of cases of invasions are categorized from the viewpoints of route of invasion, i.e., intentional or unintentional introduction, release and escape; and types of impacts of invasive alien species on ecosystems, biodiversity, and human life and health. Examples are given of species and situations exemplifying the individual types of influences.

Key words: impacts on ecosystems and biodiversity, intentional or unintentional introduction, invasive alien species, modern biological invasion

1. Scope of the Introductory Thesis

Aside from the urgent social need for investigation of invasive alien species problems, Japan is an interesting country to investigate regarding biological invasion, since it is an island country with clear oceanic boundaries, having a somewhat unique biota.

The Japanese Archipelago was a part of the Asian Continent until 15 million years ago when the Sea of Japan was a young marginal basin located between Japan and the Asian Continent (Chinzei, 1991). Before that geological age, the Japanese islands were not separated from the Eurasian continent, but formed the east end of the continent. Even after their separation from the continent, intermittent formation of land bridges during the Ace Ages (Nogami *et al*., 1980) facilitated active migration and colonization events of plants and animals including mammoths and humans from the continent to the islands. Therefore, Japanese flora and fauna are fairly similar to those of continental East Asia, but the endemism is moderately high due to the relatively long history of land isolation.

After the long period of national seclusion during the Edo Period corresponding to the period of European colonization, the country was reopened and was eager to incorporate not only western cultures and techniques, but also biotic matters. After more than one hundred years of striving, contemporary Japanese society, like an "Asian and Western" cultural chimera, has been formed with its flora and fauna well blended with plants and animals of European and North American origins (Totman, 2000). At present, Japan is clearly losing the battle against biological invaders, and now stands at a critical moment.

In this introductory essay heading this special issue, I attempt to present a brief sketch of the present status of the problem of invasive alien species in Japan, focusing on ecological as well as social mechanisms of invasions, and their impacts on biodiversity, ecosystems, and human activities and health.

2. Phases of Modern Biological Invasion

Biological invasion depends on chances for or routes of invasion on the one hand, and the presence or abundance of habitats where the introduced species can establish themselves on the other. Active foreign trade inevitably facilitates both intentional and unintentional introductions. On the other hand, human reformation of habitat conditions through development of roads, farmlands, plantations and cities prepares new habitats with ample void niches no native species have preempted.

Two eras can be distinguished in the modern history of biological invasion into Japan. One is the Meiji Era when Japan's modern foreign trade officially began after the long national seclusion under the Tokugawa shogunate (Asao, 1998). This era simultaneously marked a new departure into industrialization. The recorded years of the first naturalization of many contemporarily common non-native plant species were in the Meiji Era (Washitani, 2002). Since that time, the numbers of both naturalized alien vascular plant (Fig. 1) and insect (Kiritani, 2002) species have been constantly increasing. Therefore, 'alien species' in Japan are generally defined as the modern alien

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species that were introduced after the start of the Meiji Era (Murakami & Washitani, 2002).

Another era demarcating the different phases of alien species invasions into Japan was the rapid economic growth period starting in the 1960s when Japanese landscapes began to change greatly due to various types of development works according to a national plan to "remodel the Japanese archipelago" (Tanaka, 1972). After that era began, invasions have become more frequent than ever (Kiritani, 2002; Washitani, 2002). The globalization of trade and enhanced human habitat alterations can be considered the major reasons for accelerated invasions.

Certain currently devastating alien species are known to have begun abrupt population growth and range expansion after various lengths of lag periods after their initial invasion, and this suggests some important ecological and/or evolutionary changes or adaptations, such as establishment of a new mutualism in pine wilt disease (Kiritani & Morimoto, 2004), alterations of seasonal life cycles in the fall webworm, *Hyphantria cunea* (Gomi, 1995), and acquisition of pesticide resistance in *Erigeron philadephicus* L. var. *philadephicus* (Ito & Miyahara, 1984).

3. Route of Invasion: Intentional Introduction

Quantitative aspects of introduction are among the most important factors governing the probability of invasion of an alien species, since the invasion generally depends on various stochastic processes. Therefore, chances of invasion are optimal if the plants or animals are intentionally introduced in large quantities continuously into a region with ample void niches. This holds with alien grasses and legumes, which have been massively introduced for erosion prevention or revegetation purposes at various construction work sites (Washitani, 2001).

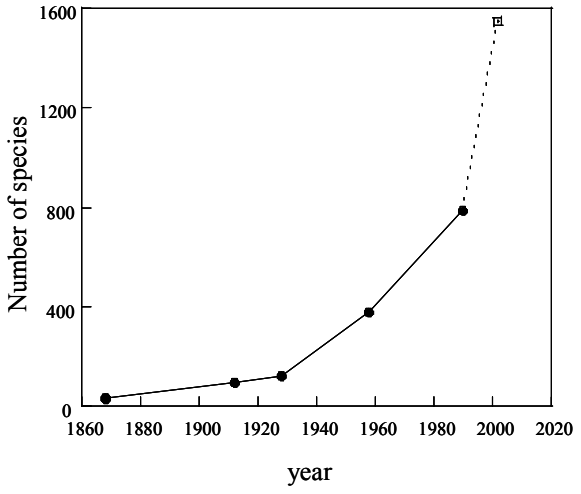

Fig. 1 Changes in the number of the naturalized plant species (drawn according to data from Washitani & Morimoto, 1993, and Ecological Society of Japan, 2002).

Erosion prevention techniques using alien perennial grasses, which cost much less than traditional techniques using *Zoysia japonica*, were first developed as afforestation and landslide prevention techniques and then also applied to construction of highways, roads and dams, and to other developmental works (Washitani, 2002). Vast quantities of seeds have been imported mainly from North America, mixed with organic malting materials and chemical fertilizer, and mechanically plastered to the denuded ground or slopes to be revegetated.

During the age of mass construction works in Japan, that is, the 1960s-1980s, alien grasses, cultivars of *Eragrostis curvula* of South African origin (seeds of which were introduced from the USA), *Lolium multiflorum* L. and *Festuca arundinacea* were popular plant materials for revegetation. These species are among the most invasive plant species in riparian habitats and up to 1999, the total area of vegetation dominated by alien grasses reached 18,000 ha, which amounted to 12% of the total river area administered by the Ministry of Land, Infrastructure and Transport (Miyawaki & Washitani, 2004).

Legume trees and shrubs were also common as revegetation plant materials. Aggressive invasions of these grasses and legumes currently contribute a profound threat to the biodiversity and ecosystem integrity of Japanese riparian habitats (Washitani, 2001; Muranaka & Washitani, 2002).

Stocking rivers and lakes with alien fishes has been also a major route of biological invasions into fresh aquatic ecosystems. Representative is the stocking of rainbow trout and brook trout imported from the USA, that began as early as 1877 (Kawanabe, 1980), and their populations have become established in regions with cooler climates in Hokkaido and Honshu. Currently, brook trout are suspected to threaten native white-spotted charr through competition and asymmetric hybridization (Kitano, 2004).

The most notorious invaders attracting contemporary public concern are some sunfish family species native to North America, which have been repeatedly released into lakes and ponds for sport fishing and have explosively multiplied (Yodo, 2002). Large-mouth bass, which are known to prey on a wide range of native species including fishes and insects such as dragonfly larva (Suda, 2002), were reported in only 23 prefectures of Japan in the early 1970s, but are now distributed in all 49 prefectures (A round - table conference on alien fish problems, 2003).

Collapse of fishery grounds due to predation by illegally stocked bass and bluegill has been reported from 305 fishery grounds subjected to fishery rights, including 257 rivers and 48 lakes, in all parts of Japan (source: interview with the National Alliance of Inland Fishery Association). Bylaws to ban the release of several alien fishes including bluegill and large-mouth bass were enacted in the late 1990s by most self-governing bodies at the prefecture level.

Biological hazards due to the naturalization of intentionally introduced agricultural biotic agents are not yet fully recognized, but it should be noted that unlike non-living materials, biotic agents may propagate, adapt to new environments through evolutionary changes and expand their ranges actively. It is possible that a minute quantity of an introduced biotic agent could have a great impact on an ecosystem after its population or range increased a million or billion fold.

A symbolic case of immediate naturalization after introduction for agricultural use is found in *Bombus terestris,* which has been introduced as a pollinator for greenhouse cultivated tomatoes since 1991. Japanese greenhouses are not closed systems in their structure, and the introduced bees can escape freely. A natural colony of the species evidencing naturalization was found in Hokkaido as early as in 1996 (Washitani, 1998), and the results of a voluntary monitoring activity suggest rapid population growth of the species in that region (Matsumura *et al.*, 2004).

4. Route of Invasion: Unintentional Introduction

One of the most influential alien species that was unintentionally introduced in the early phase of the history of the modern biological invasion into Japan is a pathogenic nematode (*Bursaphelenchus xylophilus*). The species is thought to have made its invasion by hiding in imported wood for shipbuilding from North America, and has caused tremendous damage to pine plantations throughout Honshu, Shikoku, and Kyusyu since its first record in Nagasaki in 1905 (Togashi, 2002).

Postwar Japanese foreign trade has been characterized by imports of raw materials and exports of industrial products such as automobiles (Kodansha International, 1999). Origins of various invasions into Japan can be ascribed to the intermingling of biotic and other materials imported.

In particular, mass import of cereal is likely to be most responsible for the dissimilation of weevils and arable weeds from exporting to importing countries. In Japan, only eight insect species were recorded as stored product pests in the Meiji Era, but at present as many as 108 can be listed (Nakakita, 2002). A number of notorious weed invasions into Japan demonstrated that unintentional introduction is inevitable for crop field weeds with seeds ecologically mimicking crop grains. The predominant major cereal exporting country to Japan is the USA, whose share accounted for 92.5% of corn and 78.7% of soybeans on average from 1996-1998 among the countries that export cereal to Japan (Ministry of Agriculture, Forestry and Fisheries, 2001).

Soybeans were the most important protein source in the traditional food habits of Japan, but the domestic supply of soy is very low and more than four million tons of soybeans are transported yearly from the United States. Japanese soybean food manufactures have to discard large amounts of weed seeds intermingling with imported soybeans. Therefore, the weeds can spread from the dumping grounds of such factories. Representative is *Ambrosia trifida,* native to estuarine floodplains of North America (Sickels & Simpson, 1985), but is now very common in Japanese riparian habitats and landfill sites where industrial wastes are dumped (Washitani & Morimoto, 1993).

The current Japanese livestock industry strongly depends on imported cereal for feed. Serious contamination by weed seeds of imported cereal was reported by Shimizu (1998) who inspected feed cereal cargos landed from ships at Nakaminato Port in Ibaraki Prefecture in the Kanto district. During one year of investigation, the seeds of more than 100 alien weed species were detected. The seeds of 64 weed species were found in soybean cargos imported from the USA. In another investigation of cereal cargos of 105 ships from various regions of the world, the seeds of a total of 1,482 weed species were detected intermingling with cereal (Shimizu, 2002).

Another route of mass introductions associated with foreign trade is via ballast water of ships carrying a large number of living marine organisms. Ballast water is known as a major source of many notorious invasions worldwide in the last quarter of the 20th century (Carlton, 1985, 2001). In Japan, many alien marine species have become established in the coastal areas of Tokyo Bay and Osaka Bay (Furota, 2002; Iwasaki, 2002), which are surrounded by the most densely populated industrial cities of Japan. Heavily polluted water drove away native species that were abundant in the past, and the void niches thus formed were suitable to certain alien species more resistant to polluted and deoxygenated conditions resulting from excessive nutrients (Furota, 2002). One representative is the introduced spider crab (*Pyromaia tubeuculata*) native to the Pacific coast of North to South America, which was first recorded in Tokyo Bay in the 1960s, and is now the most abundant crab in the bay (Furota, 2002). The shore protection walls of the bay are densely covered with adhesive shellfishes brought from various regions of the world, including Mediterranean blue mussel (*Mytilus galloprovincialis*), Oceanic *Xenostrobus secure,* and *Limnoperna forutunei kikuchi*, Southeast Asian *Perna viridis*, North Atlantic *Balanus eburneus* and *Molgula manhattensis*, on which Mediterranean green crabs (*Carcinus aestuarii*) wander. Off the coast, *Pyromaia tubeuculata* are abundant on the seabed especially during cool seasons when the bottom water layer is aerobic enough (Furota, 1996, 2002). In a survey performed in 2000, 80% of the total individuals and 88% of the total fresh weight of sedimentary organisms were occupied by alien species (Environmental Bureau Tokyo Metropolis, 2002). These are some of the results of invasions via ballast water.

5. Pets Naturalized by Intentional Release or Escape

Recently, pastimes or recreational uses of introduced plants and animals – such as for gardening, fishing and raising or breeding as pets – have caused serious biological invasion problems. Japan is one of the world's biggest animal and plant-consuming countries (WWF- Japan, 1999). Today, every conceivable kind of pet animal, especially reptiles, amphibians, and fishes including poisonous or hazardous ones, as well as exotic insects are massively introduced (Cabinet Office, 2001b). In 2001, 782 million items of animals were imported (Seino, 2002). If just a small proportion of the imported organisms become naturalized, the numbers could become considerably larger, and certain naturalized organisms could have a great impact on ecosystems and society.

Escapes from zoos are one of the major routes for mammal naturalization, as seen in a representative case of the Formasan squirrel (*Callosciurus erythraeus thaiwanensis*), which originated in Taiwan and is rapidly expanding in its range in Kanagawa Prefecture (Miyamoto *et al.*, 2004).

A notorious example of naturalization due to abandonment or intentional release can be seen in the case of *Trachemys scripta elegans* that has currently become the most common turtle in standing water habitats in Japan (NACS-J, 2004), because young individuals are among the most popular pets for children and are usually abandoned when they grow to ferocious-looking adults (Yasukawa, 2002).

An embargo on the introduction of tropical beetles based on the Plant Quarantine Law was partially canceled in 1997. During the first half of 2001, about 630,000 beetles were imported (Araya, 2002). A large market for the imported beetles has been established, and various species and races are now imported from various Asian countries (Traffic Japan, 2002). According to an investigation of a pet shop (Traffic Japan, 2002), they sell beetles labeled as native to countries such as India, Nepal, Bhutan and the Philippines that legally ban the export of those species. Abnormal booms of stag beetle breeding and consequent intentional and unintentional releases are suspected to be responsible for the recent increase in size of *Dorcus antaeus* caught from its natural habitats of Japan (Goka, 2004). Such an abrupt size increase cannot be explained unless strong artificial selection and/or crossing with individuals with a different genetic make-up are assumed (Goka, 2004).

The list of naturalized pet animals in Japan includes raccoons, prairie dogs, green iguanas, common snapping turtles and so on (Ecological Society of Japan, 2002). Introduced turtles (Yasukawa, 2002) and raccoons (Ikeda, 2002) are likely to deprive native turtles and raccoon dogs, respectively, of their habitats.

6. Impacts of Invasive Alien Species on Ecosystems and Biodiversity

6.1 Alteration of fundamental ecosystem structures and processes

Plants form the biological foundation of all terrestrial and aquatic communities. Therefore, mass invasions of alien plants more or less cause structural and functional changes in ecosystems, including alterations in nutrients and/or structural conditions (Schmitz *et al*., 1997). Particularly, changes in dominant plant species may lead to the replacement of dominant plant consumers, followed by their predators, and further cause a chain of changes in species compositions at every trophic level, and thus disrupt food webs and other structural and functional features of the ecosystem.

Even if the invasive species are pioneers dominating only early phases of the vegetation succession sere, the effects of the invasion may last long through persistent soil seed banks. Invasive alien plant species, when once established in an ecosystem, may cause irreversible changes by producing large seed sources above and/or under the soil surface (Harper, 1977; Thompson & Grime, 1977; Thompson, 2000). Soil seed bank strategies, using long persistent seeds and physiological mechanisms to detect temporal 'safe sites' for seedling establishment are common to most invasive alien species established in Japan (Washitani & Morimoto, 1993; Washitani, 2002). Two of the major families contributing to the invasive alien herbaceous flora of Japan are the Compositae and Graminae, the former being well characterized by highly dispersible aerochorous seeds and/or long-lived seeds that tend to be persistent in soil seed banks. Contemporary surface soils of various habitats of Japan, including wetlands, woodlands, plantations, floodplains and farmlands have more or less accumulated viable seeds of such alien plant species, even if the above-ground vegetation contains no or few alien plant species (Table 1).

Some invasive plants predominating in the riparian vegetation, such as *Ambrosia trifida* have large seeds with low specific gravities, which are apparently less mobile, but can move freely in riparian habitats with abundant persistent and temporary watercourses channeling hydrochorous seed dispersal.

Flourishing invasive alien plants furnished with strategies enhancing spatial and temporal dispersal of seeds inevitably cause alteration of the early stages of succession seres. This is likely to be one of the most conspicuous influences of plant invasions on ecosystem processes. When modern plant ecological studies on floristic succession in Japan started in the 1960s, plants predominating in the early stages of secondary succession had already been replaced by North American plants such as *Ambrosia altesiaefolia* var. *elatior*, *Erigeron annuus*, and *E. canadensis* (Numata *et al*., 1964). Accumulation of persistent soil seed

Table 1 Nonindigenous plant species found in the soil seed bank of various habitats in Japan (compiled according to Washitani, 2002, and Ajima, 2001)

major nonindigenous species	occurrence of nonindigenous species		total species number	sampled area (m^2)	method	study site	references
	percentage in seed numbers	percentage in species numbers					
Bidens frondosa, Eclipta thermalis	0.2	9.1	22	1.6	seedling emergence	riparian woodland (Kokai River)	Imahashi & Washitani (1996)
Eclipta thermalis, Lindernia dubia	9.6	13.9	36	1.6	seedling emergence	moist tall grassland (Kokai River)	Imahashi & Washitani (1996)
Lindernia dubia, Erigeron annuus	13.2	11.1	27	3.0	seedling emergence	abandoned paddy (Ibaraki Prefecture)	Koshimizu *et al.* (1997)
Erigeron philadephicus, Cerastium glomeratum	48.7	40.9	23<	2.8	seedling emergence	dredged soil (Lake Kasumigaura)	Ikeda *et al.* (1999)
Phytolacca americana	1.9	3.3	30	0.3	direct counting	Japanese cedar plantation (Kamaishi City)	Ajima *et al.* (2000)
Conyza sumatrensis, Erigeron philadephicus	8.7<	14.4	99	2.4	seedling emergence	coppice woodland (Tokyo Metropolitan)	Hamada & Kuramoto (1994)
Crassocephalum crepidioides, Conyza sumatrensis	37.4	6.7	30	0.4	direct counting and seedling emergence	secondary deciduous woodland (Kobe City)	Nakagoshi (1981)
Phleum pratense, Trifolium repens	45.5	63.6	11	0.7	floating method	Sasa grassland (Hokkaido Prefecture)	Tsuyuzaki & Kanda (1996)
Anthoxanthum odoratum	0.2	5.0	20	0.1	direct counting	Zoysia grassland (Aomori Prefecture)	Hayashi & Numata (1971)
Trifolium repens, Poa pratensis	52.9	4	33	0.3	direct counting	maritime grassland (Hokkaido Prefecture)	unpublished data

banks of alien ruderal and pioneer species has increased since then and the contemporary surface soil in various habitats with intense human intervention contains profuse seed banks of North American plants including *Erigeron*, *Solidago*, and *Oenothera* species (Ajima, 2001; Ikeda *et al*., 1999).

Once a persistent soil seed bank of an invasive species has been established, either natural or human disturbances will always bring about the domination of the alien species, which will further replenish the soil seed bank or enlarge the seed sources of the invasive species.

6.2 Changes in habitat conditions

The habitats most profoundly affected by alien plant species in Japan may be riparian floodplains and fresh aquatic habitats (Miyawaki & Washitani, 2004). Generally, invasive legume plants that are capable of nitrogen fixation with the aid of symbiotic bacteria tend to enhance soil fertility in originally infertile habitats (Schmitz *et al*., 1997). Nutrient poor substrates of gravelly floodplains characterized by specific sparse vegetation along rapid Japanese rivers are likely to be increasingly enriched by invasion of *Robinia pseudoacacia* from North America, and thus subsequent weedy plant invasions are facilitated (Miyawaki & Washitani, 2004).

Alien pasture grasses that have been extensively introduced into various construction work sites throughout Japan for the purpose of erosion prevention such as *Eragrostis curvula* and *Festuca arundinacea* have established tremendous seed sources everywhere, especially in mountainous regions (Washitani, 2001). These introduced grasses are highly invasive and if riparian habitats are invaded, the substrate condition of gravelly floodplains can be changed into sandy/silty conditions, because bunches of these grasses tend to trap sand and silt during flooding (Nakatsubo, 1997; Muranaka & Washitani, 2001a). Thusly altered substrate conditions facilitate the establishment and growth of weedy plants including those grasses themselves, which were totally absent from the original gravelly floodplains (Muranaka & Washitani, 2001b). Thus, the original conditions and vegetation of gravelly floodplains, i.e., sparse vegetation cover consisting principally of riparian endemics growing in gravelly-sandy conditions, are being lost rapidly (Muranaka & Washitani, 2003). The competitive alien plants exclude less competitive indigenous plants adapted to infertile substrate conditions of the flood plain, and the replacement of dominant plants as well as the alteration of species compositions will inevitably result in profound changes to the whole community through changes in the composition of major herbivorous animal species.

6.3 Predation and herbivory

Consumption by invasive species with rapidly growing populations has tremendous effects on the populations of native prey animals or food plant species. Predation by introduced animals is one of the most serious factors elevating the risk of extinction of rare endemic species in the biodiversity hotspots of Japan, the Ogasawara Islands and the Okinawa Islands (Nonindigenous Species Committee, 2002).

One of the most notorious introduced mammal predators threatening endangered species is the Java mongoose introduced into the Okinawa Islands for the control of poisonous snake, *Trimeresurus flavoviridis,* and/or rats (Yamada, 2001, 2002). The introduced Java mongoose preys on various native mammals, ground-nesting birds, amphibians and reptiles, threatening them critically in the Yanbaru (northern) regions of Okinawa Island and Amami-Ohshima Island (Yamada, 2002; Yamada & Sugimura, 2004).

In the Yanbaru region of Okinawa Island, the range of the endangered species *Ralus okinawae* has been reduced northwardly at a rate of approximately 1 km per year (Tanahara, 2002), probably because of Java mongooses. A control program was started in 2000, aiming at preventing the invasion from proceeding further north into an area recognized as one of the prominent hotspots for biodiversity of Japan. A national mongoose eradication program has been started recently on Amami-Ohshima Island (Yamada & Sugimura, 2004) where the mongoose threatens many rare and/or endemic mammals and birds such as the Amami black rabbit (*Pentalagus furnessi*), Ryukyu spiny rat (*Tokudaia osimensis osimensis*) and Amami Woodcock (*Scolopax mira*) (Yamada 2002).

Anolis carolinensis has been naturalized in the Ogasawara Islands, the fauna of which is characterized by extremely high endemism. Its range is rapidly expanding to cover large tracts of the main islands of the Ogasawaras (Hasegawa, 1988), and a wide range of insects and animals, including an endangered native lizard (*Cryptoblepharus boutonii nigropunctatus*), have become critically threatened (Suzuki & Nagoshi, 1999). In the range where *A. carolinensis* has already invaded, endemic insects including dragonflies, small beetles, and woodborers have totally disappeared (Karube, 2001). Predation by *A. carolinensis* is suspected to be principally responsible for the disappearance of various endemic insects, since the intact insect fauna and community are still preserved on Anijima Island, which has still avoided invasion by *A. carolinensis* (Karube, 2002).

As a result of heavy herbivory by the introduced Chinese fish (*Ctenopharhyngodon idellus*), aquatic plants are locally extinct in Lake Nojiri and Lake Kizaki in Nagano Prefecture. *C. idellus* is known to eat greedily every aquatic plant including emergent ones such as reeds and cattails (Hayashi, 2002) and denude natural aquatic vegetation along shorelines (Tachikawa, 2002).

Bluegill introduced from North America, which are one of the commonest fishes in every type of freshwater ecosystem of contemporary Japan, are one of the most influential invasive alien species because of their wide prey range (Nakai, 2002a). In Japan, naturalized bluegill prey on eggs and flies of a wide range of fishes, and exert strong negative effects on native fish fauna in various freshwater ecosystems (Azuma, 1992). Dietary planktivorous, benthivorous and herbivorous specialization closely associated with morphological differentiation suggests adaptive divergence during a relatively short period of several decades from the colonization of the species in Japanese lakes (Yonekura *et al.*, 2002). This species has become the most predominant fish species in various freshwater ecosystems in Japan, including Lake Biwa and Lake Kasumigaura (Nakai, 2002b).

A number of islands among the Ogasawaras and Southwestern Islands have experienced devastating damage to vegetation by naturalized goats, which were abandoned due to changes in human eating habits and/or drastic human population loss from the remote island areas during the period of rapid economic development (Tokita, 2002). On semi-tropical islands such as the Ogasawaras, denudation of vegetation by goats causes secondary and tertiary effects such as extensive soil erosion and damage to coral by sedimentation of the eroded soil (Tokita, 2002).

6.4 Replacement through competition

A strong competitor monopolizes resources and excludes less competitive species from the habitat. In contrast with animals, which have diverse prey differing among species, plants depend on a few kinds of common resources for their growth, i.e., light, water and nutrients. Therefore, competition tends to be severe (Grime, 1979).

Ambrosia trifida, a giant annual plant native to North America, is highly competitive and grows on fertile soils (Bazzaz, 1968; Sickels & Simpson, 1985). Its original habitat is delta floodplains (Sickels & Simpson, 1985), but the species invaded into man-made nutrient rich habitats to become a notorious weed of soybean fields in the USA. As mentioned previously, the species was presumably introduced intermingled in soybean crops imported from the USA to Japan. Competitive exclusion by this species causing a decrease in plant species diversity was suspected at nature reserve of moist tall grasslands along the Arakawa River near Tokyo, where plant species diversity was negatively correlated with the abundance of *A. trifida* (Miyawaki & Washitani, 1996).

Competitive exclusion of native bumblebees by *Bombus terrestris,* which has become naturalized in several regions of the world after commercial introduction as a greenhouse pollinator, has been suggested (Dafni & Shmida, 1996; Hingston & McQuillan, 1998). Also in the Hidaka region of Hokkaido, *B. terrestris* is suspected to be competitively replacing native bumblebees at this time according to the results

of continuous monitoring by a number of volunteers including scientists and citizens (Matsumura *et al*. 2004). The monitoring, performed in an area where greenhouse tomatoes are cultivated, widely suggests that *B. terrestris* had become dominant in the bumblebee fauna by 2003 (Matsumura *et al.*, 2004).

The introduced omnivorous turtle, *Trachemus scripta elegans,* which probably has already become one of the most common turtles in Japan (NACS-J, 2004), preys on an extremely wide range of animals and plants including fish, amphibians, shrimp, shell fish, aquatic plants and the leaves, flowers and fruits of land plants, and has higher reproductive fertility even under various environmental stresses (Yasukawa, 2002). Competitive exclusion of native common turtles is suspected. However, investigation into the effects of the species on the ecosystem has yet to be performed, though strong impacts on regional biodiversity and aquatic ecosystems are suspected (Yasukawa, 2002).

6.5 Parasite or disease transmission

The felid virus disease AIDS FIV was detected in an adult male wild lynx, *Felis bengalensis euptilura,* which is endemic to Tsushima Island of Nagasaki Prefecture, western Kyusyu, and is now highly endangered (Akuzawa, 2002). It is suspected that house cats transferred AIDS FIV to the wild lynx through bites on the occasion of fighting.

Pathogenic flukes parasitic to freshwater fishes, *Parabucephalopsis parasiluri,* have been transmitted from a bivalve species (*Limnoperna fortunei*), an intermediate host of the parasite, to native fishes of the carp family (Urabe, 2002). The bivalve species was unintentionally introduced from China. During the winter from December 1999 to January 2000, an epidemic caused by the fluke swept through the riparian system originating from Lake Biwa, and a vast number of native fishes of carp family, especially the Oikawa carp (*Zacco platypus*) were killed (Urabe, 2002).

Intentionally introduced insects, including *Bombus terrestris* as a commercial pollinator and stag beetles as pet insects, have been revealed to carry various pathogenic agents including mites, the transmission of which to native insects through naturalization of these insects is a serious concern (Goka *et al.*, 2001; Goka, 2002, 2004).

6.6 Hybridization or interference with reproduction

The Japanese monkey (*Macaca fuscata*) has the most northerly range among primates except for *Homo sapiens* (Kuroda, 1998). The Taiwan monkey (*M. cyclopis*) has established populations on the Shimokita Peninsula, Izu-Ohshima Island, and the Kii Peninsula after World War II as the result of abandonment of zoo individuals (Nakaya & Maekawa, 2002). On the Kii Peninsula the range of the populations of the Taiwan monkey have begun to overlap with that of a population of *M. fuscata* (Wakayama Prefecture, 2000), and hybridization between these species is now in progress (Nakaya & Maekawa, 2002). In order to preserve a pure linage of Japanese monkeys, the prefectural government decided to exclude hybrid individuals.

Rhodeus ocellatus ocellatus, which was unintentionally introduced through intermingling with the fry of *Hypophthalmichthys molitrix* imported from China as a fishery resource, has become established in fresh aquatic ecosystems through range expansion facilitated by human activities of stocking lakes and rivers (Nagata, 1980). *R. ocellatus ocellatus* has hybridized with *Rhodeus ocellatus kurumeus*, which was once widely distributed in western Japan but has now become endangered (Environment Agency of Japan, 1999). Hybridization with *R. ocellatus ocellatus* is assumed as the main cause of the threat.

7. Impacts on Human Life and Health

7.1 Influences on industries

Agriculture is the industry most strongly affected by alien pests and weeds. It is no exaggeration to say that in present-day Japan, almost all the influential pests are alien species (Kiritani, 2002; Shimizu, 2002; Kiritani & Morimoto, 2004). The rice water weevil, *Lissohhoptrus oryzophilus,* which is currently the most serious insect pest of rice crops, originated from the USA, was first found in Aichi Prefecture in 1976, and expanded its range through the 1990s when a vast tract of Japanese paddies was infested (Kiritani & Morimoto, 2004).

Japanese forestry has also been affected by invasive alien species, as markedly illustrated by pine wilt disease caused by a pathogenic nematode originating from North America, *Bursaphelenchus xylophilus*. A mutualistic relationship between the nematode killing the pine trees and the Japanese pine sawyer (*Monochamus alternatus*), carrying the nematode and feeding on the trees infected by the nematode, was established after the nematode invasion and has been responsible for the rapid range expansion and heavy damage to pine plantations (Kiritani & Morimoto, 2004). Aerial spraying of insecticides, which has been the major control measure against the pests, might seriously affect local biodiversity.

Dense applications of chemicals for agricultural/forestry pest control are secondary but crucial consequences of alien pest invasions. Chemical application to agricultural lands is suspected as one of the major causes of soil and/or water pollution in present-day Japan (Ando, 1990).

Freshwater fisheries are also highly vulnerable to biological invasion. Japanese freshwater fishing is an occupation with a long-held tradition at least from the Neolithic Age, but is facing a crisis of collapse. One of the factors responsible for the crisis is invasive alien fish such as large-mouth bass and bluegill, which have explosively increased after introduction and ad-

aptation to Japanese freshwater environments and heavily consume native fishes (Nakai, 2000). Together with other factors such as water pollution, eutrophication and destruction of terrestrial-aquatic ecotone vegetation, these invasive alien fishes seriously threaten Japanese freshwater fisheries and also Japanese food culture with a long tradition (Kawanabe, 2000).

Also in coastal regions, a number of invasive alien species affect fish farms. A representative case is the severe damage to oyster culture by the sedimentary annelid *Hydroides ezoensis* in the Seto inland sea, with the yearly total damage amounting to several billions of yen (Nishi, 2002).

Limnoperna fortunei is a bivalve native to China, and introduced into Japan unintentionally intermingled with imported corbicula in the 1980s (Matsuda & Nakai, 2002). The species has a habit of adhering with a proteinaceous fibrous excretion to solid materials such as stone and wood, and amassing thickly on concrete walls, obstructing water inlets of hydropower plants or water supply facilities.

7.2 Influences on human health

Some alien plants are major causes of pollinosis. Pollinosis, which is also called hay fever, is seasonally recurrent bouts of sneezing, nasal congestion, and tearing and itching of the eyes caused by allergies to the pollen of certain plants including alien *Ambrosia* species from North America and alien meadow grasses such as *Lolium multiflorm*, *L. perenne*, *L. x hybridum,* and *Dactylis glomerata* (Koizumi, 1998; Saito & Ide, 1994). In contrast to continental areas covered by large tracts of dry grasslands, in pre-westernized Japan, pollinosis would have been rather exceptional, since human residential areas were embedded in fine-grained landscape mosaics of woodland with various trees, paddies and grasslands, where no single species with anemophilous pollen dominated overwhelmingly.

In Japan, pollinosis was first recognized as an early summer hay fever caused by *Ambrosia* species in the early 1960s (Araki, 1960; Saito, 1996). It became prevalent first among school children during a boom in school swimming pool construction during those years. The disease, with symptoms similar to influenza, was misunderstood as an epidemic and was called 'pool fever.' More recently, a very high incidence of pollinosis has been reported for school children in an area adjacent to the Edo River flowing through Tokyo, the banks of which are dominated by alien grasses, especially *Lolium* species (Parent group learning on grass pollinosis, 1999).

8. Growing Public Concern and Activities toward Establishing an Effective Legal System

Until quite recently, Japanese have felt little concern about biological invasion. However, very recently, public attitudes toward introduced species began to change, as concern about environmental issues including biological invasion has rapidly grown after substantial losses of national biodiversity and ecosystem integrity due to invasive alien species and other related problems mentioned above.

An opinion poll on 'public attitudes to nature conservation' conducted by the Cabinet Office of the Japanese Government in the spring of 2001 (Cabinet Office, 2001a) revealed that more than 85% of respondents to the questionnaire approve of the need for some restrictive measures against introduction of non-native species and those approving of eradication of alien species badly influencing ecosystems accounted for more than 70% of respondents. The need to manage introduced species has gradually become understood among the public.

In December 2001, in a report submitted to the Prime Minister, the Council for Regulatory Reform of the Cabinet Office recommended urgent investigations aiming at quick establishment of national legal regulatory systems to respond to domestic biological invasion problems, including regulations on the importation and utilization of introduced species and mechanisms for the management of invasive alien species which have already naturalized (Cabinet Office, 2001b). Responding to the Council's request, the Natural Environment Bureau of the Ministry of Environment started an investigation on the status of and necessary measures against invasive alien species, and formulated a policy for quick establishment of an effective legal system against invasive alien species problems. In May 2004, a new national regulation against invasive alien species, i.e., the Invasive Alien Species Act was promulgated.

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