# Invasive Alien Species Issues

Keizi KIRITANI
*Loisir Izukogen, 1020-292 Futo, Itou City, Shizuoka 413-0231, JAPAN*

**Abstract – I address three important issues with regard to invasive alien species. First, the rate of introduction of alien species is rising sharply in association with increased trade, transportation and tourism. Second, the consequences of biological invasions are very difficult to predict as exemplified by the fall webworm, the rice water weevil and the pine wood nematode in Japan. Third, biological invasions have resulted in faunal homogenization worldwide of stored product and greenhouse pest fauna.**

## I. Introduction

Biological invasions are one of the most important issues in this century in terms of the conservation of biodiversity.

The title of this paper is not simply " Invasive Alien Species" (IAS), but I have added the word "Issues". What is the difference between IAS and IAS issues? I address three points as issues. Presently, changes in environmental factors are incomparable in the rate and dimensions with anytime in the past. Secondly, consequences of biological invasions are very difficult to predict. Finally, biological invasions result in faunal homogenization and loss of biodiversity.

First of all, I define "alien" by reference to a cut-off date, which is the beginning of the Meiji era (1868) when Japan opened the door to foreign countries after 200 years of national isolation policy. If the date is farther back in history, virtually all native species may be defined as alien, because the Japanese archipelago was originally part of a continent before its ' geographical separation. Therefore, we classify species without any obvious record of introduction as " native " , including pre-Meiji invasions.

The world population is expected to be 9 billion in 2050, increasing by 3 billion in 50 years. Ten thousands years ago, it was only less than 6 million. Currently our human population increases at a rate of one million every 4 days [1]. In addition, IPCC predicts that global-mean surface temperature will increase 1.4-5.8℃ by the year 2100 as compared to 1990. Because the temperature rise during the last 10,000 years was 5℃, the speed at which current global warming proceeds is 10 to 100 times faster than 10,000 years ago [2].

The rate of introduction of alien species beyond their natural range is rising sharply with increased transport, trade, travel and tourism between different countries and continents. These increases are not only in quantity but also in speed of movement. Increases in the speed of cargo ships made transport of insect pests possible across the equator where they would have otherwise been killed by high temperatures.

These examples strongly suggest that our environment is changing at an accelerating rate both in scale and speed. Therefore, the essentials of environmental issues should be viewed in terms of changing rates of biological processes in space and time.

## II. Increase in Vectors and Pathways for Invasion

The number of alien species that were introduced unintentionally differs greatly among the areas of Japan. Those areas where alien species usually do not first occur, for example, Shikoku Island and the Amami and the Miyako Islands, lack international air- and seaports. In other words, the alien insects invaded these areas after they became established elsewhere in Japan [3].

The economic status of alien species was examined for the 260 species in Japan. Pest, non-pest and beneficial insects accounted for 191(74%), 57(22%) and 12(4%), respectively [4]. On the other hand, pest species account only for 8% of the native insect fauna [5]. This means that exotic insects are pestiferous at a rate of almost 10 times higher than among native insects. Only a small percentage of introduced species, however, become invasive. Kiritani [6] designated only 22 species as Invasive Alien Species, which accounted for 5% of the total 413 alien species in Japan.

Biological invasions are composed of four phases: introduction, establishment, spread, and naturalization. It is often insisted that island communities are more easily invaded or that mainland species are better colonists. It may be, however, that mainland species simply have more opportunities to invade islands than vice versa. We should discriminate between the vulnerability of island communities and the opportunity of invasions.

## III. Vulnerability of Islands to Biological Invasions

The total land area of the southern islands including the Nansei and Ogasawara islands accounts for only 1.2% of the total Japanese land, but 43% of the alien insects invaded Japan are found in the southern islands. Therefore, we examined the balance of import and export concerning vegetables and fruit between Okinawa prefecture and the Japanese mainland. Obviously, Okinawa has always run a trade deficit for these agricultural products. These trade gaps may partly explain why islands had so many invasive insect species compared to the mainland. In fact, out of 98 exotic species in Okinawa, 26 species were translocated from the mainland, while only 3 species invaded the mainland from Okinawa [4,7,8].

The Ogasawara Islands were put under the trusteeship of the United State from 1945 to 1968. Fourteen insect species, most of which are agricultural pests, invaded these islands after 1968. Twelve of them probably came from the mainland in association with the import of agricultural products [9]. There are no records of insect species that became established in the mainland from Ogasawara. But clearly other factors such as subtropical climate and the poor biological community represented by oceanic islands like Ogasawara may influence the process.

## IV. Species Interchange between Japan and the USA

The international trade system of agricultural products between Japan and the United States was examined [8]. The amount of agricultural products imported from the US to Japan was 20,000 times that exported from Japan to the US. Kiritani [10] has published a comprehensive list of the insect species that have invaded the US from Japan, and those that have invaded Japan from the US. Afterward some species were added to the list. The cumulative number of alien insects that came from the US amounted to 54 species during the past 140 years after the beginning of the Meiji era. The invasion frequency during the last 30 years (1970-1999) was 10 times higher than that before World War II. Currently, one species originating from the US is becoming established in Japan every year (Table 1).

The number of species that invaded the US from Japan is 58. This almost equal number of alien species exchanged between the two countries, viz. 54 from the US and 58 to the US, seems rather strange in view of the big trade gap. If we look at the time when these alien insects invaded, however, the present imbalance in trade is clearly reflected. Invasions of the US by Japanese species show a peak in the 1920s. In contrast, more than one half of the species that have invaded Japan from the US were during the last 30 years [8].

Table 1. The number of species invaded Japan from the US.

| Period | No.species | No.species/year |
|---|---|---|
| 1860-1939 | 7 | 0.09 |
| 1940-1969 | 12 | 0.4 |
| 1970-1999 | 32 | 1.1 |

## V. IAS from the United States

Performance of alien species in newly established areas is often very difficult to predict. For example, the Japanese beetle, *Popillia japonica*, has become one of the most widespread and destructive agricultural pests in the eastern United States. Adults feed on more than 300 plant species [11]. In Japan, the pest status of this beetle is so minor that the damage has seldom been reported. A review article on the Japanese beetle by Potter and Held [11] contains 200 references with only eight (4 percent) papers published in Japan.

Among 54 species from the US, the fall webworm, *Hyphantria cunea* (introduced in 1945), the rice water weevil, *Lissorhoptrus oryzophilus* (introduced in 1976) and the pine wood nematode, *Bursaphelenchus xylophilus* (which was introduced in 1905, and the causal agent of pine wilt diseases transmitted by the Japanese pine sawyer, *Monochamus alternatus*) are the most outstanding pests. Cherry, rice, and pine are the plants representative of Japanese scenery. Each of these plants has been seriously damaged by these invasive species, and the magnitude of the damage was not predicted before their invasions [12].

Generally speaking, as was the case for the Japanese beetle, alien species often invade new areas unaccompanied by their natural enemies. Secondly, all arthropod invasions consist of a small number of tiny organisms with a restricted distribution. The inability to detect them in the process of invasion makes it difficult to eradicate them. Our analyses suggested that invasive insects have a latent period of at least 4-10 years after initial colonization before they were detected [3].

Human activities play an important role by providing alien insects with favorable habitats that have been altered and created by humans. In contrast, biological characteristics of insects, such as the rate of population increase and dispersal ability, play an important role when they expand their distribution range within a country.

Several attempts have been made to characterize successful and unsuccessful invaders [13, 14, 15]. Characteristics of successful invaders such as being polyphagous, multivoltine, parthenogenetic, associated with humans, and having good dispersal capability are generally accepted as appropriate. However, there are so many exceptions that it is not justified to use these characteristics as reliable indicators of a species potential to invade [14,15]. Indeed, the rice water weevil represents a typical example (Table 2).

Table 2. Are the characteristics of successful invaders useful to predict potential invasive alien species?

| Characteristics of successful invader | Pine wood nematode/ Japanese pine sawyer | Fall webworm | Rice water weevil |
|---|---|---|---|
| Polyphagous | X/X | O | X |
| Multivoltine | O/X | O | X |
| Parthenogenic | X/X | X | O |
| Anthropogenic | X/X | O | ± |
| Good dispersal ability | X/X 4.2 km/year [28] | X Hitchhike | O 28-47km/year |

X: yes, O: no, ±: neutral

## VI. Range Expansion and Population Dynamics

Let us compare the range expansions and population dynamics of the pine wood nematode, the fall webworm and the rice water weevil in Japan. Explosive range expansions, including to neighboring countries, i.e. Taiwan, Korea and mainland China, were associated with population outbreaks of these invasive species in Japan [12].

The fall webworm spread from Tokyo to other parts of Japan assisted by transportation systems (Type I). Its range expansion was limited by its thermo-photoperiodic response, which determines its life cycle or the number of generations a year in a newly invaded area. The rice water weevil showed a continuous diffusion (Type II) with the spread rate accelerating with time. The range of the rice water weevil depends on the availability of rice plants. Therefore, it is distributed throughout Japan, including the Nansei islands (Okinawa) and Hokkaido. The pattern of range extension of the pine wood nematode / the Japanese pine sawyer is a mixture of types I and II or stratified diffusion [16], involving short- and long-distance dispersal. Pine wilt disease was prevented from spreading further north by the cool, wet summers prevailing in Hokkaido [17].

The patterns of population dynamics of the above three species were also species specific [17]. The fall webworm suffers mortality from generalist natural enemies. It showed gradation-type outbreaks when it escaped from the control exerted by these natural enemies. On the other hand, there were no observations of effective arthropod natural enemies of the rice water weevil. Density- dependent processes involving changes in fecundity and survival rates in earlier developmental stages were suggested as regulatory factors. The density tended to stabilize after 4-5 years of invasion, fluctuating around an equilibrium density specific to each locality [18].

The pine wood nematode / the Japanese pine sawyer system is unique. The Japanese pine sawyer is attacked by various natural enemies, and is regulated by density-dependent mortality by intraspecific competition in the early larval stages [19,20]. Prior to introduction of the pine wood nematode, the Japanese pine sawyer was a rare species. When the sawyer comes into contact with the introduced pine wood nematode, pine wilt disease epidemics became destructive and continue until entire pine stands are destroyed. The pine wood nematode infection increased the density of suitable host trees for the Japanese pine sawyer, which led to its increase and the occurrence of pine wilt disease epidemics.

Our analyses demonstrated that ecological and physical conditions in the invaded areas are of paramount importance in determining the status of colonizers after establishment.

## VII. Influence of Global Warming on IAS

Global warming may result in an increase in number of generations per year and in a polar shift of the distribution range of most insects [21,22]. The reproductive performance of the rice water weevil is favored by high temperature within the range of 15°C - 32°C, and the weevil lays the highest number of eggs with the shortest preoviposition period at 32°C [23]. In order to fully realize its fecundity, the existence of rice plants is essential. The overall population density of the rice water weevil should increase under global warming, if the time of rice transplanting also advances accordingly.

Because the occurrence of pine wilt disease is limited by low temperatures in summer, global warming not only would extend its distribution to Hokkaido, but also the intensity of epidemics would become high in the northern part of Japan. In the case of the fall webworm, the trivoltine race would become predominant even north of 36°N. Range expansion further north or south beyond the current distribution depends on whether it can adjust its temperature as well as photoperiod responses to new environments in the foreseeable future.

## VIII. Homogenization of Insect Pest Fauna

### *A. Stored product pests*

Many new stored products pests had invaded Japan in the post-war period. Flour mills dealing with imported cereals harbored many alien insect pests [24,25]. Most of the mills were first established after the war due to the necessity of handling a large quantity of imported grain to cover food shortage. Mills provided alien insects with habitats favorable for breeding, especially for tropical or subtropical species. More than 25 alien species are considered to have invaded by this pathway. Among them, *Tribolium confusum* and *Ephestia kuehniella* are now commonly used as experimental materials in Japan as if they were native species.

International trade of cereal grains has resulted in the worldwide homogenization of stored product pest fauna. As a result, as many as 26 species of stored product pests were excluded from the checklist of plant quarantine as of April 1st, 1998 by the revised Plant Protection Law (1996), because they are already widely circulated in trade, and assessed as benign in their effects.

### *B. Greenhouse arthropod pests*

The protected cultivation of various vegetables and flowers provided greenhouse pests with an ecological island that was vulnerable to invasion by alien insects due to lack of natural enemies. The combination of short daylength and higher temperature created in greenhouses during the winter works in favor of non-diapausing insects. In fact, most of the stored-product and greenhouse pests are subtropical or tropical in origin and have no diapause.

A comparison of the greenhouse pest fauna among Japan, the United States and Europe has been made concerning major insect and mite pests (Table 3). When this table was first published in 1997 [4], the lettuce leafminer, *Liriomyza*

Table 3. Comparison of greenhouse pest fauna among Japan, Europe and USA (revised [4]).

| Species | Japan | Europe | USA |
|---|---|---|---|
| Thrips | | | |
| *Frankliniella occidentalis* | O# | O# | O |
| *F. intonsa* | O | O | O |
| *Thrips palmi* | O# | O# | O# |
| *T. simplex* | O# | O# | O# |
| White fly | | | |
| *Trialeurodes vaporariorum* | O# | O# | O |
| *Bemisia argentifolii* | O# | O# | O |
| Leafminer | | | |
| *Liriomyza trifolii* | O# | O# | O |
| *L. bryoniae* | O#? | O | X |
| *L. huidobrensis* | O# | O# | O |
| Aphid | | | |
| *Aphis gossypii* | O | O | O |
| *Myzus persicae* | O | O | O |
| Mite | | | |
| *Tetranichus urticae* | O | O | O |
| *Aculops lycopersici* | O# | O# | O# |
| Curculionid | | | |
| *Otiorhynchus sulcatus* | O# | O | O# |

O: present, X: absent, #: indicates invasive pests,
?: remains to be known.

*huidobrensis*, had not yet invaded Japan. It was recently discovered in Honshu and Hokkaido in June 2003. Obviously the worldwide homogenization in greenhouse pest fauna has also taken place everywhere in the world through biological invasions.

## IX. Economic Effects of the Homogenization

Discussion about the economic advantages of globalization so far has tended to ignore the impact of exotic agricultural pests. Importing countries have to bear not only the cost of the damage to their crops, but also the cost of control programs and extending them to farmers. The homogenization of stored product pest fauna worldwide resulted in an establishment of non-quarantine pest category in the regulation of plant quarantine.

Cultivation of vegetables and fruits under structure started around 1955 in Japan. The relationship between the number of insecticide applications per month and the number of invasive alien species was examined. Before 1974 when the greenhouse whitefly, *Trialeurodes vaporariorum*, invaded greenhouses in Japan, only native insect species, such as aphids, *Aphis gossypii* and *Myzus persicae*, and the common cutworm, *Spodoptera litura*, were greenhouse pests. During the last 30 years, 10 alien species have become pests of greenhouse crops. Control of these IASs has resulted in an increase in insecticide applications by 4 times in tomato, 7 times in egg-plant, and 8 times in cucumber in 1998 compared to 1973 [27].

## X. Current Approaches to IAS Issues in Japan

Finally I would like to introduce some activity relevant biological invasions in Japan.

1. Publication of “Handbook of Alien Species in Japan” edited by The Ecological Society of Japan. Chijinshokan Co. Tokyo, pp. 390. 2002.
2. International Seminar on Biological Invasion: Environmental Impacts and the Development of the Database for the Asian-Pacific Region. November 13-15, 2003, Tsukuba.
3. The Ministry of Environment is drafting legislation for “Alien Species Regulation Act (tentative)” to be introduced in Congress next year (2004).

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