INVASIVE INSECT PESTS AND PLANT QUARANTINE IN JAPAN

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ABSTRACT

A total of 284 insect species have been introduced into Japan since 1868 (Meiji era). On average, four species have become established each year for the last 50 years, and 74% of these were economic pests. Rapid increases in the number of imported cut flowers, planting materials and vegetables during the last two decades has resulted in an increasing number of exotic greenhouse pests. The worldwide homogenization of greenhouse fauna is the result of biological invasions. Personnal luggage (dunnage), packing and international tourists are important pathways for invasions of fruit flies. At least one piece of dunnage infested with fruit flies arrives every day at some port in Japan.

Out of 98 exotic species in Okinawa, 26 species were from mainland Japan, while only 3 species invaded the mainland from Okinawa. The number of insects immigrating from the United States to Japan has been estimated at 51 species, while 58 species have invaded from Japan to the United States. During the last three decades, 28 species have been introduced into Japan, while only five species have invaded the United States from Japan during the same period. The trade gaps for agricultural products may be responsible for this imbalance. Managing insect invasions by watching neighboring countries, detecting new invaders by means of early warning systems, and increasing public awareness about exotics, are of paramount importance in plant quarantine.

INTRODUCTION

Damage from exotic pests is increasing all over the world, because of expanding international air transport, tourism, and the trade in agricultural products. At the same time, areas disturbed by human activity cover a greater area each year. Invasive species not only cause economic damage, but are seen as a serious global threat to biological diversity. They may cause the disruption of ecological systems, homogenization of biota, and extinctions (SCOPE 1996).

Procedures to control the introductions of exotic species tend to conflict with policies promoting international trade and travel. The most effective way of reducing the entry of exotic pests would be to reduce trade and travel, but this approach is politically unacceptable. If increased international trade and travel are encouraged, as is the worldwide trend, the vectors of movement of exotic species will obviously increase in number and variety (Cox 1999).

One area of particular concern is the current global traffic in agricultural items, especially fresh produce. Consumer demand for fresh fruits and vegetables is increasing. Imports of cut flowers into Japan have also showed a very marked increase. This rapid increase in imported items has resulted in an exponential increase in the number of invasive insect species that have become established in Japan (Kiritani 1999, 2000a)

Most of these exotic species were introduced into Japan after the beginning of the Meiji era (1868), when Japan opened the door to foreign countries. Since Kiritani and Morimoto published their analysis in 1993, some new records have been added, and a total of 363 species have been identified as exotic species (Kiritani 1999). Because an increasing number of new invasive insects are reported each year, this figure represents the

Keywords: exotic insects, fruit fly, greenhouse pests, homogenization of fauna, Japan, trade gap, vulnerability to invasions

minimum number of exotic insect species so far established in Japan.

SOURCE AND SIGNIFICANCE OF INVASIVE INSECTS

The biological process of colonization by alien organisms can be divided into four steps: introduction, establishment, spread and naturalization (Kiritani 1998). We shall examine the colonization process with particular emphasis on the first two steps.

Details were not available for all exotic species when we focused on specific aspects of invasion (Table 1). Of the 363 known exotic species, the probable place of origin was known only for 168 (46%), and the pathway of introduction for only 98 (27%). A breakdown of the 284 exotic species, according to their taxonomic groups and their major pathway of invasion, is presented in Table 2.

Kiritani (1984a) examined the records of insects collected in the East China Sea by a weather observatory ship during 1967-87. Of the more than 300 putative species, 127 could be precisely identified. Lepidoptera, Hemiptera and Diptera comprised 91% of the total species. Only three species were exotic to Japan. All of them were long-distance migrants from mainland China which are not able to overwinter in Japan, either in the southern islands or the Japanese mainland. Almost all exotic species were introduced to Japan, whether intentionally or accidentally, by various kinds of transportation. Only some migrant lepidopterous species entered independently.

Out of 363 exotic species, the year in which they were first detected in Japan is recorded for 185 species (Table 1). These records were arranged in chronological order, according to the decade (Fig. 1) (Kiritani 1999). The number of exotic species becoming established in Japan has been increasing exponentially during the past 140 years. The maximum number (40 species) in any one decade

Table 1. Number of exotic species in Japan that were available for analysis of various phases of invasion

Total number of exotic insects	363	100%
Evidence of invasion available	284	78%
Probable time of invasion known	185	51%
Country of origin known	168	46%
Earliest occurrence in Japan known	155	43%
Probable pathways identified	98	27%
Probable latency period identified	35	10%

Table 2. Exotic insects, in Japan belonging to different orders, and their major pathways of invasion

Order	Exotic species in Japan (%)	Major pathway of invasion
Coleoptera	91 (32.0)	Accidental
Hemiptera	79 (27.8)	Accidental and spontaneous
Lepidoptera	35 (12.3)	Accidental and spontaneous
Hymenoptera	28 (9.9)	Mostly intentional
Diptera	19 (6.7)	Accidental and spontaneous
Thysanoptera	14 (4.9)	Accidental
Blattaria	11 (3.9)	Accidental
Others	7 (2.5)	Accidental
	284 (100.0)	

was recorded in the 1980s. Of the 98 exotic species for which we know the pathway of invasion, 82 were first recorded in Okinawa. The number of exotic species recorded from this subtropical island suddenly increased exponentially after World War II (Fig. 1).

We also studied the economic status of the 260 exotic insects which have become established in Japan. Of these, 191 (74%) were pest species, 57 (22%) were non-pest species, and only 12 (4%) were beneficial insects. This is in contrast to the fact that among Japan's native insect fauna, pests account only for 8% of species. It would seem that exotic insects are pestiferous at a rate almost ten times higher than for native insects (Morimoto and Kiritani 1995). Coleoptera and Hemiptera represented more than half of the alien species (Tabl 2), which is the same as in the United States (Sailer 1983) and the United Kingdom (Willamson and Brown 1986).

A comparison was made of the number of introduced insects recorded each year in different countries (Table 3) (Kiritani 1999). The United States (excluding Hawaii) shows the largest number of invasive insects and mites becoming established each year. This is not surprising, if we take into account the fact that the United States is 25 times larger than Japan. The annual rate of discovery of established exotic invertebrates in California, which has almost the same land area as Japan, is 6.1 per year during 1955-1988 (Dowell and Gill 1989). By contrast, tropical Pacific islands such as Hawaii, Guam and Okinawa all have relatively large numbers of exotic species relative to their land size.

INVASIONS OF INSECT PESTS THROUGH INTERNATIONAL TRADE

Type of commodity/transportation

There is a fairly close relationship between the kind of commodity and the insect groups represented. The type of transportation also tends to be determined by the kind of commodity (Table 4).

Changes in the number of imported consignments inspected during the period 1970 to 1998 in Japan are shown in Table 5. Among the agricultural imports, cut flowers showed the greatest increase, rising by more than 150 times over the last 20 years. Imports of planting materials and vegetables also increased rapidly (Table 5). This growth in imported horticultural items was associated with an increase in the number of exotic species,

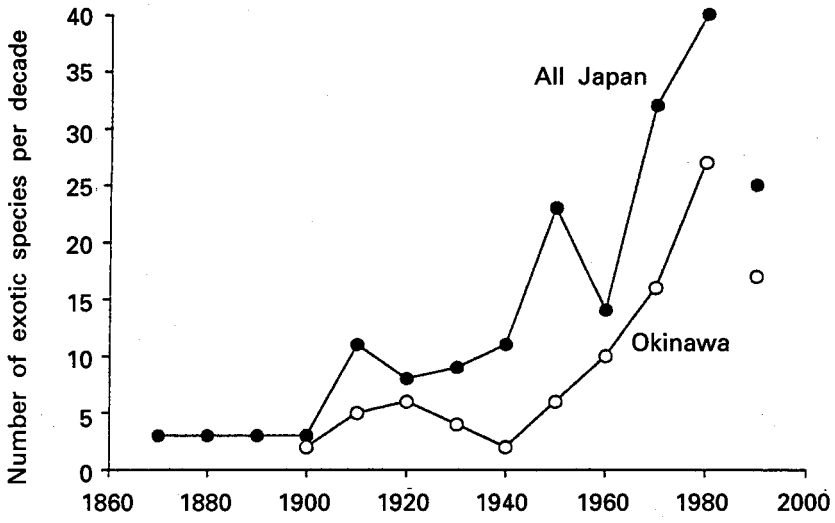

Fig. 1. Numbers of exotic insect species resident in Japan, including Okinawa, and Okinawa Prefecture, at ten-year intervals from 1860 to 1990. The points on the right are for 1990-1997

Source: Kiritani 1999

Table 3. Estimates of introduction of exotic species into different countries each year

Country	No. species introduced per year	No. years involved	Authors
USA	11 insects & mites	60	Sailer 1983
Hawaii	3.5 arthropod pests	40	Beardsley 1991
California	6.1 invertebrates	34	Dowell & Gill 1989
Guam	2.5 insects	10	Schreiner 1991
Japan (whole country)	4 insects	50**	Kiritani 1999
Okinawa	1.5 insects*	50**	KIritani 1999

* Including the species which immigrated into Okinawa prefecture from the Japanese mainland. These species account for one-third of the invasive insect species in Okinawa.
** 1945-1995

Source: Kiritani 1999

Table 4. Insect pests associated with different commodities at ports of entry

Commodities	Insect pests	Vectors
Nursery stock, grafts, bulbs, tubers and seedlings	Aphids, thrips, whiteflies and phytophagous mites	Cargo
Cut flowers	Aphids, thrips and phyto-phagous mites	Airfreight
Fruits and vegetables	Furit flies, weevils and leaf beetles	Airfreight and shipping containers
Grain, feed and oil seeds	Bean weevils and Khapra beetle	Cargo
Wood	Bark beetles, longhorn beetles, platypodids etc.	Cargo

Source: Yoshizawa 1996

particularly greenhouse pests.

CHRONOLOGICAL CHANGE IN INVASION BY INSECTS

When invasive insect species were arranged in chronological order, beginning with the earliest known years of occurrence, it was evident that the representation of the various taxonomic groups has changed markedly during the past one hundred years (Table 6).

Japan opened her borders to the world in 1868, after a long period of isolation. Of the 201 insect species which have invaded Japan since that date, 54, or a quarter of the total, were introduced before World War II (1945) (Table 6). Scale insects and mealy bugs took advantage of the early rush to import nursery stock, especially fruit trees. The second peak of invasive insects consisted mainly of those infesting stored produce, particularly coleopterous insects, during the period 1945 to 1965. They entered Japan with the large-scale imports of grain to cover the shortage of food (Kiritani *et al.* 1963). The homogenization of pests infesting stored produce worldwide, has meant that as many as 24 species were crossed off in April 1998 from Japan's checklist for plant quarantine inspection. The third period, 1966 to 1985, brought the invasion of various kinds of weevils that infest upland crops, turf, vegetables and ornamental trees. The fourth, which began in 1986 and is continuing up to the present, has been the invasion of greenhouse pests such as thrips, aphids, whiteflies, scales, mealybugs and leafminer flies.

Table 5. Changes in the number/amount of imported consignments* inspected during the period 1970 - 1998 in Japan

		1970	1975	1980	1985	1990	1994	1998
Planting materials								
Seedlings	10^6 pieces	10	12	7	23	67	166	221
Bulb	10^6 pieces	13	42	78	79	191	395	632
Seeds	10^3 mt	12	11	21	28	31	28	25
Cut flowers	10^6 pieces	-	9	84	122	358	808	1,376
Fruit	10^3 mt	997	1,268	1,254	1,323	1,487	1,756	1,528
Vegetables	10^3 mt	35	72	256	278	470	975	1,203
Grain	10^6 mt	16	20	26	28	28	31	28
Legumes	10^6 mt	4	4	5	5	5	5	5
Oil seeds & spices	10^6	2	2	3	5	8	8	9
Wood	10^7 m^3	4	4	4	3	3	2	2

* Total of ship cargoes, airfreight, containers, luggage and postal packages
Source: MAFF 1999

Table 6. Number of exotic insect species that have become established in Japan at various periods

Taxonomic group	Before World War II	1945-65	1966-85	1986-99	Total
Termites	0	0	2	0	2
Cockroaches	1	1	2	0	4
Thrips	3	0	5	4	12
Aphids	3	1	7	6	17
Whiteflies, psyllids etc.	1	1	2	1	5
Scales and mealybugs	8	1	5	8	22
Stink bugs	2	0	1	0	3
Stored produce Coleoptera	4	15	0	2	21
Weevils	5	5	11	3	24
Ladybird beetles	1	0	2	7	10
Longhorn beetles	1	2	0	1	4
Leaf beetles	5	1	1	3	10
Stored produce Lepidoptera	0	1	0	2	3
Other Lepidopteran species	4	5	8	7	24
Leafminer flies	0	0	1	3	4
Other Dipteran species	4	4	4	1	13
Ants	3	0	4	1	8
Other Hymenopteran species	3	0	0	0	3
Parasitoids	6	1	4	1	12
Total	54	38	59	50	201

Source: Kiritani and Yamamura, in press

FRUIT FLIES AND INTERNATIONAL TOURISM

Two species of fruitfly, the Oriental fruit fly, *Bactrocera dorsalis*, and the melon fly, *B. cucurbitae*, were eradicated from Japan in 1986 and 1993, respectively. The cost of these eradication programs was more than US$250 million (Kiritani 1984b). Therefore, interception of fruit flies at ports of arrival, to prevent them from infesting Japan again, is of paramount importance.

It is prohibited to import into Japan fresh fruits and fruit vegetables grown in countries with fruit fly. Consequently, commercial importation from such countries rarely occurs, unless they are treated according to the protocol agreed between Japan and the exporting countries. On the other hand, the personal baggage of travelers (sometimes known as dunnage) often contains these prohibited fruits. Surveys conducted from 1993 to 1998 found as many as 2,100 cases and suitcases infested by various kinds of fruit flies (Table 7). Of these, 93.3% were luggage, while the remaining 6.0% were postal packages, while only 0.7% was cargo. This figure suggests that personal luggage infested with fruit flies arrives almost every day in Japan (Kiritani 2000b).

EXCHANGE OF SPECIES BETWEEN THE JAPANESE MAINLAND AND OKINAWA

Of the 98 exotic species recorded in Okinawa, we were able to trace the probable place of origin or country of export for 87 species. Sometimes it was difficult to determine whether a particular species came from Taiwan or Southeast Asia. In such cases, each was recorded as the place of origin, so that a single exotic species would be recorded as having two places of origin (Table 8). Of the 97 exotic species, 26 species were considered to be immigrants from mainland Japan, where almost all of them were economic pests. In contrast, only three species were able to invade mainland Japan from Okinawa (Kiritani 1999).

The total land area of the southern islands, including the Ogasawara Islands, is 4,673 km^2. That of mainland Japan, which includes Kyushu, Honshu, Shikoku and Hokkaido, is 373,000 km^2. Thus, the southern islands have only 1.2% of Japan's total land area. This analysis clearly demonstrates that the southern islands are more much vulnerable than mainland Japan to invasion by alien species. The disproportionately large number of immigrants to the southern islands must be given special attention. This is not only because of the economic damage, but also because of the need to conserve native fauna in these islands.

Simberloff (1989) has discussed whether island communities are more easily invaded, or whether mainland species are better colonists. He suggests that mainland species may simply have more opportunities to invade islands than vice versa.

The balance between imports and exports of vegetables, fruits and cut flowers between Okinawa prefecture and the Japanese mainland was examined (Fig. 2). Okinawa had a permanent trade deficit for vegetables and fruits between 1991 and 1997. Since 1985, the area planted in chrysanthemum in Okinawa has almost doubled. The cut flowers are exported to mainland Japan. Only this one item of all the agricultural products shows an export surplus. The trade gap may partly explain why Okinawa has

Table 7. Number of intercepted consignments infested with fruit fly at ports in Japan, 1993-1998

Species	1993	1994	1995	1996	1997	1998	Total
Bactrocera correcta	0	0	27	29	64	52	172
B. cucurbitae	19	14	10	11	27	12	93
B. dorsalis species complex	218	161	189	269	277	167	1,281
B. latifrons	0	11	76	146	155	115	503
Ceratitis capitata	6	4	7	8	5	5	35
Other fruit fly species	7	5	9	29	18	23	91
	250	195	318	492	546	374	2,175

Source: MAFF 1999

Table 8. Probable places of origin of exotic insects found in Okinawa

	Mainland Japan	Taiwan	Southeast Asia	USA*	Total
No. occasions**	26	31	28	12	97
Percentage	27	32	29	12	100

* Includes Hawaii and Guam.
** e.g. Taiwan/Southeast Asia: Each was counted separately as the place of origin, giving two occasions for the species concerned

Source: Kiritani 1999

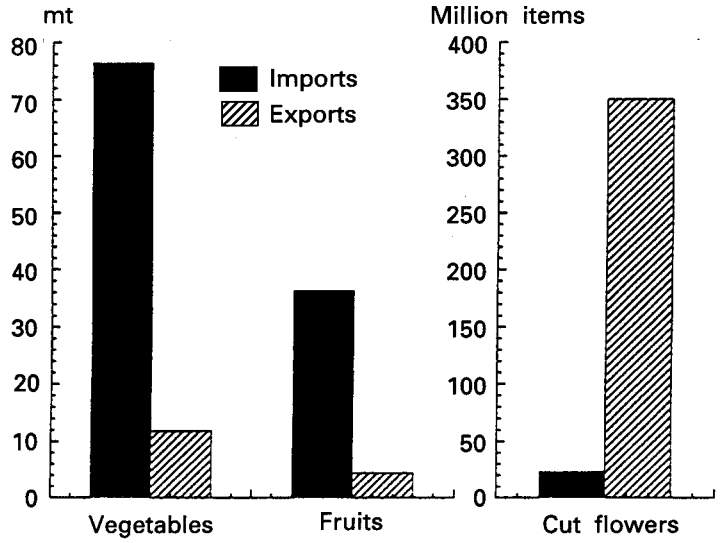

Fig. 2. Trade gap for vegetables (mt), fruits (mt) and cut flowers (million pieces) between Okinawa and the Japanese mainland. Statistics on vegetables and fruits are for 1991-1997, those on cut flowers are for 1998 and 1999.

Black column: imported into Okinawa from mainland Japan.
Shaded column: exported from Okinawa to mainland Japan.

more invasive insect species than mainland Japan, although clearly other factors are also involved.

EXCHANGE OF SPECIES BETWEEN JAPAN AND THE USA

We examined international trade in agricultural products between Japan and neighboring countries, including the United States. We focused on the agricultural products, including grain, vegetables, fruits, feed etc., that were imported into or exported from Japan in 1997 and 1998 (Fig. 3). The amount imported from the United States was 20,000 times more that the exports from Japan to the United States. The same pattern, although not to such a marked extent, was seen with other Asian countries. This import surplus suggests that Japan is exposed to a high risk of invasion by insects.

Kiritani (2000a) has published a comprehensive list of the insect species that have invaded the United States from Japan, and those that have invaded Japan from the United States. Since 1868 (Meiji Era), of the 168 invasive species for which the place of origin is known (Table 1), 51 species (30%) came from the United States. The number of species that invaded the United States from Japan was almost the same, at 58 (Table 9). This almost equal number of exotic species exchanged between the two countries seems rather strange, in view of the enormous trade gap shown in Fig. 3.

It is clear, however, that the imbalance in

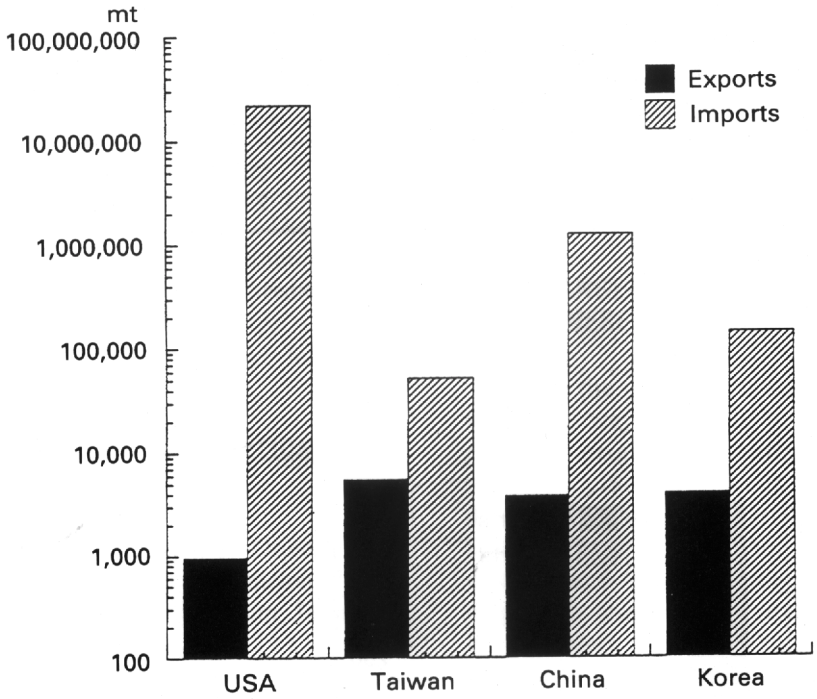

Fig. 3. The mean amount of agricultural products (mt) imported into and exported from Japan in 1997 and 1998.

source: JETRO 1999

trade is clearly reflected if we look at the time when these exotic insects invaded. When we plot the number of species that have invaded Japan or the United States against the time of invasion, the invasions of the USA by Japanese species show a peak in the 1920s. In contrast, the peak of invasions in Japan from the United States was in the 1990s, while more than half of the exotics have invaded Japan since 1970 (Fig. 4).

HOMOGENIZATION OF INSECT FAUNA

One of the problems of biological invasion is that it threatens biodiversity by homogenization of fauna. Japan has experienced four large influxes of exotic insects during the past 130 years (Table 6).

As mentioned above, the fourth major influx was of greenhouse pests during the period 1986 - 2000. The protected cultivation of vegetables and flowers in greenhouses provides greenhouse pests with an “ecological island” which is favorable to many exotic insects. The combination of short daylength and higher temperatures found in greenhouses over the winter works in favor of non-diapausing insects, most of which originate in subtropical or tropical countries (Matsuzaki and Kiritani 1972; Morimoto and Kiritani 1995).

A comparison of the greenhouse pest fauna in Japan, United States and Europe has been made, focusing on major insect and mite pests (Table 10). Obviously, a worldwide homogenization of greenhouse pest fauna has occurred as a result of biological invasions.

Despite efforts to exclude invasive insects, biological invasions will continue and some of them will be successful. They are particularly likely to succeed in favorable habitats that have been altered and created by human activity. We are not only responsible for the introduction of invasive insects, but also for the creation of conditions that promote their reproduction.

DISCUSSION

Managing insect invasions by observing neighboring countries

Common, widespread insects are much more likely to become successful invaders than are scarce species with a patchy distribution. It appears that the demographic attributes which allow a species to become widespread and abundant in one country can be transferred to another (Crawley 1987). The

Table 9. Comparison in the exotic insect fauna that have accidentally invaded Japan from the USA and vice versa (revised from Kiritani 2000)

Order	Number of species that have invaded	
	Japan	USA
Blattaria	0	1
Coleoptera	21	14
Diptera	3	1
Hemiptera	20	34
Hymenoptera	2	1
Isoptera	1	1
Lepidoptera	3	4
Orthoptera	0	2
Thysanoptera	1	0
Total	51	58

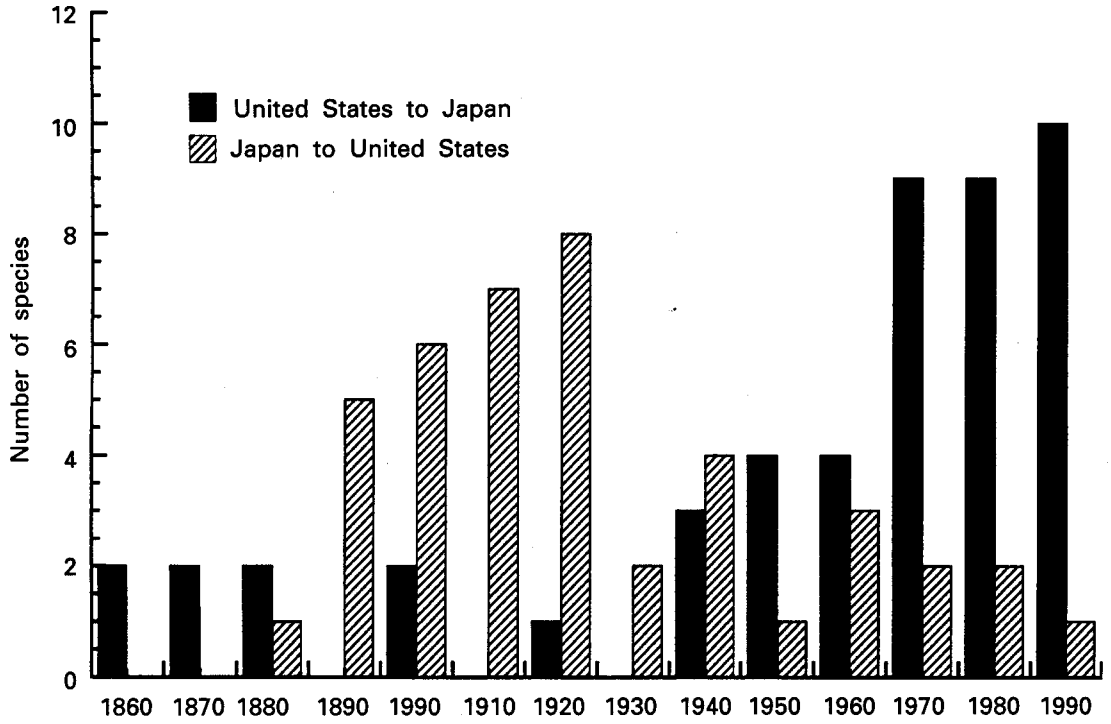

Fig. 4. No. of insect species that have invaded Japan from the USA (black column) and vice versa (shaded column)

Table 10. Comparison of greenhouse pest fauna in Japan, Europe and the United States

Species	Japan	Europe	United States
Thrips			
Frankliniella occidentalis	0#	0#	0
F. intonsa	0	0	0
Thrips palmi	0#	0#	0#
T. simplex	0#	0#	0#
Whiteflies			
Trialeurodes vaporariorum	0#	0#	0
Bemisia argentifolii	0#	0#	0
Leafminers			
Liriomyza trifolii	0#	0#	0
L. bryoniae	0#?	0	X
L. huidobrensis	X	0#	0
Aphids			
Aphis gossypii	0	0	0
Myzus persicae	0	0	0
Mites			
Tetranychus urticae	0	0	0
Aculops lycopersici	0#	0#	0#
Curculionid			
Otiorhynchus sulcatus	0#	0	0#

0: present, X: absent, #: newly invasive pest, ?: situation unclear

Source: Kiritani 1999

most robust generalizations seem to involve the reproductive rate after invasion, habitat matching and previous success at invasion. It is often said that invasions are more likely to happen in disturbed sites. However, this only reflects the fact that species are more likely both to be transported from disturbed areas and to arrive in them, because of human activity (Williamson 1996). The best approach is to be aware of which species have already been regional invasives elsewhere (Samways 1999).

Kiritani and Morimoto (in press) found that the long-distance expansion of successful invaders, e.g. the rice water weevil, *Lissorhoptrus oryzophilus*, the fall webworm, *Hyphantria cunea*, and the pinewood nematode, *Bursaphelenchus xylophilus*, was always associated with their outbreaks. The occurrences of some invasive species in this region were viewed in terms of their first discovery in each island or country (Table 11). This Table indicates that in addition to the three species mentioned above, the vegetable weevil, *Listroderes costirostris*, and the greenhouse whitefly, *Trialeurodes vaporarium*, have extended their range to neighboring countries after they first became established in Japan.

Table 11 suggests, not only the likelihood of expansion to other countries once a species has occurred in any part of the region, but also that if a species has invaded one country, we should be vigilant to prevent its occurrence in a new area, e.g. the spiral whitefly *Aleurodicus dispersus*, and leafminer spp. Some leafminer flies, *Liriomyza huidobrensis* and *L. sativa*, together with *L. trifolii*, are native to America. They have considerably extended their range in modern times, partly due to the development of the cut flower trade (Waterhouse and Norris 1987).

DETECTING NEW INVADERS AND EARLY WARNING SYSTEMS

Metcalf (1994) suggested several important points for further research to help us deal with exotic pests: (1) Risk assessment, (2) Methods for the early detection of infestations, (3) Rapid development of control or eradication procedures, and (4) Exploring the economic consequences of exotic pest introductions.

In practice, for localized newly established populations of exotics, eradication appears to be the most appropriate action. Developing systems for

Table 11. Some examples of the occurrence of invasive insects in countries and islands near Japan since 1940

Species		Mainland	Okinawa	Ogasawara	Taiwan	Korea
Insects						
Spiral whitefly	*Aleurodicus dispersus*	NP*	NP	NP	1988	NP
Banana weevil borer	*Cosmopolites sordius*	NP	1926	1912	1909	NP
Banana skipper	*Erionota torus*	NP	1971	NP	1986	NP
Leucaena psyllid	*Heteropsylla cubana*	NP	1985	1986	1986	NP
Fall webworm	*Hyphantria cunea*	1945	NP	1994	NP	1958
Legume leafminer	*Liriomyza trifolii*	1990	1993	1994	1988	1994
Rice water weevil	*Lissorhoptrus oryzophilus*	1976	1985	NP	1990	1988
Vegetable weevil	*Listroderes costirostris*	1942	1960	NP	1982	1989
Potato tuber moth	*Phthorimaea operculella*	1953	1968	NP	NP	1968
	Thrips palmi	1978	1980	1982	P**	1993
Greenhouse whitefly	*Trialeurodes vaporarium*	1974	1977	NP	1988	1977
Nematode						
Pine wood nematode	*Bursaphelenchus xylophilus*	1905	1973	1974	1985	1988

NP*: Not present
P**: Invaded long before 1978
Sources: Morimoto & Kiritani (1995), Kiritani (1999), Yasuda K. (p.c.), Chu Y.-1 (p.c.), Chen C.-N. (p.c.), Hong K.-J.(p.c.), Lee H.-J. (p.c.) and Numazawa K. (p.c.).

the early detection of new invaders, and for prompt action to prevent their spread and reduce their impact, is an urgent necessity. To achieve this, increasing research, improving data availability and sharing, and increasing public awareness about exotics are of paramount important (Cox 1999)

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