SESSION 4

MONITORING ALIEN SPECIES

Chairman: Professor Carmen Büttner
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Combining a disease model with a crop phenology model to assess and map pest risk: Karnal bunt disease (*Tilletia indica*) of wheat in Europe

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ABSTRACT

In order for plant pests to establish in a new area, the presence and distribution of food or host plants is critical. For some pathogens not only spatial but also temporal synchrony is required for survival since infection can occur only during specific host growth stages and climatic conditions. We used bread and durum wheat phenology models to predict the timing of the vulnerable developmental stages of wheat to infection by *Tilletia indica*, the causal agent of Karnal bunt, in Europe. Climatic data during these stages were then used to calculate an index of disease risk. The results were interpolated over the European landscape and mapped; summaries of the risks for each country were calculated. The arable areas of western and central Europe, particularly in France, were found to be most suitable for bread and feed wheat infection. The northern Italian plain and the important Italian pasta regions of Tuscany and Marche were most suitable for durum wheat infection.

INTRODUCTION

The successful establishment of invertebrate pests and pathogens of plants in new areas is critically dependent on the availability of the host plant species needed for their survival, development and multiplication. International standards on pest risk analysis (PRA) (FAO, 2003) require the assessor to consider whether hosts are present and are sufficiently abundant and widespread in the area at risk to allow the pest to complete its life cycle. However, they ignore the fact that some pests can only utilise host plants if their life cycles are synchronised and environmental conditions are suitable when such synchrony occurs. Although the requirements for pest-host synchrony are frequently exploited in pest control and may play an important role when predicting the impacts of climate change (Dewar & Watt, 1992), their role in alien pest establishment has received little attention. We investigated this aspect of PRA by modelling the extent to which *Tilletia indica*, a fungal pathogen of wheat and the causal agent of Karnal bunt disease, would find conditions in Europe suitable for infection and development when its principal host is at susceptible growth stages. Maps summarising our predictions for Europe at low spatial resolution are reported here. Further analyses and high-resolution predictions for England, Wales, Denmark and three provinces of Italy are given by Baker *et al.* (2004).

METHODS

For Karnal bunt of wheat to develop, conditions must be suitable for teliospores of *T. indica* to germinate to produce sporidia between the flag leaf emergence and anthesis stages of the growing wheat plant and for these spores to infect the developing ear (Nagarajan *et al.*, 1997; Murray, 2004). Two wheat phenology models, AFRCWHEAT (Weir *et al.*, 1984; Porter, 1993) and the IATA wheat development model (Miglietta, 1991), were applied to simulate these vulnerable growth stages for three cultivar maturity classes and three winter sowing dates of *Triticum aestivum* (bread and feed wheats) and *T. durum* (durum wheat). Bread wheat in this paper refers to both bread and feed wheat varieties of *T. aestivum*.

Since wheat development is predicted through the interaction of time, temperature, photoperiod and vernalization, an extensive European meteorological dataset was required. Daily synoptic 1995–2002 European meteorological data from the US National Climate Data Center (NCDC, 2004), supplemented by data from the German National Weather Service, were downloaded and checked for consistency. Annual station data with more than three consecutive missing days were removed. A seven day running mean was used to estimate missing data for three consecutive days or less. To select stations relevant to wheat growing areas, we used Geographical Information System (GIS) software (ArcView 3.2, ESRI. Inc) to filter the weather station locations based on arable grid cells in PELCOM, a 1 km resolution European land cover map (Mücher, 2000). The maximum elevation for arable land in each country was estimated by combining PELCOM with GTOPO30 (GTOPO30, 2004), a global digital elevation model with a horizontal grid spacing of 30 arc seconds (approximately 1 kilometre). We deleted all stations located 200 metres higher than the maximum elevation for arable land in each country. A buffer of 100 km was then created around each remaining weather station and all stations more than 100 km from a PELCOM arable grid cell were also removed from the data set.

Running the wheat phenology models with the meteorological data enabled the timing of vulnerable wheat growth stages to be predicted throughout Europe for 1995–2002. To determine whether conditions were suitable for *T. indica* infection and disease development, the Humid Thermal Index (HTI), a climatic index originally used to forecast Karnal bunt in the Punjab, India, (Jhorar *et al.*, 1992), was calculated for this vulnerable period. This index has been used in support of a PRA for the UK (Sansford, 1998). When the HTI, defined as the ratio of the average afternoon relative humidity to the average daily maximum temperature is between 2.2 and 3.3, conditions are favourable for infection and disease development. Below 2.2, it is too dry or too warm and above 3.3, too humid or too cold.

To display the HTIs predicted for wheat-growing areas away from weather stations, the results were interpolated over the landscape at 0.05° latitude/longitude resolution guided by elevation using ANUSPLIN, a partial thin plate smoothing spline interpolation technique

(Hutchinson, 2001). The interpolated data were then imported into the GIS. Only predictions for PELCOM arable grid cells were generated.

RESULTS

Sowing data and cultivar maturity class had a minimal impact on the HTI values for winter sown bread and durum wheat (Baker *et al.*, 2004). However, latitude and longitude had a considerable influence on both bread and durum wheat risk (Figures 1 and 2).

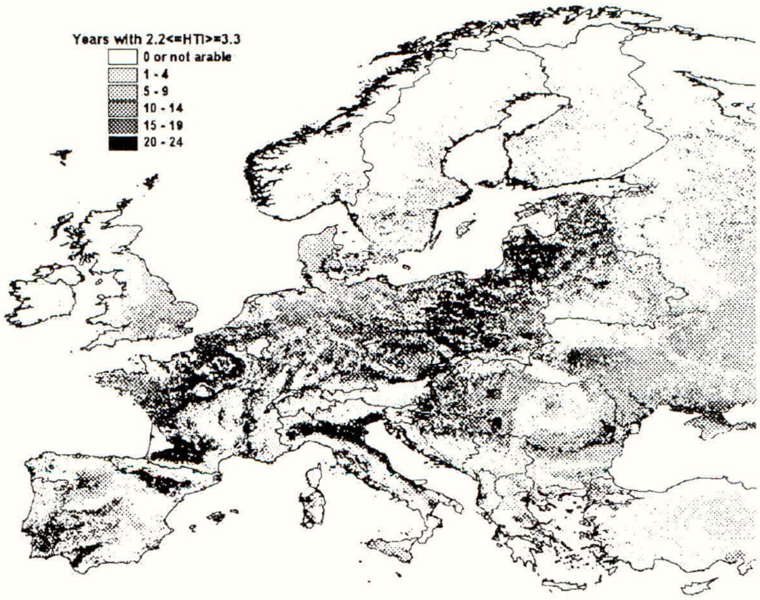

Figure 1. Risk score (out of 24) for each arable grid cell based on the number of years (1995-2002) when bread wheat sown on three Julian dates (274, 305 and 335) had a Humid Thermal Index (HTI) between 2.2 and 3.3 during the growth stages susceptible to *Tilletia indica* infection.

In the major bread-wheat-growing regions of western and central Europe, particularly France, the HTIs are often within the range suitable for infection when the crop is at vulnerable growth stages (Figure 1). More northerly regions are predicted to have critical HTI values in about one third of the cases. The risk map for durum wheat (Figure 2) shows very high frequencies of critical HTI values for the northern Italian plain and the important pasta-growing areas of Marche and Toscana. Southern Italy is at lower risk, with high temperatures raising the HTI above its critical range. Durum wheat production in France and Spain is less vulnerable than bread wheat, because durum is generally sown later than winter wheat and the susceptible phenological stages are reached when conditions are drier and warmer.

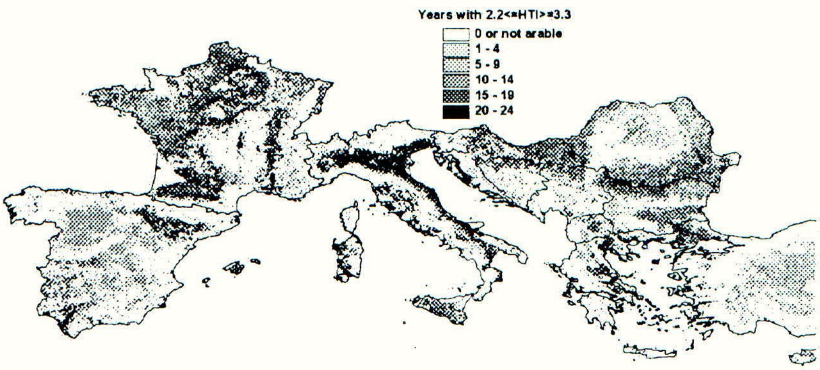

Figure 2. Risk score (out of 24) for each arable grid cell based on the number of years (1995-2002) when durum wheat sown on three Julian dates (294, 314 and 335) has a Humid Thermal Index (HTI) between 2.2 and 3.3 during the growth stages susceptible to *Tilletia indica* infection. Only data for countries with significant durum wheat production are displayed.

In order to provide a risk rating for each country, we calculated the mean score for arable grid cells and the sum of scores for all arable grids (Table 1).

Table 1. Two measures of the risks posed by *Tilletia indica* to bread and durum wheat production in European countries based on: (a) The mean score out of 24 (8 years times 3 sowing dates) for arable grid cells in each country, (b) the sum of scores for all arable grid cells in each country. Only the top five countries for (b) are given in descending order.

	Bread Wheat			Durum Wheat	
Country	(a)	(b)	Country	(a)	(b)
France	19.3 ± 0.05	230139	France	16.4 ± 0.03	196452
Poland	19.1 ± 0.04	197291	Italy	17.8 ± 0.06	101707
Ukraine	9.9 ± 0.04	146992	Spain	14.0 ± 0.04	97335
Germany	15.1 ± 0.05	145396	Romania	13.5 ± 0.05	70472
Italy	17.2 ± 0.10	98416	Turkey	11.0 ± 0.07	42643

When both the mean score per arable grid cell and the area of production is taken into consideration, French bread and durum wheat production is under the greatest threat. However, Italian grid cells have a higher mean score per arable grid cell for durum wheat.

CONCLUSIONS

Assuming the Indian HTI is also appropriate for the range of temperatures and humidities occurring in Europe and ungerminated viable teliospores are present. Figures 1 and 2 indicate that large areas of European wheat production are vulnerable to *T. indica* infection. It has not been possible to determine the extent to which the HTI is valid in countries outside India because widespread crop irrigation in areas where the pathogen has been introduced makes climatic data unrepresentative and comparative within-canopy humidity data are lacking. However, Inman *et al.* (2004) found that teliospores can survive ungerminated for at least three years in European conditions and Baker *et al.* (2004) showed that, while HTIs may not be within the critical 2.2-3.3 range every year, the maximum interval without suitable HTIs exceeds four years in only 21% of the European arable areas.

Additional sources of error were due to the variation in the availability of meteorological data from different countries. Data for Poland, Sweden, several countries in Eastern Europe and Germany for 2001–2002 were very limited and predictions were therefore based on interpolations from weather stations in neighbouring countries. Jarvis *et al.* (1999) highlight the logical inconsistencies which may result when interpolating the results of 'at a point' models rather than model inputs. However, we found only occasional instances of development stages occurring in the wrong order and these were in areas where wheat production is known to be low. Although wheat production is widespread in Europe, our use of PELCOM arable areas to represent wheat production will give an over-estimate of the area at risk. Unfortunately, there is no up to date high resolution European-wide wheat production dataset.

The methodology used here to generate European maps for potential *T. indica* teliospore germination and disease development, summarising risk by country, is applicable to other PRAs where climate and hosts are key factors in determining pest distribution and the relationships with and between these factors can be modelled or inferred.

This research has highlighted the critical lack of accurate, consistent, easily accessible high-resolution European-wide datasets for climate and crop distribution. The need to develop and enhance PRA procedures not just for individual countries but also for the European Union as a whole to justify phytosanitary measures has increasingly been emphasised. This study shows that unless such datasets can be created, PRAs valid for the whole of Europe will remain very difficult to produce.

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Biological traits of invasive insect species harmful to Moroccan agriculture

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ABSTRACT

For all important crops in Morocco, key pests are always introduced species. The biological traits of such pests were observed, in order to study principles underlying the success of their entry, establishment and spread. It appears that immature development for all the species of interest occurs over a wide range of temperatures. Such species also have short generation times, which result in overlapping generations. Although such pests are reported as polyphagous, they show some specialization in a Moroccan context. Natural enemies and temperature are the most important factors in the regulation of population densities and in the limitation of the spread of introduced species.

INTRODUCTION

Key pests for any given crop in Morocco are introduced species that necessitate costly control programmes. These pests seem to share biological traits that may have facilitated their entry and establishment. Descriptive biological attributes for any species and the estimated effects of the environment on these attributes help construct predictive tools for population dynamics (Berryman, 1981). Therefore, an understanding of the general principles underlying the capacity of establishment of invasive insect pests in Morocco could help predict the likelihood of their entry and establishment. Here, invasion is defined as involving the entry of an exotic species as well as its subsequent establishment and spread. Biological attributes have been already used by biological control workers to predict the effectiveness of natural enemies (Messenger *et al.*, 1976). Also, attempts to develop predictive tools for invasive species have been reported by Kolar & Lodge (2001) and Mack *et al.* (2004). These authors described biological traits that may have facilitated the introduction, establishment and spread of invasive species in different areas. The present paper reports on biological attributes of invasive insect pests attacking crops in Morocco. These attributes are discussed in relation to entry, establishment and spread of these pests. To achieve this objective, data from biological studies conducted in Morocco and elsewhere have been used. Because data on entry (when and how) for all species of interest are lacking, discussion is concentrated on establishment and spread.

BIOLOGICAL CHARACTERISTICS OF INTRODUCED INSECT PESTS IN MOROCCO

Dispersal

Flight allows pests to colonize new geographic areas rapidly and may facilitate multiple natural introductions, allowing a higher genetic diversity. Therefore, flying capacity is probably a key factor in the rapidity of spread of an invasive insect.

For example, the least specialized species should be the most rapid invaders. However, invasion by California red scale (CRS) (*Aonidiella aurantii*), which feeds on all plant parts, took 26 years, whereas citrus leaf miner (CLM) (*Phyllocnistis citrella*), which attacks almost exclusively new *Citrus* flushes, invaded Morocco within 3 to 4 years (Table 1). Additionally, observations within the same field showed that infestations by California red scale are more clumped in the beginning of the season, than those of CLM. Also, infestation by the latter is evenly spread over the field. Thus, the flying capacity of the insect may explain the rapidity of establishment and invasion by CLM compared with CRS.

Table 1. Comparison of the time necessary for the establishment and spread of some introduced species.

Species	Probable year of entry	Established colonies	Years to spread
Aonidiella aurantii	1935	1949	26 (1961)
Aleurothrixus floccosus	1970–1972	1973	13 (1985)
Frankliniella occidentalis	1986–1987	1987	6 (1993)
Panonychus citri	1985–1986	1986	10 (1996)
Phyllocnistis citrella	1994	1994	2 (1997)
Parlatoria blanchardi	1930	1937	43 (1973)

Mode of reproduction

The mode of reproduction may have a key role in the establishment of a species, and may be related to the mode of dispersal.

In Morocco, species with flying females have sexual reproduction, whereas species with sessile females have parthenogenetic reproduction (Table 2). Western flower thrips (*Franklinella occidentalis*) is intermediate, since it has weak-flying females and reproduces parthenogenetically.

Sexual reproduction associated with flying females increases the chances of out-breeding, resulting in higher proportion of heterozygotes. In addition, some species (e.g. agromyzid flies) require multiple mating for full egg production (CABI, 2003), which may also increase the proportion of heterozygotes. Consequently, the chances to adapt to a heterogeneous and unpredictable environments increase. However, parthenogenetic reproduction is advantageous for the colonizing phase of a new habitat, because one female can independently initiate a colony. Females of citrus red spider mite (CRSM) (*Panonychus citri*), for example, do not need mating for egg production and they produce just enough males to fertilize eggs.

Immature stages and generation time

All species of interest have short generation times (Table 2), which (in the field) result in multi-voltinism and overlapping generations.

Since immatures are the most vulnerable stages in the lifecycle of insects and mites, the shortening of generation time is valuable because it reduces the risk of death before the reproductive stage (Nylin & Gottard, 1998). This is of value, especially in disturbed and heterogeneous environment such as horticultural crops.

Table 2. Life history traits of selected introduced insect pests in Morocco.

Species	Life cycle (at 20–27°C)	Generation per year	Mode of reproduction	Progeny per ♀	Temperature range (°C)
Aonidiella aurantii	60-110 days[1]	3-4[1]	P	100-150[1]	11.7-37.8[10]
Aleurothrixus floccosus	32 days[1]	4-6[1]	S[2]	200[1]	10-35.5[11]
Bemicia tabaci	22-24 days[3]	10[3]	S[4]	160[3]	8.7-41.5[3]
Frankliniella occidentalis	18-23 days[5]	12-15[4]	P	100[5]	10.9-40[9]
Liriomyza bryoniae	23 days[8]	> 2	S[2]	104[4]	6[4]
L. trifolii	24-26 days[4]	3 – 5[4]	S[2]	400[4]	10-38[11]
Panonychus citri	8-12 days[7]	12-16[7]	P	60-110	7.9[11]
Parlatoria blanchardi	72-110 days[12]	3-4[12]	P	5-8[12]	-
Phyllocnistis citrella	13-52 days[2]	6-8[6]	S	~60	-
Pterochloroides persicae	25-30[2]	> 4	P[2]	30[2]	-

S = sexual reproduction; P = parthenogenetic reproduction; [1] Abbassi (1980); [2] CABI (2003); [3] Muniz (2000); [4] EPPO (2003); [5] Sekkat *et al.* (1997); [6] Boughdad *et al.* (1997); [7] M Bounfour (unpublished); [8] Anonymous (1994); [9] Van Rijn *et al.* (1995), Contreras *et al.* (1998); [10] Grout *et al.* (1989); [11] present study; [12] Madkouri (1976).

Temperature and development

As poikilothermic organisms, the developmental rates of insects and mites vary with temperature, which has a direct effect on metabolic processes (Logan *et al.*, 1976). Insects and mites develop over a wide range of temperatures (Table 2). For example, the minimum development temperature for western flower thrips is 10.9°C and the maximum 40°C (van Rijn *et al.*, 1995; Contreras *et al.*, 1998); the optimum is 30°C. In Morocco, thrips populations may be observed all-year-round, but the highest population densities are found from March to June (Sekkat *et al.*, 1997). Similarly, populations of California red scale may be observed all-year-round, but development slows down during summer and winter. The highest densities of the insect can be observed in June/July and in September/October (Abbassi, 1980).

In general, the temperature range for all introduced species is from 10 to 40°C except for American serpentine leaf miner (*Liriomyza trifolii*), which has a low developmental threshold of from 6 to 10°C. These temperatures fall well within the climatic range offered by Morocco throughout the year.

EFFECTS OF ENVIRONMENTAL FACTORS

Host plant

Interactions with the host plant are probably the most critical issue in the life of an insect. The host plant allows dispersal, gives shelter, and provides oviposition as well as feeding sites.

All species shown in Table 2 are adapted to sap sucking or leaf mining. These feeding habits allow the insects to compensate for water loss and to adapt to a wide range of temperatures, especially in hot, dry and unpredictable environments. There are three types of invaders: a) toxin injectors, e.g. spider mites; b) virus transmitters, e.g. thrips; and c) leaf miners, e.g. agromyzid flies (Table 2).

Feeding by spider mites results in systemic disintegration of the chlorophyll apparatus (Bounfour *et al.*, 2002), which may increase the availability of nitrogen, an essential nutrient for insects and mites. Leaf miners have direct access to nutrients since they feed directly on the inner tissues, whereas virus transmitters, such as tobacco whitefly (*Bemisia tabaci*) biotype B and western flower thrips may use the viruses to speed up processes necessary to make nitrogen readily available. Additionally, virus transmission may help overcome the resistance of endemic and wild hosts, allowing these two pests to attack many kind of hosts.

Other introduced species have developed local specializations to the Moroccan environment. For example, even though CRS, woolly whitefly (*Aleurothrixus floccosus*) and CRSM are reported as polyphagous species (CABI, 2003), they are almost exclusively found on *Citrus* in Morocco. This may result from the continuous availability of resources (Fox & Morrow, 1981). Additionally, the introduced pests may not have the necessary chemistry to overcome resistance of the natural vegetation.

Natural enemies

When first established, all introduced pest populations caused substantial amount of damage before endemic natural enemies adapted to them. In most cases however, endemic natural enemies did not achieve satisfactory 'economical' control.

Ahytis melinus (Aphelinidae) (an introduced parasitoid) along with *Comperiella bifasciata* (Encyrtidae) (an endemic species) suppressed populations of California red scale, with more than 80% parasitization (Abbassi, 1980). Currently, the scale is under biological control in many commercial *Citrus* groves (Tijani, personal communication). Populations of CRSM are effectively suppressed by two endemic phytoseiid mites, namely *Euseius scutalis* and *E. stipulatus*.

The endemic hymenopterous parasitoids *Cirrospilus pectus*, *C. vittatus* and *Pnigalio* sp. (Eulophidae) attack CLM. However, the rate of parasitism is 'economicaly' too low (16 to 51%) to consider these insects for a control programme. The parasitoid *Semielacher petiolatus* (Eulophidae) (introduced from Australia) gives economical control, with more than 60% parasitism (Krira *et al.*, 2001). Similarly, the introduced natural enemy *Cales noacki* (Aphelinidae) regulates populations of woolly whitefly, with more than 90% parasitization rates.

Therefore, the resistance of the environment reflected in the natural enemies communities should be enhanced by conservation or augmentive releases of parasitoids and predators.

CONCLUSIONS

General trends have been identified in relation to the mode of introduction and spread of non-indigenous insect pests of cultivated plants in Morocco.

1) All the pests identified have a worldwide distribution. Thus, Morocco is at risk of introduction of any pest, for which the distribution is rapidly changing, as was the case for CLM;

2) All the pests identified attack vegetative parts of crops subject to international trade. This suggests that these pests were probably introduced with plants for planting;

3) All the pests are either sap sucking or leaf miners. This makes them difficult to detect at low densities, and protects them from dessication during transport or even during establishment;

4) The pests have short generation times, and are adapted to develop over a wide range of temperatures.

Within Morocco, the pests show some specialization in the range of host plants attacked. Additionally, some of the introduced pests can be controlled by endemic natural enemies (e.g. CRSM) or introduced parasitoids (ex. CLM and CRS). Developing good research on biological control will probably be a key in limiting the spread of introduced insects and mites that are pests of agricultural commodities.

In summary, pests with the described attributes make good candidates for easy entry, rapid adaptation and establishment in Morocco.

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Ragweed, a new European biological air and soil pollutant: a call to the European Community for help to prevention of ragweed allergenic disease, a necessity of improving the quality of life of a wide range of people

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ABSTRACT

Common ragweed (*Ambrosia artemisiifolia*) is an annual plant, probably originating from North America. It was first recorded in Europe in botanical writings in the mid-1800s. The weed has begun spreading through Europe only recently, and since the 1960s in France around Lyon. In France, common ragweed is invasive; other species of *Ambrosia* are rare and not considered as problematic. Large quantities of highly allergenic pollen are produced by the plant, causing severe hayfever symptoms in both humans and animals (e.g. dogs). Pollen counts and monitoring of the distribution of the weed (the latter using satellite technology) are currently performed, in a bid to study the ecology of the weed and extent of polluted areas. Control measures and appropriate regulations are considered of importance to overcome the problems posed by common ragweed and ragweed pollinosis.

INTRODUCTION

Common ragweed (*Ambrosia artemisiifolia*) (family Asteraceae) (also known as short or annual ragweed) was accidentally introduced to the Lyon region of France with clover seeds (from Argentina) and in soil around potato plants (from North America) in the 1930s. However, only recently has this weed begun to spread through Europe (in France, since the 1960s).

When mature and in flower, common ragweed produces a highly allergenic pollen and, later, a great quantity of seed. This pollen, which is readily airborne and contains many potent allergens, has become an important cause of severe summer hay fever, with (in about 50% of cases) asthma also occurring in areas the areas that are now being invaded. Therefore, Europe is now confronted with a substantial increase in common ragweed populations and associated ragweed pollinosis. On account of this illness, warnings about this plant were launched for the first time, in France (in 1964) by allergists…and their patients.

Recognition of the invasion of waste lands and crop was recorded only later. For further information see Déchamp & Méon (2003).

COMMON RAGWEED

The genus *Ambrosia* contains several species, the precise number varying (from 15 to 48) according to the classification adopted.

In France, common ragweed is invasive; however, other species of *Ambrosia* are rare and not considered as problematic; these include: giant ragweed (*A. trifida*), perennial or western ragweed (*A. psilostachya*), sea ragweed (*A. maritima*) and slim leaf burr ragweed (*A. tenuifolia*). Although common ragweed occurs in various parts of central Europe, it is regarded as invasive only locally. Nevertheless there is a significant biological cross-reactivity between the above-mentioned *Ambrosia* species.

Insignificant morphology

The soft-green leaves are mostly opposite in the middle of the plant and alternate at its upper part; they are mostly lobed or dissected, and the lobes are lanceolate. The hairy stem is green but this green colour is often in part covered with purple. Male inflorescences are green to yellow, bractless, and composed of very small inverted cupules. Female heads are borne below them, in the axils of the upper leaves or bracts, each with a single floret; all florets are tubular. The achene (fruit) is enclosed by a nut-like involucre. Some plants have only female inflorescences and, in this case, the number of achenes is very important.

The average height of common ragweed plants is 60 to 80 cm, but individual plants may reach 2 m. The weed is particularly tall on waste land and amongst crops, where it is able to grow into large bushes.

Following seed dormancy, mass germination commences at the end of March or at the beginning of April. Depending on soil temperature and soil aspect, the plant emerges in May or June, grows fairly slowly until mid-July and the very rapidly at the end of this month. In Lyon, the flowering period begins (in most years) at the end of July. The very important period of seed production occurs in October-November. When seeds are in the ground they are able to lie dormant for 40 years.

MAIN ECOLOGICAL FEATURES

Common ragweed takes hold when ground cover is absent, on building sites and in a lot of particular crops. It grows on sandy soils, and requires an average amount of water and atmospheric humidity. However, it was the only green plant during the last extreme heatwave (summer 2003). It prefers soil rich in nitrogen, but seems to adapt to a wide range of pH. In farmers' fields, or on vacant lands, this pioneer plant tends to disappear if the soil is cultivated, as it cannot stand the competition of dense vegetation. The plant grows on land that has been cleared and left uncultivated (fallow lands), and is frequently found on communication routes: roads, motorway verges, railway embankments and riverbanks. Dividing lines between land belonging to different authorities or persons are often invaded. Nevertheless, it grows in many crops, including sunflower, pea and soybean, and in peach orchards; it is also found around fields of maize and in cereal fields after harvest. It grows on the plains but is also working its way up mountains. In Europe, it is spreading on building sites in the outskirts of large towns, which is a price paid to urban development.

Moreover, it is often found under bird cages and feeders, as its seeds are brought in amongst bird seed.

POLLEN

A large quantity of highly allergenic pollen is produced by each plant. Its specific morphology (small size (20-25 µm) and spiky bristles) facilitates airborne transport. The dimensions of the plants are very different; the taller they are, the more numerous are the inflorescences. Two million pollen grains can be emitted by a single plant in a single day, with (when the plant is dense) almost a billion grains/m^2. The plant is allergenic: the pollen is anemogamic, produced in large quantities, and contains many allergens. Although most of them have been identified, they continue to be extensively studied. Amb a 1 and Amb a 2 are relatively abundant, and are the main allergens and approximately 90% of the population presenting a ragweed allergy possesses immunoglobulin E (IgE) antibodies directed towards these substances. Several minor allergens were also identified.

POLLEN COUNTS

Pollen production and dissemination depend on climatic conditions and human sporadic interventions. Thus, it is necessary annually to make pollen counts as well as monitor weather conditions. To this end, highly receptive pollen traps (Cour type volumetric traps) are used that are well able to measuring the small amounts of pollen at the beginning of the very important pollination period.

Data produced by pollen counts

Pollen counts (graphically represented as a Gauss curve) are used both to measure the geographic spread of the weed in the country in various locations, in different years, and to inform hay-fever sufferers on a weekly basis.

In 1982, in Lyon, pollen counts were the same as those in Baltimore and Bethesda (two highly polluted towns in the east of the USA).

Pollen traps set in meteorological centres, unfortunately, show that in France common ragweed contamination is rife in areas which used to be free for contamination: namely, the south of France along the Rhône Valley and in every direction around Lyon. In 2004, Valence, Vienne and Lyon-Saint-Exupéry (a half-agricultural and partly urbanized location, with an airport) are the worst affected areas, followed by Montelimar, Lyon-Bron (semi-urbanized area), in the Rhône Valley.

In Lyon-Bron (Rhône) and Lyon-Saint-Exupéry (Nord-Isère), a medical message is sent weekly, with an indication of pollen levels (http://assoc.wanadoo.fr/afeda: no cost), during the pollination period, to help sufferers better to control their hay fever. Moreover, a pollen calendar is printed annually in December and distributed to allergists and associated members.

There has been much scientific study about climatic changes. Since common ragweed pollinates at more or less the same period in different parts of the world, it seemed interesting to see if there was any variation in the first days of pollination, from 1982 to 2004. The results point to earlier ragweed flowering, by an average of 11 days and, in extreme cases, of up to one month. From a medical point of view, the wide variation from year to year should be taken into account in the treatment of ragweed-induced pollinosis, confirming the usefulness of pollen counts and of a forecast model for ragweed produced by the French Association for the Study of Ragweed (AFEDA).

In 1994, in France, the rules of the Common Agricultural Policy (CAP) decided by the European Union and published in 1992, began to be applied. These rules made farmers set land aside (fallow lands), while subsidizing sunflower crops. For the first time, in 1994, the annual weekly mean common ragweed pollen counts (660 grains/m^3) had doubled in the Rhône department (Rd); maximum levels have been recorded only twice in 12 years (330/m^3).These observations lead us to compare annual surfaces of fallow lands (fl) and sunflower fields (sff) to common ragweed pollen counts. Rd is small: 330,334 ha; fl and sff represent about 10% of the total agricultural area. For the six years analysed (1994–1999), annual weekly averages of common ragweed pollen counts (weeks 31–43) were compared with the areas given over to fallow lands and to sunflower growing. There were strong positive correlations between pollen counts and fallow areas ($r = 0.97$, $P = 0{,}001$) and between pollen counts and sunflower areas ($r = 0.93$, $P = 0{,}006$). Therefore, the application of the rules of the CAP in the Rd focuses on the roles of the fallow lands and sunflower crops in the spreading of common ragweed.

POLLINOSIS (HAY FEVER)

Common ragweed causes severe hay fever: rhinitis, conjunctivitis, tracheitis or/and (in about 50% of cases) asthma, but rarely dermatitis. The itching of the roof of the mouth, pharynx, nose, ears and eyes is unbearable. Some patients may suffer from insomnia, mainly due to nasal obstruction, tracheitis or asthma. The intensity of these symptoms is in direct relation with the quantity of airborne pollen. Epidemiological studies showed that prevalence of ragweed pollinosis increased in exposed populations around Lyon. Recently, from 6 to 20% of the population was affected.

Dogs are sensitized to common ragweed pollen, and are particularly exposed in their direct environment because of their horizontal position and behaviour. In Lyon, common ragweed pollen is responsible for about 44% of cases of canine pollinosis: the animals develop an atopic dermatosis, but no rhino-conjunctivitis or asthma. Gundogs are affected when game hunting in crops. Parisian huntsmen who visit the Dombes area (which is north-east of Lyon), to hunt game must have their hunting dogs desensitized every year!

To improve human and animal health, it is necessary to fight common ragweed.

SATELLITE OBSERVATION OF INFESTED FIELDS: AN EXPERIMENTAL APPROACH

We need to have a sufficiently accurate mapping of the areas infested by common ragweed, in order to manage weeding campaigns and to understand the space-time evolution of the plant. The detection of dense populations of the weed, using spatial remote sensing data, seemed possible. The main difficulties in this type of exercise are due to the heterogeneous floristic composition of herbaceous stands containing a species and to the lack of knowledge of the spectral signatures of other plants.

The method we use was, at first, in the field to undertake a precise land survey of areas with *Ambrosia*; thus, it was possible to know the spectral signatures of *Ambrosia* on the map given by the satellite and to differentiate it from the other grassland components. An area in the eastern part of the Lyon region was chosen for this land survey. Different types of components were distinguished: *Ambrosia*, forests, industrial areas, maize crops, roadsides, sunflower crops, stubble fields, urban environments and water.

These items from the earth are translated on the corresponding satellite image, using mathematical processes. Results from this small surface area might be extrapolate to the whole surface (60 × 60 km). This study pinpointed some constraints, linked to the use of space products, which were both ecological and technical. It is necessary to know very precisely during which period in the year the plant growing. The meteorological conditions influence this growth and also the quality of satellite image – a cloudy sky, for example, prevents the use of the image. The satellite cycle is 21 days for Spot, and 16 days for Lansat and Terra Aster. It was not possible to have an image during the 2002 summer (because of numerous clouds over the studied areas); however, during 2003 the heatwave (which advanced plant growth) allowed the taking of a good picture during the time when the satellite was vertically situated above the region. The obtained picture of 20 m/pixel (on 14 July) is of good quality. It was not possible to evaluate the presence on roadsides or on small surfaces, because of the weak resolution of the picture. In total, 2% of the whole surface was occupied by ragweed (Table 1); surface areas smaller than 20 m^2 (roadsides, small building sites etc.) are excluded, amounting to c. 90 km^2 of the 3,600 km^2 explored. Better results from a satellite with a higher resolution (5 m/pixel), are to be expected in the future.

Table 1. Surface of the studied components.

Component studied	Surface (km^2)	Surface (%)	Component studied	Surface (km^2)	Surface (%)
Ambrosia	89	2	roadsides	182	4
forest	989	23	water	657	15
maize	366	8	urban environment	1439	33
sunflower	238	5	industry	307	7
stubble fields	146	3	total	4415	100

NON-CHEMICAL CONTROL METHODS

Several non-chemical control methods are available:

- biological control: selected fungi, selected arthropods;
- hot water: when common ragweed at a sufficient height;
- physical control: prescribed burning (gas-flame burning);

- mechanical control: sheep grazing; cutting (e.g. with a reed cutter);
- soil cover: use of cover plants, organic material (e.g. chopped bark) or plastic film.

REGULATIONS

French legislation, albeit non-specific to common ragweed (concerning 'Rules of Public Health', in a circular dated 14 April 1989, and published in the 'Journal Officiel' of 26 July 1989), presents a collection of laws which allows Prefects and Mayors to enact specific bylaws applicable to plants such as common ragweed. (These were enacted before the new Community Guidelines on air quality came into force.) Thereby, Prefects of polluted regions have made it obligatory to clear the weed from set-aside land. Also, Mayors of several polluted communes have imposed bylaws, requiring the eradication of common ragweed. However, some Mayors do not want to make such orders because in rural places they are often impossible to apply. In 2005, a decision is required that will apply to all land.

In France, in 2003, a meeting took place in Paris (which is not polluted), between concerned Ministries. The conclusion was that local State services in polluted areas should reinforce their actions. However, as always, no national regulation was imposed, so common ragweed is spreading everywhere.

The policy of the European Community (EC) (presented in the CAP, that has brought in financial support for farmers planting certain crops and establishing set-aside land) has had a direct effect on the spread of common ragweed. However, whether the new EC Guidelines on air quality hold out the hope of the implementation of more-efficient measures to eradicate this weed is open to question.

CONCLUSIONS

There is non-global strategy for the prevention and control of common ragweed at a European Union and European level. As in France, most of research has been done by AFEDA. It would be interesting to know whether other countries would be able to establish such an association to coordinate such studies and efforts. This would allow the creation of a European network to coordinate recommendations and interventions against the spread of common ragweed and its pollination, at a European level. Such a European network, in league with the EU, might be able to improve the quality of life for a large number of people.

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Evolutionary genetics of invasive species: using molecules and morphological variation to trace the origin and dissemination of exotic pests

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ABSTRACT

Analyses of the spread of invasive species have been classically based on studies of life history parameters and surveys of range spread. Population genetics and phylogeographic approaches can provide better understanding of biological invasions. Genetic tools compared with morphometric analysis are used to gain information on the biology of invasive organisms, including pathways of spread, the biology of colonization and the role of genetic variation in these processes. Invasions by an economically important pest – the coconut mite (*Aceria guerreronis*) – which has recently become a threat in several continents, have been traced. The usefulness of tracing the biogeographic origin and subsequent dissemination of exotic invasive species was studied, addressing issues to aid in the prevention of accidental pest introduction and related measures for monitoring quarantine efforts.

INTRODUCTION

Although the impact of bioinvasions involving exotic species is often well established in terms of economic losses and the threat that they pose to diversity (Pimentel, 2000), strategies for controlling invasive pests remain difficult to define in terms of cost and risks of spread. Because of the genealogical nature of genetic material, so-called neutral genetic markers are ideal for tracing the movement patterns of organisms. This information can be used to determine the origin of populations and the spread of targeted pests (Roderick, 2004). The source of introduced species is often known only very roughly. However, accurate knowledge of the source of an introduced or invading species will be useful for (i) inferring evolutionary history and predicting adaptative range, (ii) deciphering the history of introductions and the pattern of human transport, (iii) locating sources of biological control agents, and (iv) facilitating quarantine efforts. Multivariate morphometry is also a useful tool to detect variation in quantitative characters, to evaluate patterns of phenetic relationship, and to test historic phylogenetic hypotheses (e.g. Garb *et al.*, 2004). The distribution of the diversity of DNA sequences and the geographic pattern of morphological variation were analysed to examine the invasion pathways of an eriophyid mite species, the coconut mite (*Aceria guerreronis*).

The coconut mite has emerged over the past 30 years as an important pest and has recently spread to most of the coconut-production areas world wide. The origin of the mite is unknown. The species was first described in Guerrero, Mexico, in 1965. However, certain previous records indicate that it was already present in other regions in South America. The mite was reported in Africa, in the Gulf of Guinea islands in 1966, in Benin in 1967 and the East of the continent (Tanzania) in the 1980s. The most recent records of the mite in new areas concern India and Sri Lanka in the 1990s. Curiously, the mite has not been recorded in the Indo-Pacific region, the area of origin of coconut.

We use sequence-level variation to investigate the genetic relationships of coconut mite originating from most of the geographic areas where the pest has currently been reported (Africa, the Americas and the Indian Ocean region). A mite sample collected on another host, the queen palm, was also analysed to address the question of the original host plant of coconut mite. Results were compared with morphological variation of the species. This work addresses the invasion process of the species and raises questions relating to the putative source of the pest. The study also provides insights for monitoring quarantine efforts to prevent the spread of the pest.

MATERIAL AND METHODS

Twenty-eight populations of different origins were sampled on coconut: Ben1, Ben2 (Benin); Br1, Br2, Br3, Br4, Br5, Br6, Br7, Br8, Br9, Br10 (Brazil); Cu (Cuba); Ind1, Ind2 (India); Mex (Mexico); Tan (Tanzanie); USA2 (USA); Ven (Venezuela); SrL1, SrL2, SrL3, SrL4, SrL5, SrL6, SrL7, SrL8, SrL9 (Sri Lanka). In addition, a sample USA1 (USA) was collected from another palm, *Syagrus romanzoffiana*. Two independent markers, the nuclear internal transcribed region (ITS1-5.8S-ITS2) of the ribosomal cluster (1000 bp) and a fragment of the mitochondrial 16S (404 bp) were amplified and sequenced as presented in detail in Navia *et al.* (2005a). Inference on the distribution of the genetic diversity in the Americas was determined using the analysis of molecular variance (AMOVA) method (http://anthro.unige.ch/arlequin). The relationship between coconut mite samples was investigated using maximum likelihood (ML) methods and Bayesian inference to estimate solidity of nodes in the tree (see Navia *et al.*, 2005a, for a detailed description of methods). Populations analysed with molecular markers were also submitted to a morphometric analysis. Mites were mounted on slides in modified Berlese medium. Adult females were used in all morphometric analyses, because most of taxonomic descriptions of mites of this family are based on this stage. Fifteen of the best-mounted females of each population were selected for analysis. Fifty-six continuous or discrete characters were measured in each mite, using a phase-contrast microscope (Leica DMLS) (×100 objective). The characters measured were those commonly used in Eriophyoidea systematic studies (Lindquist & Amrine, 1996). Thirteen ratios between dimensions of characters were also used as variables. Analyses were done using log transformations of the raw data. Two multivariate statistical procedures were applied to the data: Principal Component Analysis (PCA) and Canonical Discriminant Analysis (CDA). Statistical analysis was conducted using SAS (SAS Institute, 1990). A cluster analysis was applied to population means of the three main canonical variables, using the single linkage method to calculate Euclidian distances (see Navia *et al.*, 2005b).

RESULTS AND DISCUSSION

Mitochondrial 16S ribosomal sequences revealed seven haplotypes, six of which were present in Brazil, two in Central and North America and a single one shared by non-American mites from Benin, Tanzania, India and Sri Lanka. Congruently, nuclear ribosomal ITS sequences examined for samples of the same origin displayed the highest nucleotide diversity (π) in Brazil (π = 1.90%) compared with samples from the rest of the Americas (π = 0.54%) from Africa (π = 0.70%) India and Sri Lanka (π = 0.49%) (data presented in detail in Navia *et al.*, 2005a). In addition, the phylogenetic trees based on both nuclear and mitochondrial data (only the mitochondrial tree is presented here, Figure 1), show that all non-American samples collected from Africa and the Indian Ocean region are monophyletic and either identical (16S) or very little diversified (ITS).

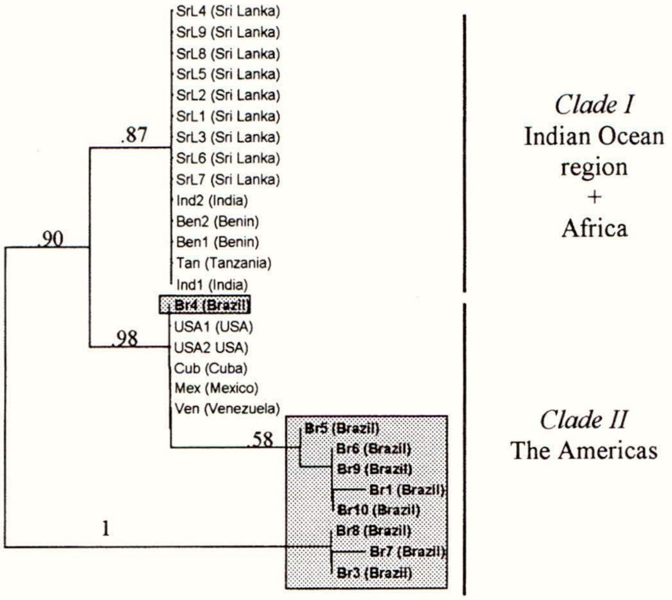

Figure 1. Tree based on a 404 bp mitochondrial fragment (16S), using maximum likelihood to reconstruct the phylogeny relationship among *Aceria guerreronis* mites from several regions in three continents. Samples from Brazil are indicated by a shaded box. The solidity of nodes has been estimated by Bayesian analysis and the posterior probabilities are indicated on the branches. All mites were sampled on coconut, except USA1 which was collected on *Syagrus romanzoffiana*.

Canonical Discriminat Analysis showed that when individuals were plotted against their respective values for the first three canonical variables, CAN1, CAN2 and CAN3 (Figure 2), the African populations (a–c) overlapped widely the Asian populations (r–z, i), and both were separated from the American population (d–q). American populations were separated in two main clusters – Brazilian populations (d–m) and non-Brazilian (n–q). Among

Brazilian populations was observed a sub-cluster – Aracaju (d) and Maceió (i). Results of morphometric analysis were widely in agreement with phylogeographic studies: (i) high morphological variation among American population; (ii) morphological similarity among African and Asian populations and (iii) morphological distance among African and Asian populations compared with American samples.

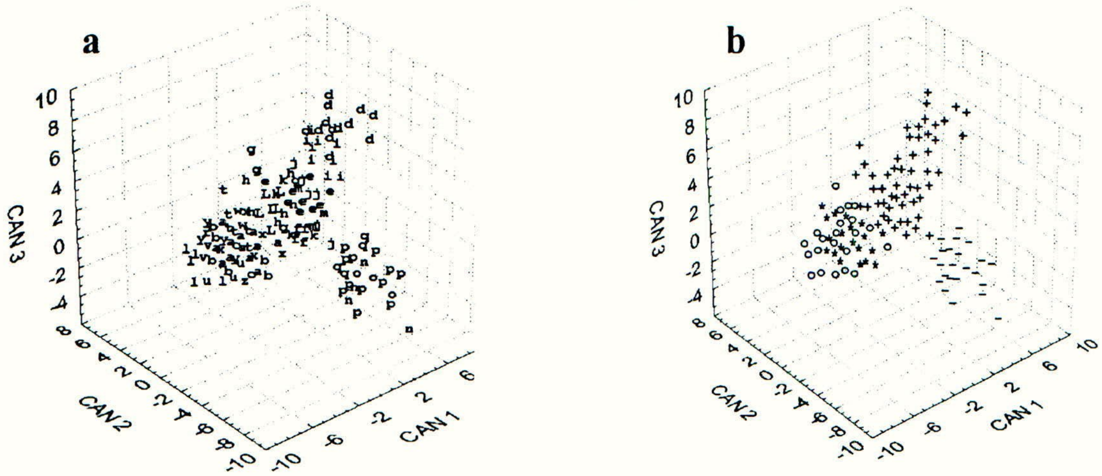

Figure 2. Canonical Discriminant Analysis of American, African and Asian populations of *Aceria guerreronis*. Individuals plotted against their values for the first three canonical variables. a) Letters represent populations from Africa (a–c), Brazil (d–m), other American countries (n–q) and Asia (r–z and I); b) signs represent Brazil (+); other American countries (-); Africa (*); and Asia (o).

Molecular and morphological results together with information on records of the presence of the mite in the world help to trace the recent expansion history of this pest. Despite the practically simultaneous report of the mite in Africa and the Americas (Moore & Howard, 1966), the highest diversity found in America suggests the origin of the species in this continent; the most plausible hypothesis seems to be South America.

With the hypothesis of an American origin of the mite, it remains unclear why none of the American haplotypes identified in this study was present in the other continents samples. One explanation could be that because genetic variation of the mite in America is high, we had only partially sampled the entire diversity of the species on this continent.

An issue of an American origin of coconut mite is the original host plant of the pest, which supports a previous hypothesis that the mite was originally on a palm tree other than coconut. As further evidence, mites collected on another palm (namely, *S. ramanzoffiana*) analysed here, does not represent a distinct genotype.

Some insights of the spread routes of the pest are here provided. The absence of polymorphism between African and Indo-Pacific samples is compatible with a recent and unique infestation of these regions, presumably from America. The dissemination of the mite in the Americas and from there to other continents appears to be a realistic hypothesis. Although wind can be considered as the main agent of the spread of mites over short distances, human activities (international trade, tourism and germplasm exchange) have obviously facilitated the rapid dissemination of the pest over long distances.

From genetics to invasive species control

The results here presented should be of interest in drawing strategies to control the pest. It is expected that effective natural enemies of a pest will be found in the place of origin of the pest, where coconut mite and its enemies have been in contact for the longest time (Hoddle, 2004). In addition, this study leads to new hypotheses concerning recent introductions of coconut mite in the Indian Ocean region. It is widely accepted that most spread of the coconut mite in remote areas results from human activity in the transport or trade in host plant propagation material. The transport of any palm tree propagation material thus represents a risk to be considered for quarantine measures, in order to prevent the spread of this invasive mite to other Asian and Pacific countries where it has not yet been reported but where it is nevertheless a potential threat.

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Monitoring and early warning systems for invasive alien species in the Plant Health sector in Europe

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ABSTRACT

The European and Mediterranean Plant Protection Organization (EPPO) and the European Union (EU) are providing the technical and regulatory framework in the field of Plant Health in Europe. Both are running databases and information exchange systems in order to achieve early warning of the responsible official bodies of the member countries on the occurrence and/or spread of invasive, plant-damaging organisms. Several ways of proceeding are applied to monitor the occurrence of those organisms on the respective national territories. The realization of the surveillance is under the responsibility of the national plant protection organizations. An overview is given on the main elements of 'general monitoring', 'import/export monitoring' and 'specific area-wide monitoring'. Within the EU, specific area-wide monitoring programmes directed on the detection of particular harmful organisms are carried out in the framework of either a Control Directive, the surveillance of Protected Zones or Commission Decisions on emergency measures. The performance and the results of such a Community-wide monitoring is demonstrated on the example of the pinewood nematode (*Bursaphelenchus xylophilus*).

INTRODUCTION

Surveillance of the occurrence of harmful organisms which may be invasive alien species is an important element of plant health regulations. Knowledge on the occurrence of invasive species in a country or a certain area and on possible pathways of introduction of those organisms is essential for early warning of the responsible official bodies, and for enabling precautionary action against the introduction and spread of harmful organisms. In this respect, the European and Mediterranean Plant Protection Organization (EPPO) and the European Commission (EC) are running databases to gather relevant information. Surveillance in the field of plant health can be distinguished into four different ways: a) general monitoring, b) import monitoring, c) export monitoring and d) area-wide monitoring. This paper provides information on the objectives, the legal background and on the practical realization of the different procedures.

EARLY-WARNING SYSTEMS

The effectiveness of phytosanitary regulations highly depends on the continuous exclusion of harmful organisms or, if an introduction already had occurred, on the period between the introduction and the first notice of the presence of the organism. Therefore, it is very important for the work of the Plant Protection Services (PPS) to obtain information on potential risks of introduction of harmful organisms as early and as quick as possible. To achieve this objective, EPPO is providing information on new threats or emerging problems with harmful organisms via the 'EPPO Reporting Service' and by compiling an 'Alert List'. The 'Reporting Service' presents a collection of new information on pests listed in the A1 and A2 lists or on other pests of potential phytosanitary concern. The information is taken from the scientific literature or from official notifications of the national plant protection organizations (NPPO) of the EPPO member countries. In contrast, the 'Alert List' compiles comprehensive data (including references to the relevant literature) on selected pests which could be candidates for the A1 or A2 lists but have not yet been subjected to pest risk analysis. The purpose of the 'Alert List' is to draw the attention of the official bodies to these organisms which already may be present in some areas in Europe or where there is an ongoing risk of introduction.

All interceptions of consignments imported into the EU irrespective of the reason for the interception (e.g. presence of harmful organisms, documentary problems) are notified by the Member States to the EC, are included into the EUROPHYT database and via this system are distributed to the other Member States. Thus, inspectors in the different Member States can obtain current notice on problems with consignments from certain origins which have been encountered at any point of entry all over the Community. This alert system enables the responsible bodies to adjust their control procedures immediately to potential new risks of introducing harmful organisms with traded goods.

GENERAL MONITORING

The general monitoring contributes to the overall surveillance of invasive species harmful to plants. As it gives early alert on the occurrence of those organisms it constitutes an important basis for taking measures against their introduction and/or spread. The information gathered in the framework of the general monitoring is an integral part of coping with the requirements set out under the International Plant Protection Convention (IPPC) and the related International Standards for Phytosanitary Measures (ISPM) in respect of pest reporting (ISPM 17) and determination of the status of a certain pest in an area (ISPM 8). In this context it also provides information which is essential for export certification.

Usually, the main objective of general monitoring is not to discover a certain harmful organism in an area but (being largely unspecific) is to cover the whole range of potential plant pests. In fact, the main focus is on the occurrence of harmful organisms on cultivated crops, but it also allows for natural habitats as well as for public and private green areas. A broad range of different sources of information is used including data which are directly available at the PPS and those which can be obtained from scientific publications, the internet, communities of interest or from personnel contacts.

According to the German Plant Protection Law, the surveillance of organisms harmful to plants is clearly attributed to the PPS of the Federal States. The Federal Biological Research Centre for Agriculture and Forestry (BBA) can assist the PPS in this respect.

IMPORT MONITORING

General import monitoring

According to Council Directive 2000/29/EC, all imported consignments of plants and plant products requiring a Phytosanitary Certificate (PC) have to be inspected by the PPS in order to prevent the introduction of harmful organisms with the imported commodities. At the point of entry into the EU, or at the place of destination, each individual consignment will be subjected to a documentary check (PC), an identity control and a physical inspection for the presence of harmful organisms. To promote a harmonized execution of the controls in the Member States (especially of the physical controls) an inspection guideline (EC-Vademecum) has been established, which contains both a description of the general procedure of import inspections (including sample size) and special information for different kinds of commodities (plants for planting, plants of Solanaceae, fruits, forestry products).

Consignments which do not meet the import requirements, especially in case of presence of harmful organisms, are intercepted and appropriate measures are imposed (rejection, destruction, treatment). Each interception is notified via the EUROPHYT system to the other Member States, in order to give alert on possible problems with consignments of a certain origin.

Specific import monitoring

In situations where a particular risk of introduction of harmful organisms is associated with certain types of commodities, or with certain countries of origin, it may be appropriate to carry out a specific import monitoring focussed on these risk commodities. Usually this is done in connection with an Emergency Decision of the Commission. Such a targeted import monitoring has been carried out in the EU since 1999 in the context of two Decisions concerning the import of packaging material made from hardwood or coniferous wood (Decisions 1999/516/EC and 2001/219/EC) and which is actually 'in use'. These Decisions have been revoked in the meantime since, with effect from 1 March 2005, new provisions on packaging wood have been incorporated into Directive 2000/29/EC implementing ISPM 15 ('Guidelines for regulating wood packaging material in international trade').

In the course of globalization and the growing worldwide trade, the use of wood for packaging purposes (e.g. pallets, crates, boxes, drums) or in the form of dunnage increases continuously. It can be assumed that there is some packaging wood in nearly every container, and it is also evident that for economical reasons low-grade and untreated wood is frequently used. Since about 97% of organisms harmful to trees which are of plant health concern, such as wood-inhabiting insects (e.g. the Asian longhorn beetle, *Anoplophora glabripennis*), wood nematodes (e.g. *Bursaphelenchus xylophilus*) or pathogenic fungi (e.g. *Ophiostoma novo-ulmi*), are associated with packaging wood, the risk for the introduction of those pests is obvious.

Until recently, packaging wood actually in use for packing and supporting commodities was practically not subjected to phytosanitary controls, as there neither was an obligation for a PC nor for a declaration in the import documents. After an increasing number of findings of the Asian longhorn beetle and pinewood nematodes in packaging material made from hard and soft wood, respectively, the Commission enacted two Emergency Decisions against the introduction of the former from China (Decision 1999/516/EC) and the latter from Canada, China, Japan and the USA (Decision 2001/219/EC). The compliance of the packaging wood with the requirements of the Decisions had to be checked by the responsible bodies of the Member States and a report on the monitoring results had to be submitted to the Commission. According to Decision 2001/219/EC a specific monitoring plan was asked from the Member States. During the planning and practical realization of the controls the PPS were faced with considerable difficulties:

- a trigger for phytosanitary controls of packaging wood is lacking (no PC and no declaration in the customs documents);
- container controls in ports are almost impossible for reason of time and costs;
- controls at the place of destination are complicated by the manifold ways of further shipment;
- after customs clearance of the commodity the legal power of the PPS to carry out controls is largely restricted.

In Germany, the monitoring plan comprised different possibilities to achieve a reasonable number of controls. The most effective way is to realize the controls at the points of entry, usually a port or an airport. A broad variety of commodities of different origins can be examined, e.g. in customs warehouses, in the free port or in the course of regular customs controls when containers are unpacked. Another possibility, particularly suitable for containerized commodities, are controls at the place of destination where the containers were moved to according to the relevant customs transit procedure. Since the control of the whole range of commodities from all countries is not feasible, the monitoring has to be focused on high-risk material which usually is made from low-grade wood (e.g. stone products from China). In both customs-related kinds of monitoring mentioned above, an intensive cooperation between the relevant customs and plant health authorities is essential. Packaging wood associated to commodities which are already cleared by customs can be inspected at the place of destination, in the context of special arrangements between the PPS and the consignee. This procedure is mainly used with big import companies.

The import monitoring on packaging wood on the one hand showed that the requirements for treatment and marking of the wood were more and more complied with by the Third Countries concerned. On the other hand, also in recent times there were many findings of living pinewood nematodes and of larvae and adults of Asian longhorn beetle in packaging material of coniferous and hard wood, respectively. Thus, the intensified monitoring activities unequivocally underlined the risk for introductions of dangerous invasive species associated with packaging wood. It can be expected that this situation will be continuously improved in the future when the relevant International Standard (ISPM 15) will be implemented in more and more countries.

EXPORT MONITORING

Imports from Third Countries into the EU require a PC. This applies for plants and plant products to be exported into Third Countries, too. The issue of a PC by the responsible PPS is based on phytosanitary inspections which have been carried out on the consignment prior to export. With the issue of a PC it is certified that the consignment a) has been inspected in an appropriate way, b) has been found free from quarantine organisms and practically free from other harmful organisms, and c) therefore meets the phytosanitary requirements of the importing country. Apart from the formal aspects of export certification, valuable information on the possible occurrence of invasive species in the own country can be obtained from the respective inspections.

AREA-WIDE MONITORING

In the EU Community-wide monitoring programmes are carried out either in a permanent, annually repeated way or on a temporary basis in the framework of emergency measures. In each case the objective is to elucidate the dissemination of certain harmful organisms within the Community and, as far as possible, to gain information suitable for risk assessment. The monitoring results are an important element to assess existing plant health regulations and those which are to be newly enacted. Usually, the realization of the monitoring is under the responsibility of the Member States. In certain cases, guidelines may be elaborated by the Commission in cooperation with experts from the Member States. The results of the area-wide monitorings have to be reported to the Commission at fixed dates.

Permanent area-wide monitoring

In the framework of the Control Directives 93/85/EC (*Clavibacter michiganensis* ssp. *sepedonicus*) and 98/57/EC (*Ralstonia solanacearum*), all Member States are obliged to carry out a targeted monitoring on the occurrence of both bacteria in the national potato production every year. To meet these requirements about 17,000 samples per year are taken in Germany from the seed and ware potato production, and these are subjected to laboratory testing for each of the bacteria. For reporting of the monitoring results a largely formalized procedure is established and the results are evaluated in the Standing Committee on Plant Health.

The whole territory of some Member States, or only parts of it, are recognized as a 'Protected Zone' for certain harmful organisms which do not occur in these areas. As the ongoing pest freedom has to be substantiated, these countries are obliged to monitor the respective areas continuously and to report to the Commission on an annual basis.

Specific area-wide monitoring related to emergency measures

Specific monitoring programmes, in most cases on a temporary basis, are carried out in the context of emergency measures which are directed against the introduction and/or further spread of certain already regulated or newly introduced, not yet regulated harmful organisms. Especially in the latter case, these Community-wide surveys are an essential element for the risk assessment. Currently, Community-wide monitoring programmes are conducted on the following harmful organisms:

- *B. xylophilus* (Decision 2000/58/EC and subsequent Decisions); sampling of coniferous stands in the Member States;
- *Pepino mosaic virus* (Decision 2000/325/EC and subsequent Decisions); inspection and sampling of tomato seed, tomato young plants and tomato crops for fruit production;

- *Phytophthora ramorum* (Decision 2002/757/EC); inspection and sampling of *Rhododendron*, *Viburnum* and other susceptible plants in nurseries, public green, private gardens and forests;
- *Diabrotica virgifera virgifera* (Decision 2003/766/EC); trapping in maize fields.

In the following, *B. xylophilus* will be taken as an example to describe some details on the realization and the results of such an area-wide monitoring.

Since the first detection of the pinewood nematode in summer 1999, in Portugal south of Lisbon (in an area of about 258,000 ha), the Portuguese authorities have been running an eradication programme. Additional measures to prevent further spread of *B. xylophilus* within Portugal, and to other areas of the Community, have been adopted with Commission Decision 2000/58/EC. This, and the subsequent Decisions, include an obligation for all Member States to carry out a survey in coniferous stands on their national territory, with the aim to clarify whether there might be other infested areas within the EU. The Commission, together with experts from some Member States, prepared a guideline (EC Survey Protocol), in order to achieve as much harmonization as possible of this monitoring in the various countries. 2004 was the fifth year of monitoring.

In Germany, the BBA, Department on Plant Health, is coordinating the monitoring, compiling the annual report to the Commission and doing reference testing, if necessary. Sampling of the trees, which is usually done in close cooperation with the forestry services, and laboratory testing are the task of the PPS. Especially in the first few years, the surveys have been intensively prepared during various technical meetings with representatives from BBA and the plant protection and forestry authorities of the Federal States.

During the five years of Community-wide monitoring (2000 to 2004), nearly 22,000 samples from conifers have been taken by the Member States and were analyzed for the presence of the pinewood nematode (2000 = 6,373 samples; 2001 = 4,918 samples; 2002 = 3,086 samples; 2003 = 3,171 samples; 2004 = 4,418 samples). To date, there were no findings of pinewood nematode outside the infested area in Portugal. Nevertheless, many other *Bursaphelenchus* species have been identified. This underlines the usefulness of such area-wide monitoring programmes, to provide supplementary information on the occurrence of other harmful organisms at which the actual monitoring is not aimed.

In conclusion, on the background of the expanding worldwide trade, and also because of the growing tourism, the introduction of invasive alien species harmful to plants and plant products is becoming an increasing serious problem. To meet these challenges, the regulatory framework of the Plant Health sector in Europe provides for a comprehensive surveillance system for invasive species which is carried out at different levels and is clearly attributed to the responsible PPS of the respective countries. As a consequence of newly identified phytosanitary risks, and the recent introduction of a variety of harmful organisms into the EU, there is an increasing need to carry out Community-wide monitoring programmes, in order to check the compliance with new provisions and/or to investigate the actual distribution of certain invasive species. This leads to further considerable charges for the responsible official bodies, which at the same time are subjected to more and more restrictions in their personal and financial capacities.

Non-native invertebrate plant pests established in Great Britain: an assessment of patterns and trends

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ABSTRACT

We constructed a database containing information on 325 non-native invertebrate plant pests that have established, or are suspected to have established, in Great Britain during the period 1787 to 2004. The database is designed to identify trends in pest establishments and to aid the prediction of future plant health risks. Records of establishment were analysed in relation to the taxon, type of environment, mode of entry, origin of the pest and changes over time. The Homoptera and Lepidoptera formed the majority of non-native species. Only 15% of establishments occurred in protected environments. Forty-seven per cent of all establishments occurred during or after 1970. Thirty-four per cent pose a significant risk to plant health, and approximately half of these became established after 1970. All but one of the significant post-1970 establishments were on ornamental plants. Of the post-1970 pests on cultivated hosts, 44% were accidentally introduced, compared with 6% colonizing naturally. The mode of entry could not be designated for the remaining species. Most non-native plant pests originated in continental Europe, with substantial minorities contributed by North America and East Asia. The numbers and composition of species that have established in Great Britain since 1970 are broadly similar to those observed in France, Italy and Spain.

INTRODUCTION

There is no up-to-date, comprehensive database of non-native invertebrates that are injurious to plants and have become established in Great Britain. Although information for certain taxa, e.g. the Lepidoptera (Bradley 2000), is relatively complete, a review by Brown (1986) and records of non-native invertebrate herbivores held in the Phytophagous Insect Data Bank (Ward 1988) are inconsistent, contain numerous omissions and are now out of date. An accurate database of non-native established species injurious to plants is required to assist the UK Plant Health Service in identifying which sectors are most vulnerable to damage from invaders. This would permit trends in non-native species establishments to be monitored, indicating which countries or regions are the sources of the most successful colonizers, and would contribute to requirements under Article VII (paragraph 2j) of the International Plant Protection Convention (FAO 1997) to maintain adequate information on pest status. Such a database also has important applications for the conservation of biodiversity (Defra, 2003).

MATERIALS AND METHODS

Published and unpublished information on non-native species was extracted from files at the Central Science Laboratory (CSL) and from the professional and amateur literature, particularly checklists of the British fauna. Non-native, terrestrial invertebrates known to be injurious to plants and to have established self-sustaining populations in Great Britain were added to the database. Species strongly suspected to be established were also incorporated, to make the database as comprehensive as possible. Species currently under official control (i.e. eradication or containment), reintroductions (e.g. of extinct natives), migrants and species forming only transient populations were excluded. Although many definitions of non-native species require human action to have been responsible for species entry, the mode of entry is often very difficult to determine for invertebrates; we have, therefore, included all newly arrived established species in the database. The database was restricted to plant pests, as defined by FAO (2002), i.e. species which are directly or indirectly injurious to plants. Indirect pests include disease vectors and species that harm organisms beneficial to plants (such as earthworms, pollinators and parasitoids of pests).

In order to gauge the threat posed by established non-native species, those that have caused or may cause economic or environmental impacts must be identified. However, with little information available for so many species, there is no straightforward method for distinguishing them. We have, therefore, adopted a surrogate method, based on administrative procedures at CSL. A separate file is opened whenever a new established non-native species is reported to have caused damage in Great Britain, and we used a list of these species files to determine the proportion of non-native invertebrate plant pests posing a significant risk to plant health.

Plant pests were analyzed in relation to the taxon, type of environment, mode of entry, origin of the pest and changes over time. We have concentrated our analysis on pests that have entered since 1970 because the data for this period are more robust, being more generally accessible in on-line bibliographic databases.

RESULTS

Records of 325 non-native plant pest species established during the period 1787–2004 were obtained. Thirty-eight species strongly suspected to be established were included, but a further 135 species, mainly nematodes, were excluded because there is no British checklist and their non-native status cannot, therefore, be confirmed. One hundred and fifty-eight (48.6%) of the 325 species were first recorded in or after 1970. However, 46 of the established non-native species (14.1%) lacked a date the first record. The majority of the 325 established non-native species were plant bugs (Homoptera: Sternorrhyncha and Auchenorrhyncha) (37.1%) and butterflies & moths (Lepidoptera) (31.3%) (Table 1). The majority of the 325 establishments (77%) occurred outside, with only 15% in protected environments (8% lacked information). A similar proportion of establishments in protected environments was recorded in the period 1970–2004.

Table 1. Taxonomic composition of the 325 non-native plant pests established during the period 1787–2004. Establishments with no date are distinguished from those first recorded before and after 1970.

Taxon	Number to date	Before 1970	After 1970	Total established
Homoptera (leafhoppers and allies)	28	46	47	121
Lepidoptera (butterflies & moths)	10	49	43	102
Coleoptera (beetles)	2	5	20	27
Hymenoptera (ants, bees & wasps)	1	5	8	14
Heteroptera (shield bugs & allies)	2	3	8	13
Orthoptera (grasshoppers & allies)	0	5	5	10
Thysanoptera (thrips)	0	2	4	6
Diptera (true flies)	0	0	6	6
Acari (mites)	0	3	11	14
Nematoda (nematodes)	0	0	4	4
Tricladia (flatworms)	3	3	2	8
Total	46	121	158	325

Of the 109 (33.7%) established species with a CSL file (indicating a significant pest risk), 59 (54.1%) species have established since 1970. Only 3 (5.1%) of these 59 species were indirect pests, either parasites of honey bees or predators of other beneficial invertebrates. The pests established on cultivated hosts were all associated with ornamental plants, apart from *Dendroctonus micans* which feeds on forest trees. In the period following 1970, 46 species (80.7%) posing a significant pest risk occurred outside protected cultivation.

Knowledge of the pathways by which plant pests enter a territory is critical to risk management. The first step in identifying sources of risk is to assess which plant pests have established naturally and which have been intentionally or unintentionally introduced by man. Although there were insufficient data for 54.1% of established species (176 out of 325), 67.8% (101) of all known cases established unintentionally. For the two largest taxa in the database, a higher proportion of the Lepidoptera compared with the Homoptera became established by natural colonization (46.5% versus 5.7%, respectively). Of the post-1970 species posing a significant pest risk to cultivated hosts, 43.6% (24) were introduced unintentionally by man, compared with 5.5% (3) that established naturally. The mode of entry could not be designated for the remaining 50.8%. After 1970 there was no clear upward or downward trend in the number of species establishing unintentionally, the proportion of unintentional establishments in each decade (including 2000-04) fluctuating ranging from 30 to 60%.

Identifying trends in the principal countries of origin for non-native pests is also of great importance. Here, origin is defined as the country or region where a pest is indigenous, rather than the direct source of entry into Great Britain, although such information is still important when identifying the principal entry pathways for non-native pests. The greatest proportion of established non-native plant pests, 19% (51), originated in Europe. However, this might be erroneous since 60% of the 325 plant pests lacked data on their origin. For plant pests posing a significant risk of damage and established since 1970, 36% (21) originated in continental

Europe, whereas 20% (12) came from North America (Table 2). Only 10% (6) of these post-1970 establishments lacked data on their origin.

Table 2. Origin of pests established since 1970 posing a significant risk to plants.

Origin	1970s	1980s	1990s	2000–04	Total	%
Africa (unspecified)	0	1	1	0	2	3.4
Asia	1	0	6	1	8	13.6
Australia & New Zealand	1	1	2	0	4	6.8
Europe	3	7	7	4	21	35.6
Japan	0	0	2	0	2	3.4
North Africa	1	0	0	0	1	1.7
North America	3	4	3	2	12	20.3
South America	0	2	0	1	3	5.1
Insufficient data	1	0	4	1	6	10.2
Total	11	15	25	9	59	

For comparison, some data on non-native plant pests are available from France (Martinez & Malausa, 1999), Italy (Pelizzari & Dalla Monta, 1997) and Spain (Pérez Moreno, 1999).

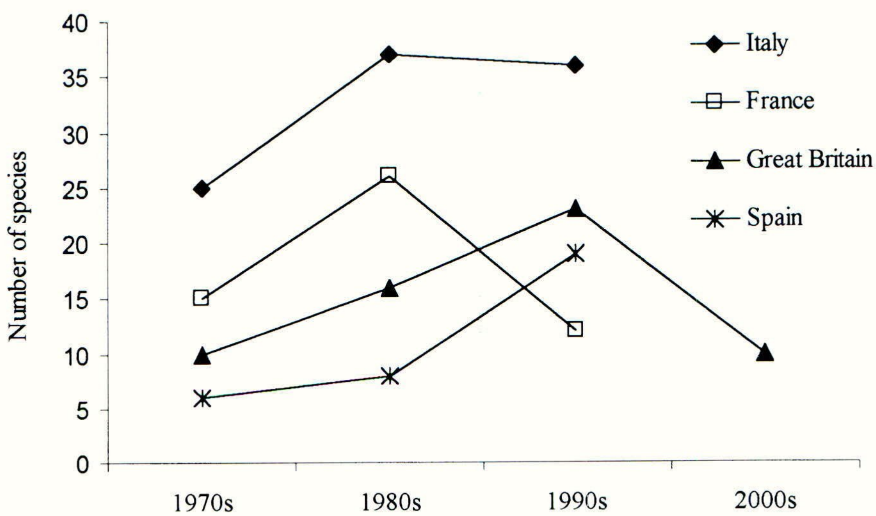

Figure 1. Trends in plant pest establishments in four European countries since 1970. Apparent declines are probably due to incomplete reporting for the decade in which the studies were published.

These countries experienced substantial increases in the number of establishments during the 1970s and the 1980s (Figure 1), and apparent declines in the 1990s are likely to be due to the lag in reporting new species. The overwhelming majority of pests belong to the Homoptera (Table 3). As in Great Britain, relatively few establishments in Italy (18.4%) have occurred in protected environments. In contrast, in the Netherlands, although strictly comparable data are unavailable, at least 30 out of 72 species (41.7%) have established in protected environments since 1900 (Van Lenteren 1987).

Table 3. Numbers of established non-native plant pests recorded from selected European states since 1970 (see text for sources).

	Great Britain	Italy	France	Spain
Homoptera	26	76	37	15
Lepidoptera	6	8	8	3
Coleoptera	8	7	3	5
Diptera	3	4	3	3
Thysanoptera	2	3	2	2
Heteroptera	3	0	0	1
Hymenoptera	4	0	0	0
Acari	3	0	0	4
Nematoda	2	-	-	-
Tricladia	1	-	-	-
Total	58	98	53	33

DISCUSSION

As for any country, it is exceedingly difficult to compile an accurate database containing all the non-native plant pests which have established in Great Britain. Even if all the original sources of reports can be read, to ensure that the new record is not a taxonomic revision or the new finding of a species which is likely to be native, some records will remain unclear. This is particularly the case for taxa, such as the Nematoda and Acari, for which no British checklists exist. In addition, new non-native records may include species which have arrived but subsequently died out. Evidence for their continued existence can be obtained only by field visits. Even with an accurate list of names, further work will be necessary to obtain the additional information for each species required to analyze trends. High priority needs to be given to obtaining accurate and up-to-date estimates of the damage caused by plant pests. Alternative surrogate measures could be based on the research effort per species, number of hosts, pesticide usage or host value. The acquisition of further information on modes of entry and pathways of introduction is also very important. The analysis of trends in establishment rates is greatly influenced by variations in recording rates over time. Allowing for such biases in establishment rates is very difficult, because they may be due to changes in such factors as the number, ability and enthusiasm of recorders, the availability of good identification keys, the number of taxonomists, the degree of general interest in non-native species and the accessibility of data.

This assessment of non-native plant pests in Great Britain suggests that, over the last 30 years, the establishment rate has been increasing by approximately five damaging species per decade. Only a thorough examination of pre-1970 records would confirm whether this is a long-term trend. However, exotic insect introductions have been shown to be correlated with trends in international trade (Levine & D'Antonio 2003). While the number of organisms invading Great Britain is too low to confirm changing trends in respect to geographical source, Asia stands out as a region supplying a relatively large number of recent introductions. Given that most damaging new pests which have recently been recorded in Great Britain are associated with non-native ornamental plants, and that this is an expanding area of trade, it seems likely that such establishments will continue to accelerate. Although the scale of introductions in Great Britain is broadly similar to that of other European states, and the pattern in taxonomic composition is repeated across countries, greater standardization in reporting is needed before robust comparisons can be made.

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