Session 8A

Invasive Alien Species Risk Analysis 1

Chairman:	Dr Ray Cannon *Central Science Laboratory, York, UK*
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Platform Papers:	8A-1 to 8A-5
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New methods for analyzing risks to New Zealand of invasive alien species

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With the primary production sector (agriculture, horticulture and forestry) representing as much as 65% of New Zealand's annual foreign exchange earnings, it is hardly surprising that New Zealanders take biosecurity and the management of the risks to invasive alien species (IAS) so very seriously.

New Zealand has a number of natural geographic advantages in the management of these risks: its isolation (now mainly historical); the limited number of ports of entry (28) to an island nation; and the uniqueness of the natural botanical environment. When compared to land-bordered countries in most of the rest of the world, the task of managing the risks from IAS to New Zealand's economy, environment and human health is relatively straightforward. This allows the New Zealand government and industries to develop and implement leading edge approaches to the management of IAS risks.

In the early to mid 1990s the New Zealand government introduced two significant pieces of legislation to manage the introduction of alien species into New Zealand; the Biosecurity Act 1993 to manage the unintentional introductions of alien species, and the Hazardous Substances and New Organisms Act 1996 (HSNO Act) to manage deliberate introductions. Unintentional introductions occur when contaminated goods or organisms that are imported into New Zealand act as vectors for IAS.

These two pieces of legislation use risk management as the basis for decision making and have common definitions for 'organisms', 'environment' and other aspects critical to the management of IAS risks. Another key similarity between these Acts is the assumption that all IAS are prohibited entry into New Zealand unless approved for import, the typical 'white list' approach. The key difference between these two Acts is that, unlike the HSNO Act, the Biosecurity Act is framed under the WTO Agreement on the Application of Sanitary and Phytosanitary Measures (SPS Agreement) and does not consider the benefits or otherwise of trade when considering the risks of any contaminating IAS.

When developing a possible framework for managing risks under the SPS Agreement, the agreement itself provides the option of using existing international standards developed for animal health and zoonoses under the International Office of Epizootics (OIE) and plant health developed under the International Plant Protection Convention (IPPC). When considering New Zealand's holistic approach to managing IAS risks to all aspects of the New Zealand economy, environment or society, these international standard-setting bodies do not necessarily cover all of the potential types of IAS threatening New Zealand. For IAS risks not covered by the above organizations, such as many invasive ant species and marine organisms, an alternative risk management process was required.

New Zealand's approach to the management of the risks of IAS in trade endeavours to encapsulate the standards of these international standard-setting bodies while ensuring the gaps between them are also appropriately managed. This single all-eclipsing process has been a relatively recent development in New Zealand IAS management and has largely arisen in response to ever-increasing incursions of IAS that would not classically be considered pests of the primary industries. Examples of such recent IAS incursions include red imported fire ants (*Solenopsis invicta*), yellow crazy ants (*Anoplolepis gracilipes*), *Didymosphenia geminata* (a freshwater alga), and *Styela clava* (a club shaped sea squirt). These IAS could best be described as both hitchhiker species that are carried as passengers in trade and ecological pests that damage the environment, and are not considered to affect animal or plant health directly, or be classified as zoonoses.

The underlying principles supporting the IAS risk management are that the process must be science based, transparent to those affected by the decisions arising, consistent both in application and outcome, comprehensive in the values assessed and precautionary in its approach to uncertainty. Not surprisingly the risk analysis and management process follows those described in international standards:

- Hazard identification, where all organisms are identified that could potentially be associated with the trade pathway, including hitchhikers and environmental pests;
- Risk assessment, where all potential impacts to the economy, the environment, and to human health and society are estimated;
- Risk management, where the management objectives are defined and management options identified.

Many limitations and uncertainties invariably underlie any risk management process. Important assumptions and uncertainties are recorded and the level of residual risk, the risk remaining after the management options have been successfully applied, is estimated to provide a guide for later performance review. Many of the assumptions and uncertainties can be reduced through better information management relating both to the movement and interception of IAS in international trade and the relevant biological information about IAS. While science disciplines such as taxonomy have been in decline over the last half century, they are fundamental to the management of the risks of IAS.

Many of the innovations in the management of IAS risks in New Zealand have arisen through the acceptance of tolerances for IAS contamination that are greater than zero. This has allowed risk analysts to make meaningful comparisons between IAS contamination limits and the efficacy of proposed measures. New Zealand has also recently introduced a number of technological and science initiatives into the management of IAS risks in an attempt to reduce aspects of this uncertainty. Comparative molecular sequencing of important agricultural and environmental organism families, such as the *Phytophthora* or 'plant destroyer' fungi-like organisms, has greatly improved our understanding of what does and does not already exist in New Zealand. The use of isotope ratio mass spectrometry has greatly enhanced our ability to identify the sources of invading IAS and determine the pathways of greatest risk into New Zealand for more targeted risk management. The application of these and other tools has greatly enhanced New Zealand's ability to effectively manage the risks posed by IAS to the economy, environment and human health of New Zealand.

Can one predict the introduction, establishment and impact of invasive alien insects using species traits?

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Introduction

Species traits are commonly used to develop invasion risk assessment schemes for plants and similar schemes have recently been developed for other exotic organisms such as fish. In contrast, species traits have rarely been considered as tools to assess invasiveness in insects. Although several biological and ecological traits have been cited in the literature as being associated with insect invasion processes, few of them have been tested. Furthermore, all former studies concerned traits associated with establishment, often using biological control agents as models, whereas those traits correlated with the entry phase of insect invasion have been largely ignored. Species traits and other predictive characters could also be used to identify those species most likely to have an impact on the economy or the environment. We used several databases and methods to test species traits and characteristics, which we believe are associated with invasion success. When possible, the different stages of the invasion process were considered separately.

Traits associated with invasion success in general

Traits associated with invasion success can be determined by comparing traits in alien and native fauna. We compared the taxonomic order/sub order and the feeding niche of immature stages between the 341 non-indigenous insects established in Switzerland and Austria and the 92,000+ European insects listed in Fauna Europaea. This analysis showed that Hemiptera, Sternorrhyncha, Psocoptera and, to a lesser extent, Coleoptera, are particularly over-represented in the alien fauna compared to the native fauna. In contrast, Diptera and Hymenoptera are underrepresented. Sap feeders and detritivores were the dominant feeding niche in the alien insect fauna whereas external defoliators, stem borers, gall makers, root feeders, predators and parasitoids were underrepresented. Such comparisons between non-native and native fauna have two limitations.

Firstly, given the large size of these databases and the limited information available for the majority of insects, only a few easily available traits can be analysed. Secondly, such comparison does not show which stage of the invasion process, i.e. entry, establishment or spread is favoured. These problems can be overcome by testing a selection of well-known insects, e.g. plant pests or biological control agents, using new datasets such as quarantine lists, interception data and biological control introductions.

Traits associated with introduction

To test which traits may favour the introduction of an insect, two databases of plant pests were compared: (1) quarantine insect pests that have been on the A1 list of EPPO for at least five years and have never been intercepted (considered as 'poor travelers'); (2) plant pests intercepted by national European phytosanitary services in the period 1995-2005 (considered as 'good travellers'). Only temperate species were considered. These two groups were compared using logistic regressions and Generalized Linear Mixed Models (GLMM). Traits and characteristics positively associated with the entry, or at least interception, of plant pests in Europe were: multivoltinism, small size, uniparental reproduction, polyphagy and 'invasiveness elsewhere'. In addition, great variations were found between taxonomic group and feeding niche, sap feeding Sternorrhyncha being proportionally much more frequently intercepted than the other groups. A logistic regression model including the factors 'feeding niche', 'voltinism', 'host range' and 'invasive elsewhere' correctly assigned 87.5% of the insects to their group.

Traits associated with establishment

Species traits correlated with establishment were tested using two methods. In the first analysis, we compared traits of alien plant pests intercepted by phytosanitary services in Europe that never became established (considered as poor establishers) with alien plant pests in Europe (considered as good establishers). Analyses were made using logistic regression and GLMM. Traits positively associated with establishment were: small size, multivoltinism, monophagy, short adult stage and being a sap feeder.

Biological control programmes using alien biological control agents against weeds and insect pests are of particular interest to study traits associated with establishment success because, firstly, the biology of biological control agents is often very well known and secondly, biological control programmes usually provide reliable information on the introduction phase, i.e. the year/season and site of release, the development stage released, the number of individuals released and the outcome of the introduction: established or not. A database was built with 1126 releases of 98 insect species introduced in the USA, Canada, New Zealand and South Africa. A GLMM was performed with the establishment result as a dependent variable and various biological traits as explanatory variables. Factors associated with establishment success were propagule size, i.e. the number of individuals released, a small body size and a long development time. In contrast, feeding niche, fecundity and voltinism were not significantly correlated with establishment success.

Traits associated with impact

Species traits have never been used to assess the potential impact of alien insects, partly because of the difficulty in quantifying their economic and ecological impact. A study is presently being carried out to identify species traits associated with the impact caused by alien insects, using a database of alien insects established in Switzerland. In a GLMM, we use the number of Swiss web pages describing any type of impact – economic, ecological, aesthetic, medical, etc, as a dependent variable and various species traits as explanatory variables. Final results will be presented at the conference.

Conclusion

The results presented in this study are only preliminary. Models have to be validated and improved using other, similar databases, e.g. from other temperate regions. A second step will be to use these data to develop new risk assessment tools that will be easily used by pest risk analysts.

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Changes in a spider mite community after the introduction of the invasive pest *Tetranychus evansi* (Acari: Tetranychidae)

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Spider mites (Acari: Tetranychidae) are important pests in agricultural systems throughout the world. The two-spotted spider mite, *Tetranychus urticae* Koch, and the strawberry spider mite, *T. turkestani* Ugarov & Nikolski, are Old World species that are very commonly associated with vegetable crops, fruit trees and weeds along the Mediterranean coast of Spain. Alien species, such as *T. ludeni* Zacher, have also been introduced to Spain, though the pathway of introduction is not known.

The tomato spider mite *T. evansi* Baker & Pritchard is an important pest of solanaceous crops, including tomato, potato and tobacco in some tropical, subtropical and Mediterranean areas. This species probably originates from the Neotropical Region and since the early 1960s has reached other parts of the world, being recorded in California (1967), Zimbabwe (1982), western Mediterranean countries such as Morocco (1988), Portugal (1992) and Spain (1995), Kenya and other countries in Africa (2002-2003) and recently in France, Italy and Israel. Since its introduction in Spain, *T. evansi* has rapidly spread throughout Mediterranean coastal areas and the Canary Islands, causing considerable damage to tomato, eggplant and potato, both outdoors and in greenhouses.

We analyzed the changes in spider mite communities inhabiting vegetable crops and weeds in this geographical area after the introduction of the tomato spider mite. Applying the same sampling methodology, data available on the distribution, abundance and host range of *T. urticae*, *T. turkestani* and *T. ludeni* immediately prior to the invasive process (year 1994-1995) were compared with data obtained ten years later (2005-2006) in the same agricultural area. Our objective was to clarify whether *T. evansi* might ultimately affect the numbers or distribution patterns of already established spider mite species via competition for common resources or by other methods.

Comparing abundance and relative abundance

The total number of mites in the samples differed between 1995 and 2005. The absolute abundance of *T. urticae* and *T. turkestani* changed significantly. Prior to 1995, spider mite communities were comprised almost exclusively of the two species. In 2005, *T. evansi* made up 62.7% of the spider mite population and the absolute and relative abundance of *T. urticae*, *T. turkestani* and *T. ludeni* decreased strikingly. When data on mite abundance in cultivated and non-cultivated plants were analyzed separately, the differences for *T. urticae* and *T. turkestani* between the two time periods were statistically significant only on weeds. Within this habitat *T. evansi* represents more than 80% of the total number of spider mites.

Comparing association between species, distribution pattern and overlap

A negative association between *T. evansi* and the other spider mite species was observed in the samples suggesting that the occurrence of the tomato spider mite reduces the probability of other *Tetranychus* species being present. However, a positive association was found between *T. urticae* and *T. turkestani*.

The establishment of *T. evansi* led to a pronounced reduction in host plant use by *T. urticae*, *T. turkestani* and *T. ludeni*, especially on non-cultivated plants. In 2005 on weeds surrounding vegetable crops, *T. urticae* and *T. turkestani* were collected on a third and *T. ludeni* occurred on a half of the host plants compared to 1995. Although it is generally considered as a Solanaceae specialist, *T. evansi* clearly dominated this habitat, occurring on 15 of the 39 species sampled,. We estimated the niche overlap in plant use between paired species by calculating the percentage overlap. The largest overlap was noted between *T. urticae* and *T. turkestani* (80.7%). Although absence of overlap does not always imply competition, the low overlap observed between *T. evansi* and other *Tetranychus* species (between 1.8% and 6.7%) suggests the change in the distribution pattern of the other species may be due to exclusion from most of the host plants they previously colonized.

Classifying host plant range of spider mites after the introduction of *T. evansi*

Non Metric Multi-Dimensional Scaling (NMDS) ordination techniques and the Analysis of Similarity (ANOSIM) using the Bray-Curtis similarity measure were employed to compare the abundance of each species on different plants. The resulting ordination graphs for the paired species *T. urticae/T. evansi* and *T. turkestani/T. evansi* show that plant species are arranged into two clearly separated groups, indicating associations between each spider mite and plant species. An agglomerative cluster analysis using Average Linkage Bray-Curtis and Euclidean distances was used to group plant family hosts for these species pairs. The resulting tree diagrams revealed that the Solanaceae forms a separate group probably due to the high density of *T. evansi* on members of this family. A threshold of 60% of similarity leads to four groups for *T. urticae/T. evansi* whereas three groups were observed with *T. turkestani/T. evansi*.

These results on the relative abundances and the comparative distribution of spider mites provide indirect evidence for interspecific competition. The establishment of *T. evansi* appears to have modified the spider mite community structure by displacing closely-related spider mite species. The data do not provide evidence on the factors that mediate the displacement. Field observations have shown that *T. evansi* is able to survive and reproduce on a wide range of host plants, promoting interspecific competition with polyphagous spider mites. Furthermore, predatory mites are absent in the colonies of *T. evansi* and escape from natural enemies may confer an advantage when the exotic species compete with native spider mites. The consequences of these findings on the economic impact of *T. urticae* and *T. turkestani* on vegetable crops are still unknown. Further investigations are required to fully assess the environmental impact of this new pest in Europe.

Biological study of the coconut hispine beetle, *Brontispa longissima* Gestro (Coleoptera: Chrysomelidae) on coconut, *Cocos nucufera* L. and lesser bulrush, *Thypha angustifolia* L. leaves

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Introduction

The coconut hispine beetle, *Brontispa longissima* Gestro is one of the most serious insect pests of coconut in Southeast Asia. The beetle is native to Indonesia and Papua New Guinea and it was accidentally introduced into continental Southeast Asian countries, presumably in the early 2000s, with ornamental palms (FAO, 2004). The beetle infests more than 20 palm species uniquely in the family Arecaceae with coconut (*Cocos nucifera*) being the favoured host. The pest attacks the youngest leaves of the palm trees. The larvae of the beetle chew on large areas of the surface of the leaflets. Less compact hearts are more susceptible to *B. longissima* attacks (CABI, 2002).

B. longissima represents a threat to the US$30 million coconut industry and the 50,000 smallholders in the southern and central parts of Thailand. It is also a threat to the tourist industry of Koh Samui and Koh Pa-ngan. Damage caused by *B. longissima* in Thailand was first recorded in Narathiwas province, the border area near Malaysia, in 2000. Heavy infestation was first reported in February 2004 in southern provinces including Surat Thani (Samui Island and Pa-ngan Island) and Prachuap Khiri Kan (FAO, 2004). According to the Thai Department of Agriculture (DOA), the total areas hit by the coconut beetle outbreaks amounted to 7,229 hectares in 2005.

Since chemical control has not been used due to its high costs and risks for the environment, biological control has been recommended. With the support of FAO, the larval parasitoid, *Asecodes hispinarum* Boucek was introduced into Thailand via Vietnam in August 2004. Mass production of the parasitoid was limited by the difficulty in gathering the unopened young coconut leaflets used for *B. longissima* rearing. Alternative food sources were investigated. During the preliminary survey, we found some adults feeding on lesser bulrush (*Thypha angustifolia* L.), a widespread aquatic weed in Thailand. A comparative laboratory study on the biology of *B. longissima* was then conducted in order to determine whether the beetle can survive and complete its life cycle on lesser bulrush.

Comparative study on the biology of *B. longissima*

Beetles were reared either on unopened young coconut leaflets or on lesser bulrush leaves. The number and duration of the developmental stages, adult longevity and survival rate from egg to adult and female fecundity were recorded and analysed (see Table 1 and 2). The number of development stages were the same on both food sources (four larval instars, a pre-pupal and a pupal stage). However, the life cycle of the beetle on lesser bulrush was statistically shorter than that on coconut.

Table 1. The number and duration of the developmental stages of *Brontispa longissima* fed on unopened young coconut leaflets and lesser bulrush leaves in laboratory conditions (28±0.5 °C and 80±2 %RH)

Stage	Developmental period (days)				T-test
	Coconut leaflets		Lesser bulrush leaves		
	mean±sd	rank	mean±sd	Rank	
Egg	3.33±0.62	3-5	3.80±0.77	3-5	2.432
Larva	21.33±0.51	18-25	18.13±0.83	17-20	5.870
1st instar	4.60±0.70	4-5	4.13±0.35	4-5	3.500
2nd instar	4.93±0.91	4-6	4.33±0.49	4-5	2.806
3rd instar	5.60±0.86	4-7	4.47±0.52	4-5	4.141
4th instar	6.20±1.80	5-7	5.20±0.41	5-6	4.583
pre-pupa	1.73±0.46	1-2	1.53±0.52	1-2	1.871^{ns}
Pupa	6.33±0.49	6-7	5.40±0.51	5-6	4.090
adult longevity					
Female	143.53±15.45	120-162	120.67±6.85	108-131	4.953
Male	94.47±4.52	90-105	93.13±4.93	85-102	1.614^{ns}

^{ns} = non-significant, d.f. = 14 (P>0.05)

Table 2. Survival rate from egg to adult and fecundity of *Brontispa longissima* fed on unopened young coconut leaflets and lesser bulrush leaves in laboratory conditions (28±0.5 °C and 80±2 %RH)

Food source	Survival rate (%)	Fecundity	
		Number of eggs per female ± sd	Oviposition period ± sd (days)
coconut leaflets	68.33	119.70±14.46	126.04±16.49
lesser bulrush leaves	51.33	66.87±9.74	90.78±6.27

Table 2 shows that females lost nearly 50% of their capability to produce eggs when forced to feed on lesser bulrush. A reduced egg to adult survival rate and oviposition period also occurred in the population reared on lesser bulrush.

Conclusion

Although survival and reproduction is reduced on lesser bulrush leaves, *B. longissima* can successfully complete its life cycle. With at least two plant families now identified as suitable hosts, *B. longissima* has a greater probability for permanent establishment in Thailand. Moreover, the lesser bulrush provides an additional and more readily available plant for mass-rearing the beetle in order to produce natural enemies, e.g. *A. hispinarum*.

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EPPO activities for the risk analysis of invasive alien species

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The European and Mediterranean Plant Protection Organization (EPPO) is a standard-setting organization created in 1951. Under the International Plant Protection Convention (IPPC), EPPO is the regional plant protection organization (RPPO) for Europe. In 2007 it has 48 member countries, which include all members of the European Union, Russia, several countries in the Commonwealth of Independent States as well as some Mediterranean countries in North Africa and the Near East. EPPO's partners are National Plant Protection Organizations, i.e. the official services that are responsible for plant protection in each country (usually part of agriculture ministries). One of EPPO's main priorities is to prevent the introduction of dangerous pests from other parts of the world, and to limit their spread within the region should they be introduced. More information on EPPO's activities is available at www.eppo.org.

In recent years, the international plant health framework has changed and a striking acceleration in EPPO activities has taken place. International trade networks have expanded and diversified, increasing the risks of introducing pests to new geographical areas. In addition, there is strong political pressure for free trade; phytosanitary regulations which are set up by governments to protect their agriculture from pests are often perceived as barriers to trade.

According to the Agreement on Sanitary and Phytosanitary measures (SPS agreement) and the IPPC, phytosanitary measures adopted by countries should be technically justified. International Standards for Phytosanitary Measures (ISPMs) on Pest Risk Analysis (PRA) have been developed in the IPPC framework and are the international standards used for technical justification in the World Trade Organization (WTO). In 2002, EPPO Council agreed that invasive alien species affecting plants are quarantine pests. Quarantine pests include pests of agriculture, forests and wild flora, and they may be plants themselves. EPPO's activities regarding the risk analysis of invasive alien species are presented below.

Development of regional standards on Pest Risk Analysis (PRA)

Since the 1990s, the EPPO Panel on PRA has been involved in developing schemes for pest risk assessment (PM 5/3 adopted in 1997) and pest risk management (PM 5/4 adopted in 2000). The first version of ISPM no. 11 on PRA for Quarantine Pests was adopted in 2001 (and its supplement in 2003 and 2004). This international standard is the reference for the SPS Agreement and would be the basis in case of disputes between countries about phytosanitary measures. EPPO member countries favoured maintaining the EPPO schemes for pest risk assessment and pest risk management since, unlike ISPM no. 11, they present logical sequences of questions which address all the elements mentioned in this ISPM (except those regarding living modified organisms). EPPO Standards have also been adapted for invasive alien plants.

The EPPO pest risk assessment and pest risk management schemes have now been combined into an EPPO decision-support scheme which is available on the EPPO website. It provides detailed instructions for the following stages of PRA for quarantine pests: initiation, pest categorization, probability of introduction, assessment of potential economic consequences and pest risk management. It provides a simple scheme based on a sequence of questions for deciding whether an organism has the characteristics of a quarantine pest and, if appropriate, to identify potential management options. The scheme can also be used for PRAs initiated by the identification of a pathway or a policy review. It is revised on an annual basis to improve the guidance given to assessors. A computerized version of the scheme is being prepared. Guidance for the use of additional tools, e.g. CLIMEX, and impact assessment tools for PRA are also being developed to assist users in mapping endangered areas for establishment and impact.

Performing and reviewing PRA to recommend regulation of invasive alien species

In order to achieve the objectives of preventing the introduction of dangerous pests from other parts of the world, limiting their spread within Europe should they be introduced and developing cooperation between member countries, EPPO Council approves two lists of pests that are recommended for regulation in all or part of the EPPO region. The first list is of A1 pests, not present in the EPPO region. The second list is of A2 pests, present in the EPPO region but not widely distributed (i.e. absent from or not widely distributed in endangered areas in certain countries, where they are subject to official control). The first lists were approved in 1975. In 2006, they contained 292 pests and are available on the EPPO website. The addition of a pest to the lists is based on a proposal by a member country in the form of a PRA, which is subsequently reviewed by the Panel on Phytosanitary Measures.

A Panel on Invasive Alien Species, created in 2002, currently concentrates on invasive alien plants. It performs and reviews PRAs on plants and is developing a process to determine which invasive alien plants should have the highest priority for PRA. It has so far compiled a list of about 40 species (see www.eppo.org) to be studied in detail and five plants are now recommended for regulation. Since 2006, Expert Working Groups (EWGs) have been created to conduct PRAs on specific pests.

The Working Party on Phytosanitary Regulations chooses the pests for which a PRA should be performed, but there is sufficient flexibility in the process to ensure that a PRA can be conducted on a new emerging pest. The EWG has an *ad hoc* membership in order that experts on specific pests can be called upon to participate when needed, as well as core members to provide consistency in conducting PRA. PRAs on pests are performed during the meetings of the EWG for PRA, following the EPPO PM 5/3 Decision-support scheme for quarantine pests. Expert Working Groups have already been organized on *Phytophthora lateralis*, *Iris Yellow Spot Virus* and *Megaplatypus mutatus*. EWGs are planned in 2007-2008 for *Tetranychus evansi*, *Bactrocera invadens*, *Aulacaspis yasumatsui*, *Diocalandra frumenti*, *Metamasius hemipterus*, *Raoellia indica*, *Eichhornia crassipes* and *Xanthomonas axonopodis* pv. *alli*. In addition, EPPO continues to review PRAs produced by individual member countries, and encourages its member countries to perform PRAs. EPPO intends to post all PRAs prepared within its framework on the public part of its website. Once a pest has been through the PRA process and has been placed on the A1 or A2 list, EPPO recommends that its member countries consider it for inclusion in their phytosanitary regulations.

Identifying and reducing the risks posed by potato ring rot to the Scottish potato industry

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Introduction

The introduction of the quarantine bacterium, *Clavibacter michiganensis* subsp. *sepedonicus* (*Cms*), the causal agent of potato ring rot, would be very costly to Scottish seed potato production and the Scottish potato industry as a whole. The cool Scottish climate would be beneficial to *Cms* survival and the ability of *Cms* to infect tubers latently could allow it to survive undetected in high numbers over several generations of seed multiplication. While Scotland is currently free from *Cms*, this disease-free status may not continue unless the risks of infection are identified and reduced.

The risks *Cms* poses to the Scottish potato industry are being evaluated using a multi-disciplinary approach involving a number of organisations (SASA, CSL and SCRI). The project includes a study of *Cms* epidemiology under Scottish conditions, detection and current control measures and stakeholder involvement. This work focuses on two aspects: susceptibility of key Scottish seed cultivars and assessment of weak points in current agronomic practices.

Cultivar susceptibility

The 10 seed cultivars most commonly grown in Scotland in 2005 (http://www.sasa.gov.uk/mediafiles/7917ED5D_D5BD_02D3_AE45C17B0AD05933.pdf) were assessed for disease susceptibility in a glasshouse trial. Thirty-day-old plants, stem-inoculated with *Cms* cells, were observed during a 21 week period. Foliar symptoms were evident in some plants during the growing season but there was no direct correlation between cultivar and symptom expression. This emphasises the difficulty in providing key cultivar-specific diagnostic information to growers and stresses the necessity to maintain post-harvest testing rather than field inspections of the growing plant alone. Tuber analysis using real-time PCR revealed all cultivars were infected; cvs Desiree and Maris Peer showed lower infections in contrast to cvs Estima and Hermes that showed the highest. Current glasshouse trials aim to evaluate the effect of infection level on disease progression in a selection of progeny from these cultivars.

Assessing weak points in current trading and agronomic practices

Rigorous cleansing and disinfection regimes are required to prevent the spread of the disease should it be introduced; however, an exclusion policy is the only approach which will guarantee Scotland remains ring rot free. A fact that has been recognised by the industry with the introduction in 2005 of the Safe Haven Scheme by The British Potato Council (http://www.potato.org.uk/media_files/campaigns_kt/safehaven.pdf). In order to gain an insight into current practices that would allow the introduction of the disease or facilitate its spread if introduced, a postal survey was constructed and sent to 548 Scottish potato growers. The 46% of growers who responded were categorised into three types of business type: seed-only, seed and ware or ware-only.

Introduction of the disease is most likely to be via infected seed potatoes (CABI, 2006). The routes through which growers source their seed for seed or ware production were classified as low risk (minituber, own classified or home saved), medium risk (same grower every year) or higher risk (merchant or open market). For seed production, the higher risk strategy is followed by 44.6% seed-only businesses and 52.1% seed and ware businesses. In contrast, 39.4% of seed and ware, and 64% of ware businesses source their seed for ware from higher risk sources.

In addition infection may also occur *via* machinery such as grading equipment. Shared machinery therefore increases risk. We confirmed that 4% of ware-only growers plant potatoes graded by packers and that a small proportion of seed-only and seed and ware growers also use packers to grade their potatoes. Grading of seed potatoes by a packer may present a risk of cross infection since packers may also be grading high risk ware material for immediate consumption.

Practices that could facilitate the spread of the disease once introduced were also identified. Of the growers who grade their own potatoes, only 57.9% seed-only, 47.8% seed and ware and 13.2% ware-only growers clean their graders to a standard that would kill *Cms* should it be present. Overall, 37% of graders are only dry cleaned and, with the exception of seed-only growers, some growers claimed never to clean their graders. In addition, over 70% of seed and ware and ware-only growers retrieve and re-use empty boxes and, when asked how potatoes were supplied to customers, over 50% of these types of business only dry cleaned the boxes. We also confirmed that some, including seed-only growers, were re-using bags. It is clear that these practices in themselves may be judged by some within the industry as posing minimal risk, however, if *Cms* was ever to be introduced into Scotland all these practices could contribute to its further spread.

The survey has confirmed that a number of potentially risky practices are occurring within the industry. These practices present other risks such as the introduction of the quarantine disease brown rot or the spread of quality diseases like black leg. Straightforward hygiene measures such as disinfecting boxes could be readily implemented and would be cost-effective. Although post-harvest testing will continue to be carried out by the authorities, it is crucial that growers are alerted to these risks so practical solutions, such as participation in the Safe Haven Scheme, can be found and adopted.

Acknowledgements
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Host preference of western flower thrips to ten vegetable seedlings in protected cultivation

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Introduction

The western flower thrips (WFT), *Frankliniella occidentalis* Pergande (Thysanoptera: Thripidae) originally found in northern America, is one of the world's major pests and is damaging to a wide range of economically important crops directly through feeding and indirectly through the transmission of harmful plant virus diseases. As an invasive alien species, it was first found in June 2003 on a protected crop of green pepper in Beijing, China. Since then, its biology, population dynamics, hosts and damage status have been studied (Wu *et al.*, 2005; Ren & Lei, 2006; Lu *et al.*, 2006, Wu *et al.*, 2007). WFT can feed on 500 plant species (belonging to 60 families) of ornamentals, orchids, vegetables and weeds worldwide. Ren &Lei (2006), in a survey conducted in 2003-2005, found that more than 35 vegetable species are damaged by WFT in Beijing. These included green beans, lettuce, cucumber, eggplant, green pepper and tomato; Holland cucumber, melon and white radish were the most seriously infested. These papers described the host range of WFT and the extent of damage but not the host preferences. This paper reports the preference of WFT for 10 vegetable species in protected cultivation in Beijing.

Material and methods

Seedlings of 10 vegetable species commonly grown in Beijing were used in this experiment. The common name and the number of seedling leaves are listed in the first two columns of the table. The vegetable seeds were sown singly in plastic cups in a glasshouse. Because each vegetable has a different development time the number of vegetable leaves differed by the time the experiment was conducted. In a green pepper field with a high density of WFT, about 100 pepper plants were pulled out leaving an empty rectangle (2m x 1m). The experiment was conducted at an average temperature of 18°C and a humidity of 88%RH). Ten vegetable species seedlings (four seedlings for each species) were then randomly planted in two lines in the middle of the rectangle. Forty-eight hours later all the adults on the seedlings were counted and then removed from the plants. The seedlings were then taken into the laboratory and kept at an average temperature of 23°C and a humidity of 54%RH until the larvae hatched and could be clearly counted by eye. All the larvae on the seedlings were then recorded. Four seedlings of each vegetable (total 200 seedlings) were grown and five replicates were made.

Results

The table shows that WFT adults significantly preferred green beans (372 adults/seedling) followed by cucumber (246 adults/seedling). Squash was third (77 adults/seedling) in the preference list but there was no significant difference between this and the other seven vegetable species. WFT adults did not show a preference for seedlings of eggplant, cabbage, cauliflower and pepper (less then 10 adults/seedling were found on these four kinds of vegetable). The data for the number of WFT larvae on seedlings (the fourth column in the table) showed that the strongest preference was for the same three vegetables in the same order as for the adults. There were a very large number of larvae on green beans (1129 larvae/seedling) and cucumber (880 larvae/seedling).

Table 1. Preference of WFT to seedlings of ten vegetable species

Vegetable	No. of leaves	Adults/seeding	Larvae/seedling
Green bean	2	372±122.8aA	1129±137.6aA
Cucumber	2	246 ±126.5 bB	880±141.0bB
Squash	2	77 ±37cC	629±195cC
Rape	6	25 ±43cC	467±80.2cC
Tomato	6	19 ±24.9cC	20±26fE
Chrysanthemum coronarium	10	19±12.9cC	288±91.9eD
Eggplant	3	7±2.7cC	67±13.5fE
Cabbage	6	6±4.1cC	41±18.1fE
Pepper	6	5±2.8C	8±4.3fE
Cauliflower	6	4±3.6C	20±7.6fE

Note: Data followed by the different letters indicated that there were significant differences between preferences of WFT for vegetables. Capital letters show where the differences are significant at $P<0.01$, small letters ($P<0.05$)

Discussion

Although the results showed that WFT did not prefer pepper (only an average of 5 adults and 8 larvae were found on each pepper seedling), as noted above, WFT can reach high densities in pepper crops when no other more favorable species are present and no control measures are undertaken. If 5-6 chemical treatments (Success 2.5SC and Abamectin 1.8EC) are applied throughout the season, the population of WFT on pepper can be kept at a low level. The greater the number of adults found per seedling, the greater the number of larvae was found. However, the ratio of larva to adults on rape and *Ch. coronarium* was much higher than that found on other vegetables. The reason might be that these two vegetable seedlings suffered from drought so that some adults may have left before investigation. Ren (2006) reported that Holland cucumber, melon and white radish were the most seriously infested vegetables in protected cultivation in Beijing. This study supports these findings by showing that WFT adults and larvae prefer cucumber and squash.

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Seed testing preventing the introduction of invasive alien pathogens

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Seed-borne plant pathogens can be easily moved around the world into new environments, which if favourable to the pathogen, can lead to poor plant establishment as well as a reduction in the yield and quality of the crop (direct costs). Trade restrictions may be imposed on the affected country or region if the pathogen concerned is listed as a quarantine pest by other importing countries (reaction costs). Affected countries may have to implement stringent and costly control strategies to deal with outbreaks in order to regain lost export markets. As such, many countries require seed to be certified free from these pathogens as part of their phytosanitary import requirements. Several organisations and initiatives publish protocols to diagnose seed-borne pathogens including ISTA (International Seed Testing Association) and ISHI (International Seed Health Initiative). Other protocols are also published in handbooks including; Albrechtsen (2006), Mathur & Kongsdal (2003), Saettler *et al.* (1989) or scientific journals like *Seed Science & Technology*. Unfortunately, many of these rely on destructively testing large numbers of seed, some of which, such as tomato and tree seed, can be extremely valuable. Unfortunately this can make some exports untenable on the grounds of cost and / or the availability of test seed.

Increasingly many modern diagnostic technologies such as ELISA and real-time PCR are being used alongside traditional methods including isolation and blotter tests to aid pathogen diagnosis and reduce the spread of plant disease around the world. The use of non-destructive methods are also employed when available. Examples of EU quarantine seed-borne pathogens which are routinely tested using modern diagnostic technologies include *Tilletia indica, Pantoea stewartii* and *Pepino mosaic virus*.

T. indica causes the fungal disease of wheat and triticale known as Karnal bunt. Infected seeds may be partially bunted containing many thousands of teliospores or they may only carry a few teliospores on their surface. These teliospores have been shown to remain viable under European field conditions for at least three years. Further, it has been estimated that if *T. indica* occurs as a small (1000 ha) or large (50,000 ha) outbreak in the UK it could cost the UK within the first year between 1.7 and 17.8 million Euro in direct, reaction and control costs (Sansford *et al.*, 2006). In 2004 the European Plant Protection Organisation (EPPO) published their standard for diagnosis of *T. indica* which has been adopted as the EU standard by many plant health laboratories. This involves sieving samples for teliospores followed by their morphological and molecular assessment if required (Anon., 2004).

P. stewartii formally known as *Erwinia stewartii* causes bacterial wilt of maize, which is thought to be indigenous to America (Anon., 2006). It is thought that this pathogen is brought to new areas by seed and once established, is spread by insect vectors (Anon., 1997). Various methods exist to diagnose infection in seed and frequently these are used in combination as outlined in the EPPO standard for *P. stewartii* (Anon., 2006).

Pepino mosaic virus can infect a number of solanaceous hosts including pepino, tomato and potato. Tomato spread to new areas is thought to be via infected seeds and seedlings and, once established in a crop, is highly contagious and can lead to the down grading of fruit costing at least £16 m^{-2} based on 2005 prices (Spence *et al.*, 2006). Seed can be tested by a number of methods including ELISA and real-time PCR. Traditionally this has been performed by destructive testing, but a recent industry funded project has shown that non-destructive methods for diagnosis can also be employed (Mumford, 2006).

Ideally, as new methods are developed, these should be made available to trade and government laboratories through peer reviewed publications. Further, they should also be independently assessed through 'blind-testing' schemes to confirm their validity and to identify if they have advantages over established tests. However, the organisation and cost of running such schemes can be enormous, as can the take up of new methods, particularly when they involve technologies such as real-time PCR, which may require high set-up and running costs. If these issues can be addressed then this will no doubt promote the uniformity and take-up of such methods and, as a consequence, reduce the spread and introduction of alien pathogens. Being able to test some seed lots using non-destructive methods, as highlighted by Mumford (2006), is also likely to bring many advantages to trade and governments alike.

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Pest risk analysis on the agent of bacterial blight of rice, *Xanthomonas oryzae* pv. *oryzae*

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Introduction

It was assumed that the agent of bacterial blight of rice, *Xanthomonas oryzae* pv. *oryzae*, has the potential to be introduced into Brazil. This pathovar is officially listed as a quarantine pest. Rice as a staple food provides a major source of calories for the Brazilian population. Although the country is responsible for 3% of the world rice production, imports are still necessary. In 2005 and 2006, rice imports increased by 35%. The PRA was initiated in response to the need to evaluate whether the bacterium could enter with imported rice.

PRA initiation

Bacterial blight of rice is a seedborne disease and hence poses a serious problem to international seed trade. The main pathway for the pathogen is imported seed. The importance of the bacterium is also due to its close relationship with pathovar *oryzicola*. Following ISPMs No. 2 and 11, a PRA for *X. o.* pv. *oryzae* was undertaken for the Ministry of Environment, in the Conservation and Use of Biological Diversity Project (PROBIO), to determine the risk of the introduction of the pathogen. The PRA area includes all regions of Brazil where rice is cultivated.

Pest risk assessment: evaluation

The likelihood of introduction of *X. o.* pv. *oryzae* considering entry, establishment, dispersal, pathways and post-harvesting treatment survival and shipment was scored by using the following scale adapted by Oliveira & Paula (2002): 0-0.9 = not significant; 1.0-1.9 = very low; 2.0-2.9 = low; 3.0-3.9 = medium; 4.0-4.9 = high, 5.0 = very high. Pest establishment was evaluated by comparing the ecological and climatic conditions in Brazil and those prevailing in various parts of the geographical distribution, including microclimatic conditions. In Brazil, the potential for establishment and spread of the pathogen was considered to be high, and also the potential for adaptation in both tropical and temperate zones of the country. In the latter area, temperatures up to 40^{0}C are commonly registered in summer.

Environmental conditions are suitable for the development of the disease in southern Brazil, where most of the irrigated rice is cultivated, and also in the northern wetlands where rice is cultivated in flooded areas without the need for a separate water supply. High temperatures are also of concern in upland rice paddies. In this cultivation system, the crop is irrigated, and it is known that irrigation water also carries the organism from field to field. Another factor that affects the probability of establishment is the presence of a few grass species that serve as alternate hosts or volunteer rice plants cultivated in both irrigated and wetland areas. The bacterium is a model for the analysis of plant-pathogen interactions, because more than 30 races differing in virulence reinforce the importance of strengthening quarantine measures. Very little information is available on strain variation from country to country. The existence of races makes it important to obtain stable or adult-plant resistance. Brazilian rice cultivars are not yet characterized in relation to the genetic basis of bacterial blight resistance. Some imports come from countries where the seed-transmitted bacterium can be present. In addition, high temperatures favour the development of the disease. Lesions enlarge quickly and leaves may die faster. The conclusion of pest introduction and dispersion assessment was high. In reference to economic impact, about 400,000 hectares were damaged by the disease annually in recent years, in Japan. Yield losses in severely diseased fields ranged from 20 to 30 percent, and occasionally up to 50 percent. In the Philippines and Indonesia, the losses are higher than in Japan. In India, millions of hectares are infected, with losses varying from 6 to 60 percent in some states.

The assessment of potential economic consequences of introducing *X. o.* pv. *oryzae* to the PRA area was found to be very high for all cultivated rice paddies. Moreover, in flooded areas, due to dispersal of the bacterium in water, the implementation of control practices would be more difficult, and the adoption of chemical control would cause a very negative impact on the environment. Overall the pest risk was assessed as high, indicating the need to adopt specific phytosanitary measures. Inspection at the port of entry does not provide sufficient security.

Pest risk management

Taking into account the probability of introducing *X. o.* pv. *oryzae* by imported seeds and its establishment in the PRA area, and the very high probability of economic consequences, inspection services and quarantine measures should be strengthened at the port of entry. The search for faster and more accurate methods of detection and identification of the seed-transmitted pathogen is of major concern. Not only new identification technologies are required, but more information about the impact of seed transmission. The economic impact of the disease in the area of origin is very high. The overall potential risk of the pathogen, its inclusion in the official quarantine pest list, the level of phytosanitary protection required and the lack of efficient disease control illustrate the necessity of producing a contingency plan to strengthen the security of rice imports into the country. Moreover, imported rice should come from bacterial blight free production areas.

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Some major invasive alien insects established on vegetables in North Carolina

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Many insects established on vegetables in North Carolina have their origin in other countries. Invasive alien species have come mainly from Europe and more recently from Asia. An invasive alien species is defined as a species that is non-native to the ecosystem under consideration and whose introduction causes or is likely to cause economic or environmental harm to human health.

Quarantines, though established, have not prevented the entry, establishment and spread of invasive alien species of insects. Identification of different life stages, their biology, natural enemies, insecticide control and management practices have been studied. However, many pests have still become established and the potential trend is anticipated to increase as borders remain porous to movement of people and goods, as transportation is more rapid and markets continue to expand through global trade.

The following five major invasive alien insects on vegetables in North Carolina are chronic and well established. A chart containing their name, place of origin, date and location of first introduction into the United States, distribution, detection and monitoring techniques and methods for containment and management has been prepared. The European corn borer (*Ostrinia nubilalis* Hubner Lepidoptera: Pyralidae), imported cabbage worm (*Artogeia rapae* (L.) Lepidoptera: Pieridae), beet armyworm (*Spodoptera exigua (Hubner)* Lepidoptera: Noctuidae), diamondback moth (*Plutella xylostella* (L.) Lepidoptera: Plutellidae) and cabbage maggot (*Delia radicum* (L) Diptera: Anthomyiidae), are economically important and widely distributed pests in North Carolina.

It is noteworthy that, of the above five pests of vegetables, four were from Europe. These numbers reflect the movement of people, products and pests over the last century. Recent pest introductions indicate the potential for increasing pest introductions from Asia and South America, as agricultural commodities reach global markets through increased demand and rapid means of transportation.

Efforts for early pest detection, prevention of movement, use of technologically sound means of effective trapping and monitoring, and multimedia training for first detectors (county extension agents, private consultants, agricultural inspectors) in the field throughout the United States have intensified. Increased training has been undertaken, with the development of prioritised pest lists, and the use of excellent training manuals containing profiles of insects with elaborate Lucid digital images and user-friendly keys.

At in-country and offshore sites of pest origin a concentration of well trained personnel, excellent resources, the latest technology in trapping and identification of all pest life stages have been established to help prevent pest introduction and/or slow the introduction and movement of exotic pests. Through extension and regulatory efforts, education and regulatory approaches have received more attention and resources. Increased efforts on research have been undertaken to better understand the pest, its biology, and pathways of movement, to improve the methods of detection, and to enhance and implement IPM strategies. The results will help restrict the movement of pests, containing them to the site of origin and to introduced hot spots and thus, prevent their establishment or spread.

The increases in the human population, global markets, cultural diversity, and the movement of host plants together with rapid means of transportation favour pest introduction and spread. However, with more effective pest monitoring, enhanced training resources, enforceable regulations, and the use of the latest post harvest handling and pest destruction methods, pest introductions could be rapidly identified and corrective action implemented to minimize pest spread and establishment.

Adoption and implementation of the management of the introductions and outbreaks of the five vegetable pests outlined above, offers some hope for dealing with future pest introductions. Some helpful strategies and tactics for living with future insect invaders include: the use of digital images of pest stages and damage, reference insect collections, pest leaflets, coloured insect identification and life history visual images, specific monitoring and trapping tactics, use of natural enemies, better understanding of potential threats and pathways of movement, the training of first detectors in the field and implementation and adoption of new and existing IPM management strategies.

Some useful web sites include:

IPM NCSU - http://ipm.ncsu.edu
NCSU - www.cals.ncsu.edu/entomology
NCSU - http://pestdata.ncsu.edu/cropprofiles/
Lucid Keys - http://lucidcentral.com
Invasive.org - http://www.invasive.org/insects.cfm
The Bugwood Network - http://www.bugwood.org/
Invasivespeciesinfo.gov - http://www.invasivespeciesinfo.gov/
Animal and Plant Health inspection Service (APHIS) - http://www.aphis.usda.gov/
National.Agricultural.Pest.Information.System(NAPIS) - http://www.ceris.purdue.edu/napis/pests/insects.html