SESSION 3

RISK MANAGEMENT AND THE REGULATORY FRAMEWORK

Chairman: Mr C Furk
Defra, York, UK

Evaluation of brown rot (*Ralstonia solanacearum*) control strategies: development of an epidemiological model

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ABSTRACT

An epidemiological model was developed to simulate brown rot prevalence and dispersal in the Dutch potato production chain. The aim of the model was to obtain insight into the contribution of certain risk factors to brown rot prevalence. Model simulations show an irregular pattern of yearly number of infections that is also characteristic for brown rot in reality. They also show the importance of contaminated surface water in brown rot prevalence. The model has many other application possibilities and will be used to evaluate the effect of control strategies on brown rot prevalence.

INTRODUCTION

Potato brown rot, caused by the bacterium *Ralstonia solanacearum* race 3, biovar 2, comprises a major threat to the potato production world wide. Particularly in warm growing areas, such as the Mediterranean region, brown rot infections can be very destructive and cause considerable yield losses (Elphinstone, 2001). Incidental outbreaks have been reported in many European countries, and within the EU brown rot has a quarantine status (Elphinstone, 2002). In the Netherlands, where potatoes are the main cash crop (CBS, 2002), brown rot has been found occasionally since 1995. Its prevalence in the Dutch potato production chain has serious economic consequences because of the need for extensive preventive and sanitation measures (Elphinstone, 1996; Janse *et al.*, 1998). Moreover, the risk of establishment of brown rot in the Netherlands threatens the Dutch export of seed potatoes (Vaals & Rijkse, 2001).

As a result of an extensive monitoring and control policy, the number of brown rot cases in the Netherlands has been reduced with approximately 75% over the past decade (Janse & Wenneker, 2002). However, the intended complete eradication has still not been achieved, and knowledge about the importance of several risk factors on brown rot prevalence is still poor. A better insight into the relative importance of these risk factors would facilitate the design of an optimal control strategy. Therefore, an epidemiological model was developed, which simulates brown rot prevalence in the potato production chain over time and space.

THE MODELLED SYSTEM

The potato production chain

The production cycle of potatoes covers one year and can be separated in an on-field and off-field period. The on-field period comprises the growing season of potatoes, which lasts from planting to harvest. During the off-field period, depending on the category and final destination, potato lots are stored, exported, sold to consumers, or industrially processed. Seed potatoes that are not exported are replanted after the storage period. All ware and starch potatoes leave the potato production chain before or after storage. During the first weeks after harvest, all seed lots and a percentage of all ware and starch lots are tested for the presence of brown rot. Positive tested lots are defined 'detected' and are destroyed. Besides, lots that had a negative test result but are highly suspected of being infected are defined 'probably infected'; such lots are downgraded to ware (or starch) potatoes and marketed under restrictions.

Brown rot infection pathways

There are three different pathways through which a potato lot can become infected with brown rot. Firstly, infections may be caused by irrigation or spraying of potatoes with contaminated surface water, in which brown rot bacteria can occur because of the presence of the host weed bittersweet (*Solanum dulcamara*), which is common along many Dutch waterways. Infection through contaminated surface water is called primary infection, because the source of infection is outside the potato production chain. In a disease-free production chain, this is the only way through which an infection can arise. In the Netherlands, the Dutch Plant Protection Service has designated regions in which surface water was found to be contaminated with brown rot as 'prohibition areas', in which the use of surface water is prohibited.

Once brown rot has entered the potato production chain, the pathogen can disperse through the chain by horizontal and vertical transmission mechanisms. Horizontal transmission means infection of a healthy potato lot where the source is another infected lot, and can – for instance – be caused by the use of contaminated machinery or equipment. Vertical transmission, also referred to as infection through clonal relationships, indicates transmission of the disease from parent to offspring. This results in an increase in the number of infected lots when an infected but yet undetected seed lot is split into daughter lots, which are subsequently replanted.

MODEL STRUCTURE

To simulate the dynamics of brown rot within the Dutch potato production chain, an individual-based model (IBM) was selected as an appropriate modelling technique (Breukers *et al.*, 2005). An IBM separately keeps track of the dynamics of all entities (called objects) in the simulation, taking into account the individuals' unique properties and their interactions. The model resembles the modelled system to a significant degree of detail, allowing for rare or unexpected events that may cause extreme outputs. Moreover, the brown rot model is spatially explicit in that it assigns a location to each individual, thus including the interactions between an individual and its environment. These characteristic makes the IBM a convenient technique for policy application.

The trading units of the potato production chain are potato lots. Potato lots are grown on fields, which belong to farms. The three nouns in this last sentence comprise the main concepts of the production cycle and logically constitute the individual objects in the model. Within a simulation, changes in the state of these individuals are caused by events. For each process in the production cycle, the model checks which events go together with this process and on which individuals these events have an effect. Examples of occurring events are 'primary infection' of a lot as a result of irrigation in a region where surface water is contaminated, or 'detection' of a lot, which is related to the process of testing.

Most events that can take place are based on probability distributions, so their occurrence is stochastically determined by the model. This allows for modelling not only the average brown rot prevalence but also the natural variation that can occur as a result of the stochastic nature of these processes (Hardaker *et al.*, 1997). Another reason to include stochastic elements is to represent the uncertainty about many events in the model, which makes it impossible to determine exactly when they take place and which consequences they have. Both variation and uncertainty play an important role in the evaluation of the effectiveness of different control strategies.

Through a geographical information system (GIS), all farms and fields in the model are assigned an x- and y-coordinate by which they can be mapped. Infected potato lots are always linked to the field on which they have been grown, so they can be visualised as well. Consequently, simulation outcomes can easily be spatially represented, allowing for the analysis of possible regional differences in brown rot prevalence. Apart from geographical coordinates, the model output includes other information about infected lots, such as the infection source (e.g. surface water, planting, transport) and the category (seed, ware or starch).

As a result of the stochastic nature of the model, one should not rely on just one simulation run. Before drawing conclusions, a large number of replications should be done to determine variances between runs. Both the number of replications and the total number of production cycles per simulation are user-defined. The parameters used for the simulations discussed below are provisional estimates of experts and still need to be optimised.

RESULTS AND DISCUSSION

As an example, a simulation was performed over a period of 15 production cycles (i.e. years), and replicated 50 times. The first five production cycles of the simulation period were excluded from the results because the output of these years may be affected by the initial simulation settings. Figure 1 shows the fluctuation of the number of infected lots over time, for one replication and for the average of all replications. The trend line representing the average yearly number of infections remains rather constant, showing between 20 and 25 infections per year. However, the results of one simulation show a strong fluctuation over the years, indicating a large variation in number of infections between years and between replications. This result corresponds with the typical pattern of brown rot dynamics observed in practice.

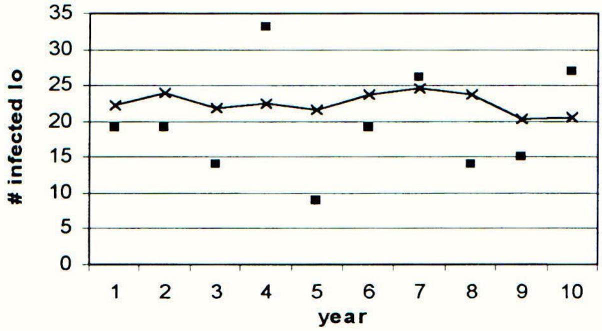

Figure. 1. Number of infected lots over time during a period of 10 years, for one arbitrary replication (■) and averaged over 50 replications (continuous line marked with ×).

In Figure 2, the average relative contribution of each infection source is shown. It is clear that surface water is a very important factor in brown rot prevalence, whereas horizontal transmission plays a minor role. Vertical transmission (i.e. clonal infection) is also a significant factor; however, this source of infection is directly related to all other sources since it represents the multiplication of already existing infections in seed lots that are replanted within the country. The importance of surface water is also reflected in Figure 3, which shows a geographic representation of brown rot prevalence in one year of a replication. The grey areas are prohibition areas where the use of surface water for potato cultivation is prohibited. The model run that is presented here assumes there is a small chance that this prohibition is ignored, explaining the infections within these areas. Infections just outside prohibition areas can still be caused by contaminated surface water, because the risk that surface water within one km from a prohibition area contains low densities of brown rot is also taken into account. These areas are especially sensitive as the use of surface water is allowed but may still cause a new infection.

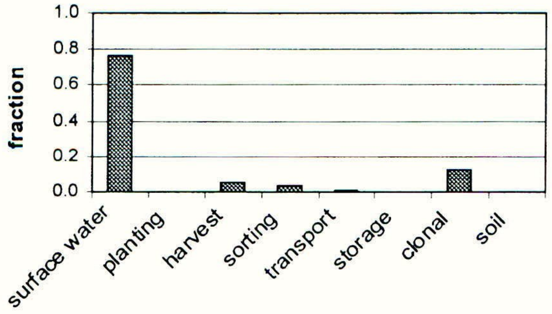

Figure 2. Relative contribution of different infection sources to the total number of brown rot infections.

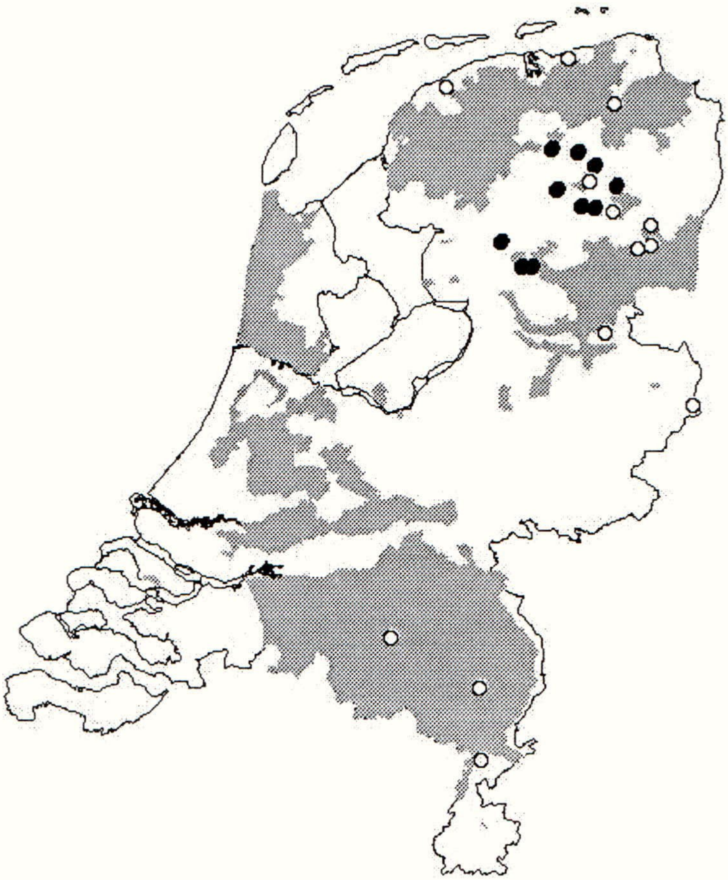

Figure 3. Map of brown rot infections in one year of a simulation run. Shaded areas represent prohibition areas. Infected lots occurring in any of the ten years are indicated by ●; infections caused by contaminated surface water are indicated by o.

CONCLUSION

The discussed model gives a detailed and realistic representation of brown rot dynamics in the Dutch potato production chain. It is the first model that we know of that applies an individual-based modelling approach to plant disease processes at this level of spatial hierarchy. Only a few results have been shown here; the model has many other possibilities for analysis and can be used to analyze, for example, regional differences in prevalence and effectiveness of detection. In a later stage of the research, an economic module will be developed and combined with the epidemiological model, resulting in a bio-economic model by which control strategies can be evaluated on their cost-effectiveness. This model will then serve as a management tool to optimize brown rot control policy.

REFERENCES

Breukers A; Hagenaars T; Van der Werf W; Lansink A O (2005). *Modeling of brown rot prevalence in the Dutch potato production chain over time: from state variable to individual-based models.* Nonlinear Analysis part B: real world applications (in press).

CBS (2002). Statline database Centraal Bureau voor de Statistiek.

Elphinstone J G (1996). Survival and possibilities for extinction of *Pseudomonas solanacearum* (Smith) Smith in cool climates. *Potato Research* **39**, 403-410.

Elphinstone J G (2001). Monitoring and control of the potato brown rot bacterium (Ralstonia solanacearum) in the UK: A case study. *Proceedings of the FNK/EAPR/ESA/UEITP 2nd European Potato Processing Conference.*

Elphinstone J G (2002). The current bacterial wilt situation: A global overview. *Proceedings of the 3rd International Bacterial Wilt Symposium.*

Hardaker J B; Huirne R B M; Anderson J R (1997). *Coping with risk in agriculture.* CAB International: Wallingford.

Janse J D; Araluppan F A X; Schans J; Wenneker M; Westerhuis W (1998). Experiences with bacterial brown rot *Ralstonia solanacearum* biovar 2, race 3 in the Netherlands. Bacterial wilt disease: molecular and ecological aspects. In: *Reports of the 2nd International Bacterial Wilt Symposium, Gosier, Guadeloupe, France, 22-27 June 1997*, eds P Prior; C Allen & J Elphinstone. Springer: Berlin.

Janse J D; Wenneker M (2002). Possibilities of avoidance and control of bacterial plant diseases when using pathogen-tested (certified) or treated planting material. *Plant Pathology* **51**, 523-536.

Van Vaals M; Rijkse H (2001). *De Nederlandse Akkerbouwkolom: het geheel is meer dan de som der delen.* Rabobank International: Utrecht.

The Global Invasive Species Database (GISD) and international information exchange: using global expertise to help in the fight against invasive alien species

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ABSTRACT

Sharing information and expertise internationally on the ecology, impacts and practical management of invasive alien species (IAS) is a priority for successful management. In addition, knowledge of past invasiveness of IAS elsewhere is critical information for use in pest and weed risk assessments to prevent new invasions. International 'vehicles' for such exchange of information and expertise include: 1) The Global Invasive Species Database (GISD); 2) the planned development a global master list of invasive species; 3) Aliens-L and other listservers; and, 4) the planned development of a Global Invasive Species Information Network. Discussion includes the role of a centralised database, such as the Global Invasive Species Database, in the context of a distributed network and recent thinking on the 'Conservation Commons'.

INTRODUCTION

Since 1999, the International Plant Protection Convention (IPPC) has been clarifying its role with regards to invasive alien species (IAS) – sensu CBD (2002) – that are plant pests. This includes clarification on how environmental impacts are included under the term 'economic harm' (ISPM 5) (www.ippc.int/IPP/En/ispm.jsp) and a revision of the standard for Pest Risk Analysis for Quarantine Pests (ISPM 11 Rev1) (www.ippc.int/IPP/En/Archive/IAS2003/IAS-WORKSHOP-Home.htm). In order adequately to include environmental impacts into their mandate, Plant Protection Agencies will need to deal with a wide scope of impacts, and often with a high level of ecological complexity (De Poorter, 2003; De Poorter & Clout, 2005). Sharing information and expertise internationally on the ecology, impacts and management of such IAS is a priority. In addition, knowledge of past invasiveness elsewhere is particularly important in assessing potential risks from new introductions (see CBD, 2002), given that "Only one factor has consistently high correlation with invasiveness: whether or not the species is invasive elsewhere" (Wittemberg & Cock 2001). The Invasive Species Specialist Group (ISSG) is a network of expert volunteers, organised under the auspices of the Species Survival Commission of IUCN (The World Conservation Union); its mission is: 'to reduce threats to natural ecosystems and the native species they contain, by increasing awareness of alien invasions and of ways to prevent, control or eradicate them' (see: www.issg.org). It is involved in several 'vehicles' for such information exchange, including 1) The Global Invasive Species Database; 2) the planned development of a global master list of invasive species; 3) The listserver Aliens-L; and 4) the Global Invasive Species Information Network (GISIN). Some other examples of international IAS information exchange are also described.

THE GLOBAL INVASIVE SPECIES DATABASE (GISD)

The Global Invasive Species Database is a free, online source of authoritative information about alien species that negatively impact biodiversity. It contains comprehensive profiles of all kinds of invasive species from plants, mammals, invertebrates, birds, reptiles, fish and amphibians, to macro-fungi and micro-organisms. GISD profiles cover the biology, ecology, native and alien range of invasive species and include references, contacts, links and images. Information in the GISD is either created or reviewed by acknowledged international invasive species experts and is being updated on an ongoing basis.

The GISD was developed as part of Phase I of the Global Invasive Species Programme (GISP). It is managed, maintained and under continuous development by ISSG with support from a number of partners.

Users of the GISD can search for IAS information by scientific, common name or synonym, country or location, life form, habitat type or by any combination of these. A taxonomic search is also available. The information available in the GISD is presented in species profiles, which are constructed using core information elements, including:

- taxonomy, scientific and common names, descriptions, images to help identify invasive species;
- distribution records;
- impacts (focus on biodiversity);
- pathways, vectors;
- prevention and management information;
- contact details of specialists for advice.

Each species profile contains links back to local, national and regional resources, where more detailed and locally specific information can be found.

Following extensive consultation and user analysis, it was decided that the GISD should be primarily a management and awareness-raising/educational tool delivering summary information, rather than a source of primary data for researchers. Its focus is more on users 'at the coal face' of IAS prevention and management, rather than those conducting more academic pursuits. In consideration of the fact that a large proportion of the potential audience of the GISD do not have English as a first language, may not have scientific training and perhaps have poor or limited access to the Internet, information is presented in plain English in a standard format and as simply as possible.

With 270 profiles already completed and reviewed by experts, the GISD currently receives an average of more than 40,000 hits per day (~900 unique visitors/day). The GISD search for invasive species on the Eurasian continent (Europe-Asia) currently produces the names and profiles of 70 introduced species, plus 70 more that are invasive elsewhere but native to Europe-Asia. From information we have gathered in the course of our work, we estimate that most countries in Europe face threats from between 500 and 1,000 IAS with known biodiversity impacts. There is a lot of work yet to be done, and we would welcome assistance to further develop the 'European component' of the GISD.

A GLOBAL MASTER LIST OF INVASIVE SPECIES

National and regional IPPC implementation agencies need to be able to access information on the biodiversity impacts of alien species anywhere in the world (see above). A global master list will be a crucial tool in risk assessment. ISSG is planning to develop such a master list, if sufficient financial resources can be obtained. To develop a global master list we need to collect and standardise information about alien species that are considered to have biodiversity impacts. This information will come from national and regional collection and observation databanks, as well as from practitioners, and will include information not formally published elsewhere. A large proportion of this information is not currently available on the Internet and initially many source lists will need to be digitised.

After digitisation, standardisation of lists is one of the major challenges. There is a great deal of variation in the definitions used in lists and in the criteria used to place organisms on those lists. Many lists are described as 'preliminary' reflecting the fact that, often, very little is know about the situation being assessed. The overall aim of the list is to provide an alert if an alien species has been considered to have biodiversity impacts anywhere in the world, so that users can follow up on those cases that are potentially most relevant to them.

ALIENS-L AND OTHER LISTSERVERS

A helpful contribution to information exchange on biodiversity impacts of alien species can be achieved through the use of Listservers. For example, a message posted on the well-established Aliens-L listserver (www.issg.org) along the lines of "there is some deliberation about plans to use alien species 'X' for purpose 'Y' in our country or region" will usually 'flush out' several responses if the species in question has been problematic elsewhere. Another listserver with a Asian-Pacific regional range, and more of an agricultural pest and weed emphasis, is PestNet (http://groups.yahoo.com/group/pestnet). It offers a rapid species identification service using expert taxonomists to identify pest and weed species from users' images.

Listservers may lack some aspects of consistency, standardisation and quality control, compared with a global database or a distributed network, but they offer an important contribution to empowerment and horizontal information transfer (e.g. practitioners helping each other and others) because of their great flexibility and their ability to deal quickly with ad-hoc, time-critical issues.

THE GLOBAL INVASIVE SPECIES INFORMATION NETWORK (GISIN)

The development of a Global Invasive Species Information Network was proposed at the sixth meeting of the Conference of the Parties to the Convention on Biological Diversity held at The Hague in April 2002.

The GISIN will provide a platform through which IAS information from hundreds of databases and web sites can be accessed (see http://invasivespecies.nbii.gov/as/gisin.htm). The GISIN will use a web services architecture consisting of:

- IAS data standards;
- standardised data elements;
- IAS terminology – thesauri – closed vocabularies for data elements;
- aggregation of data and information in standardised 'Invasive Species Profiles';
- service discovery mechanisms;
- search and presentation tools.

It will enable the sharing of species profiles or fact sheets, expertise lists, observation and bibliographic information, as well as information about research and management projects. The databases and web sites providing information could be local, national or regional in scope, or they may have a thematic focus, such as (for example) aquatic IAS or rodent eradications.

Since the majority of countries lack resources and capacity in information management with regard to biological invasions issues, the GISIN will disseminate tools and experience to other countries. The tools being developed by GISIN include a 'capacity building' database that will be offered at no cost to users. Its use will promote the adoption of a common system for collecting, storing and sharing information on invasive species.

ISSG contributions to development of the GISIN include sharing the GISD's core elements, which will be reviewed and used as a model for a species profile schema for sharing IAS information. We have also shared our extensive experience in locating and evaluating IAS information from many diverse sources for use by a broad international audience.

DISCUSSION

Role of ISSG and the GISD within a distributed network

IAS information is typically widely dispersed and difficult to access. Much of it has not been digitised (especially information about IAS in the developing world), and it would not be available on the Internet if it were not for the activities of the GISD and other initiatives that have maintained a focus on creating relevant content. Examples include:

- Structuring information from 'Invasive species in the Pacific: A technical review and draft regional strategy', SPREP 2000 in order to produce IAS lists and distribution records for the region.
- Digitising information from important hard-copy publications, such as Gherardi & Holdich (1999).
- Collecting experts' knowledge in their heads, in notes or otherwise unpublished.
- Collecting management expertise that is either not published or only available in internal technical reports.
- Adding up-to-date content from IAS listservers and other networks.

Different user groups have different IAS information requirements. Quarantine officers, land managers, environmental and biodiversity specialists, extension agents and other individuals and organisations concerned with the environment need quick access to a user-friendly source of relevant, summarised information. Rather than simply providing access to IAS information and leaving the user to manage issues of variation, complexity and potential gaps in that information, staff at the GISD locate, summarise and check relevant material for accuracy, in order to meet the information needs of a broad range of users in the most user-friendly manner possible.

In the longer term, our experience and networks will make the ISSG a strong candidate to play a role in the global coordinating centre and clearing house of GISIN. The purpose of such a centre would be to filter, summarise and package information in a local context for the needs of those regions that do not have the capability to do it themselves. In turn, the GISD will use GISIN as a major source of information for our profiles, alongside our ongoing digitising and data discover activities.

Free access to information for biodiversity conservation purposes

'Information is power' is just as true in conservation as elsewhere. Social equity requires that communities are empowered to solve their problems, including those created by IAS issues. IUCN strongly believes that information related to biodiversity conservation must be easily and freely available. Recently, several organisations have started to develop this concept further.

The Conservation Commons (http://concervationcommons.org) at its simplest encourages organisations and individuals alike to place documents, data and other information resources related to conservation in the public domain. The Conservation Commons is characterised by an underlying set of principles:

- Principle 1. Open Access – The Conservation Commons promotes free and open access to data, information and knowledge for conservation purposes.
- Principle 2. Mutual Benefit – The Conservation Commons welcomes and encourages participants to both use resources and to contribute data, information and knowledge.
- Principle 3. Rights and Responsibilities – Contributors to the Conservation Commons have full right to attribution for any uses of their data, information or knowledge and the right to ensure that the original integrity of their contribution to the Commons is preserved. Users of the Conservation Commons are expected to comply, in good faith, with terms of uses specified by contributors and in accordance with these Principles.

Providing Internet access is not enough

Potential users of the GISD were interviewed about their information requirements and access to the Internet. Since many of those interviewed have very slow, unreliable, or no access to the Internet (e.g. South Pacific and parts of Africa), alternative methods of disseminating IAS information must be provided. ISSG is hopeful of making IAS information available across the 'digital divide', through hardcopy and CD-ROM, but financial resources for this are currently lacking.

ACKNOWLEDGEMENTS

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The GISD has also received funding and/or support from: Pacific Island Ecosystems at Risk (PIER), The Global Environment Facility (GEF), La Fondation TOTAL, New Zealand Aid, US Fish and Wildlife, The Pacific Development and Conservation Trust, Terrestrial and The Freshwater Biodiversity Information System (TFBIS).

REFERENCES

CBD (2002). *Report of the 6th Meeting of the Conference of the Parties to the Convention on Biological Diversity, UNEP/CBD/COP/6/20, 2002.* http://www.biodiv.org/doc/meetings/cop/cop-06/official/cop-06-20-en.pdf

De Poorter, M (2003). *Combining of CBD and IPPC implementation: maximising biodiversity and conservation outcomes when carrying out pest risk assessment: the challenge of ecological complexity.* Unpublished presentation given at the Invasive Alien Species and the International Plant Protection Convention, Braunschweig, Germany, September 2003.

De Poorter, M & Clout, M (2005). Biodiversity conservation as part of plant protection: the opportunities and challenges of risk anaylsis. In: *Plant Protection and Plant Health in Europe: Introduction and Spread of Invasive Species. BCPC Proceedings No. 81.* BCPC: Alton.

Gherardi F; Holdich D M eds (1999). *Crayfish in Europe as alien species. How to make the best of a bad situation?* A A Balkema: Rotterdam.

Wittenberg R; Cock M J W eds (2001). *Invasive Alien Species: A Toolkit of Best Prevention and Management Practices.* CAB International: Wallingford.

Biodiversity conservation as part of plant protection: the opportunities and challenges of risk analysis

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ABSTRACT

Until recently, the International Plant Protection Convention (IPPC) mandate was implemented rather narrowly to guard against plant pests that affect the primary sector. However, recent revisions have clarified its mandate to also deal with environmental impacts, including risk analysis. One of the most important factors in identifying such risk of invasiveness is prior invasiveness elsewhere. International exchange of information on invasive alien species is crucial. Addressing environmental impacts from IAS creates several challenges.

INTRODUCTION

Owing to the ancient history of human settlement in Europe, alien species have naturalised and become 'integrated' in many ecosystems. However, given the exponential increase in trade transport, and travel in the last century or two, there has been a tremendous increase in the introduction – here, 'introduction' refers to the movement by human agency, indirect or direct, of an alien species outside of its natural range (CBD, 2002). Note the difference with the concept of 'introduction' (under the International Plant Protection Convention (IPPC)) of species to ecosystems where they are alien – 'alien species' refers to an introduction outside the natural past or present distribution (see CBD, 2002). For example, the presence of exotic plants in Portugal has increased probably more than 1,000% during the last two centuries (Almeida *et al.*, 2003). Even though the majority of alien species may well be harmless, tremendous damage can result from others. Farmers have been fighting agricultural weeds and pests since the beginnings of agriculture, but the problem of impacts on native species, habitats and ecosystem function has been brought to the world's attention relatively recently (e.g. Lowe *et al.*, 2000). Invasive alien species (IAS), as defined by the Convention on Biological Diversity (CBD) are those alien species whose introduction and/or spread threaten biological diversity (CBD, 2002).

PREVENTION AND RISK ASSESSMENT

Invasive alien species constitute an insidious 'biological pollution'. Unlike many other types of pollution, they are not diluted in time but, on the contrary, can expand in numbers, density and geographic spread – often exponentially. Prevention of IAS introduction is the first and most cost-effective option, from the point of view of environmental costs as well as direct monetary costs (Wittenberg & Cock, 2001).

Risk analysis plays an important role in the prevention of new IAS introductions across national boundaries, by underpinning decision-making in compliance with international trade-related obligations. In the agricultural context of plant protection, this has been relatively well developed over time but the environmental impacts have rarely been included in pest risk analysis or other sanitary or phytosanitary (SPS) measures. However, since 1999, the IPPC has been clarifying its role with regard to IAS (*sensu* CBD) that are plant pests. Revision of ISPM 5 (Glossary) and ISPM 11 (Pest Risk Analysis for Quarantine Pests) clarified the inclusion of environmental impacts. This has been reflected at the regional European level (Schrader, 2003) and it is to be expected that in future more European national plant protection agencies will include environmental impacts in risk analysis (Unger, 2003).

INFORMATION REQUIREMENTS: INVASIVENESS ELSEWHERE

The crucial question is how to predict which alien species would become problems if they were introduced and which would remain innocuous. A match of climate and habitat helps in predicting invasiveness, but many species are known to expand to other habitat types once outside their native range. Only one factor has a consistently high correlation with invasiveness: whether or not the species is invasive elsewhere (Wittenberg & Cock, 2001). "The best predictor of which species will become problematic is whether or not a species has proven to be invasive elsewhere, especially under similar (climatic and geographic) conditions and in related ecosystems" (Simberloff, 1999). Characteristics of the species itself in its native range (including reproductive and dispersal mechanisms, tolerance to environmental factors such as shade or salinity, life-form or habit, such as climbing vine or an aquatic species, and adaptive mechanisms, such as the ability of a plant to fix nitrogen) are less accurate risk predictors for prevention, although they are somewhat more useful for predicting rate and extent of spread if prevention failed and the alien species established. In short: knowledge of past invasiveness elsewhere is particularly important for IAS prevention.

In addition, given that similar IAS problems are repeatedly faced in different parts of the world, sharing information and expertise internationally on the ecology, impacts and management of IAS is also critical for the management of established IAS. The Invasive Species Specialist Group of IUCN (the World Conservation Union) is involved in developing and maintaining The Global Invasive Species Database and several other tools for such international information exchange (De Poorter & Browne, 2005)

CHALLENGE: SCOPE AND COMPLEXITY OF ENVIRONMENTAL IMPACTS

The environmental impacts caused by IAS are wide ranging and often more complex and surprising than the impacts of, for example, agricultural weeds. For example:

- 'Dual personality species': alien species that are desirable and commercially important in parts of the landscape but damaging invaders elsewhere, for instance in Protected Areas (Rouget *et al.*, 2002).
- Time lags: an established alien species may show no signs of being invasive for years or decades, before rapidly expanding in range and abundance and becoming invasive.

- Indirect impacts on native species can be surprising: in the South African St Lucia Protected Area, the invasive plant *Chromolaena odorata* has been linked to Nile crocodiles' sex ratio changes (Leslie & Spotila, 2001).
- Interactions between two alien species (that do not cause environmental impacts when they occur on their own) can trigger invasiveness: e.g. the arrival of a pollinator for an invasive plant, or of a vector for an alien pathogen.
- Invasion by one alien species can facilitate and accelerate further invasion by other species – sometimes reaching the level of 'invasional meltdown' (see box).
- Alien species, over time, may exhibit evolutionary adaptation to their new environment (Cox, 2004).
- Effects of invasion are being compounded by global climate change and habitat change (Mooney & Hobbs, 2000)

> **Invasional meltdown**: Alien crazy ants (*Anoplolepis gracilipes*) have formed extensive super colonies on Christmas Island (Australia) since the mid-1990s. Red crabs (*Gecarcoidea natalis*) are highly vulnerable to these crazy ants. This has manifold further consequences for the dynamics and structure of the native forest, including deregulation of seedling recruitment, seedling species composition, litter breakdown and density of litter invertebrates. Owing to the crab's migratory nature, effects also result, in areas not (yet) invaded by the crazy ant. In addition, mutualism between this invasive ant and introduced/cryptogenic scale insects has amplified and diversified rain forest impacts (O'Dowd *et al.*, 2001). On top of this, crazy ant invasion has facilitated the invasion of native rainforest by the giant African land snail (*Achatina fulicata*), woody alien weeds and alien cockroaches (Green *et al.*, 2001).

Solutions

Precautionary principle

Intentional introductions, efforts to identify and prevent unintentional introductions, and other prevention or mitigating decisions should be based on the precautionary principle. Precautionary measures are advocated, required or allowed by several international instruments, including the CBD, the Biosafety Protocol and the SPS agreement. The preamble of the CBD states that a lack of full scientific certainty shall not be used as a reason to postpone measures to avoid or minimise a threat of significant reduction or loss of biodiversity (see also: Cooney, 2004). Precaution is particularly relevant to IAS, because of the inherent scientific uncertainty when trying to predict impacts on biodiversity. In the context of alien species, unless there is a reasonable likelihood that an introduction will be harmless, it should be treated as likely to be harmful (IUCN, 2000); or, every alien species needs to be managed as if it is potentially invasive, until convincing evidence indicates that it presents no such threat (McNeely *et al.*, 2001).

Wide ranging stakeholder involvement and consultation

Wide consultation including with other agencies, industry, NGOs, community groups and the research community increases the likelihood that all relevant matters are covered in risk analysis.

Promoting the use of native species

It has been stressed over and over that prevention is the key to addressing IAS problems. An important aspect of prevention is to reduce the need (or want) for introduction of new alien, potentially invasive, species, by encouraging the use of alternatives (either less risky alien species or native species). Promotion of the use of native species, could be considered (e.g. in gardening, erosion control, aquaculture, forestry, and in aid and development assistance programmes).

CHALLENGE: ECOLOGICAL BOUNDARIES – NOT POLITICAL ONES

An alien species is defined in relation to whether it is in its natural range or not. In other words, the concepts of alien and native relate to ecological boundaries rather than to country boundaries. This has two ramifications: firstly, a species can be an alien and a harmful invasive alien within the same country where it is native; secondly, an alien species introduced into one nation may be in a position to easily spread to neighbouring nations because there are no bio-geographical barriers between the countries, or through secondary, unintentional human mediated introductions (e.g. transport). An example of the latter is the introduction of the moth *Cactoblastis cactorum* as a biocontrol agent against prickly pear in the Caribbean. Once in that area, it was unintentionally spread to the USA where it is now threatening native Mexican species of *Opuntia* (*Platyopuntia*) (Soberón *et al.*, 2001).

Solutions

Prevention of movement across ecological boundaries within one country

There must be procedures to prevent introduction of IAS within a country, across a bio-geographical boundary, e.g. from mainland to islands, between watersheds or across mountain ranges.

Regional approach to risk analysis

Risk analysis at the national level should include the risks of spread to neighbouring or nearby countries. This will likely require cooperation with agencies in the countries concerned. In addition, regional risk analysis should be considered and developed (e.g. to decide on whether a species will be introduced into Europe at all).

CHALLENGE: FRAGMENTATION AND GAPS IN NATIONAL MANDATES

IAS are found in all taxonomic groups: they include introduced fungi, algae, mosses, ferns, higher plants, invertebrates, fish, amphibians, reptiles, birds and mammals. Currently, at national level, the application of SPS measures is usually limited to the mandates of IPPC, OIE etc. and, as a result, many components of the nation's environment are not adequately covered. For instance, what government agency has the mandate to implement SPS measures to protect native invertebrates or wild native birds?

Another challenge is that in many countries, national agencies do not co-ordinate their activities, and do not share information adequately. This can lead to a situation where one agency promotes an alien species (e.g. a plant for erosion control) while another agency needs to spend taxpayer's money eradicating it because it is invading Protected Areas.

Solutions

Mandates of relevant government agencies should be widened. All taxa of IAS should be subject to SPS measures as required, and all components of the environment should be adequately protected. This may require some 'thinking outside the square'. An example is the New Zealand Import Health Standard for spiders on table grapes (www.biosecurity.govt.nz/imports/plants/procedures/spiders-grapes.htm), which was developed to protect native invertebrates. Adequate resourcing for agencies should be ensured.

Cooperation between different government agencies is crucial. While there is no single 'recipe', one of the most important aspects is to achieve leadership and co-ordination of national efforts, to achieve cooperation between different agencies, and to ensure appropriate participation of all stakeholders (including non-governmental ones). This may include the establishment of one national lead agency for all IAS issues, including primary production, environment/conservation, fisheries, human health, (e.g. in New Zealand (www.biosecurity.govt.nz), or an overall co-ordinating agency (e.g. in the USA (www.invasivespecies.gov/council/mp.pdf)) that co-ordinates the various other agency activities at a national level.

CONCLUSIONS

National Plant Protection Organisations can play an important role in conservation by addressing the environmental impacts of invasive alien species that are within their mandate. They are in a good position to set an example and influence others. However, to address IAS adequately at the national level, relevant government agencies will generally need to widen their mandate(s) so that all taxa of alien species can be subject to SPS measures, and all environmental components can be protected from impacts. Resourcing for such agencies should be ensured and be adequate. Agencies will also need to develop close cooperation with each other, and with key stakeholders. Prevention of IAS introductions needs to target not only national boundaries but also Regional (multi country) and local (within country) ones. Precaution needs to be applied throughout IAS management, so that all alien species are managed as if potentially invasive, until convincing evidence indicates that they presents no such threat. Finally, an overall change of attitude is required, reducing the need for new introductions, using native species wherever possible in the development of aquaculture, forestry horticulture, etc.

REFERENCES

Almeida J D, Marchante E; Marchante H, Freitas H (2003). A brief report on the invasive flora of Portugal. *Aliens* **18**, 16-18.

CBD (2002). *Report of the Sixth Meeting of the Conference of the Parties to the Convention on Biological Diversity*, UNEP/CBD/COP/6/20, 27 May 2002.

Cooney R (2004). *The Precautionary Principle in Biodiversity Conservation and Natural Resource Management.* IUCN: Gland.

Cox P (2004). *Alien Species and Evolution.* Island Press.

De Poorter M; Browne M (2005). The Global Invasive Species Database (GISD) and international information exchange: using global expertise to help in the fights against invasive alien species. In: *Plant Protection and Plant Health in Europe: Introduction and Spread of Invasive Species. BCPC Proceedings No. 81*. BCPC: Alton.

Green P T; O'Dowd D J; Lake P S (2001). From resistance to meltdown: secondary invasion of an island forest. In: *Proceedings of the International Conference on Tropical Ecosystems*, eds K N Ganeshaiah, R Uma Shaanker & K S Bawa, pp. 451-455. Oxford-IBH: New Delhi.

IUCN (2000). IUCN Guidelines for the Prevention of Biodiversity Loss Caused By Alien Invasive Species. Published by ISSG as special lift out in: *Aliens* **11**, 2000. Also on web site: *http://iucn.org/themes/ssc/pubs/policy/invasivesEng.htm.*

Leslie A J; Spotila J R (2001). Alien plant threatens Nile crocodile (*Crocodilus niloticus*) in Lake St Lucia, South Africa. *Biological Conservation* **98**, 347-355.

Lowe S; Browne M, Boudjelas S; De Poorter M (2000). 100 of the World's Worst Invasive Alien Species. A selection from the Global Invasive Species Database. Published by ISSG as special lift-out in: *Aliens* **12**, 12 pp.

McNeely J A; Mooney H A; Neville L E; Schei P J; Waage J K eds (2001). *Global Strategy on Invasive Alien Species.* Published on behalf of the Global Invasive Species Programme (GISP). IUCN: Gland.

Mooney H A; Hobbs R J (2000). *Invasive Species in a Changing World.* Island Press.

O'Dowd D, P Green & P Lake (2001). Invasional meltdown in island rainforest. In: *Proceedings of the International Conference on Tropical Ecosystems*, eds K N Ganeshaiah, R Uma Shaanker & K S Bawa, pp. 447-450. Oxford-IBH: New Delhi.

Rouget M; Richardson D; Nel J; Van Wilgen B (2002). Commercially important trees as invasive aliens: Towards spatially explicit risk assessment at a national scale. *Biological Invasions* **4**, 397-412.

Schrader G (2003). New working programme of the European and Mediterranean Plant Protection Organisation on invasive alien species. *Aliens* **18**, 14-15.

Shine C; Williams N; Gündling L (2000). *A Guide to Designing Legal and Institutional Frameworks on Alien Invasive Species.* IUCN Environmental Law Centre: Gland.

Simberloff D (1999). The ecology and evolution of invasive non-indigenous species. *Paper presented at GISP Workshop on Management and Early Warning Systems, Kuala Lumpur, Malaysia.*

Unger J (2003). The IPPC standard on environmental risks of plant pests. *Aliens* **18**, 13-14.

Wittenberg R; Cock M J W eds (2001). *Invasive Alien Species: A Toolkit of Best Prevention and Management Practices.* CAB International: Wallingford.

Ten years of experience with the invasive horse chestnut leaf miner (*Cameraria ohridella*) in Austria

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ABSTRACT

First mass outbreaks of the horse chestnut leaf miner (*Cameraria ohridella*) on horse chestnut trees in Austria were detected in 1993/1994. Owing to its enormous reproduction potential, and its ability of rapid dispersal, the pest has not only spread within Austria and adjacent countries within a very short time. Since its appearance, control measures for horse chestnut trees were urgently required, especially for trees in parks and in public and historic areas of cities. In the past 10 years, several control strategies against this alien species have been tested or proposed in Austria, at the Institute for Plant Health, especially investigations into biological control, but most with little success or practical applicability.

INTRODUCTION

The horse chestnut leaf mining moth (HCLM) (*Cameraria ohridella*) (Lepidoptera: Gracillariidae), was first observed and detected on planted horse chestnut trees (*Aesculus hippocastanum*) in the surroundings of lake Ohrid in Macedonia in 1985 (Deschka & Dimic, 1986). In Central Europe, first records come from Upper Austria, in 1989 (Puchberger, 1990). Since then, HCLM has spread in most countries in Central and Western European, and is now regarded as widespread in Europe, often causing mass infestations. Brown-coloured blotches (mines) are visible on the surface of the leaves of infested trees, resulting from the feeding of the leaf-mining larvae. With a heavy infestation, the whole leaf is covered with mines, turning completely brown, and finally dies and falls to the ground. Therefore, sometimes, in August, completely defoliated trees can be seen. Owing to this stress, in autumn the production of new green leaves and a second period of flowering often occurs. However, investigations on the photosynthetic performance, water relations and hydraulics of mined leaves have shown that the damage to the trees has less impact than has been supposed from visual impressions (Raimondo *et al.*, 2003). However, Thalmann *et al.* (2003) discovered that heavily attacked horse chestnut trees produced smaller seeds, which may influence severely the growth and survival of horse chestnut trees in the natural forests in South East Europe. Another important point is that although horse chestnut is the main host of HCLM, the moth is also able to develop on other species of *Aesculus* and even on *Acer* spp. (Freise 2001). Thus, there is a possibility of a host-shift by HCLM to other tree species. In summary, there appears to be no imminent danger to the continued existence of horse chestnut trees in urban areas, although they are subject to heavy damage; however, the implications for the future of natural stands of horse chestnut trees is uncertain.

In consideration of these facts, great efforts have been made in Austria and neighbouring countries to find effective control measures for use against HCLM. A brief survey of such work and experiences with the HCLM in Austria is given in the present paper.

MATERIALS AND METHODS

Chemical control

Various control strategies against the HCLM have been investigated during the last 10 years. In 1995, the first chemical control strategies were tested (using insect growth regulators) at the Institute for Plant Health in Vienna (Blümel & Hausdorf, 1996). Three products were tested: diflubenzuron (Dimilin), triflumuron (Alsystin Bayer) and fenoxycarb (Insegar 25 WG). Sprays were applied during the first period of egg laying, which more or less coincided with the peak of the adult HCLM emergence in spring.

Two years later, experiments with tree injections were conducted at the same institute, in cooperation with the agrochemical company Bayer and FBVA (Federal Research and Training Centre for Forests, Natural Hazards and Landscape). This kind of control measure seemed to be very attractive, because of its systemic mode of action and because of its more practicable application technique for use on trees, compared with the difficulties of traditional spray applications. The method should be particularly suitable for the treatment of individual trees or for trees which are reachable only with difficulty, e.g. those in enclosed courtyards. For this work, several trees of different sizes were selected in an avenue in the Viennese Prater; there were two application dates (one in spring and one in autumn). The active ingredient (imidacloprid) was injected into each tree (every 5–10 cm around the trunk) c. 1.2 m above ground level.

Cultural control

Cultural measures play an important role in the control of the HCLM, especially the removal and destruction of fallen leaves which contain the overwintering pupae. Several places with and without leaf removal were evaluated during various trials. In addition, public gardeners were asked to observe the intensity and time of infestations. Within the scope of the EU project CONTROCAM, laboratory experiments were done to test the tolerance of overwintering pupae of HCLM to temperature and relative humidity, to obtain basic recommendations for the suitable composting of infested horse chestnut leaves. In total, 1,020 pupae were removed from fallen leaves in autumn and placed in plastic boxes. They were then subjected to warm (24°C to 45°C) and low (0°C to –21°C) temperatures, with two different moisture regimes (30% and 95% RH). In spring, the number of emerged and dead moths were counted.

Biological control

Although, at an early stage, successful control of HCLM was achieved with diflubenzuron, chemical control was not regarded as a sustainable solution, and it was clear that alternative approaches were required. Thus, just one year after the first chemical trials, investigations began in Austria on the natural enemies of HCLM and their potential for use in biological control. In subsequent years, several biocontrol-related projects were undertaken at the Institute for Plant Protection: by C Lethmayer (from 1996 to 2001), by G Grabenweger (from 1996 to 1998) and by M Stolz (from 1996 to 1999). A 2000–2004, EU-funded project (CONTROCAM) was also progressed, with Austria as one of the involved partners. The aims of this EU-funded project were to develop alternative, sustainable, environmentally friendly measures against HCLM. Concerning biological control, the main tasks of the Austrian team were to make qualitative and quantitative assessments of the parasitoids of HCLM throughout Europe and to obtain data on predators.

Biotechnical measures

After identification and synthesis of the special sex pheromone of HCLM in 1999 (Svatos *et al.*, 1999) experiments started to develop pheromone-based monitoring and control methods. In Austria, the first trials with pheromones were done in the field in 2001, again within the scope of the EU-funded project CONTROCAM, with the aim of reducing the high infestation levels of the pest. In the following years, several mass-trapping methods were tested, using various types of trap (sticky sheets and bottle-traps in the lower branches of tree; glue rings around tree trunks), involving different arrangement of host trees (solitary, isolated trees; groups of trees; trees in rows (= alleys)). The number and position of the traps and pheromones varied from trial to trial; the investigations also involved trees with and without fallen-leaf removal.

Other measures tested included the confusion technique, using pheromones.

Finally, more recently, the company Calantis tried a new approach with attractants, using plant odours as kairomones, to lure the females of HCLM.

RESULTS

Chemical control

In trials with the insect growth regulators, best results were obtained with the WP formulations of diflubenzuron and triflumuron: 98–100% of the larvae were killed, depending on the number of applications. To date, this is still the main method of control used in public urban areas.

The evaluation of tree-injection treatments showed that dispersion of the insecticide within the tree was very limited, the active ingredient reaching only some parts of the treated trees. However, on branches that were successfully impregnated, efficacy of treatment persisted for more than 2 years.

Cultural measures

The autumn removal and destruction of infested leaves (e.g. burning or composting) proved to be an effective method for reducing and delaying the first generation of HCLM in the following year (spring), especially in isolated places with individual horse chestnut trees, such as those in enclosed courtyards and private gardens.

In addition, observations showed that watering and nutrient supply were also important measures to increase the tree's own defense mechanisms, especially during dry periods in summer.

The laboratory experiments resulted in pupal mortality of 10–40% at temperatures up to 36°C, but total (100%) mortality at 39°C (for 30% RH) and at 42°C (for 95% RH) ($P = 0.01$; $r = 0.647$). In contrast, the pupae showed a high tolerance to low temperatures (with a maximum of 20% dead pupae (with one exception) at 30% RH and a maximum of only 14% at 95% RH) at temperatures down to -18°C. Increasing mortality was indicated at -21°C, but no significant correlation existed between the mortality of HCLM pupae and these cold temperatures.

Biological control

The initial studies on the parasitoids of HCLM revealed 22 species of Hymenoptera, mainly Chalcidoidea (Eulophidae) with two to three dominating species, plus a few individuals of Ichneumonoidea (Grabenweger & Lethmayer, 1999; Stolz, 1997). All of these were polyphagous ecto- or endoparasitoids of various leaf-mining insects. In general, the rate of parasitism was very low, ranging from 1% to 15%, depending on the locality and host generation.

Attempts to rear the parasitoids, and to breed HCLM itself, all failed.

The results of the CONTROCAM investigations confirmed that the most important enemies of HCLM were hymenopterous parasitoids: chalcids (Chalcidoidea) and ichneumonids (Ichneumonoidea). In total, 36 species were identified from the investigated sites in Europe, including the Balkans, and in each country virtually the same species complex was present. The dominating species were *Minotetrastichus frontalis*, *Pnigalio agraules* and *Pediobius saulius* (Chalcidoidea: Eulophidae). However, in all areas, the rate of parasitism was generally very low (on average, 6.2%). No density-dependent response (the relationship between host population densities and parasitism) could be established.

Interesting observations were made on the predators of HCLM. In the past decade, birds (especially tits), gained in importance as predators, having found that the larvae and pupae were suitable food sources. More surprising was the discovery of the southern oak bush cricket (*Meconema meridionale*) (Saltatoria: Tettigoniidae) as an active predator of HCLM, the insects opening the leaf mines to prey upon the larvae and pupae.

Biotechnical measures

The results of all experiments were unpromising, with no apparent differences between treated and untreated trees. Although quite large numbers of moths were caught with sticky sheets, and also with the glue-rings, there were still large numbers of mines in the leaves (i.e. trees remained heavily infested). Further, no statistically significant reduction in infestation levels was achieved with the confusion technique.

DISCUSSION

Although diflubenzuron has proved effective against HCLM, with just one annual treatment, this cannot be regarded as the definitive solution to the problem. Other chemical methods have been tried, including tree injections, but none was suitable for use in practice, owing to there being too little efficacy or registration difficulties, or because of the application technique itself (as in the case of the tree injections, where the boreholes in the tree not only cause necrosis but also act as sites of secondary infections). Another important point governing the use of tree injections is the current status of authorization; to date, for example, such treatment is not permitted in Austria.

In the wake of these 'chemical' problems, the demand for sustainable, environmental friendly control measures has increased. Although, in many investigations, much emphasis has been placed on natural enemies, and their potential use for controlling HCLM, there is still no satisfactory, practical or effective biocontrol method. Natural rates of parasitism are still very low. It seems that the native parasitoids are still poorly adapted to this alien host, as is demonstrated by the non- synchronization of the parasitoids (Grabenweger, 2004), even after such an extended period of occurrence. Although very slight tendencies towards an adaptation are recognizable, there are still no significant signs of parasitoids having a real impact. Predators also still have too little influence on the high population densities of HCLM to be truly effective. Although results in studying the possibilities of natural enemies have been disappointing, other non-chemical control strategies might fulfil expectations. Following the identification of the sex-pheromone of HCLM, the use of attractants might have considerable promise. However, no conspicuous reduction in infestation levels could be achieved with pheromones, either with mass trapping or with the male confusion technique. The main problems were the vast masses of HCLM adults, which were far too great for 'normal' trapping methods and (especially) the confusion technique to work, even on sites with reduced HCLM populations following careful removal of leaf litter. The initial results of these investigations revealed that specific control against only males did not result in a sufficient reduction in infestation levels. Therefore, it is necessary to devise viable means of control against both males and females. This new approach is already being investigated, using kairomones as attractants for the females.

The removal and destruction of infested leaves in autumn is an effective method to reduce infestation levels in the next (spring) generation, and to lower population densities, especially in places where chemical treatments are not possible. However, this method cannot replace the need for additional treatments. Also, in forest areas and large parklands, where complete removal of fallen leaves is not possible, this method is inefficient.

The results of the laboratory experiments demonstrated the sensitivity of overwintering HCLM pupae to warm temperatures. Thus, in practice, a minimum temperature of +40°C is necessary within compost heaps to kill the pupae in the leaves. On the other hand, the pupae show high tolerance to low temperatures, enabling them to survive heavy frosts in winter without a problem.

At present, the use of the insect growth regulator diflubenzuron is the only possibility for chemical treatment, as it is the only plant protection product registered for the control of HCLM in Austria. To date, diflubenzuron treatment in spring, in combination with careful leaf removal, is the best strategy. The use of pheromone traps is recommended for determining the best timing for the diflubenzuron spray.

One of the most important problems affecting all tested control measures against HCLM is the extremely high population density of the pest. Thus, only an integrated pest management system, that involves the combination of various cultural and control measures, is likely to prove successful at controlling HCLM. International cooperation will become far more important, and necessary, if effective and practical control measures against this (and many other) invasive alien species are to be found.

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REFERENCES

Blümel S; Hausdorf H (1996). Versuche zur Bekämpfung der Roßkastanienminiermotte. *Gärtner & Florist* **10**, 4-6.

Deschka G; Dimic N (1986). *Cameraria ohridella* n. sp. aus Mazedonien, Jugoslawien (Lepidoptera, Lithocolletidae). *Acta entomologica Jugoslavica* **22**, 11-23.

Freise J (2001). *Untersuchungen zur Biologie und Ökologie der Roßkastanien-Miniermotte,* Cameraria ohridella *Desch. & Dim. (Lep., Gracillariidae).* PhD Thesis, Department of Applied Zoology, Technical University of Munich.

Grabenweger G (2004). Poor control of the horse chestnut leafminer, *Cameraria ohridella* (Lepidoptera: Gracillariidae), by native European parasitoids: a synchronisation problem. *European Journal of Entomology* **101**, 189-192.

Grabenweger G; Lethmayer C (1999). Occurrence and phenology of parasitic Chalcidoidea on the horse chestnut leafminer *Cameraria ohridella* Deschka & Dimic (Gracillariidae, Lepidoptera). *Journal of Applied Entomology* **123**, 257-260.

Puchberger K M (1990). *Cameraria ohridella* Deschka & Dimic (Lepidoptera-Lithocolletidae) in Österreich. *Steyrer Entomologenrunde* **24**, 79-81.

Raimondo F; Ghirardelli L A; Nardini A; Salleo S (2003). Impact of the leaf miner *Cameraria ohridella* on photosynthesis, water relations and hydraulics of *Aesculus hippocastanum* leaves. *Trees* **17**, 376-382.

Stolz M (1997): Untersuchungen über Larval- und Puppenparasitoide von *Cameraria ohridella* in Hinblick auf ihre Eignung zur Laborzucht. *Forstschutz Aktuell* **21**, 31.

Svatos A; Kalinová B; Hoskovec M; Kindl J; Hrdý I (1999). Identification of a new lepidopteran sex pheromone in picogram quantities using an antennal biodetector: (8E,10Z)-tetradeca-8,10-dienal from *Cameraria ohridella*. *Tetrahedron letters* **40**, 7011-7014.

Thalmann C; Freise J; Heitland W; Bacher S (2003). Effects of defoliation by horse chestnut leafminer (*Cameraria ohridella*) on reproduction in *Aesculus hippocastanum*. *Trees* **17**, 383-388.