 ISSN 0250–8052. DOI: 10.1111/epp.2545

A decision-support scheme for mapping endangered areas in pest risk analysis*

R. H. A. Baker[1], J. Benninga[2], J. Bremmer[2], S. Brunel[3], M. Dupin[4], D. Eyre[1], Z. Ilieva[5], V. Jarošík[6,7], H. Kehlenbeck[8], D. J. Kriticos[9], D. Makowski[10], J. Pergl[6,7], P. Reynaud[11], C. Robinet[4], T. Soliman[12], W. Van der Werf[12] and S. Worner[13]

[1]*Food and Environment Research Agency, Sand Hutton, York YO41 1LZ (UK); e-mail: richard.baker@fera.gsi.gov.uk*
[2]*Landbouw-Economisch Instituut B.V., 19 Burgemeester Patijnlaan, The Hague, 2585 BE, part of Wageningen UR, Alexanderveld 5, The Hague 2585 DB (The Netherlands)*
[3]*European and Mediterranean Plant Protection Organization 21 Boulevard Richard Lenoir, Paris 75011 (France)*
[4]*Institut National de la Recherche Agronomique, IUR633, Zoologie Forestière, F-45075 Orléans (France)*
[5]*Plant Protection Institute, 35 Panayot Volov, Kostinbrod 2230 (Bulgaria)*
[6]*Institute of Botany, Academy of Sciences of the Czech Republic, Zámek 1, CZ 25243, Průhonice CZ 25243 (Czech Republic)*
[7]*Faculty of Science, Department of Ecology, Charles University in Prague, CZ 128 44 Prague (Czech Republic)*
[8]*Julius Kühn-Institut (JKI), Bundesforschungsinstitut für Kulturpflanzen, Stahnsdorfer Damm 81, 14532 Kleinmachnow (Germany)*
[9]*Cooperative Research Centre for National Plant Biosecurity, Bruce ACT 2617, Australia and CSIRO Entomology, GPO Box 1700, ACT 2601 Canberra (Australia)*
[10]*Institut National de la Recherche Agronomique, UMR 211 INRA AgroParisTech 78850 Thiverval-Grignon (France)*
[11]*Anses Laboratoire de la Santé des Végétaux, Station d'Angers, 7 rue Jean Dixméras, F49044 Angers (France)*
[12]*Wageningen University, Plant Sciences, Centre for Crop Systems Analysis, Crop & Weed Ecology Group, P.O. Box 430, 6700 AK Wageningen (The Netherlands)*
[13]*The Bio-Protection Research Centre, PO Box 84, Lincoln University, Lincoln, Canterbury (New Zealand)*

This paper describes a decision-support scheme (DSS) for mapping the area where economically important loss is likely to occur (the endangered area). It has been designed by the PRATIQUE project to help pest risk analysts address the numerous risk mapping challenges and decide on the most suitable methods to follow. The introduction to the DSS indicates the time and expertise that is needed, the data requirements and the situations when mapping the endangered areas is most useful. The DSS itself has four stages. In stage 1, the key factors that influence the endangered area are identified, the data are assembled and, where appropriate, maps of the key factors are produced listing any significant assumptions. In stage 2, methods for combining these maps to identify the area of potential establishment and the area at highest risk from pest impacts are described, documenting any assumptions and combination rules utilised. When possible and appropriate, Stage 3 can then be followed to show whether economic loss will occur in the area at highest risk and to identify the endangered area. As required, Stage 4, described elsewhere, provides techniques for producing a dynamic picture of the invasion process using a suite of spread models. To illustrate how the DSS functions, a maize pest, *Diabrotica virgifera virgifera*, and a freshwater invasive alien plant, *Eichhornia crassipes*, have been used as examples.

Introduction

This paper summarises the work undertaken by the PRATIQUE project (Baker *et al.*, 2009; Baker, 2012) to develop a decision-support scheme (DSS) for pest risk analysts when mapping endangered areas. The full scheme is freely available as a module linked to the EPPO DSS for pest risk analysis (PRA) (http://capra.eppo.org/deliverables; http://www.pratiqueproject.eu) and integrated with modules for modelling and mapping climatic risk (Eyre *et al.*, 2012) and pest spread (Kehlenbeck *et al.*, 2012).

*This paper is an outcome of PRATIQUE (Enhancements of Pest Risk Analysis Techniques) a research project funded by the European Union under its 7th Framework Programme.

As specified in the outline of requirements of the International Standard for Phytosanitary Measures (ISPM) number 11 (FAO, 2004), a key objective of a PRA is to identify the endangered area which is defined as: '*an area where ecological factors favour the establishment of a pest whose presence in the area will result in economically important loss*' (FAO, 2010). ISPM 11 shows that this is a two step process. Firstly, following the assessment of entry, establishment and spread (paragraph 2.2.4.1), '*the part of the PRA area where ecological factors favour the establishment of the pest should be identified in order to define the endangered area. This may be the whole of the PRA area or a part of the area.*' Secondly, following the assessment of potential economic consequences (paragraph 2.3.3.1), '*the part of the PRA area where presence of the pest will result in economically* *important loss should be identified as appropriate. This is needed to define the endangered area.*' The first step of the process thus identifies the area where establishment is possible (the area of potential establishment) that contains the endangered area which is identified in the second step.

The identification of the endangered area is important not only as part of a PRA to support quarantine listing for pests that have yet to invade, but, following their invasion, it can also play a role in justifying the maintenance of official control if it can be shown that the pest is not widely distributed in the endangered area. A clearly defined endangered area, e.g. with a map, is also very useful when targetting actions following outbreaks and for designing efficient and effective surveillance programmes and contingency plans.

Like all ISPMs, ISPM 11 does not describe or recommend the particular methods that should be used when undertaking any component of a PRA. EPPO, in common with a number of other national and regional plant protection organisations worldwide, has therefore designed a DSS to assist with the qualitative assessment of risk. This is based on expert judgement supported, as far as possible, by documentary evidence. While modelling and mapping can be undertaken to evaluate particular issues such as endangered areas in detail, this is not essential and the EPPO DSS for PRA states that such areas can, if appropriate, be defined simply by reference to existing ecoclimatic zones, geographic areas, crop distributions, production systems (e.g. protected cultivation) and ecosystems. None of the other qualitative schemes reviewed by PRATIQUE, provides guidance on how to identify endangered areas. This is primarily because, apart from referring to predefined zones, further investigation requires the application of some form of risk mapping technique and this tends to be confined to detailed PRAs, undertaken, for example, to combat a specific new threat, to determine whether expensive or stringent phytosanitary measures are justified or to respond to legal or trade challenges. As such, methods for mapping endangered areas can generally only be inferred by examining these detailed PRAs.

However, maps in detailed PRAs tend to have shortcomings because they: (i) do not follow a common methodology, (ii) are frequently limited to identifying the area of potential establishment based on climatic suitability, (iii) may include host distribution but rarely combine this with other key factors, (iv) exclude economic and environmental impact factors, (v) do not show the areas at highest risk or the endangered area and (vi) do not attempt to represent spread and uncertainty. However, the suite of models available through NAPPFAST (Magarey *et al.*, 2007) allows risk assessors to model pest phenology and pathogen infection combining the results with host distributions to map pest risk in the USA. NAPPFAST is now being extended to include a technique for climatic matching, pathway risk maps and a method for combining maps using pareto dominance (Magarey *et al.*, 2011).

Venette *et al.* (2010) have set out the principal challenges in pest risk mapping, providing a road map for improvement. Mapping the area of potential establishment is already difficult but mapping endangered areas creates additional challenges primarily because the maps need to show where the population density of the pest is likely to reach the Economic Injury Level (EIL) (Pedigo *et al.*, 1986) and thus cause an 'economically important loss'. The EIL is difficult to determine because, although Oerke (2006) provide yield loss data for many crops, these need to be extrapolated to the crop, pest management and market conditions in the PRA area. However, even in the rare cases where an appropriate EIL is available, it is difficult to make sufficiently accurate estimates of population abundance because population dynamics models are complex to construct and difficult to parameterise reliably.

Additional challenges include: (i) the lack of consistently accurate and up to date data for all the key parameters particularly if the PRA area includes several countries, e.g. the European Union, (ii) the difficulty of combining datasets at different resolutions and formats without clear combination rules, (iii) the complexity of many geographic information systems (GIS) and (iv) the absence of clear techniques or conventions for representing pest risk uncertainty in maps.

This paper describes a DSS for mapping endangered areas that attempts to address these challenges by: (i) showing pest risk analysts when an attempt to map an endangered area is appropriate, (ii) setting out procedures for combining maps of different factors to identify crops and other plants at highest risk, (iii) utilising a simple computer program for creating and combining maps and (iv) describing how to incorporate spread/economic impacts. To illustrate how the DSS functions, the maize pest, *Diabrotica virgifera virgifera* (the western corn rootworm), is used as the principal example. Procedures for mapping the risks posed by *Eichhornia crassipes* (water hyacinth), a highly invasive freshwater plant, are also described to illustrate the procedures for an organism that primarily causes environmental impacts.

The DSS has two sections. Section A provides an introduction to the DSS and the DSS itself is described in Section B. There are also 18 annexes available from the website that provide additional tools, datasets and guidance, particularly to support climatic risk mapping (Eyre *et al.*, 2012).

Section A: Introduction to the DSS for mapping endangered areas

Section A outlines the context by defining the endangered area and showing where it fits into the EPPO DSS for PRA. To ensure that pest risk analysts only undertake endangered area risk mapping having carefully thought through all the options and implications, the following issues are then highlighted:

- Risk mapping may not be necessary because it may be sufficient to estimate the endangered area by referring to existing national boundaries, climatic zones, ecoclimatic zones, host distribution, habitats or latitudes and longitudes.
- Considerable time and expertise may be needed. Although the DSS provides some of the data required, e.g. crop maps, the automation of several processes using the 'R' software language (http://cran.r-project.org/) and a user-friendly method for combining maps using the MCAS-S multi-criteria software (see below), some experience with GIS software may also be

necessary. In addition, for modelling and mapping key factors, such as climatic suitability, an appropriate level of proficiency with relevant software packages, e.g. CLIMEX (Sutherst *et al.*, 2007), is required.

- Without sufficient or reliable data on the distribution and magnitude of the key factors that influence the area of potential establishment, the areas at highest risk and the endangered area, these areas cannot be defined accurately and there may be a danger of misinterpretation. Although there may be substantial difficulties in obtaining adequate information on several key factors, such as the distribution of hosts (or suitable habitats for plants), in general, if there is insufficient information to map climate suitability, it will also be inappropriate to map endangered areas.
- Mapping the endangered area will be most useful when: (i) the endangered area is not already clearly identifiable from the qualitative EPPO PRA scheme, (ii) the pest does not pose a similar threat throughout the area of potential establishment, (iii) the impact assessment section has identified some spatially distinct 'worst cases' where major or massive impacts may occur that cannot readily be described in words, (iv) surveillance strategies are under consideration or there is a requirement to prioritise eradication, containment or suppression actions following an outbreak, (v) the imposition of phytosanitary measures to particular parts of the PRA area may be challenged or (vi) an existing PRA with an endangered area map is being updated or reviewed.
- As the difficulties of representing risk and uncertainty are magnified when mapping combinations of risk factors, the DSS stresses the importance of ensuring that maps displaying the different risk factors are presented before combination. Where possible, maps showing the most likely outcome and the extremes should also be provided to risk managers. For example, this can be done by presenting three maps depicting a 'best case' (e.g. 10% percentile outcome), median scenario (50%) and 'worst case' scenario (90%). In some cases, it will be appropriate to investigate different scenarios, especially when considerable changes in risk over time are expected.

Section A also sets out the work that needs to be undertaken before starting Section B. Risk assessors should have completed (at least in draft) the EPPO DSS for PRA so that they already have the following information that is required to map the endangered area:

- A list of the key factors that set the limits to the area of potential establishment.
- A description of the area of potential establishment.
- A list of the key factors that influence the suitability of the area of potential establishment.
- Ratings and justifications for the key factors that influence the suitability of the area of potential establishment, the most likely points of entry, natural and human-assisted spread and economic, environmental and social impacts.

Section A describes the four stage structure of the DSS and the reasons for the approach that has been adopted:

- In Stage 1 the key factors are confirmed and the data are assembled and mapped.
- In Stage 2 priority is given to combining maps to represent the areas of highest risk rather than endangered areas due to the difficulties (noted above) in determining where economic loss occurs.
- However, in Stage 3 some methods for mapping endangered areas are provided based on worst-case scenarios using a logistic growth model and climatic suitability estimates modelled in CLIMEX.
- Stage 4 provides a suite of spread models that allows the invasion process to be portrayed dynamically. This stage is described by Kehlenbeck *et al.* (2012) and is not discussed further here.

Section B Stage 1: Confirming, assembling and mapping the data for the key factors

Having completed the EPPO DSS for PRA, at least in draft, and decided that mapping endangered areas is appropriate, risk analysts start Stage 1 of Section B by assembling the data and mapping the key factors that determine the suitability of the area of potential establishment described in question 3.08. These factors have already been identified and given a risk rating in questions 3.01–3.16 in the EPPO DSS for PRA. Sources of data and any existing maps can be accessed through the Capra Data Explorer (http://capra.eppo.org/). A map showing areas of climatic suitability is particularly important and this may be created using the climatic mapping DSS (Eyre *et al.*, 2012). For *D. virgifera virgifera*, the key factors are climate and host (grain maize and forage maize) distribution and these were obtained respectively from a CLIMEX model (Kriticos & Reynaud, 2012) and the McGill University database (Monfreda *et al.*, 2008). For *E. crassipes*, climate and habitat are most important.

Data and any existing maps then need to be assembled for the factors that determine the area of potential impact – where hosts or habitats are at highest risk from impacts (excluding the factors that enhance establishment selected above). Guidance is given for selecting the economic and environmental receptors at highest risk. The most vulnerable cultivated plants include crops:

- of susceptible cultivars
- grown in conditions that favour pest impacts, e.g. soils that are not sandy (for *D. virgifera virgifera*)
- of high value, e.g. seed potatoes compared to ware potatoes and, for *D. virgifera virgifera*, grain maize compared to forage maize
- with high quality standards, e.g. dessert fruit
- with long replacement times, e.g. timber and fruit trees
- with pest friendly management practices, e.g. no rotation (for *D. virgifera virgifera*)
- that form a significant proportion of national production or the export market
- of heritage varieties
- with organic status and/or biological control systems
- with no effective control methods available.

The most vulnerable environmental vulnerabilities include:

- Keystone and indicator species
- Rare and endemic species

- Nature reserves and special areas of conservation under, e.g. the EC Habitats Directive
- Islands and other isolated habitats
- Species, habitats and ecosystems providing important ecosystem services.

Guidance, data and tools are provided to ensure that all the key datasets are available at 10 km × 10 km resolution across the EU by appropriate reprojection, up-scaling and down-scaling so that MCAS-S, the Multicriteria Analysis Shell for Spatial Decision Support program (Australian Bureau of Agricultural and Resource Economics and Sciences, 2009) can be employed. MCAS-S is a free, user-friendly software tool that allows different spatial datasets to be displayed and combined to represent risk using a variety of arithmetical, logical and matrix methods that can be set by the user. Tables can also be generated to summarise the maps, e.g. to give the number of 10 km × 10 km grid cells for each risk class for all EU member states.

MCAS-S allows the user to set the thresholds for data classification. In this DSS the pre-classification of factors generally into six (absent, very low, low, medium, high and very high) or two (absent and present) classes is provided before combining them with other factors because at this stage it is generally easier for the assessor to attempt a judgement of the relationship between outputs from, e.g. a climate suitability model or a particular level of host abundance, with the likelihood of establishment. For CLIMEX, guidance is provided to help with this judgement. However, it is recommended that great care is taken when classifying factors and that it may be worthwhile to explore the effect of different classifications. An example is given for *D. virgifera virgifera* representing the most likely, the best and the worst case scenarios showing how changing scenarios influences uncertainty. As map combinations based on pre-classification can lead to a loss of information (Dupin *et al.*, 2011) they can also be compared with those created by post-classifying continuous variables that can be combined using arithmetical methods.

Section B Stage 2: Combining maps to identify the areas at highest risk

In Stage 2 the maps of the key risk factors prepared in Stage 1 are combined: first to map the area of potential establishment, second to map the area of potential impacts and third to map the areas at highest risk. Any assumptions and combination rules utilised need to be documented. Seven matrix rules (with examples) have been implemented MCAS-S (see Table 1).

Examples

Diabrotica virgifera virgifera

To map the area of potential establishment for *D. virgifera virgifera* in Europe (Fig. 1C), maps of the areas harvested for grain and forage maize (in ha per 10 km × 10 km grid cell) were added, divided into two classes (presence and absence) (Fig. 1A) and combined using a minimum rule matrix with a map of climatic suitability based on the CLIMEX Ecoclimatic Index (EI) (Fig. 1B). As the *D. virgifera virgifera* CLIMEX maps were generated, new information has come to light that shows that the CLIMEX model needed to be rewritten to correctly reflect the role of soil moisture. The new model is described and outputs are provided by Kriticos *et al.* (2012).

A map of the area of potential impact for *D. virgifera virgifera* was constructed by taking into account two factors: the production of grain and forage maize and the presence of sandy soils. Grain maize is approximately five times as valuable as forage maize and values of €250 and €50 per tonne respectively were chosen based on data from Eurostat (2011) so that production could be expressed in euros per grid cell. Hungarian observations that yield losses from *D. virgifera virgifera* do not occur on sandy soils were also taken into account. Maps representing the production of grain and forage maize crops (Fig. 1D,E) were first produced separately by combining maps of the area harvested and yields taking into account the price difference between the two crops. They were then added together to provide a map of total maize production (Fig. 1F). The modified average matrix was then used to combine this map with the presence of sandy soils (see Fig. 1H) from the European Soils Database (JRC, 2010) to produce the area of potential impact (Fig. 1G).

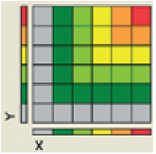
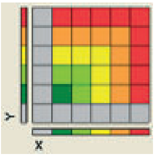
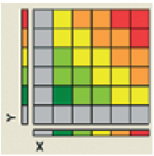
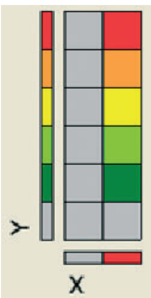
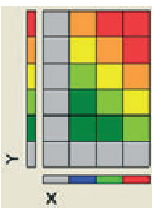
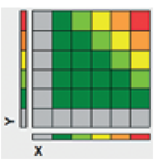
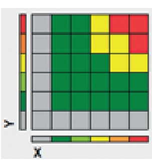
The area at highest risk (Fig. 1I) was then constructed by combining the areas of potential establishment (Fig. 1C) and potential impact (Fig. 1G) using the high risk matrix. The highest risk occurs in the grid cells where: the climate is most suitable for pest establishment, crop production (or output) is highest, there are no additional factors that may decrease the likelihood of impacts and there are additional factors that may increase the likelihood of impacts. For *D. virgifera virgifera*, the areas at highest risk were based on climatic suitability, host (grain and forage maize) production and soil suitability (see Fig. 2 for a summary of the process). Other factors, such as the absence of crop rotation, could not be mapped because of the lack of data for all EU member states.

Eichhornia crassipes

For *E. crassipes*, the area of potential establishment was constructed by using a limiting factor matrix to combine a CLIMEX climatic suitability map with a map representing habitats (inland marshy areas, watercourses and water bodies) suitable for establishment based on Corine Land Cover (EEA, 2011a). To map the areas of potential impact (highest conservation importance), the extent to which this DSS could help identify Natura 2000 sites (special areas of conservation established under the 1993 EU habitats directive) (EEA, 2011b) that could be invaded by *E. crassipes* was explored.

Eichhornia crassipes colonises still or slow moving water resulting in thick extensive mats. It occurs in estuarine habitats, lakes, urban areas, water courses, and wetlands. It can tolerate extremes of water level fluctuation and seasonal variations in flow velocity, and extremes of nutrient availability, pH, temperature and toxic substances (Gopal, 1987), but does not tolerate brackish or salt water (Muramoto *et al.*, 1991). Based on this evidence, the authors of this paper selected five Natura 2000 habitats: natural eutrophic lakes with *Magnopotamion* or *Hydrocharition*, constantly flowing Mediterranean rivers with *Glaucium*

Table 1 Matrices available for combining two factors (*X* and *Y*) in two, three of five classes. Once combined, the sequence of colours goes from grey (absent) through dark green (very low) to red (very high)

Matrix diagram	Matrix description
	**1. Minimum rule matrix** This is used when both factors, e.g. climatic suitability and host presence, are required so that the factor with the most severe constraint (lowest classification) dominates and the other factor is ignored. Equivalent scores for each factor impose equivalent levels of constraint.
	**2. Maximum rule matrix** This is the inverse of the minimum rule matrix. The factor with the highest classification is what matters and the classification of the other factor is ignored. For example, if protected environments are present, the climate, as measured at weather stations, may not be important.
	**3. Addition rule matrix** This sums both factors, e.g. combining lack of rotation (which may increase population densities of *Diabrotica virgifera virgifera*) with the amount of crop production in the area of potential establishment.
	**4. Limiting factor matrix** This can be used when the absence of one factor, e.g. soil above a pH threshold or host absence prevents establishment but, if present, has no additional effect on habitat suitability.
	**5. Modified Average** This changes the classification by ±1 if favourable or unfavourable, e.g. an early harvest date may prevent some pests from completing their life cycle whereas a late harvest date may allow time for all individuals to develop.
	**6. High risk matrix** This can be used to identify locations where there is a coincidence of high classes, e.g. when combining the suitability of the area of potential establishment with factors influencing impact, to produce a five level risk classification.
	**7. Cox's risk matrix** This can be used as for the high risk matrix but when combining the area of potential establishment and area of potential impact into three classes (Cox, 2008).

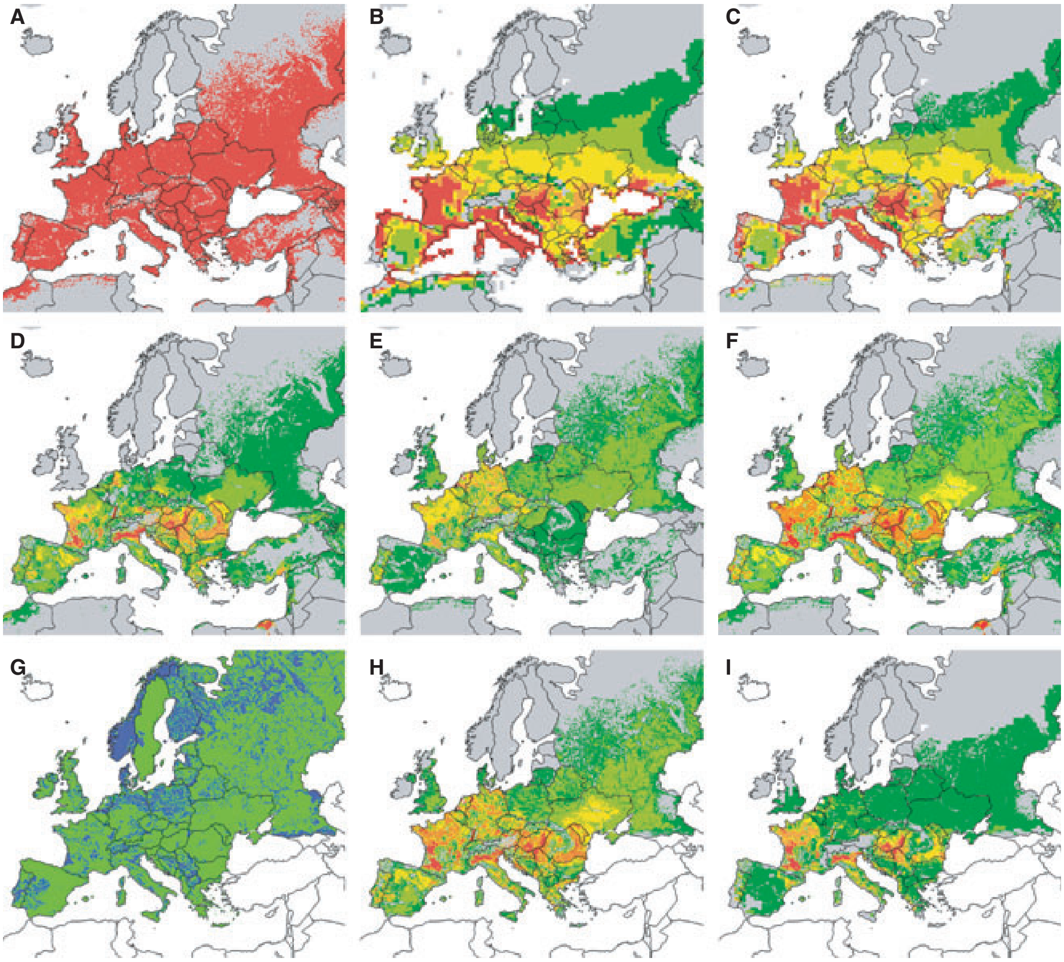


Fig. 1 Maps produced to identify the area at highest risk from *Diabrotica virgifera virgifera*. In Fig 1A: grey indicates absence and red is presence. In Fig 1B: grey is unsuitable (Ecoclimatic Index (EI) = 0), dark green is very low suitability (EI between 1 and 15), green is low suitability (EI between 15 and 20), yellow is moderate suitability (EI between 20 and 25), orange is high suitability (EI between 25 and 30) and red is very high suitability (EI greater than 30)). In Figs 1C, 1H and 1I: grey is zero, dark green is very low, green is low, yellow is moderate, orange is high and red is very high. In Fig 1D, 1E and 1F: grey is zero, dark green is very low (between 1 and 100 000 euros), green is low (between 100 000 and 500 000 euros), yellow is moderate (between 500 000 and 1 million Euros), orange is high (between 1 million and 2.5 million euros) and red is very high (greater than 2.5 million Euros). In Fig 1D, soils with sandy texture are coloured in blue (all other soils are in green).

flavum, watercourses of plain to montane levels with *Ranunculion fluitantis* and *Callitricho-Batrachion* vegetation, rivers with muddy banks with *Chenopodion rubri* p.p. and *Bidention* p.p. vegetation and constantly flowing Mediterranean rivers with *Paspalo-Agrostidion* species and hanging curtains of *Salix* and *Populus alba*. The area of the Iberian peninsula at highest risk (Fig. 3) from *E. crassipes* was created by overlaying the raster map of the area of potential establishment and the vector map of Natura 2000 sites that are particularly suitable for *E. crassipes* colonization.

Section B Stage 3: Mapping endangered areas

As noted above, to estimate the area where economically important losses are likely to occur, it is important not only to identify the areas at highest risk (from Stages 1 and 2) but also to indicate the extent to which the conditions necessary for pest populations to exceed the EIL are present in the PRA area. In the absence of models of pest abundance and the extent to which they are likely to exceed the EIL, yield and quality loss scenarios can still be explored, e.g. by applying the worst case scenario, where it is assumed that the pest has already reached its maximum geographical extent but at an extremely low initial abundance, requiring many generations for the population to build up before economic impact is observed. The authors have therefore: (i) provided a method based on a logistic growth model (model C, see Kehlenbeck *et al.*, 2012) for identifying the areas that are likely to have the highest population density based on climate and (ii) described how climatic suitability in areas where high impacts have already been observed can be used to help identify where

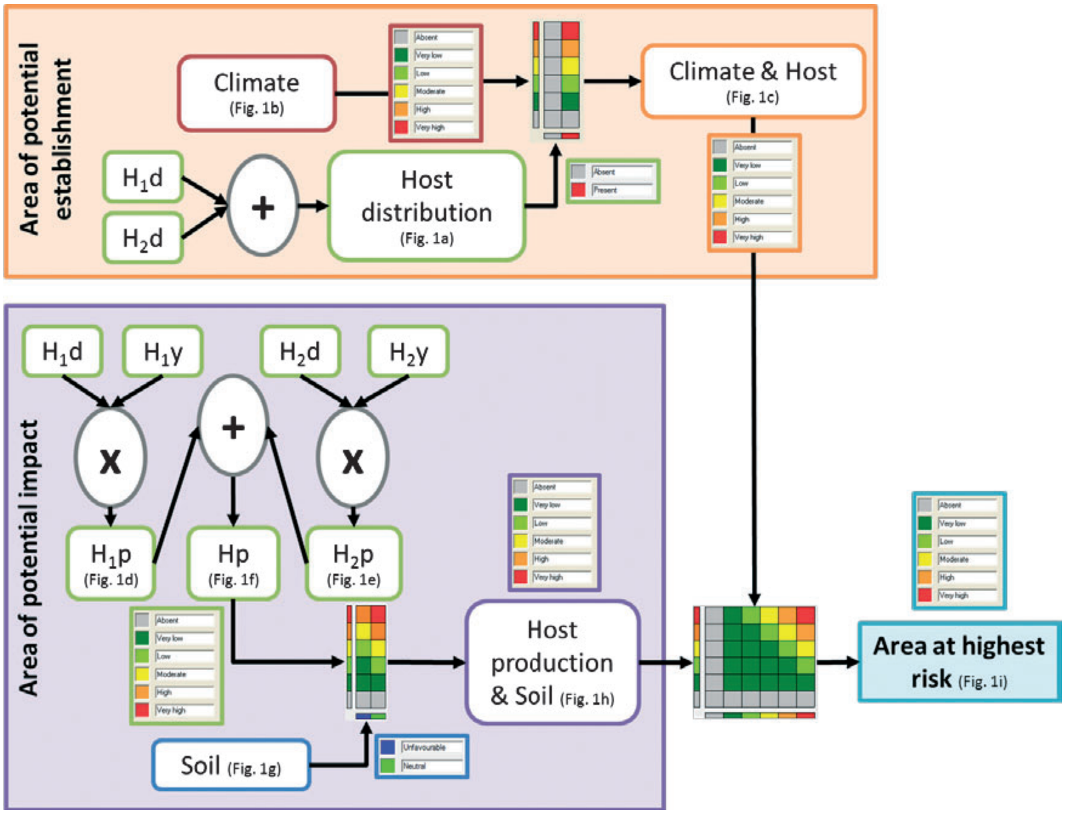


Fig. 2 Summary of the combination process for mapping the area at highest risk from *Diabrotica virgifera virgifera*.[H_1d: grain maize harvested area (ha); H_1y: grain maize yields (tonnes ha^{-1}); H_1p: grain maize production (€); H_2d: forage maize harvested area (ha); H_2y: forage maize yields (tonnes/ha); H_2p: forage maize production (€)].

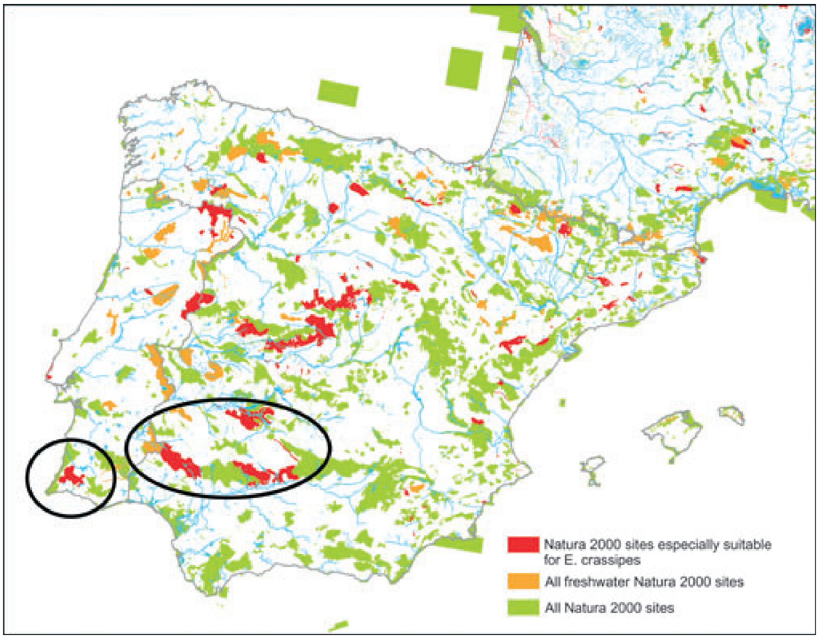


Fig. 3 Freshwater Natura 2000 sites (special areas of conservation established under the 1993 EU habitats directive) especially suitable for *E. crassipes* colonization based on climate and habitat. Sites in red within the black circles are at highest risk.

economic loss may occur in the PRA area. Yield loss scenarios can also be explored. Where yield and quality loss scenarios are being explored for polyphagous species, decision rules for combining maps of economic impact for different hosts have also been provided.

To estimate the population densities in the area of potential establishment based on climatic suitability and relate these to areas where economically important losses might occur, model C from Stage 4 (Kehlenbeck *et al.*, 2012) can be applied to the grid cells in the area of potential establishment for, e.g. 10 years, assuming that the same initial population is introduced to all suitable cells. As the model C is based on a growth parameter constant (the maximum year to year multiplication factor λ_{max} or the finite growth rate derived from the literature) and a variable for favourable climate (GI_A, the CLIMEX annual Growth Index) that influences the growth parameter, the finite growth rate varies in the area of potential establishment according to the GI. As such, maps of GI (constrained to the area of potential establishment) may also indicate areas with the highest potential population abundance based on climate. For some species, it may be appropriate to map the number of degree days available for growth over the minimum threshold of development, the number of generations per year or the CLIMEX EI.

Relationships between modelled climatic suitability and measurements of pest impact can also be explored. Pinkard *et al.* (2010) described a technique for regressing simple qualitative assessments of site suitability for a pathogen that can be used for the *post-hoc* classification of climate suitability for pest impact. However, the regression approach exposes the variability in the system that encompasses the climate itself, the relationship between the organism and climate variables, the climatic suitability model and experimental observations of impact. Impacts recorded in the literature are often based on limited, disparate studies that measure impacts in different ways. The challenge lies in transforming these disparate measures into a coherent dataset with a single measure of impact (Kriticos DJ, Leriche A, Palmer D, Cook DC, Brockerhoff EG, Stephens AEA & Watt MS, unpublished data). When using data that summarise climate over a long sequence of years (commonly 30 years) care needs to be taken because published impacts may only refer to the year when the maximum was recorded. It is also important to note that: the relationship between climate suitability and pest impact will probably be non-linear as the amount of host damage can depend on a complex interaction between the suitability of the climate for the pest and for the host plant and the mere presence of the pest at any non-zero level of density may be sufficient to trigger phytosanitary regulations based on loss of area freedom.

Conclusions

This DSS provides pest risk analysts with guidance and tools for mapping and combining the key components of endangered areas. It focuses on mapping areas of highest risk due to the difficulties in identifying areas where economic loss will occur. Further testing and additional developments are required to identify best practice. These include:

- Identifying the most appropriate methods for calculating and representing uncertainty in risk maps
- Accurately reflecting current climate and taking climate change into account
- Mapping organisms with complex life cycles
- Mapping areas where economic loss will occur
- Providing guidance on the choice of models in particular situations

Acknowledgements

PRATIQUE was funded by the European Union 7th Framework Programme Grant No. 212459.

Un schéma d'aide à la décision pour cartographier les zones menacées dans les analyses de risque phytosanitaire

Cet article décrit un schéma d'aide à la décision pour cartographier la zone dans laquelle les pertes économiquement importantes sont susceptibles de se produire (la zone menacée). Il a été conçu par le projet européen PRATIQUE pour aider les analystes du risque phytosanitaire à faire face aux nombreux problèmes pour cartographier le risque et décider des méthodes les plus appropriées. L'introduction du schéma indique le temps, l'expertise et les données qui seront nécessaires ainsi que les situations pour lesquelles cartographier les zones menacées est le plus utile. Ce schéma d'aide à la décision est constitué de quatre étapes. Dans l'étape 1, les facteurs clés qui influencent la zone menacée sont identifiés, les données sont assemblées et, si nécessaire, les cartes des facteurs clés sont produites en listant les hypothèses importantes. Dans l'étape 2, les méthodes pour combiner ces cartes pour identifier la zone d'établissement potentiel et la zone la plus à risque d'impact par l'organisme nuisible sont décrites, en documentant les hypothèses et les règles utilisées pour les combiner. Quand cela est possible et pertinent, l'étape 3 peut ensuite être suivie pour montrer si des pertes économiques se produiront dans la zone la plus à risque et pour identifier la zone menacée. Au besoin, l'étape 4, décrite par ailleurs, fournit des techniques pour produire une image dynamique du processus d'invasion en utilisant un ensemble de modèles de dissémination. Pour illustrer le fonctionnement du schéma, un ravageur du maïs, *Diabrotica virgifera virgifera*, et une plante exotique envahissante d'eau douce, *Eichhornia crassipes*, ont été utilisés comme exemples.

Схема поддержки принятия решений для картирования зон, подверженных опасности, при анализе фитосанитарного риска

В работе дается описание Схемы поддержки принятия решений (DSS), позволяющей провести картирование зоны, где по всей вероятности будет иметь место экономически значимый ущерб (зона, подверженная

опасности). Схема была разработана в рамках проекта ЕС «PRATIQUE» с целью помочь аналитикам фитосанитарного риска решать многочисленные проблемы картирования риска и дифференцированно выбирать оптимальные методы борьбы. Во введении к DSS указывается время и необходимый опыт, требования, предъявляемые к данным, а также те ситуации, когда картирование зон, подверженных опасности, является наиболее целесообразным. Схема картирования DSS подразделяется на четыре стадии. На стадии 1 определяются ключевые факторы, влияющие на зоны, подверженные опасности, производится сбор данных и, там где это целесообразно, на карту наносятся ключевые факторы с перечнем различных значимых гипотез. На стадии 2 проводится описание методов комбинирования этих карт для выявления зоны потенциальной акклиматизации и зоны риска наиболее высокого воздействия вредных организмов с документированием всех гипотез и используемых правил комбинирования. Если это считается возможным и целесообразным, может проводиться стадия 3, призванная показать, произойдет ли экономическая потеря в зоне наиболее высокого риска, и выявить зону, подверженную опасности. В случае необходимости, на стадии 4, описанной в другом месте, указываются методы динамичного отображения процесса инвазии, с использованием набора моделей распространения. Для того чтобы проиллюстрировать функционирование DSS, в качестве примеров

References

Australian Bureau of Agricultural and Resource Economics and Sciences (2009) *Multi-Criteria Analysis Shell for Spatial Decision Support. Version 2.1 User Guide*. http://www.daff.gov.au/abares/data/mcass [accesssed on 20 March 2012].

Baker R (2012) An introduction to the PRATIQUE Research Project. *EPPO Bulletin*, this issue.

Baker RHA, Battisti A, Bremmer J, Kenis M, Mumford J, Petter F, Schrader G, Bacher S, De Barro P, Hulme PE, Karadjova O, Lansink AO, Pruvost O, Pysek P, Roques A, Baranchikov Y & Sun JH (2009) PRATIQUE: a research project to enhance pest risk analysis techniques in the European Union. *Bulletin OEPP/EPPO Bulletin* **39**, 87–93.

Cox LA (2008) What's wrong with risk matrices? *Risk Analysis* **28**, 497–512.

Dupin M, Brunel S, Baker R, Eyre D & Makowski D (2011) A comparison of methods for combining maps in pest risk assessment: application to *Diabrotica virgifera virgifera*. *EPPO Bulletin* **41**, 217–225.

EEA (2011a) Corine Land Cover 2000. http://www.eea.europa.eu/data-and-maps/data/clc-2006-vector-data-version-1 [accesssed on 20 March 2012].

EEA (2011b) Natura 2000 data – the European network of protected sites. http://www.eea.europa.eu/data-and-maps/data/natura-1 [accesssed on 20 March 2012].

Eurostat (2011) http://epp.eurostat.ec.europa.eu/portal/page/portal/eurostat/home/ [accesssed on 20 March 2012].

Eyre D, Baker R, Brunel S, Dupin M, Jarosik V, Kriticos DJ, Makowski D, Pergl J, Reynaud P, Robinet C & Worner S (2012) Rating and mapping the suitability of the climate in pest risk analysis. *EPPO Bulletin*, this issue

FAO (2004) Pest risk analysis for quarantine pests including analysis of environmental risks. *International Standards for Phytosanitary Measures*. Publication No. 11. Rev. 1. FAO, Rome.

FAO (2010) Glossary of phytosanitary terms. *International Standards for Phytosanitary Measures*. Publication No. 05. FAO, Rome.

Gopal B (1987) *Water Hyacinth*. Elsevier, Amsterdam.

JRC (2010) European Soils Database. http://eusoils.jrc.ec.europa.eu/esdb_archive/ESDB/Index.htm [accesssed on 01 March 2012].

Kehlenbeck H, Robinet C, van der Werf W, Kriticos DJ, Reynaud P & Baker RHA (2012) Modelling and mapping spread in pest risk analysis: a generic approach. *EPPO Bulletin*, **42**, 74–80 this issue.

Kriticos DJ, Reynaud P, Baker RHA & Eyre D (2012) The potential global distribution of the western corn rootworm (*Diabrotica virgifera virgifera*). *EPPO Bulletin* **42**, 56–64 (this issue).

Magarey RD, Fowler GA, Borchert DM, Sutton TB, Colunga-Garcia M & Simpson JA (2007) NAPPFAST: an internet system for the weather-based mapping of plant pathogens. *Plant Disease* **91**, 336–345.

Magarey RD, Borchert DM, Engle JS, Colunga-Garcia M, Koch FH & Yemshanov D (2011) Risk maps for targeting exotic plant pest detection programs in the United States. *Bulletin OEPP/EPPO Bulletin* **41**, 46–56.

Monfreda C, Ramankutty N & Foley JA (2008) Farming the planet: 2. Geographic distribution of crop areas, yields, physiological types, and net primary production in the year 2000. *Global Biogeochemical Cycles* **22**, 1–19.

Muramoto S, Aoyama I & Oki Y (1991) Effect of salinity on the concentration of some elements in water hyacinth (*Eichhornia crassipes*) at critical levels. *Journal of Environmental Sciences and Health* **26**, 205–215.

Oerke OC (2006) Crop losses to pests. *The Journal of Agricultural Science* **144**, 31–43.

Pedigo LP, Hutchins SH & Higley LG (1986) Economic injury levels in theory and practice. *Annual Review of Entomology* **31**, 341–368.

Pinkard EA, Kriticos DJ, Wardlaw TJ & Carnegie AJ (2010) Estimating the spatio-temporal risk of disease epidemics using a bioclimatic niche model. *Ecological Modelling* **221**, 2828–2838.

Sutherst RW, Maywald GF & Kriticos DJ (2007) *CLIMEX Version 3. User's Manual*. Hearne Scientific Software Pty Ltd., Melbourne, Australia.

Venette RC, Kriticos DJ, Magarey RD, Koch FH, Baker RHA, Worner SP, Gomez R, Nadilia N, McKenney DW, Dobesberger EJ, Yemshanov D, De Barro PJ, Hutchison WD, Fowler G, Kalaris TM & Pedlar J (2010) Pest risk maps for invasive alien species: a roadmap for improvement. *BioScience* **60**, 349–362.