



ENHANCEMENTS OF PEST RISK ANALYSIS TECHNIQUES

Protocol for mapping endangered areas taking climate, climate change, biotic and abiotic factors, land use and economic impacts into account accessed via a hyperlink in a project web page and integrated into the web-based EPPO PRA scheme

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Analysis Techniques

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PROJECT OVERVIEW: PRATIQUE is an EC-funded 7th Framework research project designed to address the major challenges for pest risk analysis (PRA) in Europe. It has three principal objectives: (i) to assemble the datasets required to construct PRAs valid for the whole of the EU, (ii) to conduct multi-disciplinary research that enhances the techniques used in PRA and (iii) to provide a decision support scheme for PRA that is efficient and user-friendly. For further information please visit the project website or e-mail the project office using the details provided below:

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Table of Contents:

A	Introduction to the Decision Support Scheme for Mapping Endangered Areas.....	5
B.	The Mapping Endangered Areas Decision Support Scheme (DSS)	11
	Stage 1: Confirm the key factors that influence the endangered area based on the draft PRA, assemble the data and, if appropriate, provide or produce maps of the key factors listing any assumptions made.....	11
	Stage 2: Combine the maps to identify the areas of potential establishment and the areas at highest risk from pest impacts documenting any assumptions and combination rules utilised	19
	Stage 3: When possible and appropriate, distinguish the endangered areas (those areas where economically important loss is likely to occur).....	52
	Stage 4: When possible and appropriate, provide a dynamic picture of the invasion process using spread models.....	56

Decision Support Scheme for Mapping the Endangered Area 11th July 2011

GUIDANCE FOR USING THIS DOCUMENT

The Decision Support Scheme (DSS) for Mapping Endangered Areas is designed to help pest risk analysts (a) to decide whether it is appropriate to try and create a map of endangered areas and (b) to provide guidance on the most suitable methods to follow. The DSS can be found in Section B (page 12) of this document. Before using the DSS for the first time it is recommended that pest risk analysts read the whole of Section A (the introduction to the scheme). Guidance on whether it is appropriate to try to map endangered areas is given in pages 6-7: see sections A4 (time and expertise required), A5 (data requirements) and A6 (situations when mapping the endangered areas is most useful).

A Introduction to the Decision Support Scheme for Mapping Endangered Areas

A1 Contents of the Decision Support Scheme (DSS) for Mapping Endangered Areas

Following this introduction, the main section of the DSS consists of the four stages related to mapping endangered areas (see section A8). There are also numerous annexes (see Appendix 1) that provide:

- A review of best practice for mapping endangered areas (Annex 1)
- The PRATIQUE Climatic Suitability Risk Mapping Decision Support Scheme and related documents (Annexes 2A – 2L)
- The key datasets used in the DSSs, the PRATIQUE Datapack (Annexes 3A-3D)

A2 Defining the endangered area

The PRA scheme consists of a sequence of questions that generally require a qualitative response, a risk rating and an uncertainty score based on the available information and expert judgement. However, following ISPM11 (FAO, 2004), the EPPO PRA scheme also requires the identification of:

- a) the area of potential establishment
 - *The part of the PRA area where ecological factors favour the establishment of the pest*
- b) the endangered area
 - *The part of the PRA area where the presence of the pest will result in economically¹ important loss.*

A2 Describing and mapping the endangered area

In question 6.15 of the EPPO DSS for PRA scheme, the risk assessor is asked to refer back to the area of potential establishment defined in question 3.08 and identify the area which is economically most at risk (i.e. the endangered area). At the qualitative level, the two areas

¹ Environmental and social impacts are also included in economic impacts, following Supplement 2 of ISPM5 (FAO, 2010).

can be described in words, e.g. in relation to national boundaries, climatic zones, ecoclimatic zones, host distribution, habitats or latitudes and longitudes. Guidance for describing these areas is given in the qualitative EPPO PRA scheme. Such descriptions, i.e. without modelling or mapping, are sufficient for many PRAs.

This DSS for mapping endangered areas will be linked to question 6.15 to allow risk assessors to go further by providing guidance to those who would also like to map the endangered area in addition to the area of potential establishment (which sets the boundaries for the part of the PRA area that the pest can colonise). A linkage to question 3.08 will also be provided to provide guidance to those who also wish to map the area of potential establishment. It is important to note that, because of the difficulties in determining whether the thresholds for economic impacts are likely to be exceeded, this DSS for mapping endangered areas is primarily designed to help risk assessors identify and map areas at highest risk.

A4 Time and expertise for mapping the endangered area

Mapping the endangered area and areas at highest risk requires considerable time and expertise and should only be undertaken after careful consideration. While this DSS provides some of the data required, e.g. crop maps (see Annex 3B), the automation of several processes using the “R” software language (see Annex 2I) and a user-friendly method for combining maps using the MCAS-S multi-criteria software (see Stage B2 below), some experience with geographical information systems (GIS) software may also be necessary. For the modelling and mapping of key factors, such as climatic suitability, an appropriate level of proficiency with relevant software packages, e.g. CLIMEX, is required. Separate climatic mapping and spread modelling DSSs are also provided (See Annex C to this document and PRATIQUE deliverable 2.6).

A5 Data Requirements

Without sufficient 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 dangers of misinterpretation. This issue is explored in detail in the climatic mapping DSS (See Annex 2A). Although there may be substantial difficulties in obtaining sufficient information on 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.

A6 Situations when mapping the endangered area is most useful

Mapping the endangered area is most likely to be useful if:

- The endangered area is not already clearly identifiable from the qualitative EPPO PRA scheme
- The pest does not pose a similar threat throughout the area of potential establishment
- The impact assessment section has identified some spatially distinguishable “worst cases” where major or massive impacts may occur that cannot readily be described in words

- Surveillance strategies are under consideration or there is a requirement to prioritise eradication/containment/suppression actions following an outbreak (Venette et al., 2010)
- The imposition of phytosanitary measures to particular parts of the PRA area may be challenged
- An existing PRA with an endangered area map is being updated or reviewed

A7 Difficulties in communicating uncertainty in endangered area maps

It is important to recognise that it is very difficult to communicate uncertainty in maps, particularly to risk managers who may only focus on one map. The strong visual message that maps provide can be misleading because the use of primary colours, such as red, to indicate high risk, and lines or abrupt changes in colour to denote differences in risk levels may appear to indicate greater certainty than actually exists.

This DSS also provides guidance for risk managers to interpret some components of the endangered area maps, e.g. for CLIMEX (Annex 2G). Since 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 factors, before combination, are also presented. 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. An example of uncertainty analysis, based on different classifications of CLIMEX output thresholds for *D. virgifera virgifera* is given in Section B.1.2 This is an important area of further research that, in PRA, is being led by the International Pest Risk Modelling Workgroup with significant contributions from PRATIQUE personnel (Venette et al., 2010).

A8 Summary of the four possible stages in the mapping endangered area DSS

Mapping endangered areas can be seen as a possible four part process:

- Stage 1: Confirm the key factors that influence the endangered area based on the draft PRA, assemble the data and, if appropriate, provide or produce maps of the key factors listing any assumptions made.
- Stage 2: Combine the maps to identify the area of potential establishment and the area at highest risk from pest impacts, documenting any assumptions and combination rules utilised.
- Stage 3: When possible and appropriate, distinguish the endangered areas (those areas where economically important loss is likely to occur)
- Stage 4: When possible and appropriate, provide a dynamic picture of the invasion process using spread models

In many cases, it will either not be possible to undertake Stages 3 and 4 or the time and effort required will be inappropriate for the PRA.

The DSS for mapping endangered areas assumes that assessors have already completed (at least in draft) the qualitative PRA scheme. For Stage B1, the assessors will therefore already

have, at minimum, the following important 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 (from the table which is completed at the start of the establishment section)*
- *A description of the area of potential establishment (from question 3.08)*
- *A list of the key factors that influence the suitability of the area of potential establishment (from questions 3.01-3.07 which are completed at the start of the establishment section)*
- *Information and ratings for the key factors that influence the suitability of the area of potential establishment (from questions 3.09-3.16). To justify these ratings, in most cases the areas of, e.g. climatic suitability and host/habitat distribution, will have already been described.*
- *Information on the most likely points of entry (from question 2.10). This is particularly relevant for modelling spread (see Stage 4)*
- *Information and ratings for natural and man-assisted spread (from questions 4.01-4.06). This is relevant for modelling spread (see Stage 4)*
- *Information and ratings for economic, environmental and social impacts (from questions 6.01-6.15). To justify these ratings, in most cases a description of the “worst cases” will have also been provided.*

In addition, maps on distribution and magnitude for some of the key factors may have already been obtained or generated by modelling (see, for example, the Climatic Risk Mapping Decision Support Scheme in Annex 2A). To map the endangered area, the distribution and magnitude of all the key factors need to be determined. For those key factors which cannot readily be mapped, assumptions on their distribution and magnitude will have to be made for the endangered area mapping process to continue.

Once maps or assumptions of the distribution and magnitude of all the key factors have been obtained, in Stage B2 they need to be combined first to map the area of potential establishment (if not already mapped) and secondly to map the areas at greatest risk from pest impacts. When there are sufficient data to estimate where impacts, e.g. yield losses, are sufficiently high to cause economic damage, stage B3 can be carried out to distinguish the endangered areas where economically important losses are likely to occur. Stage B4 can be undertaken when there is a requirement to provide a representation of the invasion process over time based on particular scenarios, e.g. to support surveillance or containment strategies.

A9 Mapping the endangered area of the EU at 10 km x 10 km resolution

Although this DSS describes a generic process, it particularly provides guidance, data and tools for those key factors for which the available data can be upscaled or downscaled to 10 km x 10 km resolution across the EU. Many such maps, e.g. of crop distribution, are included (See Annex 3A). With all the key factors scaled to the same 10 km x 10 km resolution, additional tools, such as multi-criteria analysis software (MCAS-S) and spread models, can be employed. Detailed guidance and computer programs written in the “R” software language have been provided to rescale data to 10 km x 10 km resolution (See Annex 2I). GIS software, e.g. ArcGIS (© ESRI), can also be used to rescale data (See Annex 3C).

A10 Mapping areas at highest risk and areas of economically important loss

The third stage of this process is particularly challenging since the identification of areas where pest presence will result in “economically important loss” depends on complex factors such as the relationship between pest population density and crop yield or quality loss that exceeds the “economic injury level” (EIL) (Pedigo *et al.*, 1986). Even if the pest population density that will cause significant damage is known; predicting exactly where and when the EIL will be exceeded generally requires a detailed modelling approach that will rarely be possible within the PRA process. In addition, economic impact will be influenced by many factors, e.g. crop variety, cultivation methods and the availability of plant protection products, in addition to pest density. This DSS therefore provides guidance primarily for stages 1-2 of the endangered area mapping process and limits guidance on stage 3 to the exploration of scenarios to predict locations where the pest has the potential to cause significant damage. The spread module (see PRATIQUE Deliverable 2.6) provides guidance and a DSS for modelling and mapping the population density within cells over time (Model 1: The Simple Logistic Growth or Population Dynamics Model) which can be applied to map areas with high pest densities. As noted above, spread models (Stage 4) are most likely to be required to explore the development of impacts over time and scenarios for contingency planning.

A11 Examples

The DSS provides examples for *Diabrotica virgifera virgifera*, the western corn rootworm and *Eichhornia crassipes*, the water hyacinth.

A12 Discussion

It is important to recognise that although we have used one technique, MCAS-S, for displaying and combining the maps, maps could also be combined, albeit with much greater difficulty, using geographical information systems (GIS) software packages, e.g. ArcGIS. MCAS-S is not commonly used worldwide but we have found it to be a particularly user-friendly method of mapping data, combining maps and presenting the results.

The need for detailed work before using MCAS-S to rescale and re-project the datasets to one common resolution may be seen as a handicap but (a) such a process of generalisation or interpretation will be necessary whatever technique is used to combine different datasets, (b) considerable work has been undertaken by PRATIQUE to provide key datasets for PRA in Europe at the same resolution (see Annex 3A and 3B) and (c) detailed instructions are provided for rescaling and projecting datasets (see Annex 3C).

The need to choose one resolution for MCAS-S has influenced the types of data (Annex 3A) that we have used to present and display the DSS. A 10 km x 10 km resolution was selected but other resolutions can be used, for example, 0.5° latitude/longitude. Although gridded datasets, in degrees of latitude and longitude or in set distances, can readily be used, considerable errors may arise when trying to convert data from polygons, especially irregular polygons such as those used by EUROSTAT to summarise crop data by EU NUTS region. This problem was highlighted when trying to convert the data in SEAMLESS² SEAMLESS is a comprehensive dataset that combines data on climate, soil, host distribution and various economic indices to provide values for agro-environmental zones of different sizes that

² <http://www.seamless-ip.org/> and <http://www.seamlessassociation.org/>

represent consistent environmental and agricultural conditions. Although some SEAMLESS datasets were converted into the 10 km x 10 km resolution for MCAS-S, we decided not to use them when presenting the DSS for mapping endangered areas because:

- The maize distribution dataset, once uploaded and rescaled from SEAMLESS, was inferior to that obtained from the global database provided by Monfreda et al. (2008). SEAMLESS is limited to 25 EU member states and only has 30 crops. When compared to the official distribution maps (Anonymous, 2010), the distribution in France provided by SEAMLESS was clearly less accurate than that provided by Monfreda et al. (2008).
- Although daily climate values are provided, these have an exceedingly coarse resolution, with only 13 climate types covering the whole of Europe (Metzger et al, 2005). As Trnka et al (2011) have observed, the climate in Europe is very much more variable than this, especially in the zones with a continental climate and those influenced by the Atlantic.

Nevertheless, we recognise that there are problems with all datasets. For example, Monfreda et al. (2008) do not provide Irish data for maize. If accessible, crop distribution data at 25 km resolution from the Joint Research Centre in Ispra³ should be used.

A pareto based ranking technique has also been developed (Yemshanov et al., 2010) and is being applied to the NAPPFAST pest forecasting mapping system in the USA (Magarey et al., 2007; Magarey et al., 2011) for combining two or more variables without needing to define any equation, matrix, or weights for the combination. This technique does not give any ranking among combinations of variables belonging to the same Pareto level. This is both an advantage (it is very neutral) and a disadvantage (different combinations of variables will belong to the same risk level even if this is not the case for the decision maker). The Pareto levels are defined from the set of simulated individual variable combinations. In other words, different sets of simulated combinations may lead to different Pareto levels. The scale is defined from the simulated combinations (locations belonging to the highest Pareto level are not necessary very risky; they are just the most risky among the simulated combinations). Although it appears to be a useful technique for comparing the risk levels of various locations for a given invasive species, it is likely to be less useful to identify areas with high risk in absolute terms and to compare risk levels between different species. The Pareto based ranking technique is also very demanding in terms of computation time, there is currently no user friendly software available and it is not very well adapted to deal with a limited number of ratings (i.e. the five ratings in the EPPO scheme).

This DSS for mapping the endangered area demonstrates how maps can be combined to map the area of potential establishment, the area at highest risk, the endangered area (based on scenarios) and the invasion process over time. However, the way in which these maps are presented to risk managers so that they can take them into account when reading the PRA and deciding what preventative, remedial or surveillance action to take is also very important. While PRATIQUE has engaged in some dialogue with risk managers, it is clear that further discussion is needed. In most cases, for ease of interpretation, the risk managers are likely to require the component maps in addition to the final combined maps. Further work is also required to develop the most appropriate method for displaying uncertainty. Figures 2.3 4 and Table 16 and 17 below demonstrate one method of doing this using “most likely”, “best” and “worst” case scenarios.

³ <http://mars.jrc.ec.europa.eu/mars/About-us/AGRI4CAST/Crop-Area-Estimates>

B. The Mapping Endangered Areas Decision Support Scheme (DSS)

Before using this DSS, please answer, at least in draft, all the questions in the EPPO PRA scheme. It is most appropriate to start this DSS from question 6.15, the question on endangered areas at the end of the Impact section.

Example responses (coloured in light blue) are provided for *Diabrotica virgifera virgifera* in the EU.

Stage 1: Confirm the key factors that influence the endangered area based on the draft PRA, assemble the data and, if appropriate, provide or produce maps of the key factors listing any assumptions made.

In this context, data include descriptions, maps and assumptions concerning the distribution and magnitude of the key factors based on the draft PRA and other sources.

B1.1 Describe the area of potential establishment and the key factors that define its limits

Notes:

- *A list of the key factors that influence the area of potential establishment is provided in the table which was completed at the start of the establishment section.*
- *The area of potential establishment has already been described in response to question 3.08.*

Hosts, climate

All areas where maize is grown in the EU, except for cold tolerant forage maize in northern EU where the annual degree day threshold base 9°C does not exceed 666 (modified from Baufeld et al., 1996).

B1.2 Summarise the information available for the key factors that determine the suitability of the area of potential establishment

Complete Table 1 by reviewing and summarising the responses made in the EPPO PRA scheme to identify the key factors that influence the suitability of the area of potential establishment.

Table 1: A Summary of the data and maps available for the key factors that determine the suitability of the area of potential establishment. Example responses for *Diabrotica virgifera virgifera* in the EU are provided

Factors	Is the factor likely to have an influence on the suitability of the area of potential establishment? If so, provide a risk rating and uncertainty score	Are data and maps already available for the PRA area?	General Information Sources
Host plants and suitable habitats	Yes Abundant Low Uncertainty	Yes. EU grain and forage maize maps	See Appendix 3B and the Capra Data Explorer
Alternate hosts and other essential species	No		See Appendix 3B and the Capra Data Explorer
Climatic suitability	Yes Largely similar Low Uncertainty	Yes. CLIMEX and regression model maps	See the climatic mapping DSS module (Annex 2A) and the Capra Data Explorer
Other abiotic factors	Yes Largely similar Low Uncertainty In Hungary impacts are not recorded where maize is grown on sandy soil	Yes. Soil maps	See the Capra Data Explorer
Competition and natural enemies	No		See the Capra Data Explorer
The managed environment	Yes Highly favourable Low Uncertainty	In part. Some maps show areas of no crop rotation and irrigation.	See the Capra Data Explorer
Protected cultivation	No		See the Capra Data Explorer

Notes:

- For Column 2, questions 3.01-3.07 which was completed at the start of the establishment section in the PRA scheme, provides the list of the key factors that influence the suitability of the area of potential establishment for this pest
- To complete Column 2 and 3, information and ratings for the key factors that influence the suitability of the area of potential establishment are available from the

responses to questions 3.09-3.16 in the PRA scheme. To justify these ratings, in many cases the areas of, e.g. climatic suitability and host/habitat distribution, will have already been described.

B1.3 Summarise the data and maps that are already available for the key factors that determine the area where hosts or habitats are at highest risk from impacts (excluding factors that enhance establishment considered in B1.2, points of entry and spread)

In Table 2, review and summarise the responses made in the EPPO PRA scheme to identify the key factors that determine the area where economic loss may occur (or at least the area at highest risk). The factors that are likely to cause the highest economic, environmental and social impacts should be considered separately.

Table 2: A Summary of the key factors that determine the area where economic loss may occur (or at least the area at highest risk). Example responses for *Diabrotica virgifera virgifera* in the EU are provided

Factors	Key factors	Are data and maps already available for the PRA area?	General Information Sources
The level of economic impact	Areas of high/low crop value: Forage or grain maize. Areas of high production, e.g. yield. Areas where there is no rotation. Impacts are lower on sandy soils in Hungary.	Maps are available for forage/grain maize production, and, for total maize, yield and prices. Maps of areas where no rotation is practised are available for some countries, e.g. France. Soil maps for Europe indicating where sandy soils are located.	See the Capra Data Explorer
The level of environmental impact	None	-	See the Capra Data Explorer
The level of social impact	Not significant	-	See the Capra Data Explorer

Notes

Information and ratings on these factors are provided in the responses to the questions on economic, environmental and social impacts (see questions 6.01-6.15). To justify these ratings, in most cases a description of the “worst cases” will have also been provided.

Factors that put crops at highest risk from economic impacts include:

- *Pest friendly management practices, e.g. no rotation for *D. virgifera virgifera**
- *Especially high value, e.g. seed potatoes, salad crops and ornamentals in heated glasshouses*
- *Very high quality standards, e.g. dessert fruit*

- Long replacement time, e.g. timber & fruit trees
- Significant proportion of national production including a lack of suitable alternative crops
- Significant proportion of the export market
- Heritage varieties,
- The crop at risk is important in a crop rotation

Factors that put uncultivated species, habitats and ecosystems at highest risk from environmental impacts include:

- “Keystone”, indicator species
- Protected, rare and endemic species
- Special areas of conservation (e.g. Natura 2000 (EEA, 2011)) and other nature reserves
- Islands and other isolated habitats
- Most frequently invaded habitats (Chytrý et al. 2008a,b; Pyšek et al. 2009)
- Fragile ecosystems, e.g. sand dunes, that are not resilient to species loss
- Species, habitats and ecosystems providing important services

Factors that put the human population at highest risk from social impacts include:

- Risks to human health
- The local economy of an area is dependent on the species at risk (i.e. alternative sources of employment are limited)
- The cultural significance of the threatened species
- Areas of high amenity value

B1.4 Summarise the information available for the key factors that determine the location and rate of spread in the area of potential establishment (excluding factors that enhance establishment)

Answer this question only if a spread model is being considered because it is important to provide a dynamic model of the invasion process (For more details, see Stage 4 of the DSS).

Review and summarise the responses made in the EPPO PRA scheme to identify the locations where entry may occur and the key factors that affect the rate of spread to complete Table 3.

Table 3: A Summary of the key factors that determine the location and rate of spread in the area of potential establishment (excluding factors that enhance establishment). Example responses for *Diabrotica virgifera virgifera* in the EU are provided

Factors	Key factors	Are data and maps already available for the PRA area?	General Information Sources
Areas close to the most likely points of	Airports	Entry points are airports but unpredictable	See the Capra Data Explorer

entry			
The rate of natural spread	Mainly flight. The spread rate (60-100 km/yr) depends on maize abundance	A map of potential spread can be generated using the generic spread module	See the Capra Data Explorer
The rate of man-assisted spread	Movement with vehicles used for harvest	A map of potential spread can be generated using the generic spread module (models 3 and 5) at different time steps.	See the Capra Data Explorer
Area invaded after 5 years		Model 3 gives 4.0 to 9.2% of the area of potential establishment invaded after 5 years (model 3, 60-100 km/yr, entry point: 44°.82'N, 0°.30'E).	From the generic spread module
Time needed to spread to the area of potential establishment		Model 3 gives 31 to 51 years (31 for 100 km/year, 51 for 60 km/year) as the time needed to spread to the area of potential establishment. This will be faster if man-assisted spread and new introductions are taken into account.	From the generic spread module

Information and ratings on these factors are provided in the responses to the questions on the points of entry and the rate of spread (see question 2.10 and questions 4.01-4.06).

B1.5 List the maps of key factors already available

To map the areas at highest risk, these must include, at a minimum, maps of the host (or plant pest habitat) distribution and climatic suitability. However, a detailed map may not be necessary if the host plants are ubiquitous.

The assumptions made in producing the maps need to be described.

B1.6 Rescale the maps to the same spatial resolution

Detailed guidance has been provided to rescale data to 10 km x 10 km resolution for mapping risk at the EU level using (i) ArcGIS and (ii) computer programs written in the “R” software language (See Annexes 2I and 3C). The Multi-Criteria Analysis Shell for Spatial Decision

Support (MCAS-S)⁴ is a free, user-friendly software tool developed by the Australian Bureau of Agricultural and Resource Economics and Sciences that allows different spatial datasets to be displayed and combined using a variety of techniques that can be set by the user (see Annex 2J). Before the data can be combined, they must be converted to the same spatial resolution.

If host data are only available as a presence-absence layer known as a mask, the mask can be used to delimit the area where impacts are possible, but such data cannot add to the predictive power of the climatic model in areas where the host is present.

B1.7 Upload, classify and map in MCAS-S

MCAS-S allows factors to be classified in three ways: equal interval, equal area and according to user preference (custom). The user preference (custom) option enables thresholds to be set. Between 2 and 10 classes are allowed. Values that are out of bounds can be truncated or discarded. In this DSS we recommend the pre-classification of factors 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 a climate suitability model or a particular level of host density with the likelihood of establishment. In some cases (see below for CLIMEX), guidance is available to help with this judgement. Nevertheless great care must be taken when classifying factors and it may be worthwhile to explore the effect of different classifications (e.g. representing the most likely, the best and the worst case scenarios to show how this affects uncertainty, see below) and to compare map combinations based on pre-classification with those created by post-classifying combinations of continuous variables.

Climate Classification:

The number of classes is defined at the outset. Here (Tables 4 and 5), we have used six classes for the climate maps: one for the absence of risk and five for increasing levels of risk (from very low to very high). The results of climatic models can also be split into two classes, e.g. $EI=0$ and $EI>0$ (where EI is the Ecoclimatic Index) for CLIMEX and $p=0$ and $p>0$ can be used for other species distribution models, to define the area of potential establishment. Models based on phenology and the likelihood of infection (the generic infection model) can also be classified in this way.

For CLIMEX, although there are guidelines for setting the EI thresholds for unsuitable, marginal, suitable and optimal climatic conditions for establishment, these are arbitrary and need to be considered on a species by species basis (Stephens et al., 2007). EI can be classified by looking at where the pest is (a) present but with very low populations, (b) present but not abundant and (c) generally abundant and if (a), (b) and (c) are clearly primarily influenced by climate and not other factors they can be used to classify the EIs. EI values close to zero can be considered marginal, and we would generally expect that a species distribution in climatically marginal habitat would be patchy, and restricted to more climatically favourable sites. In this zone, we would also expect that a species presence would be patchy in time, and metapopulation dynamics might play a strong role in maintaining its presence on a regional basis. If the EI, which is scaled from 0-100, is greater than 30, the climate can

⁴ <http://adl.brs.gov.au/mcass/background.html>

generally be considered to be very favourable for establishment (Sutherst *et al*, 2007; Pinkard *et al.*, 2010). However, the maximum climate suitability that a species can experience under field conditions depends upon the interplay between the seasonality of temperature and moisture variables and the individual species' climatic niche. In climatic terms, it is possible to have too much of a good thing. As noted by Brown (1998), biotic factors tend to define a species range where resources are abundant. These factors underline why the climate suitability classification needs to be considered on a species-specific basis.

CLIMEX:

Table 4 : An example of classifying the CLIMEX Ecoclimatic Index (EI)

Class	EI
Absent	0
Very Low	1 → 5
Low	6 → 10
Moderate	11 → 20
High	21 → 30
Very High	> 30

Other Species Distribution Models (e.g. Maxent, openModeller, and DIVA-GIS) based on climate:

The probability of presence (p) is rescaled between 0 and 100.

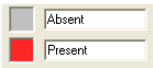

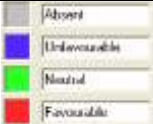
Table 5 : An example of classifying Other Species Distribution Models based on climate

Class	p
Absent	0
Very Low	1 → 20
Low	21 → 40
Moderate	41 → 60
High	61 → 80
Very High	> 81

Other biotic and abiotic factors:

The other biotic and abiotic factors can also be classified in several ways:

Table 6 : Classifying non-climatic variables

Classes	Explanations
	Boolean variable. Present and Absence is what matters and “density” has no influence. Usually, the “absent” class has an unfavourable effect or is a limiting condition. The “present” class has a favourable or neutral effect.
	Discrete variables are useful when “density” is what matters. The absent class is optional.
	Discrete variable with four classes including unfavourable <u>AND</u> favourable. The absent class is optional.
It is possible to consider other types of variables.	

A presence- absence classification is particularly appropriate for vectors and soil type. Host/habitat distribution and abundance may be divided into a number of classes. Although it is possible to consider a threshold above which increasing host/habitat density has little additional effect on the likelihood of establishment, generic guidance on this cannot readily be provided.

Stage 2: Combine the maps to identify the areas of potential establishment and the areas at highest risk from pest impacts documenting any assumptions and combination rules utilised

Two types of maps are required:

- (i) a map of the **area of potential establishment** produced by identifying areas where both the key climatic and the non-climatic abiotic and biotic factors are suitable
- (ii) a map that shows **where hosts or habitats are at highest risk**

This DSS describes how to produce both types of map.

B2.1 Combine maps using MCAS-S software

The MCAS-S software provides a simple and straightforward method for combining maps.

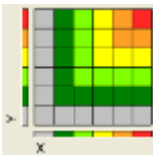
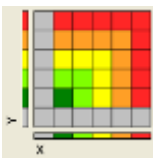
B 2.1.1 *Combining maps using data that have been pre-classified*

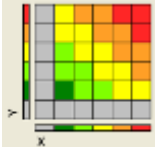
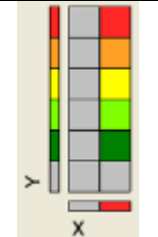
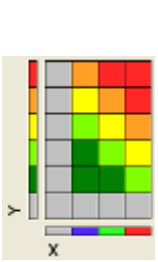
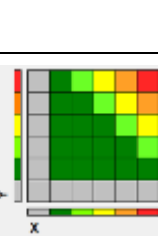
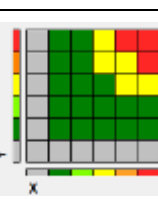
The table below provides some useful matrices for combining maps in PRAs. Apart from the addition matrix, X represents non-climatic factors and Y climatic factors.

For the X maps (non-climatic factors), an absent class is always considered as a limiting factor. Except for matrix 4 (see Table 4), the absent class is optional because it:

- sometimes does not exist (e.g. in a soil texture map)
- can be included in another class
- cannot be used only as a limiting factor (e.g. when the absence of the factor only has a neutral effect).

Table 7 : Combination rule matrices for combining two factors (X and Y)

Matrix	Explanations	Examples
	<p>1. Minimum rule matrix: It assumes that: i) the most severe constraint (the factor with the lowest classification) is the dominant factor and the classification of the other factor is ignored ii) equivalent scores for each factor impose equivalent levels of constraint. The minimum matrix is appropriate when both factors (X and Y) are required.</p>	<p>Combining climatic suitability and host presence. This assumes that when climatic suitability or host presence are above a certain level then it is the other factor that will have the overriding influence on the result.</p>
	<p>2. Maximum rule matrix: This is the inverse of the minimum rule matrix. The factor with the highest classification is what matters and the</p>	<p>This matrix can be used to produce a map based on climate suitability and the availability of protected host crops or irrigation, assuming protection or irrigation. i.e. when protected</p>

	classification of the other factor is ignored. The maximum matrix is appropriate when either factor is sufficient on its own.	environments are present the climate, as measured at weather stations, is no longer relevant to potential survival
	3. Addition rule matrix: This matrix simulates the addition of both factors.	Combining lack of rotation (which may encourage the build-up of pest populations) with crop production in the area of potential establishment
	4. Limiting factor matrix: The absence of X is a limiting condition and leads to absence of Y. The presence of X has a neutral effect on Y.	Combining a soil factor (which prevents pest presence) that is either present or absent (which allows pest presence) and climatic suitability
	5. Modified Average: Unfavourable/Neutral/Favourable factor. Decrease by 1 if unfavourable and increase by 1 if favourable.	Harvest date. An early harvest date may prevent a pest completing its life cycle whereas a late harvest date may allow time for all individuals to develop, spread or an extra generation of pests.
	6. High risk matrix: The colour grid is set to identify locations where there is a coincidence of high X and high Y classes.	Combining area of potential establishment and area of potential impact. The result (area at highest risk) is classified in 5 classes.
	7. Cox's risk matrix: A 5x5 matrix compatible with Risk = Probability x Consequence (Cox, 2008).	Combining area of potential establishment and area of potential impact. The result (area at highest risk) is classified in 3 classes.
MCAS-S is a user-friendly software which allows the user to customize matrices depending on the effects (favourable, neutral, unfavourable or limiting condition).		

The methods used in this DSS are described in two tables below. Table 5 describes the methods to combine maps of the biotic and abiotic factors to produce a map of potential establishment classified according to host/habitat distribution or climatic suitability depending on the factor which provides the greater constraint. Table 8 provides methods for producing a classified map of areas at highest risk by combining the map of potential establishment with additional factors related to economic, environmental and social impacts.

Table 8: Methods for producing a classified map of potential establishment by combining maps of key biotic and abiotic factors

<u>First factor</u>	<u>Second Factor</u>	<u>Combination Rule</u>	<u>Map Combination Result</u>	<u>Assumptions and Comments</u>
First host/habitat distribution	Additional host/habitat distribution	Do not combine by classifying and using matrices but add the actual data (e.g. the number of hectares per 10 km x 10 km grid cell ⁵) together before classifying.	Total host/habitat distribution (hectares per 10 km x 10 km grid cell or 10000 hectares) divided into 6 classes by equal area	In some situations it may be possible to set a threshold above which increases in host density do not increase pest risk
Additional biotic factor, e.g. presence of vectors	Total host/habitat distribution	Limiting factor matrix	Area where biotic factors are suitable for establishment classified according to host/habitat distribution	Additional biotic factors, e.g. hosts, are either considered to be present or absent.
Climatic suitability	Area where biotic factors are suitable for establishment	Minimum rule matrix	Area where biotic and climatic factors are suitable for establishment classified according to host/habitat distribution or climatic suitability depending on that which provides the greater constraint	The biotic factor and climate classes are equally important in the matrix. The factor with the lowest class in the combination is recorded.
Area where biotic and climatic factors are suitable for establishment	Additional abiotic factors, e.g. presence of key soil factors	Limiting factor matrix	Area of potential establishment without additional management factors such as irrigation or protection from the weather classified	Additional abiotic factors, e.g. hosts, are either considered to be present or absent.

⁵ One 10 x 10 km grid cell contains 10000 hectares

			according to host/habitat distribution or climatic suitability depending on that which provides the greater constraint	
Areas with irrigation or protection from the weather	Area of potential establishment outdoors without additional management factors such as irrigation or protection from the weather	Maximum rule matrix	Area of potential establishment with additional management factors such as irrigation or protection from the weather classified according to host/habitat distribution or climatic suitability depending on that which provides the greater constraint	This assumes that irrigation or protection overcomes the climatic limiting factor. Additional management factors (irrigation or protection) are either considered to be present or absent. Additional irrigation may enhance the suitability of areas that are already climatic suitable but this is ignored.

Table 9 : Methods for producing a classified map of areas at highest risk by combining the map of potential establishment with economic impacts factors when crop production values are known

<u>First factor</u>	<u>Second Factor</u>	<u>Combination Rule</u>	<u>Map Combination Result</u>	<u>Assumptions and Comments</u>
First host crop distribution (hectares per 10 km x 10 km grid cell or 10000 hectares) divided into 6 classes by equal area	First host crop production (e.g. yield in tonnes per hectare)	Multiply data per hectare by 10000 to obtain values per 10 km x 10 km grid cell and then multiply the two factors together. If the value or relative value of the first crop is known compared to other crops also multiply the result by this value.	Total first host crop production (e.g. yield in tonnes per 10 km x 10 km grid cell or 10000 hectares) divided into 6 classes by equal area. If comparing with other crops for which the value (in euros) or relative value is known and the relevant multiplication value has been applied then the result will be in output (euros) per grid cell or relative value per grid cell.	These procedures are only required if there are more than one host crop of different values and it is important to try to combine the risks to all crops in one map. Otherwise highest risk maps can be produced for each crop separately. An estimate of relative crop value, e.g. grain maize is five times more valuable than forage maize, is more likely to be realistic than actual values since they vary so widely.
Second (or subsequent) host crop distribution (hectares per 10 km x 10 km grid cell or 10000	Second (or subsequent) host crop production (e.g. yield in tonnes per hectare)	Multiply data per hectare by 10000 to obtain values per 10 km x 10 km grid cell and then multiply the two factors together. If the	Total second (or subsequent) host crop production (e.g. yield in tonnes per 10 km x 10 km grid cell or 10000 hectares) divided into 6 classes by	As above

<p>hectares) divided into 6 classes by equal area</p>		<p>value or relative value of the second crop is known compared to other crops also multiply the result by this value.</p>	<p>equal area. If comparing with other crops for which the value (in euros) or relative value is known and the relevant multiplication value has been applied then the result will be the output (euros) per grid cell or relative value per grid cell.</p>	
<p>First host crop production in tonnes per grid cell (or output (in euros) per grid cell or relative value per 10 km x 10 km grid cell)</p>	<p>Second (or subsequent) host crop production in tonnes per grid cell (or output (in euros) per grid cell or relative value per 10 km x 10 km grid cell)</p>	<p>Addition matrix</p>	<p>Total crop production in tonnes per grid cell (or output (in euros) per grid cell or relative value per 10 km x 10 km grid cell)</p>	<p>As above</p>
<p>Additional factor placing the host crops at higher risk, e.g. no rotation, or lower risk, e.g. sandy soil, e.g. for <i>Diabrotica virgifera virgifera</i></p>	<p>Total host crop production in tonnes per grid cell (or output (in euros) per grid cell or relative value per 10 km x 10 km grid cell)</p>	<p>Modified average matrix. If the factor is likely to reduce impacts the risk classification is reduced by 1 and increased by 1 if impacts are likely to be more severe. There is no change if the factor is not likely to have an effect.</p>	<p>Map showing total crop production or output (in euros) per grid cell or the relative value per 10 km x 10 km grid cell) taking into account other factors that may increase or decrease the impacts caused by the pest. In this DSS we have called this the area of potential impact.</p>	<p>If the additional negative factor is present, it increases the risk class by one (except for the maximum class). If the additional positive factor is present, it decreases the risk class by one (except for the minimum class). If absent, the risk class is unchanged.</p>

Map showing the area of potential establishment based on climate suitability and host presence	Map showing total crop production (or output (in euros) per grid cell or relative value per 10 x 10 km grid cell) taking into account other factors (unrelated to the area of potential establishment) that may increase or decrease the impacts caused by the pest.	High risk matrix	Map showing the area at highest risk based on climatic suitability and total crop production in the area of potential establishment taking into account other factors (unrelated to the area of potential establishment) that may increase or decrease the impacts caused by the pest.	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
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Table 10 : Methods for producing a classified map of areas at highest risk by combining the map of potential establishment with economic (when crop production values are unknown), environmental and social impacts

<u>First factor</u>	<u>Second Factor</u>	<u>Combination Rule</u>	<u>Map Combination Result</u>	<u>Assumptions and Comments</u>
Map showing the area of potential establishment based on climate suitability and host or habitat presence	<u>Map of factors that represent areas at highest risk from economic, environmental and social impacts</u>	High risk matrix	Map showing the area at highest risk based on climatic suitability, host/habitat presence (and abundance) combined with areas of intrinsic high economic, environmental or social value.	The highest risk occurs in the grid cells where the climate is most suitable for pest establishment, hosts (or pest habitats) are present and abundant and the hosts (or pest habitats) are of intrinsic high value

B 2.1.2 *Examples of Map Combinations: Diabrotica virgifera virgifera*

Using the matrices presented above, maps of the area of potential establishment and the area at highest risk have been generated for *Diabrotica virgifera virgifera*, a pest of maize.

The following data sources were used:

Climatic suitability:

- This is based on the CLIMEX Ecoclimatic Index with parameters (see Table 11) developed by Darren Kriticos and Philippe Reynaud using a 1961-90 gridded climatology at 0.5° latitude x longitude (Climate Research Unit, University of Norwich, UK). This was rescaled to a 10 km x 10 km grid and divided into six classes see Table 12 for MCAS-S. A Maxent model has also been applied.

Table 11 CLIMEX parameters for *Diabrotica virgifera virgifera*

Moisture Index					
SM0	SM1	SM2	SM3		
0.1	0.2	1	2		
Temperature Index					
DV0	DV1	DV2	DV3		
9	18	24	31		
Diapause Index					
DPD0	DPT0	DPT1	DPD	DPSW	
14	7.5	7	60	0	
Cold Stress					
TTCS	THCS	DTCS	DHCS	TTCSA	THCSA
0	0	8	-0.00028	0	0
Heat Stress					
TTHS	THHS	DTHS	DHHS		
31	0.009	0	0		
Dry Stress					
SMDS	HDS				
0.2	-0.005				
Wet Stress					
SMWS	HWS				
2.5	0.002				
Day-degree accumulation above DV0					
DV0	DV3	MTS			
9	31	7			
Day-degree accumulation above DVCS					
DVCS	*DV4	MTS			
8	100	7			
Day-degree accumulation above DVHS					

DVHS	*DV4	MTS			
28	100	7			
Degree-days per Generation					
PDD					
666					

Host distribution:

- Maize is considered to be the only host. *D. virgifera virgifera* is not able to establish in the areas where grain or forage maize are absent.
- Forage maize at 5 minute latitude x longitude resolution from Monfreda et al., (2008) was rescaled to provide the percentage hectares per 10 km x 10 km grid cell and divided into six classes based on equal area (with one absent class)
- Grain maize at 5 minute latitude x longitude resolution from Monfreda et al., (2008) was rescaled to provide the percentage hectares per 10 km x 10 km grid cell and divided into six classes based on equal area (with one absent class)

Soil:

- Sandy soil (defined as Clay < 18% and Sand > 65%) from the European Soil Database version 2 (JRC, 2010) at a resolution of 1:1,000,000 was rescaled to a 10 km x 10 km grid and divided into two classes (presence or absence).
- This is based on observations from Hungary (Dr. Géza Ripka (personal communication, January 2011) who said that in Hungary “the damage caused by larvae of *D. virgifera virgifera* on sandy soil is insignificant. In order to take this factor into account, the map of total maize production is combined with the map of soil textures. If the soil texture is defined as sandy (i.e. damage is expected to be low), the impact level is decreased by one and if the soil texture is not sandy, the impact level is not changed.

Host production (yield) and value:

- Maize production in tonnes per hectare at 5 minute latitude x longitude resolution from Monfreda et al., (2008) were rescaled to a 10 km x 10 km grid cell (and divided into six classes based on equal area (with one absent class).
- The grain and forage maize production maps (in tonnes per 10 km x 10 km grid cell) have been generated using the equation below:

$$\text{Grain or forage maize production} = \text{harvested area (\% of grid square covered by maize)} \times 100 \text{ (to convert to ha)} \times \text{grain maize yield (tonnes/ha)}$$
- The grain maize and forage maize production were multiplied by the estimated price per tonne for each crop (€50 per tonne for forage maize and €250 per tonne for grain maize), resulting in the production value per crop per grid cell.
- The grain maize and the forage maize production value maps have then been combined to generate the total maize production value map to represent the areas at highest risk of impacts based on economic data.

Rotation

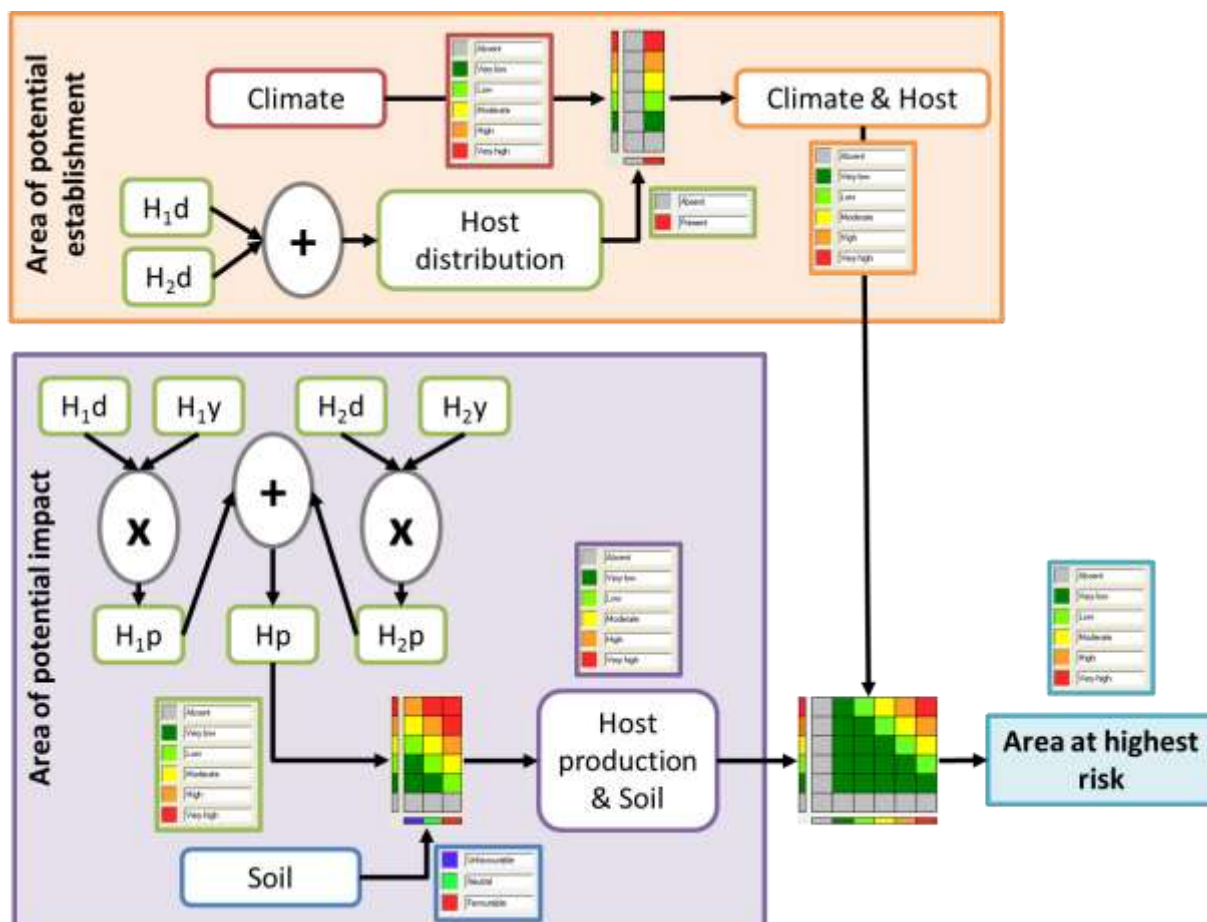
- Maps showing the proportion of maize that is not rotated (that present a much higher risk) are available only for some countries, e.g. France, and so cannot be mapped at the European scale.

Environmental and Social Impacts

- The environmental and social impacts of *D. virgifera virgifera* are considered to be negligible.

The area at highest risk from *D. virgifera virgifera* results in the combination of the area of potential establishment and the area of potential impact.

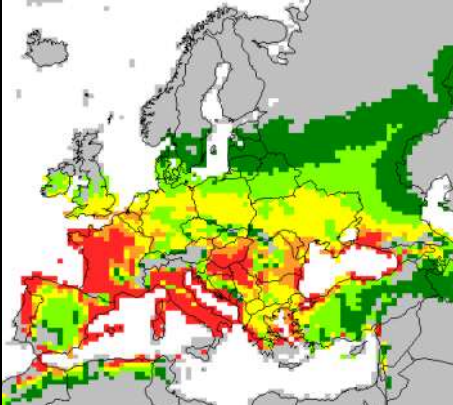
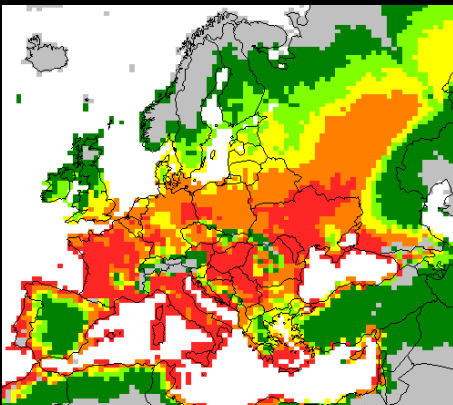
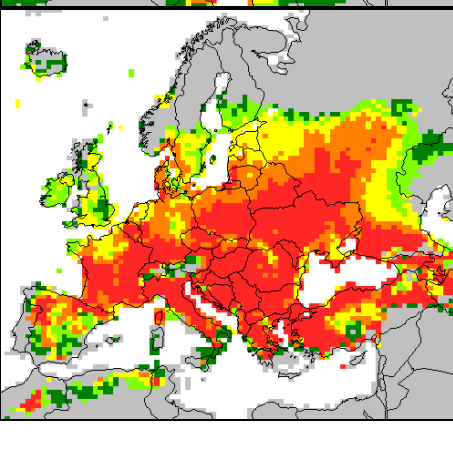
Figure 1 below provides an overview of the procedure used for combining the maps for *D. virgifera virgifera*. The area of potential establishment map for *D. virgifera virgifera* is produced by combining the climatic suitability map based on a bioclimatic model and the host distribution map. The area of highest risk is produced by combining the area of potential establishment with the “area of potential impact” which is based on host production (value per grid cell) and area where the soils are not sandy.



H₁d, Host distribution (%) ; H₁y, Host yield (tons/ha) ; H₁p, Host production (tons)

Figure 1: Overview of the map combination procedures for *Diabrotica virgifera virgifera*

Table 12: Maps of the primary factors used in mapping *Diabrotica virgifera virgifera* risk

Title and description	Map	Legend																		
<p><u>Climatic suitability from the Climex model (Climate):</u> CLIMEX Ecoclimatic Index based on parameters in Table 11 and a 1961-90 gridded climatology at 0.5° latitude x longitude rescaled to a 10 km x 10 km grid and divided into six classes</p>		<table border="1"> <tr><td>Absent</td><td>From</td><td>0</td></tr> <tr><td>Very low</td><td>From</td><td>1E-05</td></tr> <tr><td>Low</td><td>From</td><td>5</td></tr> <tr><td>Moderate</td><td>From</td><td>10</td></tr> <tr><td>High</td><td>From</td><td>15</td></tr> <tr><td>Very high</td><td>From</td><td>20</td></tr> </table>	Absent	From	0	Very low	From	1E-05	Low	From	5	Moderate	From	10	High	From	15	Very high	From	20
Absent	From	0																		
Very low	From	1E-05																		
Low	From	5																		
Moderate	From	10																		
High	From	15																		
Very high	From	20																		
<p><u>Climatic suitability from the Climex model:</u> CLIMEX Growth Index based on parameters in Table 11 and a 1961-90 gridded climatology at 0.5° latitude x longitude rescaled to a 10 km x 10 km grid. The GI map is principally used in the spread models</p>		<table border="1"> <tr><td>Absent</td><td>From</td><td>0</td></tr> <tr><td>Very low</td><td>From</td><td>1</td></tr> <tr><td>Low</td><td>From</td><td>15</td></tr> <tr><td>Moderate</td><td>From</td><td>20</td></tr> <tr><td>High</td><td>From</td><td>25</td></tr> <tr><td>Very high</td><td>From</td><td>30</td></tr> </table>	Absent	From	0	Very low	From	1	Low	From	15	Moderate	From	20	High	From	25	Very high	From	30
Absent	From	0																		
Very low	From	1																		
Low	From	15																		
Moderate	From	20																		
High	From	25																		
Very high	From	30																		
<p><u>Climatic suitability from the Maxent model (Climate) :</u> Maxent probability value based on 6 variables (Bio1, Bio10, Bio11, Bio12, Bio18 and Bio19) and a 1961-90 gridded climatology at 0.5° latitude x longitude. The decision threshold is set to 10. The initial map from Maxent was rescaled between 0 and 100 setting to 0 all the values below the decision threshold.</p>		<table border="1"> <tr><td>Absent</td><td>From</td><td>0</td></tr> <tr><td>Very low</td><td>From</td><td>10</td></tr> <tr><td>Low</td><td>From</td><td>20</td></tr> <tr><td>Moderate</td><td>From</td><td>30</td></tr> <tr><td>High</td><td>From</td><td>40</td></tr> <tr><td>Very high</td><td>From</td><td>50</td></tr> </table>	Absent	From	0	Very low	From	10	Low	From	20	Moderate	From	30	High	From	40	Very high	From	50
Absent	From	0																		
Very low	From	10																		
Low	From	20																		
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High	From	40																		
Very high	From	50																		

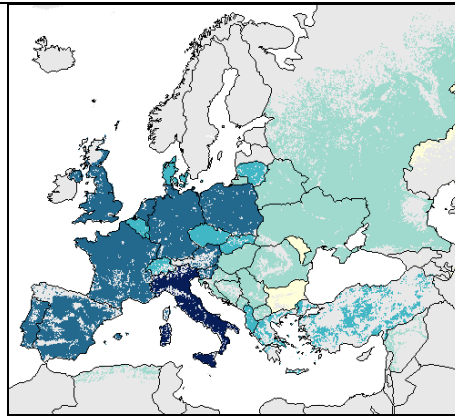
<p>Soil texture (Soil) : Soil texture from the European Soil Database⁶ version 2 at a resolution of 1:1,000,000 rescaled to a 10 km x 10 km grid and divided into two classes: Unfavourable “sandy” soil is defined as Clay < 18% and Sand > 65% (blue) and Neutral soil is defined as other textural classes (green).</p>		<table border="1"> <tr><td>Blue</td><td>Unfavourable</td></tr> <tr><td>Green</td><td>Neutral</td></tr> <tr><td>Red</td><td>Favourable</td></tr> </table>	Blue	Unfavourable	Green	Neutral	Red	Favourable									
Blue	Unfavourable																
Green	Neutral																
Red	Favourable																
<p>Area of harvested grain maize (H_{1d}): Area (hectares) of harvested grain maize in Europe at 5 minute latitude x longitude resolution rescaled to a 10 km x 10 km grid (Monfreda et al., 2008). The result is divided into 5 classes based on equal area. The unit is the percentage of each 10 km x 10 km grid cell.</p>		<table border="1"> <tr><td>Class 1</td><td>From</td><td>0.001</td></tr> <tr><td>Class 2</td><td>From</td><td>0.005</td></tr> <tr><td>Class 3</td><td>From</td><td>0.01</td></tr> <tr><td>Class 4</td><td>From</td><td>0.02</td></tr> <tr><td>Class 5</td><td>From</td><td>0.03</td></tr> </table>	Class 1	From	0.001	Class 2	From	0.005	Class 3	From	0.01	Class 4	From	0.02	Class 5	From	0.03
Class 1	From	0.001															
Class 2	From	0.005															
Class 3	From	0.01															
Class 4	From	0.02															
Class 5	From	0.03															
<p>Area of harvested forage maize (H_{2d}): Area (hectares) of harvested forage maize in Europe at 5 minute latitude x longitude resolution rescaled to a 10 km x 10 km grid (Monfreda et al., 2008). The result is divided into 5 classes based on equal area. The unit is the percentage of each 10 km x 10 km grid cell.</p>		<table border="1"> <tr><td>Class 1</td><td>From</td><td>0.001</td></tr> <tr><td>Class 2</td><td>From</td><td>0.005</td></tr> <tr><td>Class 3</td><td>From</td><td>0.01</td></tr> <tr><td>Class 4</td><td>From</td><td>0.02</td></tr> <tr><td>Class 5</td><td>From</td><td>0.03</td></tr> </table>	Class 1	From	0.001	Class 2	From	0.005	Class 3	From	0.01	Class 4	From	0.02	Class 5	From	0.03
Class 1	From	0.001															
Class 2	From	0.005															
Class 3	From	0.01															
Class 4	From	0.02															
Class 5	From	0.03															
<p>Grain maize yields (H_{1y}) : Grain maize yields in Europe at 5 minute latitude x longitude resolution rescaled to a 10 km x 10 km grid (Monfreda et al., 2008). The result is divided into 5 classes based on equal area. The unit is tonnes per hectare.</p>		<table border="1"> <tr><td>Class 1</td><td>From</td><td>0.116</td></tr> <tr><td>Class 2</td><td>From</td><td>4.5</td></tr> <tr><td>Class 3</td><td>From</td><td>8</td></tr> <tr><td>Class 4</td><td>From</td><td>13.5</td></tr> <tr><td>Class 5</td><td>From</td><td>18</td></tr> </table>	Class 1	From	0.116	Class 2	From	4.5	Class 3	From	8	Class 4	From	13.5	Class 5	From	18
Class 1	From	0.116															
Class 2	From	4.5															
Class 3	From	8															
Class 4	From	13.5															
Class 5	From	18															

⁶ http://eusoils.jrc.ec.europa.eu/ESDB_Archive/raster_archive/ESDBv2_ETRS_LAEA_raster_archive.html

Forage maize yields (H₂y) :

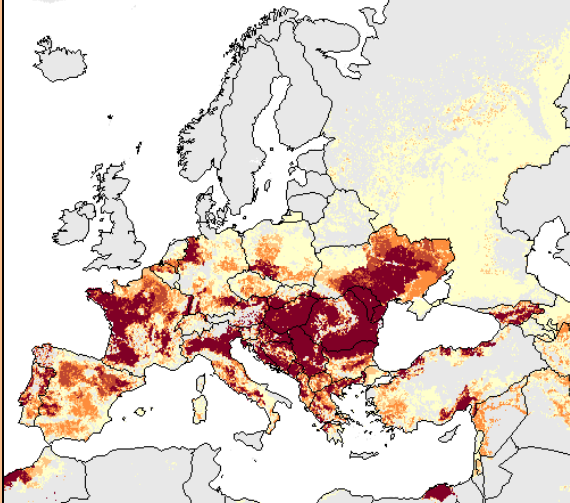
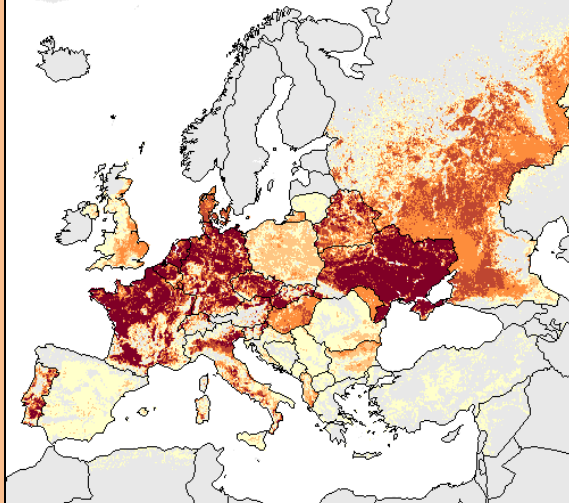

Forage maize yields in Europe at 5 minute latitude x longitude resolution rescaled to a 10 km x 10 km grid (Monfreda et al., 2008). The result is divided into 5 classes based on equal area.

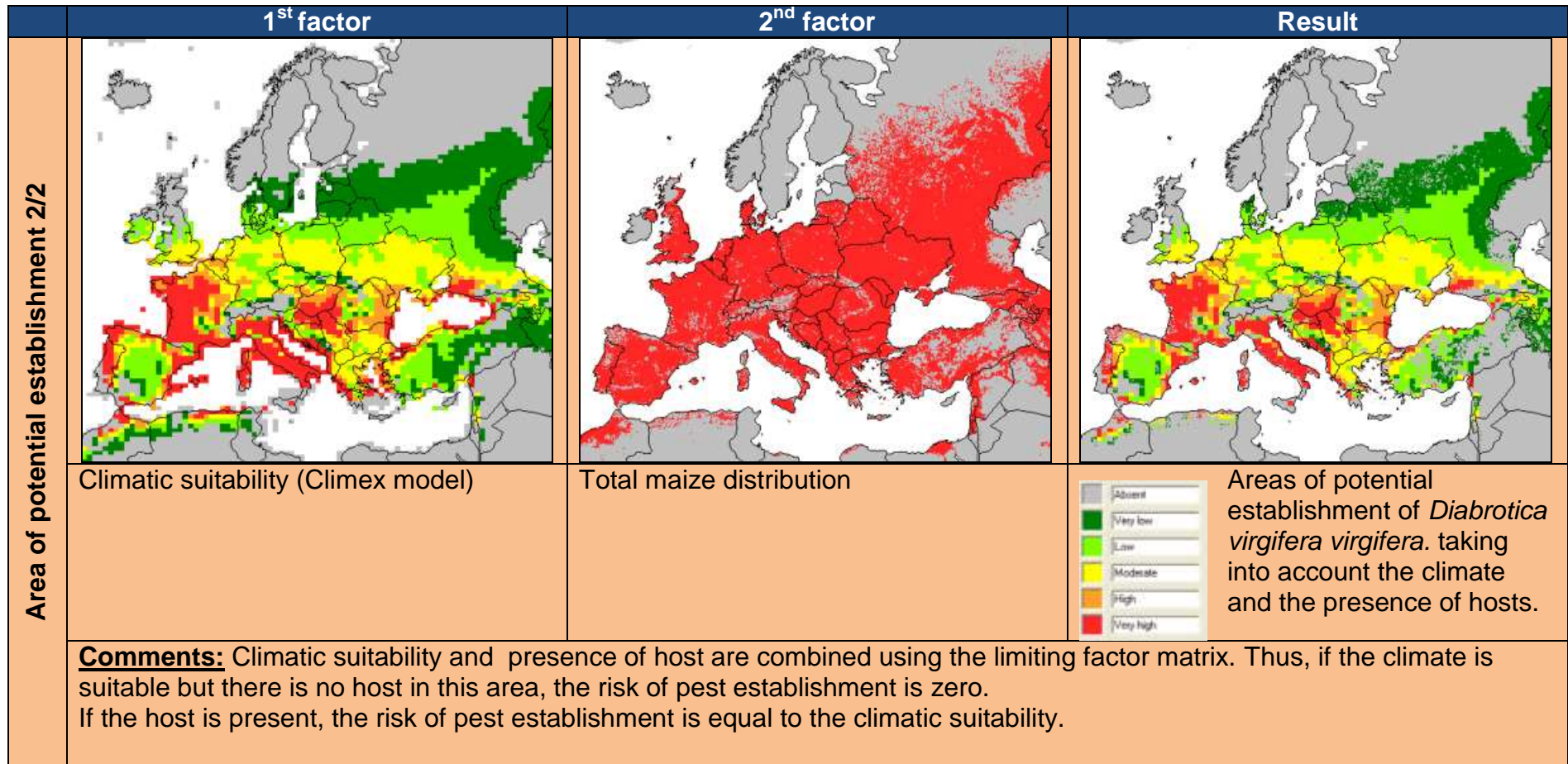
The unit is tonnes per hectare.

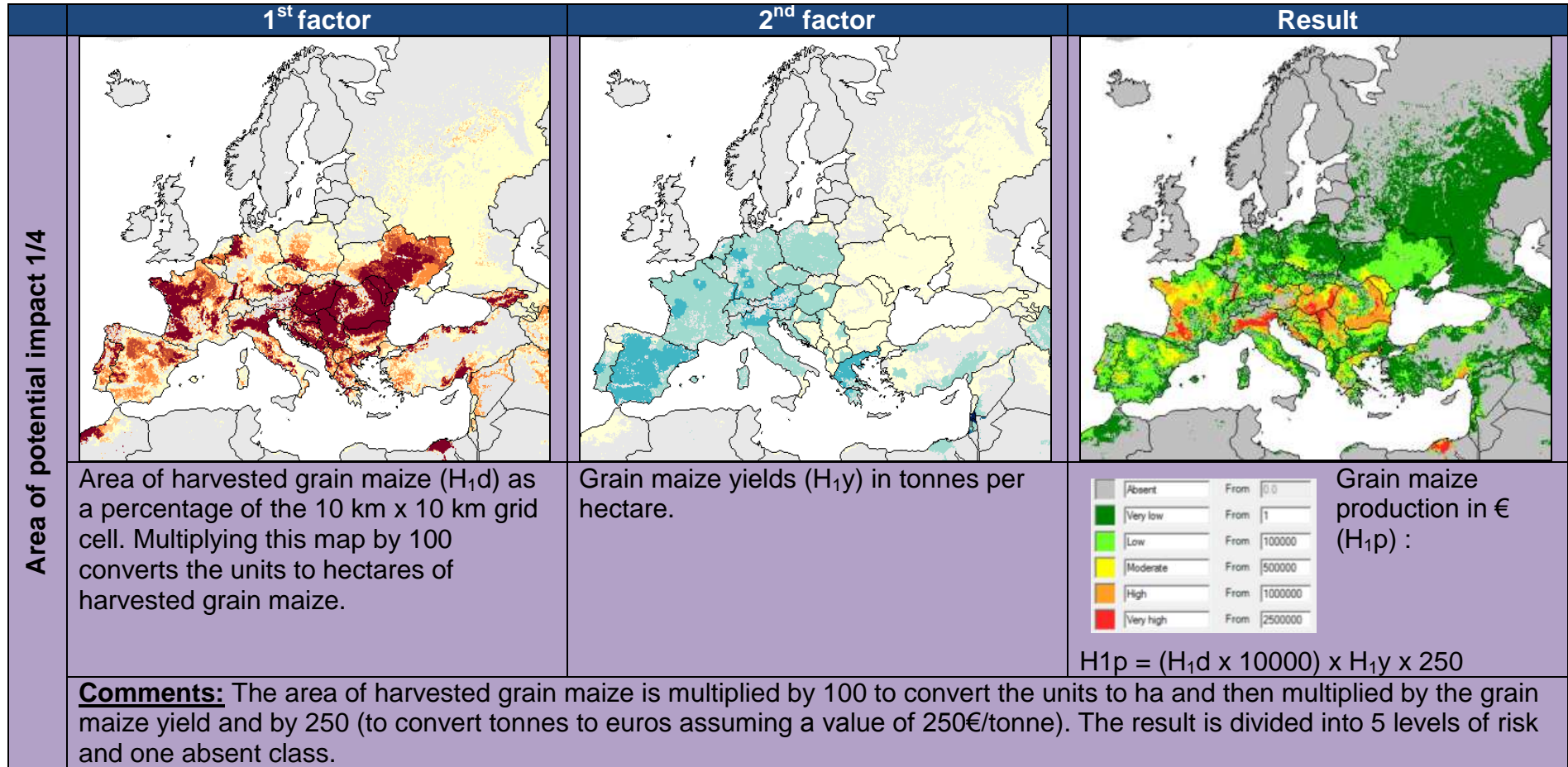


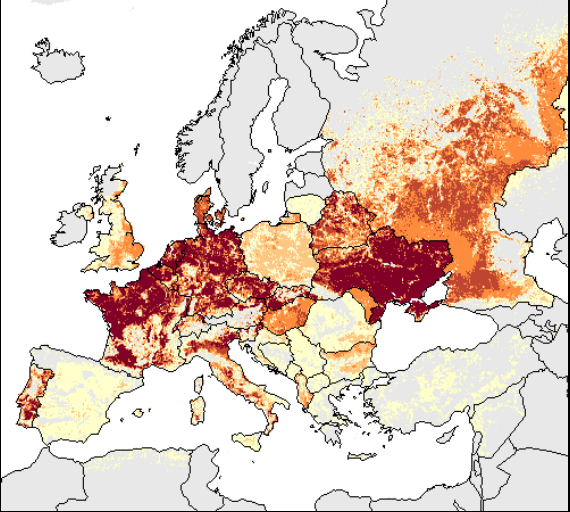
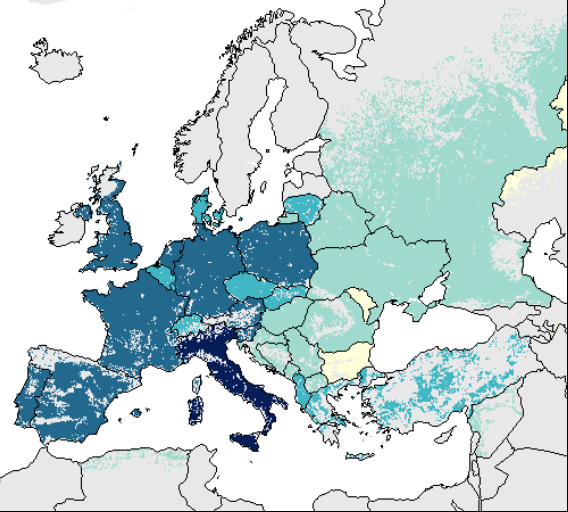
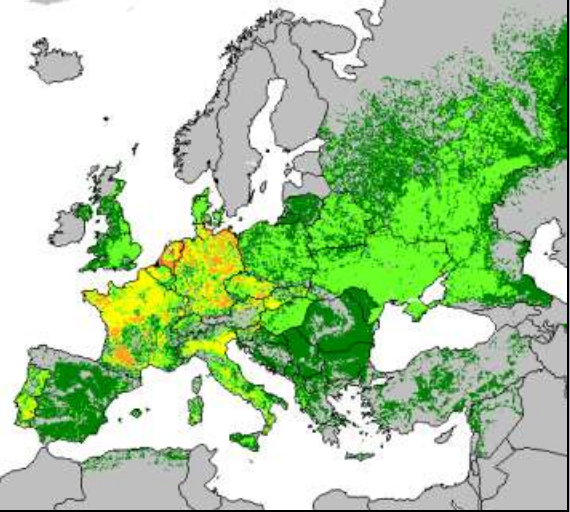
Class	From
Class 1	From 110
Class 2	From 17
Class 3	From 24
Class 4	From 36
Class 5	From 48

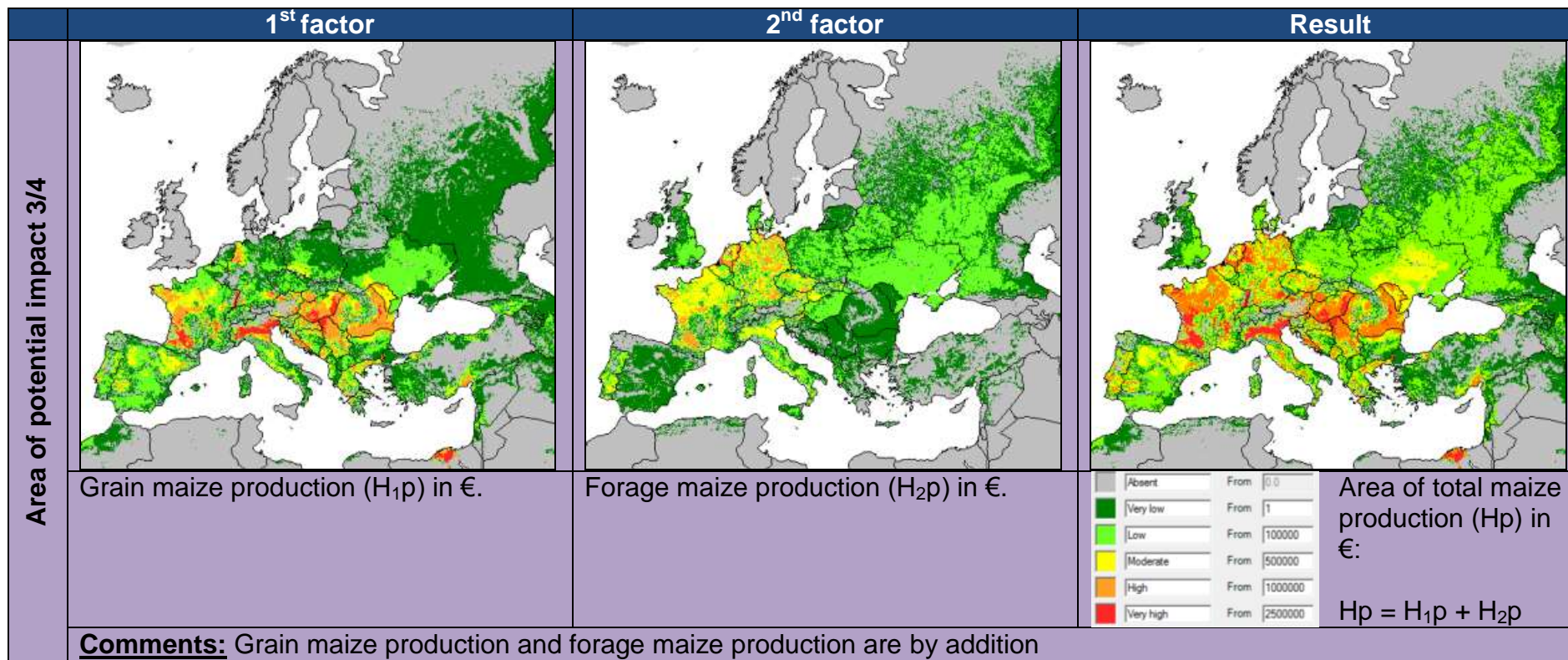
Table 13: Combining maps of the primary factors to map the area of potential establishment and highest risk for *Diabrotica virgifera virgifera*

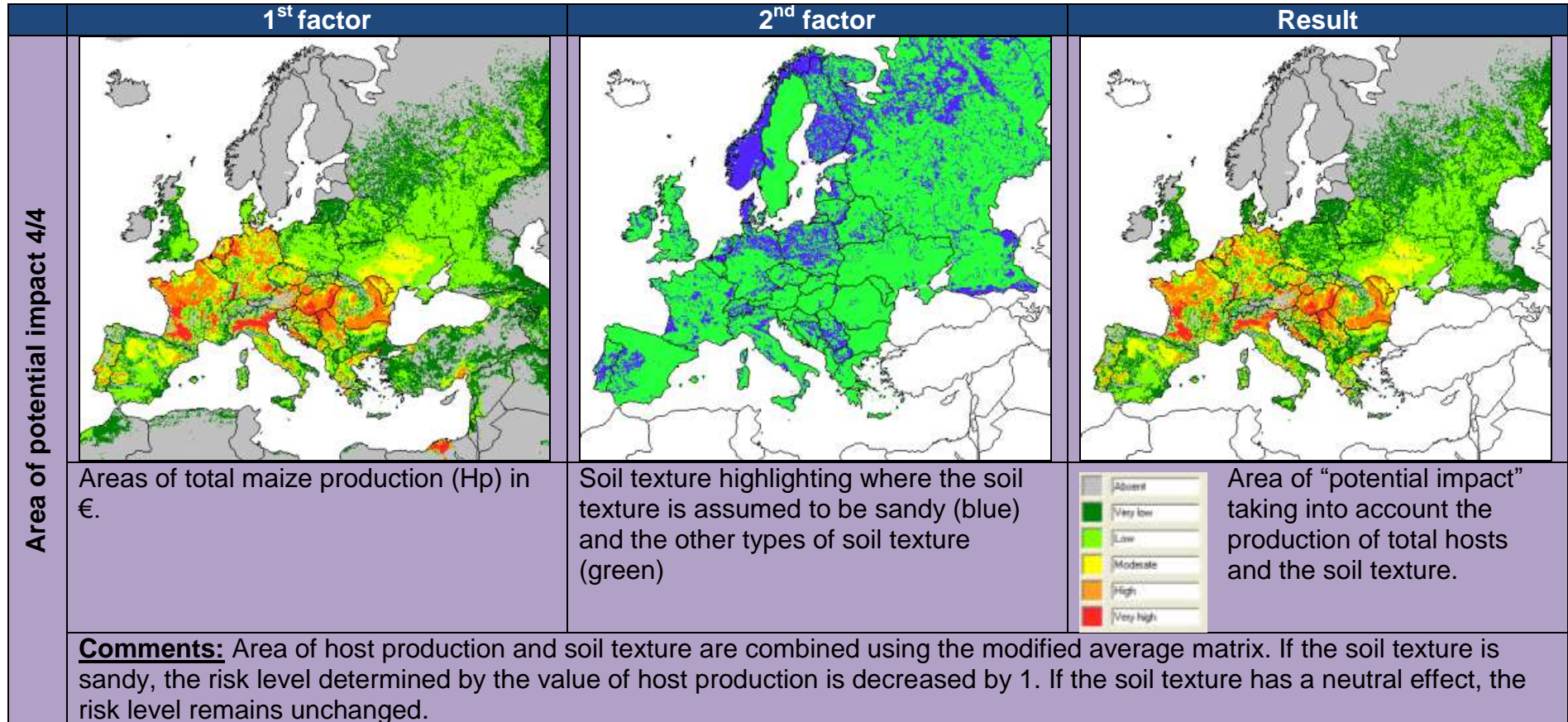
	1 st factor	2 nd factor	Result			
Area of potential establishment 1/2						
	Area of harvested grain maize (H _{1d}).	Area of harvested forage maize (H _{2d}).	<div data-bbox="1460 932 1736 991" style="border: 1px solid gray; padding: 2px;"> <table style="width: 100%; border-collapse: collapse;"> <tr> <td style="width: 30px; border: 1px solid gray;">Absent</td> <td style="border: 1px solid gray;">From 0.0</td> </tr> <tr> <td style="width: 30px; border: 1px solid gray;">Present</td> <td style="border: 1px solid gray;">From 0.0009999</td> </tr> </table> </div> <p>Total maize distribution (H_d) generated using the following equation $H_d = H_{1d} + H_{2d}$</p>	Absent	From 0.0	Present
Absent	From 0.0					
Present	From 0.0009999					
<p>Comments: Forage maize and grain maize harvested areas are added and the result is divided into 2 classes (presence or absence).</p>						

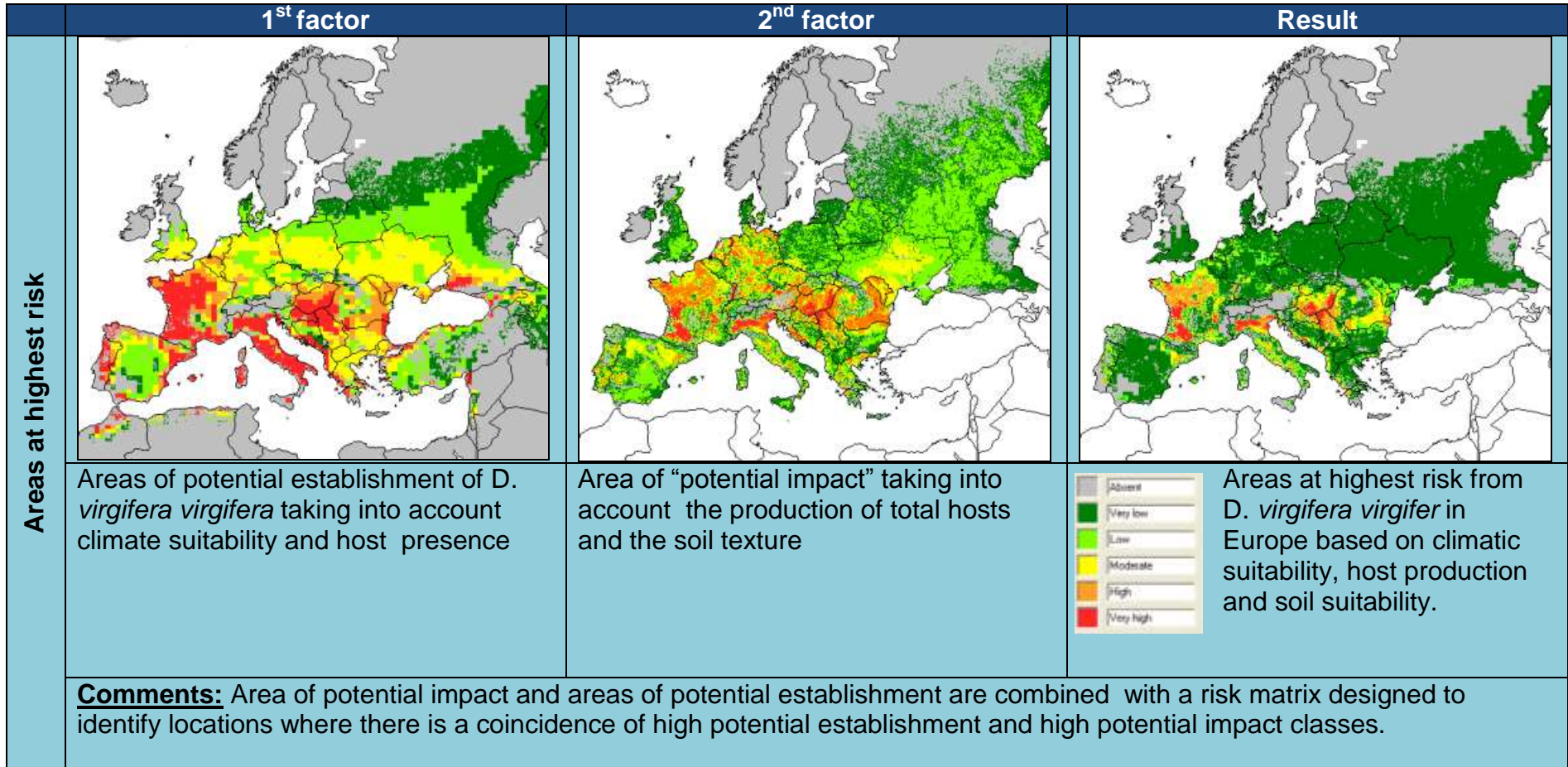


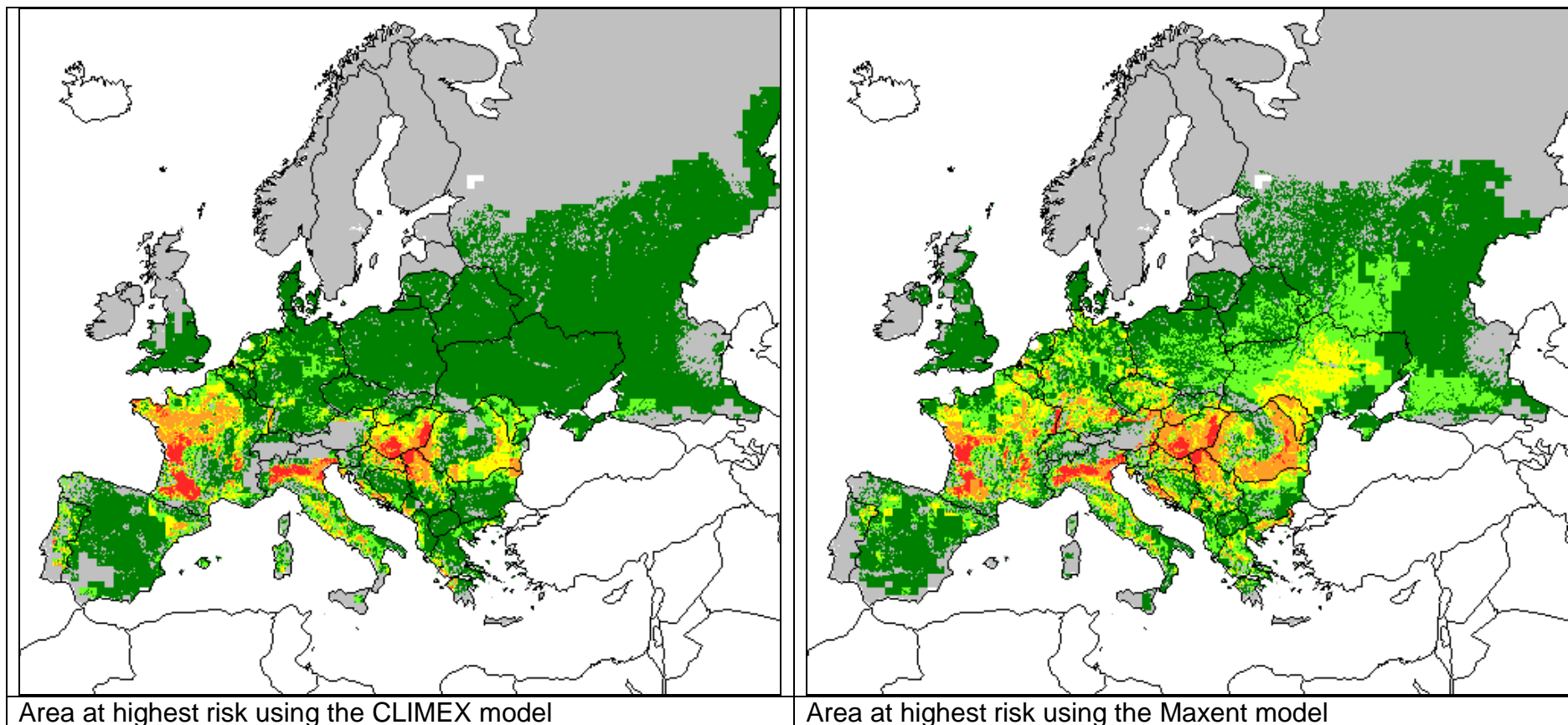


	1 st factor	2 nd factor	Result																	
Area of potential impact 2/4																				
	<p>Area of harvested forage maize (H_{2d}) in percentage of each 10 km x 10 km grid cell. Multiplying this map by 100 converts the unit to hectares of harvested forage maize:</p>	<p>Forage maize yields (H_{2y}) in tonnes per hectare.</p>	<table border="1"> <tr> <td>Absent</td> <td>From</td> <td>0.0</td> </tr> <tr> <td>Very low</td> <td>From</td> <td>1</td> </tr> <tr> <td>Low</td> <td>From</td> <td>100000</td> </tr> <tr> <td>Moderate</td> <td>From</td> <td>500000</td> </tr> <tr> <td>High</td> <td>From</td> <td>1000000</td> </tr> <tr> <td>Very high</td> <td>From</td> <td>2500000</td> </tr> </table> <p>Forage maize production in € (H_{2p}) :</p> <p>$H_{2p} = (H_{2d} \times 10000) \times H_{2y} \times 50$</p>	Absent	From	0.0	Very low	From	1	Low	From	100000	Moderate	From	500000	High	From	1000000	Very high	From
Absent	From	0.0																		
Very low	From	1																		
Low	From	100000																		
Moderate	From	500000																		
High	From	1000000																		
Very high	From	2500000																		
<p>Comments: Forage maize harvested areas is multiplied by 100 to convert the unit to ha and then multiplied by the forage maize yield and by 50 (to convert tonnes in euros assuming 50€/tons). The result is divided into 5 classes of risk levels and one absent class.</p>																				









The MCAS-S software allows the user to generate reports to summarise the maps per EU member state. The table below show the statistics of the area at highest risk map Europe based on climatic suitability from the CLIMEX model (using the Ecoclimatic Index), soil suitability and the tonnes of maize produced. The ranks are defined by adding together the number of cells classified as high risk and those classified as very high risk.

Table 14: The number of 10 km x 10 km grid cells for each EU member state at five levels of risk from *Diabrotica virgifera virgifera*

Rank	Region ⁷	Number of cells at each risk level per country						Percentage of each risk level per country					
		Absent	Very low	Low	Moderate	High	Very high	Absent	Very low	Low	Moderate	High	Very high
1	FRANCE	700	1356	897	864	1099	486	0.13	0.25	0.17	0.16	0.20	0.09
2	ITALY	896	656	569	274	310	212	0.31	0.22	0.20	0.09	0.11	0.07
3	HUNGARY	5	92	126	288	213	190	0.01	0.10	0.14	0.32	0.23	0.21
4	ROMANIA	327	775	391	642	228	8	0.14	0.33	0.16	0.27	0.10	0.00
5	SPAIN	1141	3276	317	130	55	0	0.23	0.67	0.06	0.03	0.01	0.00
6	BULGARIA	92	728	177	64	46	0	0.08	0.66	0.16	0.06	0.04	0.00
7	PORTUGAL	336	235	148	71	38	3	0.40	0.28	0.18	0.09	0.05	0.00
8	GREECE	255	687	149	49	25	7	0.22	0.59	0.13	0.04	0.02	0.01
9	AUSTRIA	540	126	73	80	23	0	0.64	0.15	0.09	0.10	0.03	0.00
10	SLOVENIA	74	71	17	12	15	0	0.39	0.38	0.09	0.06	0.08	0.00
11	GERMANY	188	2695	575	119	11	0	0.05	0.75	0.16	0.03	0.00	0.00
12	NETHERLANDS	0	190	61	43	8	0	0.00	0.63	0.20	0.14	0.03	0.00
13	SLOVAKIA	104	248	64	47	5	0	0.22	0.53	0.14	0.10	0.01	0.00
14	CZECH REPUBLIC	37	668	65	7	1	0	0.05	0.86	0.08	0.01	0.00	0.00
15	BELGIUM	6	203	67	24	0	0	0.02	0.68	0.22	0.08	0.00	0.00
16	DENMARK	5	373	0	0	0	0	0.01	0.99	0.00	0.00	0.00	0.00
17	ESTONIA	407	0	0	0	0	0	1.00	0.00	0.00	0.00	0.00	0.00
18	FINLAND	3278	0	0	0	0	0	1.00	0.00	0.00	0.00	0.00	0.00
19	IRELAND	636	0	0	0	0	0	1.00	0.00	0.00	0.00	0.00	0.00
20	LATVIA	617	8	0	0	0	0	0.99	0.01	0.00	0.00	0.00	0.00
21	LITHUANIA	110	557	0	0	0	0	0.16	0.84	0.00	0.00	0.00	0.00
22	LUXEMBOURG	0	25	0	0	0	0	0.00	1.00	0.00	0.00	0.00	0.00
23	POLAND	182	2929	8	0	0	0	0.06	0.94	0.00	0.00	0.00	0.00
24	SWEDEN	4379	0	0	0	0	0	1.00	0.00	0.00	0.00	0.00	0.00
25	UNITED KINGDOM	1246	1047	0	0	0	0	0.54	0.46	0.00	0.00	0.00	0.00

⁷ Cyprus and Malta are missing

Uncertainty :

We have seen previously that to generate the map of area at highest risk, we recommend the classification of some maps into one class of absence of risk and 5 risk levels. In this step, uncertainty can occur when choosing the class limits. Hence, instead of providing a unique value for each class, we recommend that the user provides a range based on expert opinion.

In this example, we will focus on the uncertainty in classifying the climatic suitability map based on the CLIMEX Ecoclimatic Index for *Diabrotica virgifera virgifera*. It may be possible to set these levels by comparing EI values at particular locations or in particular regions with reports of pest impact. For example, if a pest is found to establish in one country in regions where the EI is 1, but in geographically distinct countries it only establishes where the EI is 5 or greater, these values could be used to develop best and worst case scenarios. Table 15 shows an example of how the different class limits for each scenario can be set.

Table 15 : Classification of the Ecoclimatic Index into 5 risk levels. Uncertainty due to the choice of class limits is captured by arbitrarily defining 3 scenarios: Worst case, Best case and Most likely.

Level	Worst	Best	Most likely
Absent	EI = 0	EI = 0	EI = 0
Very low	>0 EI <3	>0 EI <7	>0 EI <5
Low	3<=EI <6	7<= EI <14	5<= EI <10
Moderate	6<= EI <9	14<= EI <21	10<= EI <15
High	9<= EI > 12	21<= EI > 28	15<= EI > 20
Very high	EI >= 12	EI >= 28	EI >= 20

Figures 2, 3 and 4 below show the consequences of varying the class limits of the climatic suitability map based on the CLIMEX EI on the area of potential establishment map and on the area at highest risk map.

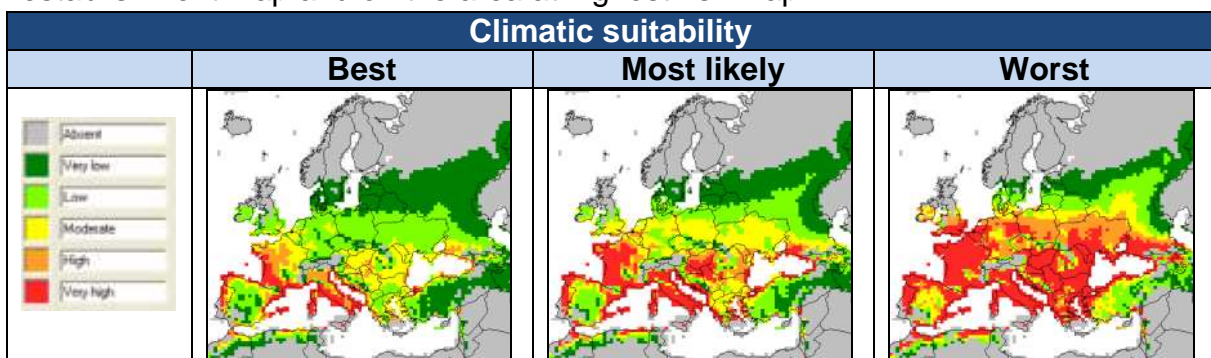


Figure 2: Maps of *Diabrotica virgifera virgifera* climatic suitability based on three classifications of the CLIMEX Ecoclimatic Index for, (a) the best case, (b) the most likely and (c) the worst case scenarios.

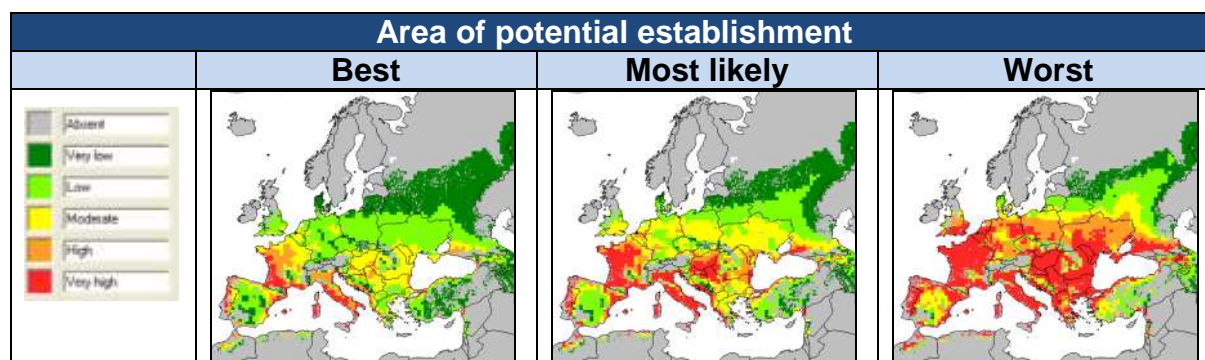


Figure 3: Maps of the *Diabrotica virgifera virgifera* area of potential establishment by taking into account three different classifications of the CLIMEX Ecoclimatic Index, (a) the best case, (b) the most likely and (c) the worst case scenarios.

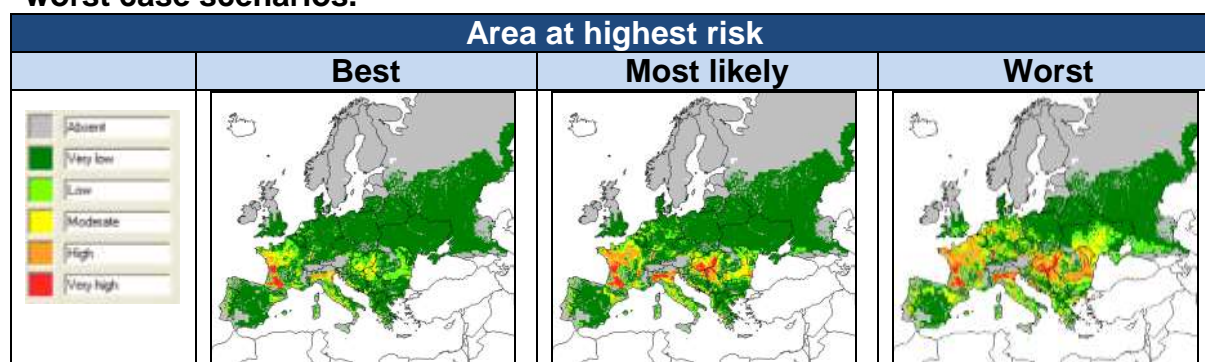


Figure 4: Maps of the areas at highest risk from *Diabrotica virgifera virgifera* in Europe by taking into account three different classifications of the CLIMEX Ecoclimatic Index, (a) the best case, (b) the most likely and (c) the worst case scenarios.

The MCAS-S software allows the user to easily export data and statistics from the combined maps. Tables 16, 17 and 18 below show the statistics of the area at highest risk map for each scenario (worst case, best case and most likely). Only the five countries at highest risk are presented. The ranks are defined by adding together the number of cells classified as high risk and those classified as very high risk.

Table 16: Statistics for the 5 countries at highest risk from the map of the areas at highest risk based on the best case scenario.

Best case scenario													
Rank	Region	Number of 10 km x 10 km grid cells of each risk level per country (x 100 to convert in km ²)						Percentage of each risk level per country					
		A	VL	L	M	H	VH	A	VL	L	M	H	VH
1	FRANCE	700	2075	1009	931	342	345	0.13	0.38	0.19	0.17	0.06	0.06
2	ITALY	896	894	470	332	300	25	0.31	0.31	0.16	0.11	0.10	0.01
3	HUNGARY	5	249	408	221	31	0	0.01	0.27	0.45	0.24	0.03	0.00
4	PORTUGAL	336	309	111	45	27	3	0.40	0.37	0.13	0.05	0.03	0.00
5	SPAIN	1141	3473	227	56	22	0	0.23	0.71	0.05	0.01	0.00	0.00

Table 17: Statistics for the 5 countries at highest risk from the map of the areas at highest risk based on the most likely scenario.

Most likely scenario													
Rank	Region	Number of 10 km x 10 km grid cells of each risk level per country (x 100 to convert in km ²)						Percentage of each risk level per country					
		A	VL	L	M	H	VH	A	VL	L	M	H	VH
1	FRANCE	700	1356	897	864	1099	486	0.13	0.25	0.17	0.16	0.20	0.09
2	ITALY	896	656	569	274	310	212	0.31	0.22	0.20	0.09	0.11	0.07
3	HUNGARY	5	92	126	288	213	190	0.01	0.10	0.14	0.32	0.23	0.21
4	ROMANIA	327	775	391	642	228	8	0.14	0.33	0.16	0.27	0.10	0.00
5	SPAIN	1141	3276	317	130	55	0	0.23	0.67	0.06	0.03	0.01	0.00

Table 18: Statistics for the 5 countries at highest risk from the map of the areas at highest risk based on the worst case scenario.

Worst case scenario													
Rank	Region	Number of 10 km x 10 km grid cells of each risk level per country (x 100 to convert in km ²)						Percentage of each risk level per country					
		A	VL	L	M	H	VH	A	VL	L	M	H	VH
1	FRANCE	700	792	905	992	1442	571	0.13	0.15	0.17	0.18	0.27	0.11
2	ROMANIA	327	472	241	286	979	66	0.14	0.20	0.10	0.12	0.41	0.03
3	HUNGARY	5	27	71	156	431	224	0.01	0.03	0.08	0.17	0.47	0.25
4	ITALY	896	589	606	294	305	227	0.31	0.20	0.21	0.10	0.10	0.08
5	GERMANY	188	1452	936	654	315	43	0.05	0.40	0.26	0.18	0.09	0.01

The maps and their inferred statistics allow the risk assessor to obtain a quick view of the area at highest risk in Europe.

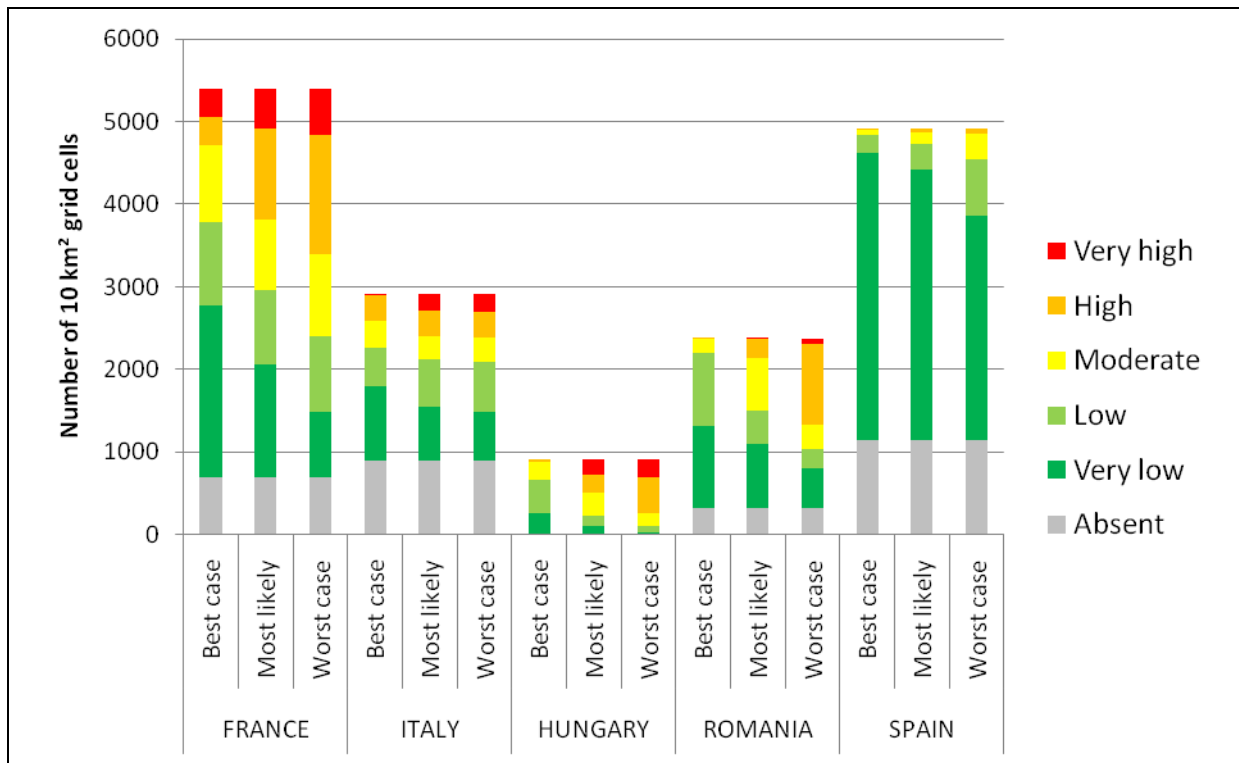


Figure 5: Number of 10 km x 10 km grid cells at each risk level for the five EU countries at highest risk for the three scenarios based on different classification of the Ecoclimatic Index

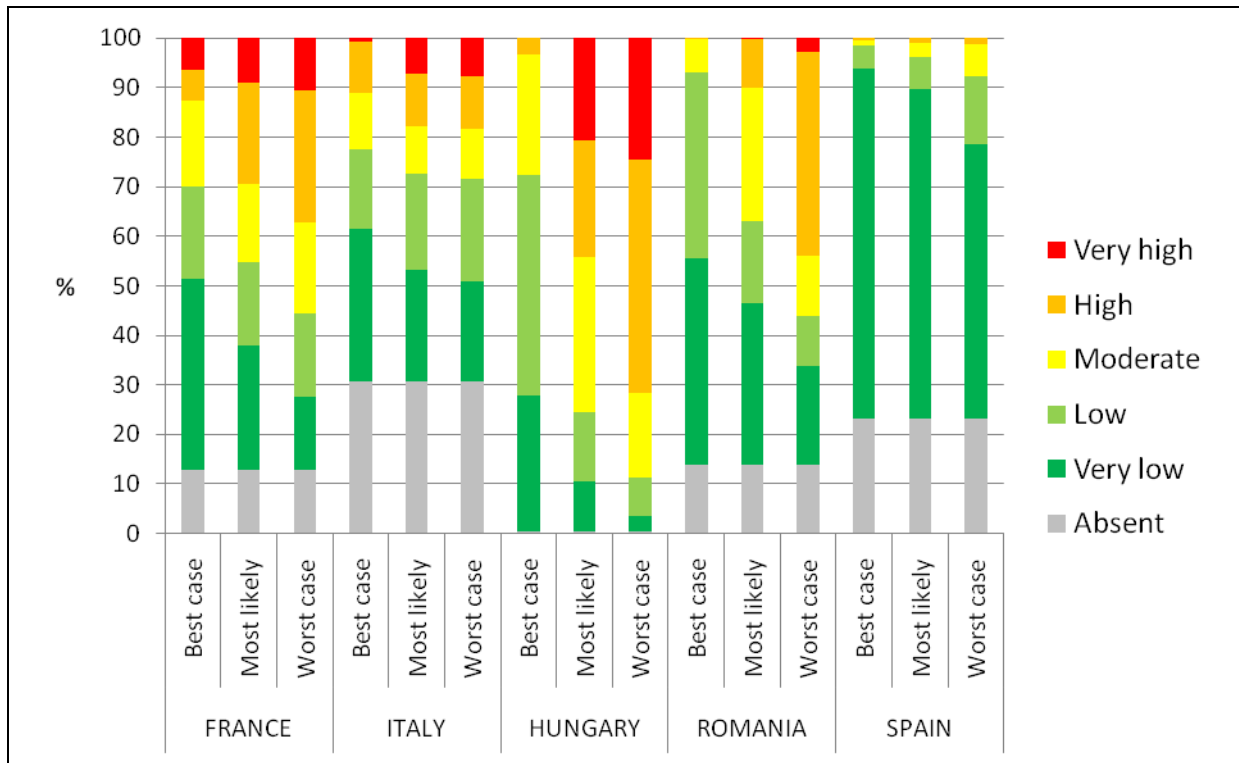


Figure 6: Percentage of each risk level for the five EU countries at highest risk for the three scenarios based on different classification of the Ecoclimatic Index

B 2.1.3 *Examples of Map Combinations: Eichhornia crassipes*

The following data sources were used:

Climatic suitability:

- This is based on the CLIMEX Ecoclimatic Index with parameters (see Table 19) developed by Sarah Brunel and Darren Kriticos using a 1961-90 gridded climatology at 0.5° latitude x longitude (from the Climatic Research Unit). This was rescaled to a 10 km x 10 km grid and divided into six classes for MCAS-S.

Table 19 CLIMEX parameters for *Eichhornia crassipes*

Temperature Index					
DV0	DV1	DV2	DV3		
12	25	30	31		
Cold Stress					
TTCS	THCS	DTCS	DHCS	TTCSA	THCSA
0.5	-0.01	10	-0.00035	0	0
Heat Stress					
TTHS	THHS	DTHS	DHHS		
37	0.001	0	0		

Habitat distribution:

E. crassipes can only establish in fresh water habitats. The distributions at 100 metres resolution of three fresh water habitats: inland marshes, watercourses and water bodies, in Europe were obtained from the Corine Land Cover Map 2000⁸, aggregated to provide the percentage land cover for each 10 km x 10 km grid cell and then divided into 5 classes based on equal area.

Table 20 : Primary factors for *Eichhornia crassipes*

Title and description	Map	Legend
<p><u>Climatic suitability from the Climex model</u> <u>(Climate):</u> CLIMEX Ecoclimatic Index based on parameters in Table 19 and a 1961-90 gridded climatology at 0.5° latitude x longitude reprojected to a 10 km x 10 km grid and divided into six classes.</p>		

⁸ <http://www.eea.europa.eu/publications/COR0-landcover>



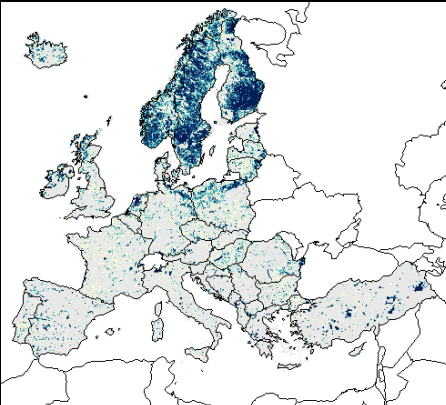
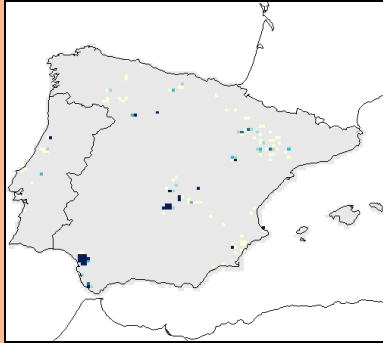

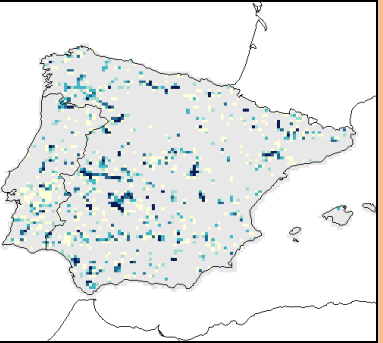
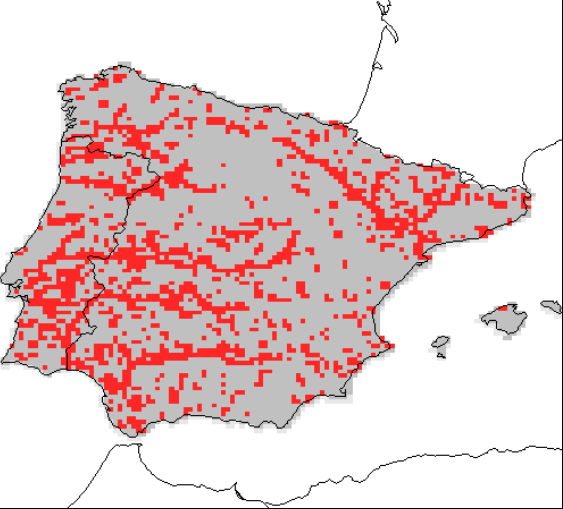

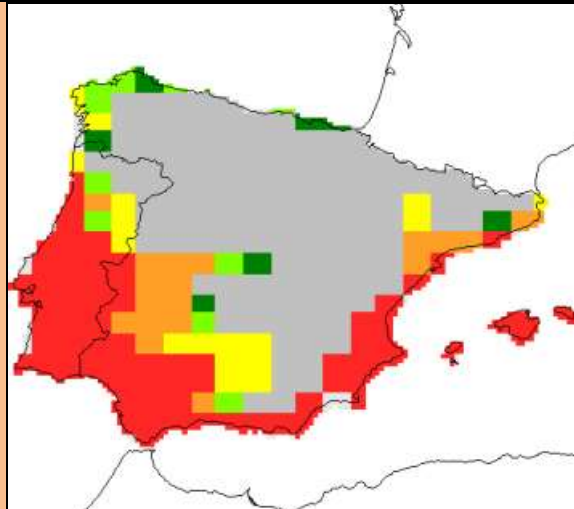
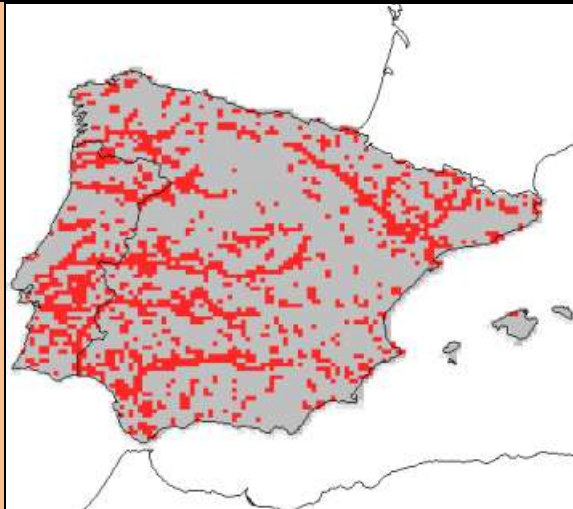
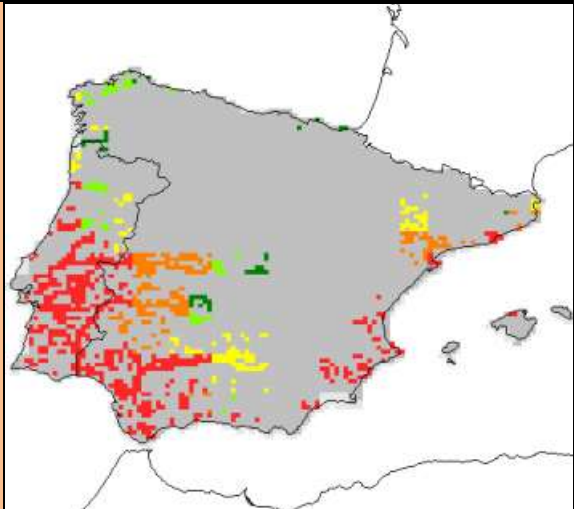

<p><u>Inland marsh areas (H1):</u> Based on a 2000 gridded Corine land cover at 100 m x 100 m resolution aggregated to a 10 km x 10 km grid. The result is divided into 5 classes based on equal area.</p>		<table border="1"> <tbody> <tr> <td>class 1</td> <td>From</td> <td>0.01</td> </tr> <tr> <td>class 2</td> <td>From</td> <td>0.75</td> </tr> <tr> <td>class 3</td> <td>From</td> <td>1.5</td> </tr> <tr> <td>class 4</td> <td>From</td> <td>2.25</td> </tr> <tr> <td>class 5</td> <td>From</td> <td>3</td> </tr> </tbody> </table>	class 1	From	0.01	class 2	From	0.75	class 3	From	1.5	class 4	From	2.25	class 5	From	3
class 1	From	0.01															
class 2	From	0.75															
class 3	From	1.5															
class 4	From	2.25															
class 5	From	3															
<p><u>Water course areas (H2):</u> Based on a 2000 gridded Corine land cover at 100 m x 100 m resolution aggregated to a 10 km x 10 km grid. The result is divided into 5 classes based on equal area.</p>		<table border="1"> <tbody> <tr> <td>class 1</td> <td>From</td> <td>0.01</td> </tr> <tr> <td>class 2</td> <td>From</td> <td>0.8</td> </tr> <tr> <td>class 3</td> <td>From</td> <td>1.6</td> </tr> <tr> <td>class 4</td> <td>From</td> <td>2.4</td> </tr> <tr> <td>class 5</td> <td>From</td> <td>3.2</td> </tr> </tbody> </table>	class 1	From	0.01	class 2	From	0.8	class 3	From	1.6	class 4	From	2.4	class 5	From	3.2
class 1	From	0.01															
class 2	From	0.8															
class 3	From	1.6															
class 4	From	2.4															
class 5	From	3.2															
<p><u>Water body areas (H3):</u> Based on a 2000 gridded Corine land cover at 100 m x 100 m resolution aggregated to a 10 km x 10 km grid. The result is divided into 5 classes based on equal area.</p>		<table border="1"> <tbody> <tr> <td>class 1</td> <td>From</td> <td>0.01</td> </tr> <tr> <td>class 2</td> <td>From</td> <td>0.8</td> </tr> <tr> <td>class 3</td> <td>From</td> <td>1.6</td> </tr> <tr> <td>class 4</td> <td>From</td> <td>3.2</td> </tr> <tr> <td>class 5</td> <td>From</td> <td>7.2</td> </tr> </tbody> </table>	class 1	From	0.01	class 2	From	0.8	class 3	From	1.6	class 4	From	3.2	class 5	From	7.2
class 1	From	0.01															
class 2	From	0.8															
class 3	From	1.6															
class 4	From	3.2															
class 5	From	7.2															

Table 21 Combining maps of key factors to identify habitats of higher risk from *Eichhornia crassipes*

	1 st factor	2 nd factor	3 rd factor	Result
Area of potential establishment 1/2				
	Inland marsh areas (H1)	Water course areas (H2)	Water body areas (H3)	 Presence of habitats suitable for establishment (H) : $H = H1 + H2 + H3$
	<p>Comments: The area of inland marshes, watercourses and water bodies are added and the result is divided into 2 classes (presence or absence).</p>			

To see the results more clearly, only maps for Spain are provided here. For the legend, see Table 20.

	1 st factor	2 nd factor	Result
Area of potential establishment 2/2			
	<p>Climatic suitability : Ecoclimatic Index from CLIMEX</p>	<p>Presence of habitats suitable for establishment (H) : $H = H1 + H2 + H3 + H4$</p>	 <p>Area of potential establishment for <i>Eichhornia crassipes</i> considering Climatic suitability and Habitats suitability.</p>
<p>Comments: Climatic suitability and presence of habitats are combined using the limiting factor matrix. If the climate is suitable but there is no habitat in this area, the risk of pest establishment is zero. If the habitat is present, the risk of pest establishment is equal to the climatic suitability.</p>			

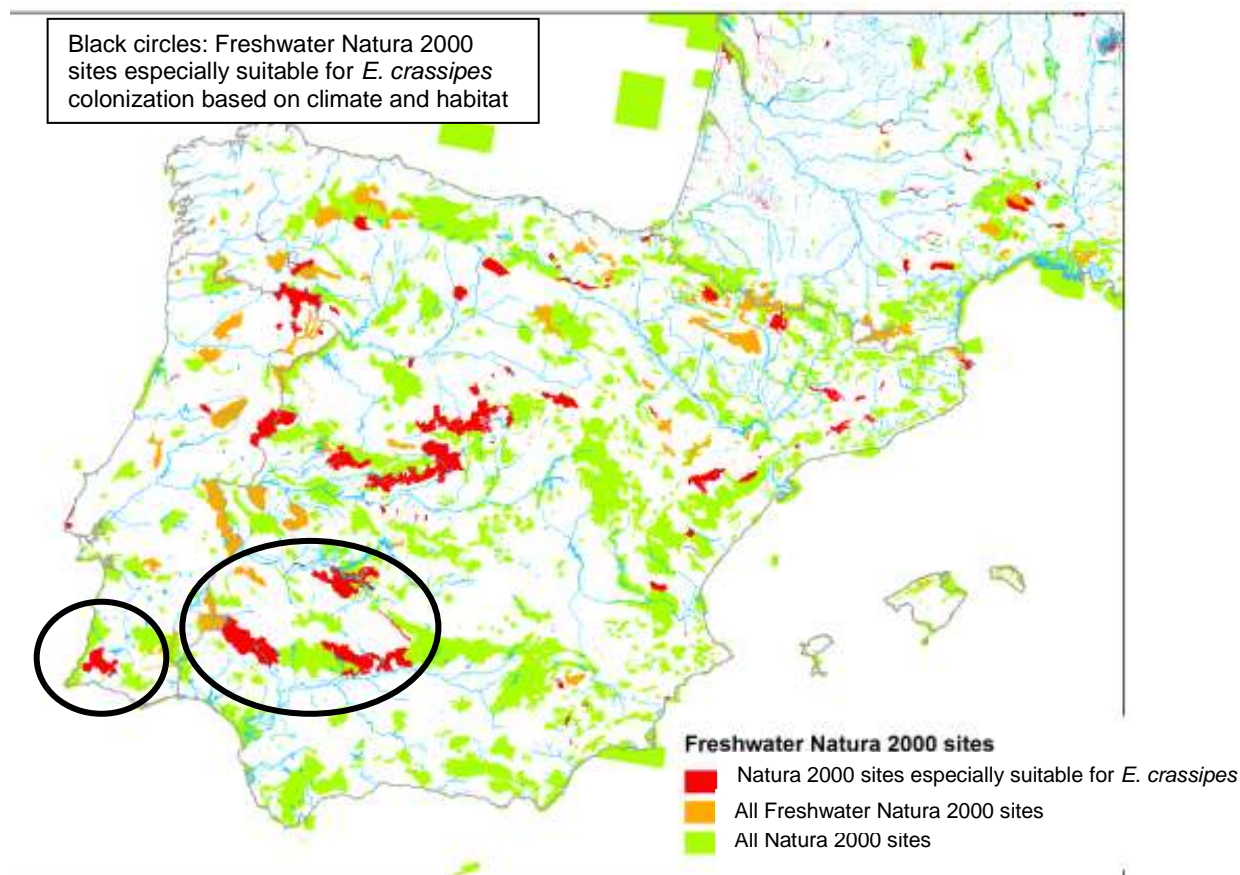


Figure 7 Natura 2000 sites in Spain suitable for *Eichhornia crassipes*. Sites in red within the black circles are at highest risk

In order to map the areas of highest risk (highest conservation importance) we explored the extent to which we could identify which Natura 2000⁹ sites (special areas of conservation established under the 1993 EU habitats directive) could be invaded by *E. crassipes*.

E. 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 and saline water (Muramoto *et al* 1991). Based on this evidence, we selected the Natura 2000 habitats (and codes) as follows.

Since the species grows in standing waters (31), and prefers nutrient rich waters, we presume that 3110, 3120, 3130, 3140 and 3160 represent a lower risk (when they are not polluted with nutrients). Mediterranean temporary ponds may not allow the establishment of the species and were not considered to be relevant. Turlough, peat bogs, northern and mountain watercourses are also excluded. So the higher risk is therefore likely to be for:

⁹ http://ec.europa.eu/environment/nature/natura2000/db_gis/index_en.htm

3150 Natural eutrophic lakes with *Magnopotamion* or *Hydrocharition* - type vegetation

3250 Constantly flowing Mediterranean rivers with *Glaucium flavum*

3260 Water courses of plain to montane levels with the *Ranunculion fluitantis* and *Callitriche-Batrachion* vegetation

3270 Rivers with muddy banks with *Chenopodion rubri* p.p. and *Bidention* p.p. vegetation

3280 Constantly flowing Mediterranean rivers with *Paspalo-Agrostidion* species and hanging curtains of *Salix* and *Populus alba*

Figure 7 maps all Natura 2000 sites in the Iberian peninsula and highlights freshwater sites and those particularly suitable for *E. crassipes* colonization based on the selection above and climate suitability.

Although the Natura 2000 database is clearly a useful method for mapping areas of high conservation importance in the EU, it has the following drawbacks:

- Austrian sites are not included
- UK sites do not provide the same habitat classifications
- Natura 2000 sites vulnerable to damage from an invasive alien species may include habitats at high risk but they may be classified as different habitats in the database. Thus the Coto Doñana in southern Spain contains many waterways suitable for *E. crassipes* but, for Natura 2000, it is included because of its rare sand dune ecosystem.

Stage 3: When possible and appropriate, distinguish the endangered areas (those areas where economically important loss is likely to occur)

B3.1 Introduction

Before mapping the endangered area (area of economically important loss), it is important to have a clear understanding of what economically important loss is, in terms of the PRA. For producers, economically important loss occurs when the economic injury level (EIL) is exceeded. The EIL is the population density at which the cost to control the pest equals the amount of damage it is likely to cause (Pedigo & Higley, 1992; Pedigo et al., 1986; Stern et al., 1959). When the EIL is exceeded, it then becomes economically prudent for the farmer to carry out an intervention such as to treat the crop with a plant protection product.

To predict the area where economically important losses are likely to occur, not only is it important to identify the areas at highest risk (see stages 1 and 2) but, in addition, some knowledge is required of the extent to which the conditions necessary for pest populations to exceed the economic injury level are present in the PRA area. In the absence of models predicting pest population densities and the extent to which they are likely to exceed the economic injury level, 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 reached its maximum geographical extent and the maximum pest density.

With sufficient data it would not only be possible to map the area where economic loss may occur but also the estimated losses in terms of € per 10 km x 10 km grid cell. For example, if €100,000 worth of a susceptible crop is grown in a particular grid cell and losses due to a pest are likely to be around 10%, then losses could be mapped as €10,000. However, it is likely to be very difficult to make such estimates because of the range of influences on pest populations. For example, in addition to the relationship between population densities and the likely level of yield or quality loss, the climate, crop variety, agronomic practices, other crops grown in the area and the surrounding non-crop habitat also have to be taken into account.

In this stage, we provide a method based on a simple logistic model (SLG) for identifying the areas that are likely to have the highest population density (based on climate) and describe how climatic suitability in areas where high impacts have been observed can be used to help identify where economic loss may occur in the PRA area.

Where yield and quality loss scenarios are being explored for polyphagous species, we have also provided decision rules for combining maps of economic impact for different hosts

B3.2 Estimate the population densities in the area of potential establishment based on climatic suitability and relate these to areas where economically important loss occurs.

Apply the simple logistic growth model or population dynamics model (see Model 1 SLG in Stage 4 and the Spread Module in PRATIQUE Deliverable 2.6) for the cells within the area of potential establishment for e.g. $t = 10$ years. It is assumed that the same initial population is introduced in all suitable cells. Since the SLG model 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, the CLIMEX 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) will also indicate areas of highest population density based on climate. For some species, it may be easier to map the number of degree days available for growth over the minimum threshold of development, the number of generations per year or the Ecoclimatic Index.

B3.3 Estimate the extent to which the economic injury level is likely to be exceeded

Map the predicted population densities based on the SLG model or climatic suitability based on the CLIMEX GI, CLIMEX EI, the degree days above the minimum threshold of development or the generation number and, if possible, compare these to the economic injury levels (EILs) known for the pest taking into account the fact that the EILs levels are often expressed as sample units or relative units, e.g. the numbers per plant or leaf or the number of leaves infested so the EILs may need to be scaled to the units of the logistic model. Identify areas where impacts are to be expected.

Information on yield losses from specific pests may be obtained from expert opinion, the pest-specific literature and from the synthesis by Oerke et al (2004). Since impacts recorded in the literature are often based on one year's records and often reflect the maximum recorded, it is particularly important to take this into account when using climatic data that summarise climate over a long sequence of years (commonly 30 years).

However, when relating a species' climate suitability to the potential for pest impact, a series of additional factors need to be considered. The relationship between climate suitability and pest impact may be non-linear. If, for example, a pest species damages a host plant, the amount of damage suffered may depend on a complex interaction between the climate suitability for the pest and the suitability for the host plant. In economic terms, the relationship could be discontinuous. The mere presence of the pest at any non-zero level of density may be sufficient to trigger biosecurity procedures based on loss of area freedom that means that impacts are effectively maximised.

It is possible to uncover relationships between modelled climate suitability and measurements of pest impact. Pinkard et al. (2010) describe a technique for regressing simple qualitative assessments of site suitability for a pathogen. Such an assessment can be used for the post-hoc classification of climate suitability for pest impact. Kriticos et al. (submitted) regressed modelled GI_A against fitted juvenile growth rates for Scotch Broom, *Cytisus scoparius*. The relative growth rate of a range of temperate woody weeds in relation to the growth rate of *P. radiata* had been shown previously to be closely related to the level of impact on *P. radiata* productivity. Kriticos

et al. (in prep.) regressed measurements of impact for *Thaumetopoea pityocampa* against modelled climate suitability at a number of European sites. The modelled climate suitability was combined with a simple spread model to estimate the present (discounted) value of a hypothetical invasion by this pest.

The regression approach exposes the variability in the system. This variability encompasses the climate (covariate) surfaces, the relationship between the organism and climate variables, the CLIMEX model, and the experimental observations of impact. Measurement errors and the variability not explained by the regression relationship also need to be taken into account.

B3.4 Decision rules for combining maps of economic impact for different hosts

Many plant pests are polyphagous, i.e. attack more than one host species. Different host plants generally have different economic values and the same host plant may also have different economic values per kg or tonne depending on the variety grown and the end use. For example, grain maize is worth much more per tonne than forage maize and seed potatoes are more valuable per tonne than ware potatoes. Here, we recommend the decision rules that should be applied to combine maps that represent yield loss or the area at highest risk for different crops.

In the introduction of the impact section of the qualitative PRA scheme, the following guidance is given to help decide whether a combined risk analysis should be executed or separate analyses conducted for multiple hosts or production systems:

'In any case, providing replies for all hosts (or all habitats) and all situations may be laborious, and it is desirable to focus the assessment as much as possible. The study of a single case may be sufficient, e.g. if the effect on one host exceeds the effect on all other hosts together. It may be appropriate to consider all hosts/habitats together in answering the questions once, if effects on these hosts are comparable. If a selection is made, it should be justified. Only in certain circumstances will it be necessary to answer the questions separately for specific hosts or habitats. This is the case if the majority of the affected producers suffer minor or moderate impacts, but a small group suffers major or massive impacts. Differences can be caused by different host plants; differences between crops and amenity plants or differences between cropping system: conventional and organic production.'

The need to consider more than one host species is dependent upon the distribution of the hosts, their relative importance and the size of the PRA area. Combining maps of impacts on different hosts is thus required primarily when undertaking a quantitative assessment of impacts and providing a detailed map of endangered areas (or areas of highest risk).

An evaluation of the areas where economically important loss is most likely to occur is also dependent on mapped data of host distribution. Some plants within the same genus may be more susceptible than others, and some cultivars may be more susceptible than others. However, if host distribution data are only available at a coarse scale, then the impacts can only be assessed at this scale.

Combining the distribution data of different hosts can be relevant in different stages of the mapping process. Decision rules for producing the area of potential establishment are given in Table 5 and for mapping the area at highest risk in Table 6. In order to combine economic data from different hosts, the following steps should (ideally) to be executed:

1. For each crop, the production (yield in tons per grid cell) should be multiplied by the market price per tonne to obtain the production value per ha. The number of host plants per unit (ha or grid cell) and the value per host plant can also be multiplied to derive the host plant value.
2. For each crop, the level of damage (% of yield) needs to be estimated based on scenarios or significant regression models relating climatic suitability to losses in areas where impacts are already observed (see B3.3).
3. The level of damage will be then need to be adjusted to account for areas where the agronomic circumstances are likely to prevent the pest reaching its maximum population size.
4. The level of damage (% of yield) should be multiplied by the production value to obtain the total loss of production value per host per grid cell.
5. The loss of production value of each host can be added to obtain the total loss of production value per grid cell.

Stage 4: When possible and appropriate, provide a dynamic picture of the invasion process using spread models

Introduction

Table 22 summarizes the information required to run the spread models, the model output and the recommendations for their use. All the spread models require data on the climatic suitability of the PRA area which is most readily provided by a CLIMEX model. Other factors influencing spread can also be taken into account, e.g. host plant distribution (e.g. from crop maps) and soil characteristics. Once a CLIMEX model has been built, setting up and running the spread models is relatively straightforward.

However, additional data are needed to estimate population development and the rate of spread since it can be difficult and time consuming to derive these data from the literature or by expert consultation. Table 23 shows the relative ease with which parameters can be estimated for the test species.

B4.1. Is it appropriate to map spread?

Please answer the following five yes/no questions:

B4.1.1 Is the qualitative rating of spread within the EPPO DSS for PRA insufficient and quantitative data are needed to indicate when the pest is expected to arrive at particular location (depending on the entry/starting point)? **Yes/No**

B4.1.2 Is more detailed information required to answer questions within the EPPO PRA scheme (questions 4.05 (*What is your best estimate of the time needed for the pest to reach its maximum extent in the PRA area?*) and 4.06 (*Based on your responses to questions 4.01, 4.02, and 4.05 while taking into account any current presence of the pest, what proportion of the area of potential establishment do you expect to have been invaded by the organism after 5 years?*))? **Yes /No**

B4.1.3 Are detailed estimates required to quantify impacts as they build up over time (e.g. the infested area per year)? **Yes/No**

B4.1.4 Are detailed dynamic information on spread over time required to design and target surveillance campaigns, contingency plans or phytosanitary measures? **Yes/No**

B4.1.5 Are quantitative data required for the analysis of costs and benefits of phytosanitary measures (e.g. to compare the rate of spread with and without measures)? **Yes/No**

If at least one question has been answered with yes – go to B4.2.

If no question has been answered with yes, spread mapping is not appropriate. STOP

B4.2 What kind of maps, information and data are already available for the suitability of the PRA area for the organism?

Please answer the following questions:

B4.2.1 Is a map of endangered areas already available?

If YES, go to B4.3
 If NO, go to B4.2.2

B4.2.2 Is a CLIMEX model and map already available?

If YES and available for the PRA area, go to B4.2.4
 If YES but needs to be adjusted for the PRA area, rerun the CLIMEX model and go to B4.2.4

If NO, go to Annex C and attempt to construct a CLIMEX model and go to B4.2.3

B4.2.3 Has a CLIMEX model and map been successfully constructed?

If YES, go to B4.2.4
 If NO, STOP. You cannot apply this spread module

B4.2.4 Is a map of hosts (or habitats) already available?

If YES, you can apply the spread module, go to B4.3
 If NO, you can apply the spread module but must assume that suitable hosts (or habitats) are available everywhere go to B4.3

B4.3 What are the key factors that influence the spread of the pest and how much information is available?

Collect available information from the answers to questions 4.01 – 4.06 from the EPPO PRA scheme, from datasheets or literature and try to either derive a spread rate (km/year) or to indicate whether short or long distance dispersal is relevant for the species.

Spread mechanism	Yes/No	Specify	Short distance (within a range of 1 m – 10 km)	Long distance (move/jump to new areas)
			Yes/No (and/or spread rate)	Yes/No (and/or spread rate)
Active movement		e.g flight of adult beetles		
Passive movement with wind, water, ...		e.g. spore dispersal with splash water		
Human assistance		e.g with vehicles, trade, hithchiking		
Vector needed		e.g. beetle,		

		psyllid, aphid		
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Go to B4.4

B4.4 How much information is available on the key data for parameter estimation?

Consider the information available and describe any uncertainties

Key data for parameters (for pest and/or vector)	Specify	Information available Yes / No	Uncertainty of available data (low – medium – high)
B4.4.1 spread rate(s) (question 3)	<i>(already done in 3)</i>		
B4.4.2 entry points, locations of observations	e.g. airports, harbours, ...		
B4.4.3 data on pest densities observed for at least two different years (without eradication or containment measures if possible)	e.g. 5 trees infested in one year, 500 trees infested 3 years later		
B4.4.4 data on highest observed pest densities (carrying capacity of host plant or habitat)	e.g. 20 <i>Anoplophora</i> exit holes per tree; 2 - 2.5 Million <i>Diabrotica</i> beetles per ha		
B4.4.5 data on the lowest pest density to establish a new population	e.g. one male and one female		
B4.4.6 distribution maps for two different time steps			

Go to B4.5

B4.5. Based on the information, data and maps available for the organism (questions B4.4.1 – B4.4.6) how easy is it to estimate the spread model parameters and therefore to model spread?

- **Only yes answers with**
 - low to medium uncertainty
 - very easy and straightforward, all the spread models can be used; go to B 4.2
 - medium to high uncertainty
 - very easy, all the spread models can be used but best, likely and worst

case scenarios must be simulated in detail to evaluate the spread uncertainty;
go to B 4.2

- **More yes than no answers, with**
 - low to medium uncertainty
 - quite easy, some spread models can be used;
 - go to B 4.2
 - medium to high uncertainty
 - quite easy, some spread models can be used but best, likely and worst case scenarios must be simulated in detail to evaluate the spread uncertainty;
 - go to B 4.2
- **Same number of yes and no answers,**
 - with low to medium uncertainty
 - possible, some spread models can be used;
 - go to B 4.2
 - with medium to high uncertainty
 - possible, some spread models can be used but best, likely and worst case scenarios must be simulated in detail to evaluate the spread uncertainty;
 - go to B 4.2 or Stop
- **More no than yes answers, yes answers**
 - with low to medium uncertainty
 - it might be possible to apply one or two models,
 - go to B 4.2 or Stop
 - with medium to high uncertainty
 - impossible, Stop
- **Only no answers**
 - impossible, Stop

B4.6 Modelling and mapping the spread potential

Before modelling and mapping spread, the area of potential establishment must have already been identified and mapped (see Stages 1 & 2 of this DSS). A CLIMEX ecoclimatic index map is also required. Further work is required to use the outputs from other models.

One or more spread models can be applied. A short description of the spread models is given below, but, for further details and assistance in model application, see the spread module guide in PRATIQUE Deliverable 2.6.. These models are designed to help to map changes in the endangered area through time and space.

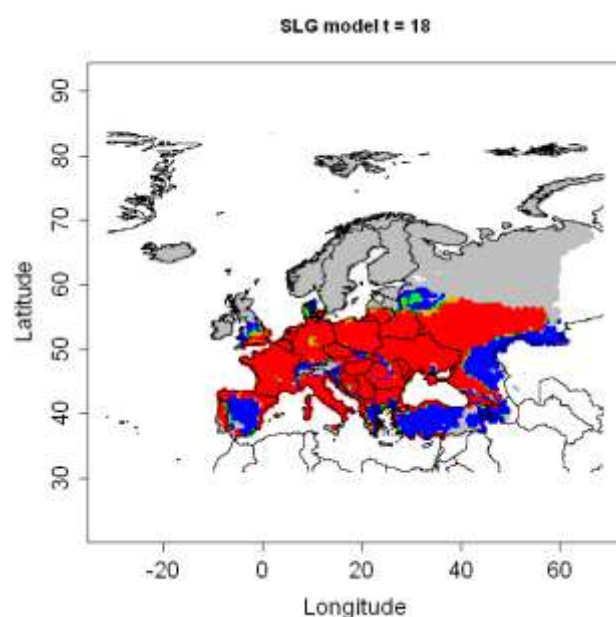
When to use which model?

Recommendations and testing experiences for the different spread models are provided in Tables 22 and 23 below. The models differ in their output but also the parameters and data they require. Therefore the decision on which model to apply may depend not only on the expected result (presence/absence of the pest or population abundance) but also on the time and expertise that is required for the estimation of the parameters and the data available.

The following five models are available:

- (i) **Simple logistic growth model or population dynamics model (Model 1 SLG)**
- (ii) **Temporal spread over cells integrated with impact (LG-Econ)**
- (iii) **Radial range expansion model (Model 3, RR)**
- (iv) **Random Radial Rate Expansion Model (Model 4, Rand-RR)**
- (v) **Dispersal Kernel Model (Model 5, DK)**

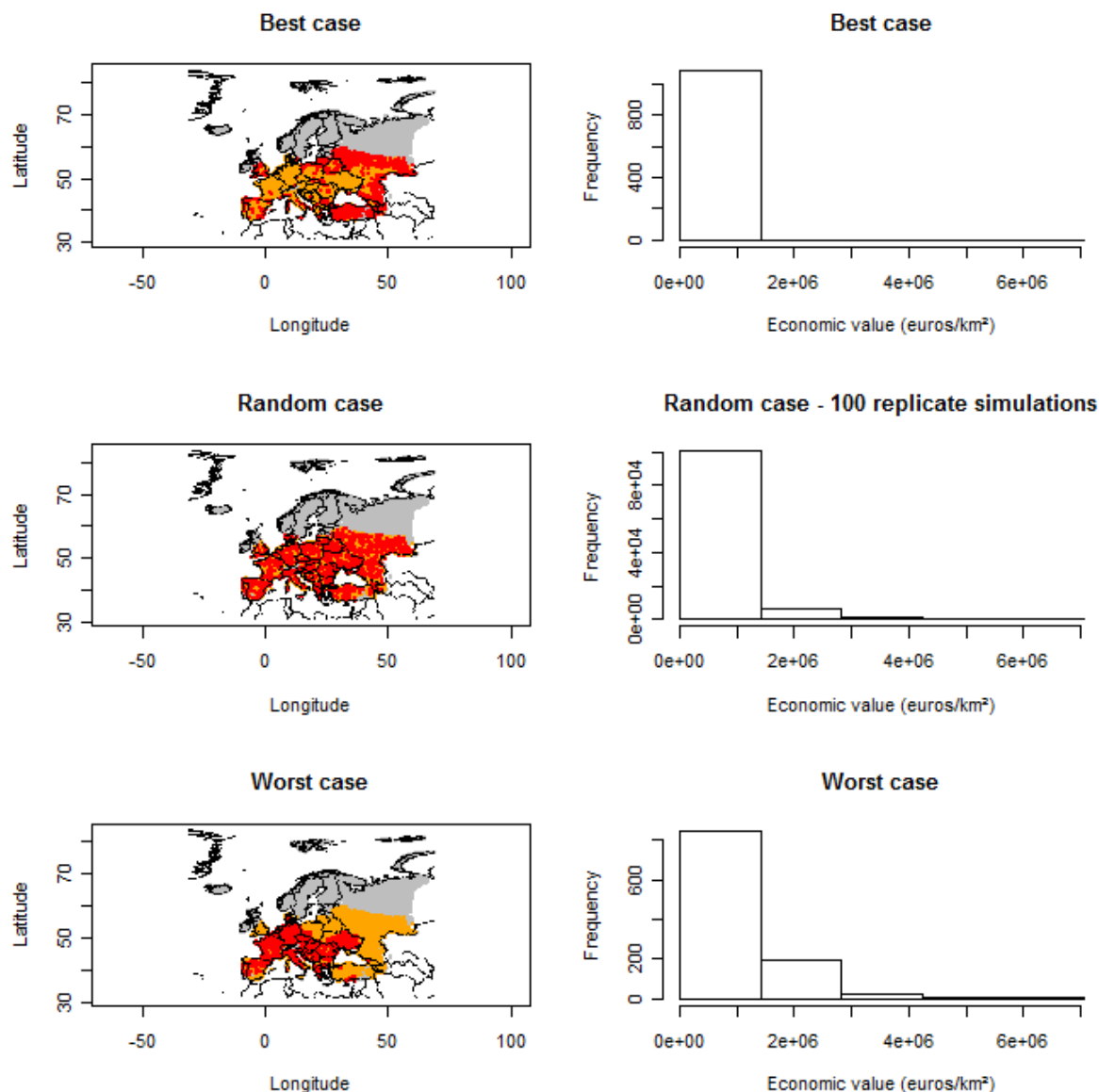
Model 1 (Simple logistic growth model or population dynamics model, SLG) provides information and data on the temporal increase in pest abundance (expressed in percentage of the carrying capacity) within the grid cells, assuming that a given population abundance is introduced in all suitable cells. The output maps can be used for identifying areas where high pest abundance (and therefore economic impacts) are to be expected after different time intervals. The population density does not increase in the same way in all suitable cells because this depends on the climate represented here by the growth index (the CLIMEX GI). This model should be applied in Step B 3.2 before calculating impacts. It may also be of interest to risk managers when deciding where phytosanitary measures should be applied.



Output of Model 1 (SLG model) for *D. virgifera virgifera* after 18 years (t=0 in 1992, year of discovery, so t = 18 represents 2010)

$N_0 = 1.6 \cdot 10^{-7} \%$, $\lambda_{max} = 40$,
based on a CLIMEX model from
Philippe Reynaud and Darren Kriticos
(blue dots: $0 < N_t \leq 25$, green dots:
 $25 < N_t \leq 50$, orange dots: $50 < N_t <= 75$, red dots: $75 < N_t \leq 100$, grey
dots: $N_t=0$, white: no data)

Model 2 (Temporal spread over cells integrated with impact (LG-Econ)), is a logistic growth model based on economic values. It maps the presence or absence of a pest in an area and simulates at the same time the economic impact for the best case, worst case and most likely scenario (see deliverable PRATIQUE D2.6 for further explanations). However, these results very much depend on the data that are available on the economic value of the host plants or habitats and they can only provide a very approximate estimate of impacts.

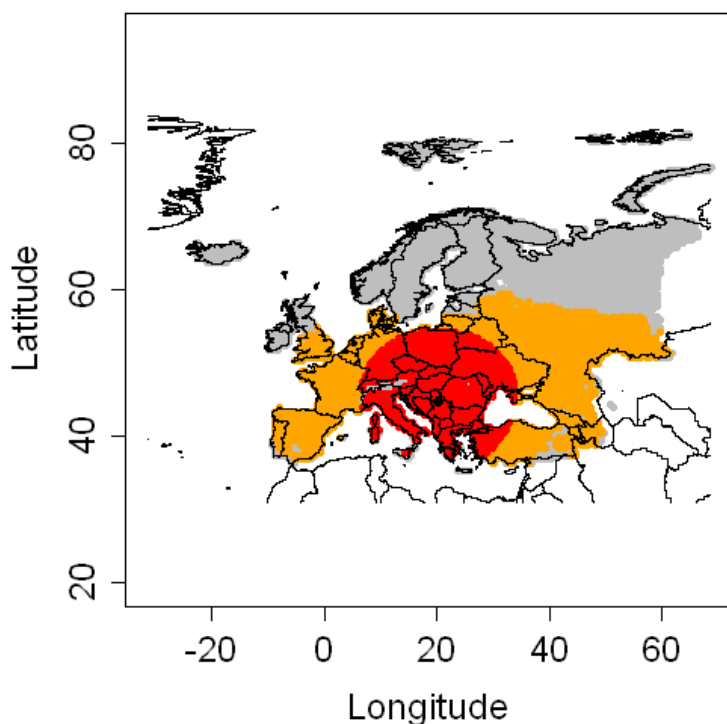


Output of Model 2 (LG-Econ) for *D. virgifera virgifera* for 18 years (in 2010)

based on a CLIMEX model from Philippe Reynaud and Darren Kriticos (red dots: invaded cells, orange dots: non invaded but suitable cells, grey dots: EI=0, white: no data on climate suitability)

Model 3 (Radial range expansion model, RR) gives information on the spatial expansion of a species from its entry point or points according to its spread rate. Either the pest is already present in the PRA area and the entry locations are known, or the pest has not yet arrived in the PRA area and it is possible to test various hypothetical entry points (e.g. at airports or ports). Since it does not take population dynamics into account, no data on pest abundance are provided and only the presence or absence of a pest species in a location is mapped. This rather simple model can be based on the qualitative rating of spread in Question 4.01 of the EPPO PRA scheme.

Radial expansion

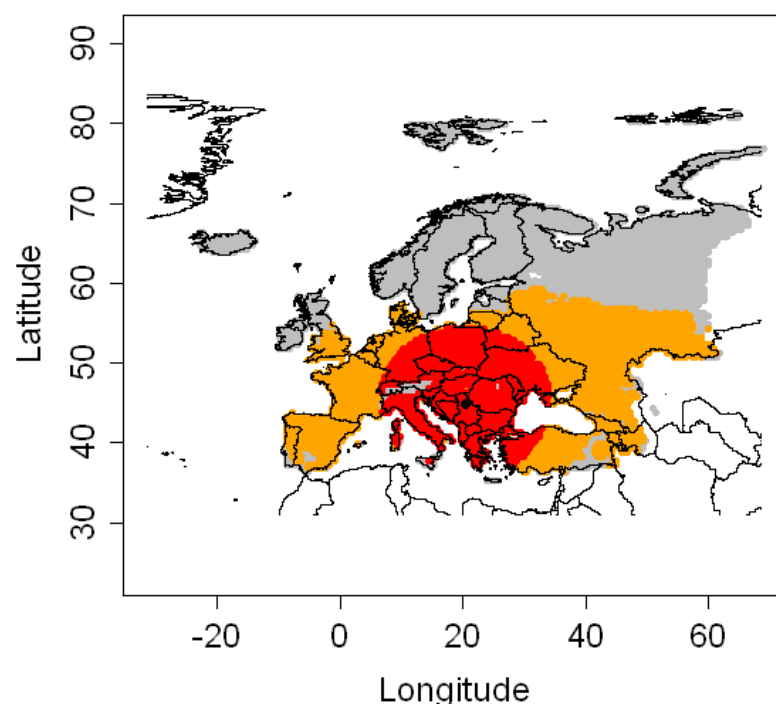


Output of Model 3 (RR mode) for *D. virgifera virgifera* for 18 years (in 2010)

(spread rate (RR) = 60km/year)
based on a CLIMEX model from
Philippe Reynaud and Darren Kriticos
(red dots: invaded cells, orange dots:
non invaded but suitable cells, grey
dots: EI=0, white: no data)

Model 4 (Random Radial Rate Expansion Model, Rand-RR) maps the presence or absence of a species in an area according to its radial range expansion (spread rate) but the invasion process of the cells is simulated at random and it therefore probably provides more accurate estimates for the potential spread than Model 3 because it does not assume that all the cells within this area are invaded. Only one replicate simulation has been made but it is possible to run the model several times to have an overview of the possible outcomes. This model does not provide information on the population abundance within the invaded cells. The parameter estimation differs from model 1 and 3 (see table 22) since here the relative rate of spatial increase (r) is used. This parameter can be derived if distribution maps of the species are available for two different time steps.

Random radial expansion

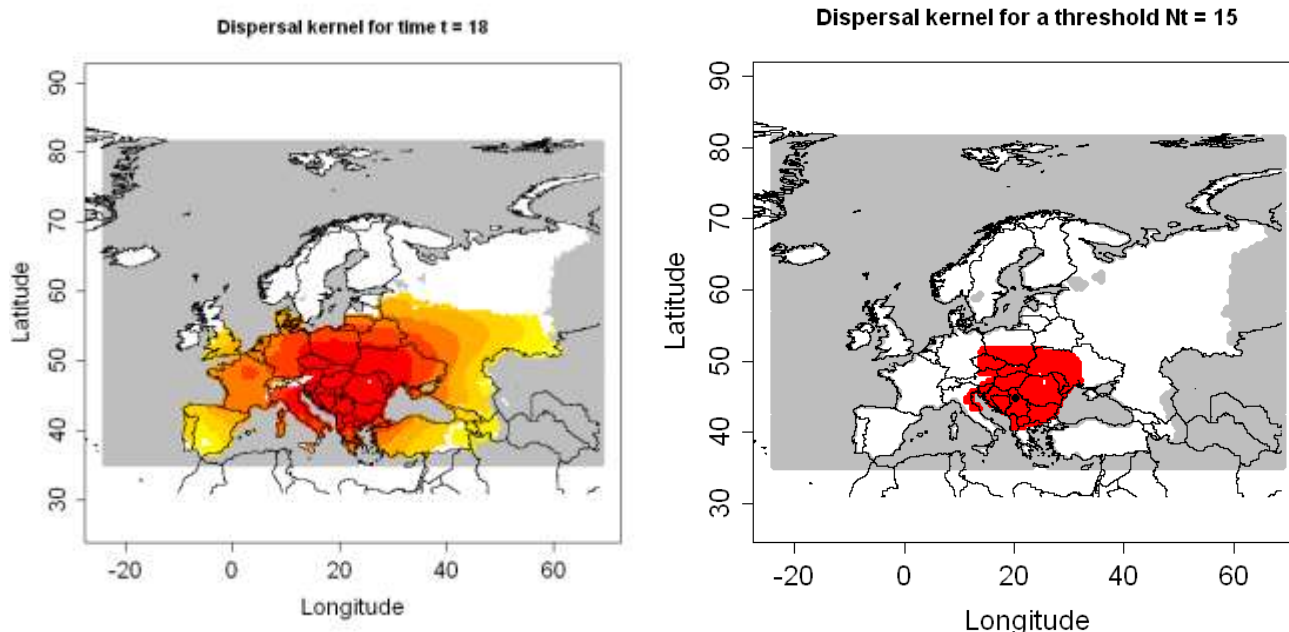


Output of Model 4 (Rand-RR mode) for *D. virgifera virgifera* for 18 years (in 2010)

(spread rate (RR) = 60km/year) based on a CLIMEX model from Philippe Reynaud and Darren Kriticos (red dots: invaded cells, orange dots: non invaded but suitable cells, grey dots: EI=0, white: no data)

Note that, in this case, the outputs of model 3 and 4 look similar, but this is not always the case. The outputs of model 4 converge towards the output of model 3 when the number of invaded cells covers all the area defined by model 3. If not, only some cells are chosen randomly within the area defined by model 3.

Model 5 (Dispersal Kernel Model, DK) provides information and data on the spatial distribution of a pest species and also data on the pest's abundance (expressed in percentage of the carrying capacity) at a specific time and place. Compared to the other two models it needs more time for running the model and for deriving and adjusting the parameters of the dispersal kernel. Although it also requires some understanding of the dispersal kernel, it provides a more realistic representation of spread.



Output of Model 5 (DK-model) for *D. virgifera virgifera* after 18 years (in 2010)
 (Nt: population abundance (%); left picture: graduated colors from white ($N_t < 10^{-6}$ %) to yellow, orange and red ($N_t \geq 10\%$). Grey means no data); right picture: The population abundance (%) is above this threshold of 15% in red cells. (red dots: cells where $N_t \geq$ threshold, white: cells where $N_t <$ threshold. Grey means no data).

Table 22: The information required, model output and recommendations for the application of the different spread models

Model	Information required			Results / model output	Recommendations
	all the models require: - data on climatic suitability (CLIMEX-model results) - host distribution data where appropriate - basic data on population development, e.g. a year to year multiplication factor and carrying capacity - a maximum elevation limit, if appropriate)				
	Data	Time	Expertise		
Model 1 (SLG)	See above	Little - Medium	Some understanding of population development and dynamics. Interpret with caution (does not model spatial spread).	Population abundance in every cell of the area suitable for establishment	<ul style="list-style-type: none"> • Use for step B3.2 • Interesting for identifying areas where high pest abundance (and therefore economic impacts) are to be expected after different time intervals
Model 2	The prerequisites	Medium Depends on	Some understanding	Presence/ absence of the	<ul style="list-style-type: none"> • economic impacts can directly be simulated

(Econ)	above + Economic data on host plants + relative rate of spatial increase r (requires maps of the species distribution at two time steps)	data availability and time for data search	of population development and dynamics	pest	<ul style="list-style-type: none"> shows its potential in simulating best case to worst case economic impact scenarios
Model 3 (RR)	- needs less + spread rate + start location	Little	Easy to apply if spread rate is known, simple in its assumptions	Presence/absence of the pest (visualizes the spread rate on a map)	<ul style="list-style-type: none"> good results for several tested insect species for presence /absence of the pest could be based on the qualitative spread rating in the PRA scheme by applying the spread rate considered there easy to apply
Model 4 (Rand-RR)	+ spread rate + start location + relative rate of spatial increase r (requires maps of the species distribution at two time steps)	Medium – additional estimation of r	Easy to apply, calculation of r needed according to guidance document on spread module	Presence/absence of the pest	<ul style="list-style-type: none"> more accurate estimates for the potential spread compared to model 3 because it does not assume that all the cells within the area of the spread rate are invaded (simulation at random)
Model 5 (DK)	+ kernel parameters	Most time compared to others for running the model and testing of parameters	Some understanding of population dynamics as well as of the dispersal kernel	Population abundance	<ul style="list-style-type: none"> good results for several tested insects for spatial explicit population abundance results depend on kernel parameters, especially on the shape parameter p. This needs some time and guidance to adjust it for each species

Table 23: Ratings for the easiness of parameter estimation for different test species based on feedback from risk assessors (+ = difficult, ++ = less difficult, +++ = quite easy)

Species tested	Group	Parameters						Feedback on parameter estimation
		Carrying capacity K	Yearly multiplication factor Λ_{max}	Spread rate RR	Relative rate of spatial increase r	Shape parameter of DK p	Scale parameter of DK u	
<i>Diabrotica virgifera</i>	Insect	++	+	+++	++	+(+)	+++	Lots of data from literature and expe-

								ience available
Anoplophora chinensis	Insect	++	++	+++		+	+++	Good expert knowledge
Anoplophora glabripennis	Insect	++	++	+++		+	+++	Good expert knowledge
Saperda candida	Insect	++	+	+		+	+	little data and literature is available
Eichhornia crassipes	Plant	+	+	+		+	+	Difficult and not easy to understand
Meloidogyne enterolobii	Nematode	+++	+	+		default value used	+	Spread rate also takes human assisted spread into account
Bursaphelenchus xylophilus / Monochamus	Nematode / vector: insect (beetle)	+	+	+	++	+	+	Difficult, human assisted spread hard to take appropriately into account and specific CLIMEX model not available
Gibberella circinata	Pathogen	+	+	+		+	+	Problems with parameter estimation

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Appendix 1 List of Annexes to the DSS for Mapping Endangered Areas

Section	Title	Location or File Name
Annex 1	Review of best practice for mapping endangered areas	Annex 1 review pest risk mapping best practice
Annex 2A	PRATIQUE Climatic Suitability Risk Mapping Decision Support Scheme	Annex 2A Climatic Mapping DSS final
Annex 2B	Location data category diagrams	Location data category diagrams
Annex 2C	Summary of model performance based on climate response information and location data categories	Summary of model performance based on climate response information and location data categories
Annex 2D	Qualitative comparisons of different species distribution modelling techniques	Qualitative comparisons of different species distribution modelling techniques
Annex 2E	Links to climatic mapping data, software and explanations of methods	Links to climatic mapping data, software and explanations of methods
Annex 2F	Comparison of the performance of nine species distribution models for <i>Diabrotica virgifera virgifera</i>	Comparison of the performance of nine species distribution models for <i>Diabrotica virgifera virgifera</i>
Annex 2G	Instructions for the Use and Interpretation of CLIMEX	Instructions for the Use and Interpretation of CLIMEX
Annex 2H	Climatic mapping in PRA – A tutorial	Climatic mapping in PRA – A draft tutorial
Annex 2I	R functions related to Ecological Modelling: Setting thresholds and rescaling model outputs	R functions related to Ecological Modelling: Setting thresholds and rescaling model outputs
Annex 2J	Getting started MCAS-S for PRATIQUE	Getting started MCAS-S for PRATIQUE
Annex 2K	Bayesian selection of parameters for the Generic Infection Model	Bayesian selection of parameters for the Generic Infection Model
Annex 2L	Thermal requirements in phenological models	Thermal requirements in phenological models
Annex 3A	PRATIQUE (MCAS-S) Datapack	Annex 3A PRATIQUE DataPack for MCAS-S.docx
Annex 3B	Host & Alternate Hosts Distribution maps	The files available from the link below are in a format that is designed to be read by MCAS-S

		and GIS software. Host & Alternate Hosts Distribution maps Image files that can be easily inserted into e.g. Microsoft Office programs here
Annex 3C	Guidance to rescale data to 10 km x 10 km resolution using GIS for MCAS-S	Guidance to rescale data to 10 km x 10 km resolution using GIS for MCAS-S
Annex 3D	CliMond Database for climatic mapping	CliMond Database for climatic mapping
Annex 4	Rating Guidance for Climatic Suitability	Annex 4 Rating Guidance for climatic suitability.doc