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Rating and mapping the suitability of the climate for pest risk analysis*

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The assessment of the suitability of the climate for pest establishment is an important part of pest risk analysis (PRA). This paper describes the work undertaken by the EU 7th Framework project PRATIQUE (Enhancements of Pest Risk Analysis Techniques) to develop guidance for this component of PRA. Firstly, there is a guide to rating the suitability of the climate in the PRA area using qualitative methods. Secondly, a Decision-support scheme (DSS) has been created to assist analysts in deciding whether to map climatic suitability, and to guide the selection of the most appropriate method from the large number available. The process of selecting a climatic mapping method is based on a review of the pest's climatic responses and distribution. A spreadsheet provides a comparison of the potential problems that can arise, depending on the mapping method and on the amount and quality of available data. Diagrams are provided to help choose the location data category that best represents the possible biases in the known distribution of the pest. A second spreadsheet provides general information on the differences and similarities of each method in terms of categories such as functionality, ease of use and quality assurance. A variety of data, tools and supporting documents are available as appendices to the DSS. All of the tools and guides are freely available online.

Introduction

This paper summarizes the work undertaken by the PRATIQUE (Enhancements of Pest Risk Analysis Techniques) project (Baker, 2012, pages 1–2 in this issue) to: (i) provide guidance for pest risk analysts when selecting a rating for the suitability of the climate in the pest risk analysis (PRA) area; and (ii) develop a Decision-support scheme (DSS) for use when mapping this component of risk. The DSS is intended to allow analysts to decide whether creating pest risk maps is likely to be appropriate to their circumstances, and describes how different models may perform based on the species and the data available.

Both the rating guidance and the DSS for mapping climatic suitability are available online (http://capra.eppo.org/deliverables; http://www.pratiqueproject.eu) and are provided, together with a variety of data, tools and supporting documents, as appendices to the DSS for mapping endangered areas (Baker *et al.*, 2012).

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Assessing the suitability of the climate for establishment is an important part of all PRAs. The rating guidance developed by PRATIQUE and outlined in this paper is intended to help assessors give a quick, appropriate and consistent qualitative risk rating, an uncertainty score and a written justification without the need for risk mapping when answering question 3.11 in the EPPO DSS for PRA.

'Based on the area of potential establishment already identified, how similar are the climatic conditions that would affect pest establishment to those in the current area of distribution?'

Although qualitative risk assessments are often sufficient in PRAs, there are also situations where climate suitability maps are required to assist in modelling spread, mapping endangered areas or supporting tactical responses to a pest incursion (Baker, 2012; Kehlenbeck *et al.*, 2012). A DSS has also been provided for the more demanding process of modelling and mapping the areas where the climate is suitable for establishment, indicating when it is appropriate to undertake such work. A review of existing PRA

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schemes by PRATIQUE revealed that none of them provides clear guidance on how to model or map climatic suitability, and methods can generally be inferred only by examining detailed PRAs. Although there are increasing numbers of model comparison papers (e.g. Heikkinen *et al.*, 2006; Jeschke & Strayer, 2008; Dupin *et al.*, 2011), none of these reports provides the overall guidance required by pest risk assessors.

Species distribution models can be broadly divided into two categories. Firstly, deductive models (also called mechanistic models), such as phenology models based on degree days (DD) (e.g. Hartley *et al.*, 2010), use data, often recorded in a laboratory, on the relationship between factors such as temperature and the growth, mortality and fecundity of organisms to predict where a species is likely to occur. Secondly, correlative models (also called inductive or regression models), e.g. MAXENT (Phillips *et al.*, 2006), infer the climatic tolerances and preferences of a species from an analysis of the climatic conditions at locations where the species is currently known to occur. NAPPFAST (Magarey *et al.*, 2011) includes both deductive and correlative models, while CLIMEX (Sutherst *et al.*, 2007) provides an integrated approach. To produce the DSS, the authors reviewed examples of the different types of models available.

Rating guidance for climatic suitability for qualitative assessments

The rating guidance to help assessors select a risk rating for question 3.11 in the EPPO DSS for PRA uses published or pre-prepared climate maps and a table. Four questions need to be answered to help identify the climates suitable for the pest to establish:

(1) What is the pest's current area of distribution?
(2) What climates occur in the pest's current area of distribution?
(3) Where in the PRA area are there hosts and/or suitable habitats?
(4) Which climates in the pest's current area of distribution occur in the PRA area where there are suitable hosts/habitats?

Maps are provided of global climate (CABI, 2010); Köppen-Geiger climate zones (Kottek *et al.*, 2006; see also Kriticos *et al.*, 2011); world hardiness zones (Magarey *et al.*, 2008); annual degree days above base 10°C (Baker, 2002); and EU environmental zones (Metzger *et al.*, 2005). For example, if the assessor knows that a pest requires 750 DD in excess of 10°C to complete its life cycle, Fig. 1 can be used to determine that, based on just this criterion, only a small area in the south of the UK could be suitable for establishment, whereas all of Spain with the exception of high-altitude areas in the north would be suitable.

Decision-support scheme

The DSS is designed to help assessors decide whether it is appropriate to map climate suitability and provide guidance on how the methods are likely to perform depending on the data available. There are five stages, designed to answer five questions:

(1) Is it appropriate to map climatic suitability?
(2) What type of organism is being assessed and what are the key climatic factors affecting distribution?
(3) How much reliable information is available on the key climatic factors affecting distribution?
(4) What category of location data is available?
(5) Based on the type of organism, the information available on its climatic responses and the category of location data, how well is each climatic mapping method likely to perform?

Stage 1: Is it appropriate to map climatic suitability?

The first part of the DSS asks the assessor to review the available data on the pest's distribution, biology and ecology to determine what particular difficulties may be involved in climatic suitability mapping and whether the process is likely to be useful. In common with the rest of the PRA process, the decision to invest time and resources to create climatic suitability maps is influenced by the availability of skills, materials and time to carry out the work and also the magnitude of pest impacts.

Creating a climatic suitability map is less likely to be informative when it is clear that the climate in the known distribution of the pest is either: (i) extremely similar to that in the PRA area (in which case climate is unlikely to present a barrier to establishment); or (ii) extremely dissimilar (in which case establishment is very unlikely to be possible). Creating climatic suitability maps is more likely to be useful when the extent of climate similarity between the known range and the PRA area is unclear.

The assessor is then asked to consider whether the life cycle of the pest is likely to make climatic suitability modelling particularly difficult. This is the case when the conditions within the habitat of the pests are dissimilar to the climate recorded at weather stations, for example, pests in protected or irrigated cultivation, submerged aquatic habitats, the soil, thick woody plant tissue or vectors. Lastly, assessors are advised that creating climatic suitability maps will be less reliable when the pest's distribution and climatic responses are very poorly known, when the pest distribution appears to be expanding rapidly, or when the distribution appears to be extremely dependent on factors other than climatic conditions, such as the presence of hosts, geographical barriers, competitors, natural enemies and crop management measures. In such situations, climatic mapping may indicate only the minimum area likely to be climatically suitable for the pest, and interpretation of the maps may therefore be problematic.

Stage 2: What type of organism is being assessed and what are the key climatic factors affecting distribution?

Having an understanding of the climatic factors that limit the distribution of an organism is critical for creating deductive models of pest distribution, for example for creating phenology models. It is also important for correlative models where the modeller has to select and prioritize the bioclimatic variables (Dupin *et al.*, 2011) that are the most relevant covariates for creating pest distribution maps. If the scientific literature on a pest does not

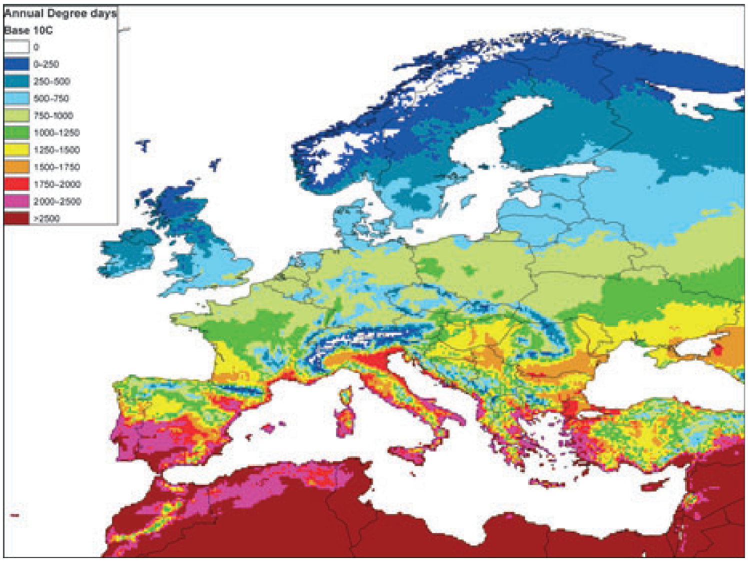

Fig. 1 Degree days over a threshold of 10°C using 1961–90 monthly average maximum and minimum temperatures taken from the 10 min latitude and longitude Climatic Research Unit database (New *et al.*, 2002).

indicate which climatic factors may be of importance, further guidance on the type of factors that can be of importance for particular types of organism is given in Table 1.

Stage 3: How much reliable information is available on the key climatic factors affecting distribution?

In this section, the assessor rates the availability of appropriate climatic response data. For example a rating of '+' is given when there are few data or there is high uncertainty for a particular climatic response, whereas '+++' indicates that a particular climatic response is supported by detailed experiments in more than one study. This information has been summarized in Table 2 for *Drosophila suzukii*. A database of the thermal requirements of a range of invertebrates has been provided as an output of PRATIQUE (Annex 2L), which provides the data from over 2700 climate response experiments (Jarošik *et al.*, 2011). If no climate

Table 1 Climatic factors that are often of importance to particular groups of pests

Climatic factor	Examples of organisms affected
Winter temperature	Plant distribution is limited by cold hardiness
Summer temperature	May determine whether one or more invertebrate generations can be completed in Northern Europe
Rainfall	Often critical for plant survival
Humidity and leaf wetness	Plays an important role in many pathogen life cycles.
Soil and substrate temperatures	Important for invertebrates that spend part of their life cycle below ground.
Soil and substrate moisture	Important for plants

Table 2 Summary of information on the pest's climatic responses and location data

Limiting climate factor	Limiting climate factor responses known?*	Location data category
Summer temperature sum	++ +	2. Native plus exotic locations 4. Locations biased to the centre of the range
Winter temperature minima	++	8. Locations influenced by land-use (and other non-climatic) factors
Soil moisture		9. Locations influenced by seasonal invasion

*'+' = Few data or high uncertainty in climatic responses.
'++' = Data from only one study or from more than one study with no clear consensus.

response data are available, assessors could use as a guide published papers on the factors determining the distribution of closely related species that have a similar life cycle and habitat.

The ability to apply climatic modelling and mapping programs for a particular species depends on the extent to which its climatic responses for development and survival:

- can be inferred from its current distribution;
- are available from field or laboratory experiments;
- can be calculated or inferred from field studies at known locations where climatic factors have been recorded.

Even for the few species that have known climatic responses obtained from experiments in the laboratory, evidence from field studies and knowledge of their current distribution are still important because:

- climatic factors may limit the distribution of a species indirectly;
- laboratory experiments cannot replicate field conditions;

- the laboratory data may have been generated from small sample sizes and the genetic composition of the populations may be different from the potential invaders considered by the PRA.

Stage 4: What category of location data is available?

In this stage, the assessor reviews the data available on the distribution of the pest and selects from the list below the location data categories that are most appropriate. It may not be possible for assessors to detect biases within their dataset before modelling, but creating a distribution map, e.g. by using geographical information system (GIS) software, will assist in making decisions.

(1) Native range locations only: the distribution of the species in its native range is well known but it may not have invaded new areas or locations in the new areas are unknown.
(2) Native plus exotic range locations: the distribution of the species in both the native and invaded region is well known.
(3) Locations biased to the periphery of the range (Fig. 2A): the periphery of the range is similar to the zone of occasional abundance defined by Hill (1987) where climatic conditions are less suitable, e.g. cooler or drier, with greater variation in suitability than in the centre of its range. Here the population may be kept low by climatic conditions and the pest only rarely causes significant damage.
(4) Locations biased to the centre of the range (Fig. 2B): the centre of the range is similar to the (endemic) zone of natural abundance (Hill, 1987) where the pest is always present, often at high density. Here climatic conditions are relatively favourable and the species is regularly a pest of some importance. This could be the case for cryptic pests that are reported only when they are causing noticeable levels of damage.
(5) Few location data points.
(6) Very few location data points.
(7) Erroneous locations included (Fig. 2C): errors cannot be directly identified and deleted.
(8) Locations influenced by land use, e.g. irrigation practices, and other non-climatic factors apart from hosts. It includes situations where the pest distribution is constrained by major geographical features, e.g. the sea (Fig 2D).
(9) Locations influenced by seasonal invasion (Figs 2E and 2F).
(10) Distribution constrained by hosts (Fig. 2G).
(11) Regional distribution data only (Fig. 2H).
(12) Locations influenced by climate change: where historical data are available, it is possible that climatic conditions are no longer suitable at these locations.
(13) Location category unknown: location data are available but cannot be assigned to categories 1–12 because too little is known about what they represent.

These categories play an important role in determining what, if any, model to use and how to parameterize, run and interpret the results.

Stage 5: Based on the type of organism, the information available on its climatic responses and the category of location data, how well is each climatic mapping method likely to perform?

At the beginning of this stage, the information obtained in Stages 2–4 is summarized (see Table 2 for *D. suzukii*). Armed with this knowledge, risk assessors then need to (i) judge how well each method is likely to perform for the pest in relation to the PRA area; and (ii) make an appropriate selection taking into account other more general attributes of each model, e.g. usability and functionality. Two detailed spreadsheets (available online) are provided to assist with both of these processes.

The first spreadsheet (Annex 2C to the mapping endangered area DSS) provides an indication of model performance based on climate response information and location data. A summary of this spreadsheet is shown in Fig. 3 for four methods of climatic mapping. It does not indicate whether one model is better than another in estimating potential distribution. It compares the susceptibility of each modelling system to problems that can arise from different input data quality issues, and is intended as a cautionary guide to alert the assessor to data quality issues that can arise when using each model system. It is important to note that, in practice, input data may suffer from more than one type of bias or data quality issue at the same time. The assessor needs to be vigilant to these issues and seek to understand the behaviour of the selected modelling system sufficiently well to understand signs that the input data may be subject to biases. Some modelling systems provide information tools to identify such problems.

The second spreadsheet (Annex 2D to the mapping endangered area DSS) provides general information on the differences and similarities of each climate risk modelling and mapping method under the following headings: functionality (e.g. whether climate data are included, number of climatic variables, time step and ability to modify parameter variables); ease of use (e.g. complexity, training requirements, availability, cost and speed); quality assurance and user confidence (e.g. sensitivity analysis and outlier identification, relationship between model methodology and known biological/ecological processes); and appropriateness for use with different location data categories.

Discussion and conclusion

Phenology models based on degree days (for insects) and infection probability, e.g. the NAPPFAST Generic Infection Model (Magarey *et al.*, 2005), are highly dependent on the availability of accurate climate response data (though Bayesian methods for estimating key parameters were also explored within PRATIQUE by Makowski *et al.* (2011) and location data are largely irrelevant (see Annex 2C). These methods focus on a particular aspect of climate that is critical to the pest under the assumption that other factors are of lesser importance. This assumption is more likely to be true in the central area of a species' theoretical climatic niche. Towards the range periphery, stress factors, such as drought, extreme heat or cold, tend to determine survival

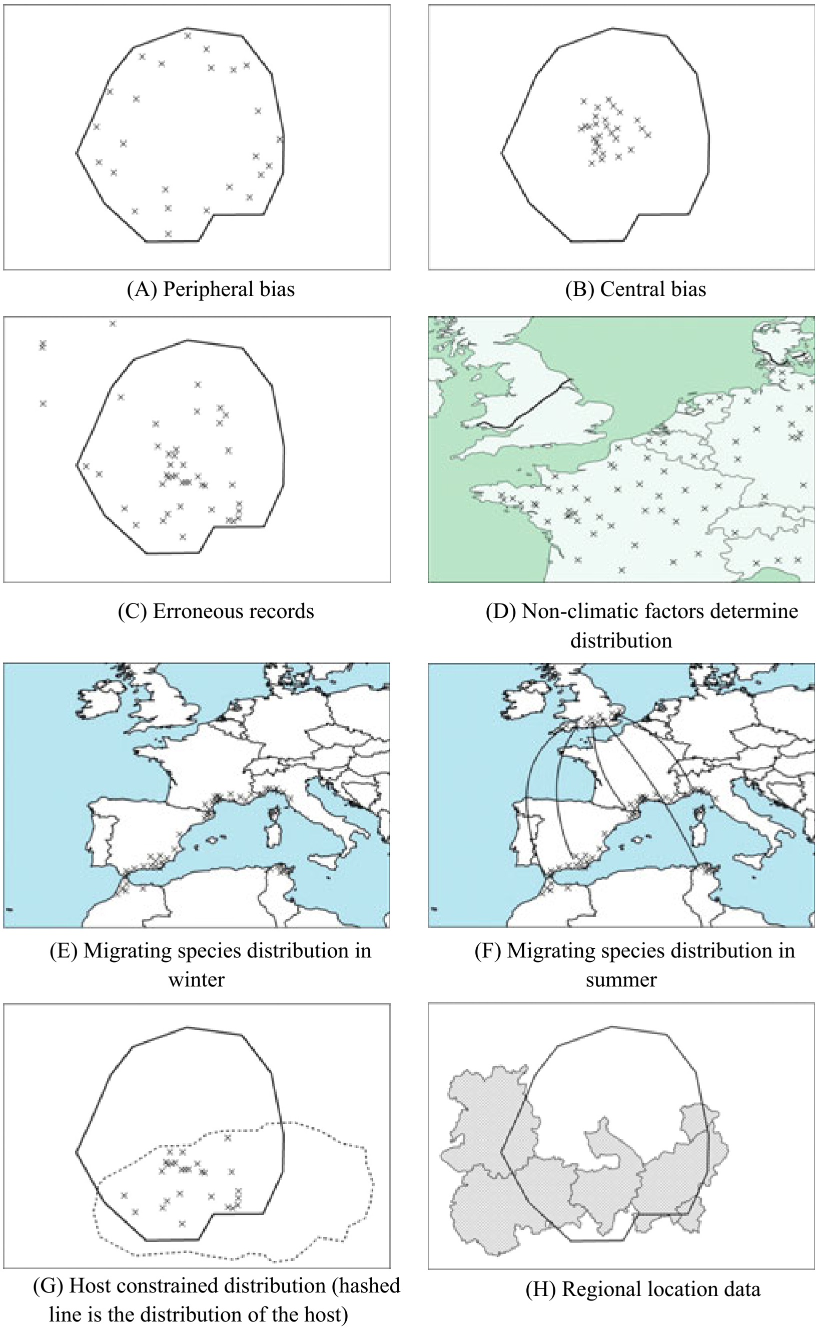

Fig. 2 Some categories of location data that may cause difficulties when mapping climatic suitability. The solid black line in Figs A-D and G-H represents the theoretical climatic limits of a species. In all figures, each '×' represents a distribution record for the species being studied.

(Brown *et al.*, 1996). An advantage of phenology models is that their predictions have direct relevance to an element of the life cycle of the pest and thus are easy to understand, whereas the measures of environmental suitability that are a product of correlative models and the ecoclimatic index (EI) generated in CLIMEX are indices and thus can be more difficult to interpret.

Using correlative models, the relationship between climate and distribution is determined statistically without assuming that a species' distribution is directly determined by physiological tolerance (Jeschke & Strayer, 2008). Correlative models generally require presence (and sometimes absence) records of the species as input data. Thus, if there are only a few location records or the records are biased or inaccurate, then the model developed from this data is likely to reflect this (Graham *et al.*, 2008; Elith *et al.*, 2010). Models that rely upon discriminatory statistical approaches are reliant upon the modeller defining unsuitable conditions using absence or pseudo-absence data. The assumptions and methods of specifying absence data therefore have very

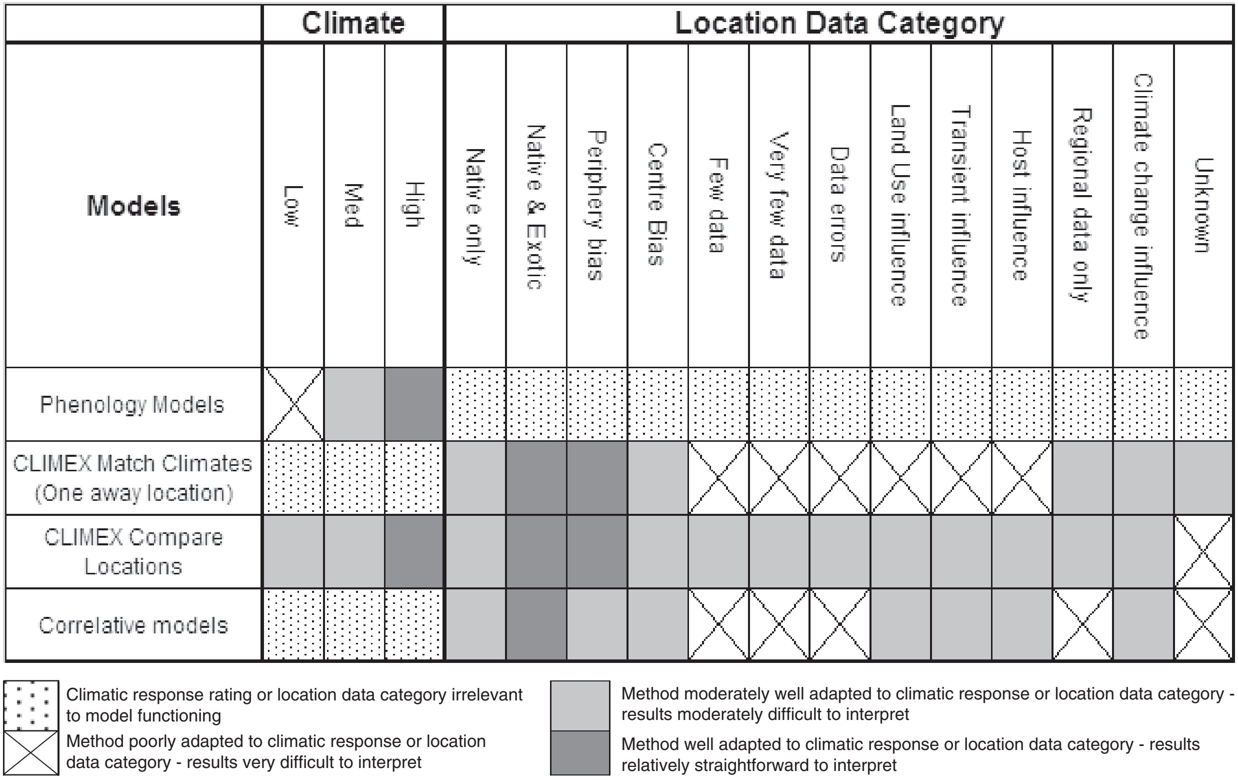

Fig. 3 Anticipated model performance based on climate response data and location data.

important effects on the resulting model. The choice of relevant climatic variables and the method for setting thresholds for establishment also play an important role (Dupin *et al.*, 2011). By dividing presence records, ideally from distinct geographical regions, into training and test data sets it is possible to conduct a statistical evaluation of model sensitivity (Dupin *et al.*, 2011). Some of the benefits of using correlative models are: (i) they are open access; (ii) they are relatively quick to use; and (iii) the outputs are more likely to be the same for different users because the model parameters are fitted independently of the modeller.

The CLIMEX Compare Locations model can make use of a range of data types, including climatic response data, phenological observations, records of species distribution or theoretical expectations. CLIMEX differs from correlative models in that it demands more ecological interpretation on the part of the modeller, and the model produced will reflect the level of ecological interpretation and experience of the modeller. The process of creating models using CLIMEX involves the adjustment of parameters to ensure the model fits with available knowledge. As part of this process, data from different knowledge domains can be compared to cross-validate parameters, and the modeller will be alerted to discrepancies between different data sources. If modellers are aware of all available distribution and climate response data, validation of the whole model is possible only by qualitative methods because there are no independent test data. Some of the benefits of using CLIMEX are that (i) models are structurally constrained to conform to the tenets of basic ecological laws and principles; (ii) the model parameter thresholds are transparent and understandable; and (iii) models can be informed by all available data on a species' climatic responses and its distribution.

For the purposes of PRA, assessors will often require a model that can be fitted to data in the native area of a pest and projected onto the risk assessment area (usually a different continent), and that experiences a novel set of climatic patterns. The ability of a model calibrated in a native region does not always coincide with its ability to represent new situations, i.e. in different geographical areas or using climate change scenarios, with the same calibration (Araujo & New, 2006). For example, in a recent comparative study to project the distribution of *Acacia* sp. in novel climates, some correlative models generated by experienced modellers provided unreliable results (Webber *et al.*, 2011).

Jeschke & Strayer (2008) considered three assumptions of bioclimatic models to be unreasonable. Although these relate primarily to factors that are taken into account elsewhere in the PRA process, they can also be taken into account when modelling climatic suitability. Firstly, 'biotic interactions are either unimportant or constant over space and time'. This issue can be partly overcome if it is possible to include an appropriate climate response function in a model that simulates the effect of biotic stress (e.g. the hot-wet stress function used by Wharton & Kriticos (2004) to mimic inter-specific competition among different clades of *Pinus* hosts for *Essigella californica*. Secondly, 'the genetic and phenotypic composition of a species is constant over space and time'. Invasive species can arrive with limited genetic diversity species, e.g. *Diabrotica virgifera virgifera* (Miller *et al.*, 2005). In addition to arriving with a subset of the genotypic diversity that exists in the native range, there is mounting evidence that invasive species may evolve rapidly in exotic environments where they experience different patterns of selection pressure (Urban *et al.*, 2007). Thirdly, 'species are unlimited in their dispersal'. The necessity for modellers to be cautious when the distribution of a species is restricted by geographical barriers is noted in stage 4 of the DSS. This difficulty can be partly overcome when climate response data are available or there are distribution records from an exotic environment.

To conclude, the PRATIQUE DSS for mapping climatic suitability is intended to guide pest risk assessors in how to use climate response data and distribution data to determine (i) whether climate mapping is liable to be useful; and (ii) how different modelling methods could be expected to perform. As modelling techniques develop and more work is done to evaluate model function with different species and data types following the road map for pest risk mapping outlined by Venette *et al.* (2010), it should be possible to draw more conclusions about how climatic mapping methods can be expected to perform.

Evaluer et cartographier l'adaptation du climat pour l'analyse du risque phytosanitaire

Evaluer si le climat est adapté à l'établissement d'un organisme nuisible est une partie importante de l'analyse de risque phytosanitaire (ARP). Cet article décrit le travail entrepris par le projet européen PRATIQUE pour développer des recommandations pour ce composant de l'analyse du risque phytosanitaire. Premièrement, il comprend un guide pour noter l'adaptation du climat dans la zone ARP en utilisant des méthodes qualitatives. Deuxièmement, un schéma d'aide à la décision (DSS) a été élaboré pour aider les analystes à décider s'il faut cartographier les zones où le climat est adapté, et pour guider la sélection de la méthode la plus pertinente parmi les nombreuses méthodes disponibles. Le processus de sélection d'une méthode de cartographie climatique est basé sur une étude des réponses de l'organisme nuisible au climat et sur sa répartition géographique. Un tableau synthétique donne une comparaison des problèmes qui peuvent se poser selon la méthode de cartographie, et la quantité et la qualité des données disponibles. Des diagrammes permettent de choisir la catégorie de données de répartition qui représente le mieux les biais éventuels dans la répartition connue de l'organisme nuisible. Un second tableau donne une information générale sur les différences et les similarités de chaque méthode selon des critères tels que la fonctionnalité, la facilité d'utilisation, l'assurance qualité. Un ensemble de données, outils, de documents de référence sont disponibles en annexes du DSS. Tous les outils et les guides sont disponibles gratuitement en ligne.

Оценка и картирование пригодности климата для анализа фитосанитарного риска

Оценка пригодности климата для акклиматизации представляет собой существенную часть анализа фитосанитарного риска (АФР). В статье описывается работа, предпринятая в рамках проекта ЕС «PRATIQUE», по разработке практического руководства для этого компонента анализа фитосанитарного риска. Во-первых, уже существует руководство по оценке пригодности климата в зоне АФР с использованием качественных методов. Во-вторых, была создана «Схема поддержки принятия решений» (DSS), помогающая аналитикам в решении вопроса о том, следует ли картировать климатическую корреляцию, и направляющая выбор наиболее подходящего метода из большого числа имеющихся. Процесс выбора метода климатического картирования основан на изучении реакции вредного организма на воздействие климата и его (организма) распространения. Электронная таблица обеспечивает сравнение потенциальных проблем, которые могут возникнуть в зависимости от метода картирования, а также от количества и качества имеющихся данных. Приводятся диаграммы, позволяющие выбрать категорию данных о местонахождении, которая лучше всего представляет возможные пробелы в известном распространении вредного организма. Вторая электронная таблица дает общую информацию относительно сходств и различий каждого метода в плане таких категорий, как функциональность, простота использования и обеспечение качества. В качестве приложения к DSS приводится большое количество данных, средств и документации. Все средства и руководства имеются в свободном онлайновом доступе.

References

Araujo MB & New M (2006) Ensemble forecasting of species distributions. *Trends in Ecology and Evolution* **22**, 22–47.

Baker RHA (2002) Predicting the limits to the potential distribution of alien crop pests. In: *Invasive Arthropods in Agriculture. Problems and Solutions*, (Eds Hallman GJ & Schwalbe CP), pp. 207–241. Science Publishers Inc., Enfield (USA).

Baker RHA, Bemminga J, Bremmer J, Brunel S, Dupin Eyre D, Ilieva Z, Jarošík V, Kehlenbeck H, Kriticos DJ, Makowski D, Pergl J, Reynaud P, Robinet C, Soliman T, Van der Werf W & Worner S (2012) A decision support scheme for mapping endangered areas in pest risk analysis. *Bulletin OEPP/EPPO Bulletin* **42**, 65–73.

Baker RHA (2012) An introduction to the PRATIQUE Research Project. *Bulletin OEPP/EPPO Bulletin* **42**, 1–2.

Brown JH, Stevens GC & Kaufman DM (1996) The geographic range: size, shape, boundaries, and internal structure. *Annual Review of Ecology and Systematics* **27**, 597–623.

CABI (2010) Cabi crop protection compendium. http://www.cabicompendium.org/cpc/home.asp [accessed on 24 February 2010].

Dupin M, Reynaud P, Jarošik V, Baker R, Brunel S, Eyre D, Pergl J & Makowski D (2011) Effects of the training dataset characteristics on the performance of nine species distribution models: application to *Diabrotica virgifera virgifera*. *PLoS ONE* **6**, e20957.

Elith J, Kearney M & Phillips S (2010) The art of modelling range shifting species. *Methods in Ecology and Evolution* **1**, 330–342.

Graham CH, Elith J, Hijmans RJ, Guisan A, Peterson AT & Loiselle BA (2008) The influence of spatial errors in species occurrence data used in distribution models. *Journal of Applied Ecology* **45**, 239–247.

Hartley S, Krushelnycky PD & Lester PJ (2010) Integrating physiology, population dynamics and climate to make multi-scale predictions for the spread of an invasive insect: the Argentine ant at Haleakala National Park, Hawaii. *Ecography* **33**, 83–94.

Heikkinen RK, Luoto M, Araujo MB, Virkkala R, Thuiller W & Sykes MT (2006) Methods and uncertainties in bioclimatic envelope modelling under climate change. *Progress in Physical Geography* **30**, 751–777.

Hill DS (1987) *Agricultural Insect Pests of Temperature Regions and their Control*. Cambridge University Press, Cambridge (UK).

Jarošik V, Honek A, Magarey RD & Skuhrovec J (2011) Developmental database for phenology models: related insect and mite species have similar thermal requirements. *Journal of Economic Entomology* **104**, 1870–1876.

Jeschke JM & Strayer DL (2008) Usefulness of bioclimatic models for studying climate change and invasive species. (Special Issue: The year in ecology and conservation biology 2008.). *Annals of the New York Academy of Sciences* **1134**, 1–24.

Kehlenbeck H, Robinet C, Van der Werf W, Kriticos D, Reynaud P & Baker R (2012) Modelling and mapping spread in pest risk analysis: a generic approach. *Bulletin OEPP/EPPO Bulletin* **42**, 74–80.

Kriticos DJ, Webber BL, Leriche A, Ota N, Macadam I, Bathols J & Scott JK (2011) CliMond: global high resolution historical and future scenario climate surfaces for bioclimatic modelling. *Methods in Ecology and Evolution* **3**, 53–64.

Magarey RD, Sutton TB & Thayer CL (2005) A simple generic infection model for foliar fungal plant pathogens. *Phytopathology* **95**, 92–100.

Magarey RD, Borchert DM & Schlegel JW (2008) Global plant hardiness zones for phytosanitary risk analysis. *Scientia Agricola* **65**, 54–59.

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

Makowski D, Bancal R & Vicent A (2011) Estimation of leaf wetness duration requirements of foliar fungal pathogens with uncertain data - An application to *Mycosphaerella nawae*. *Phytopathology* **101**, 1346–1354.

Metzger MJ, Bunce RGH, Jongman RHG, Mücher CA & Watkins JW (2005) A climatic stratification of the environment of Europe. *Global Ecology and Biogeography* **14**, 549–563.

Miller N, Estoup A, Toepfer S, Bourget D, Lapchin L, Derridj S, Kim KS, Reynaud P, Furlan L & Guillemaud T (2005) Multiple transatlantic introductions of the western corn rootworm. *Science (Washington)* **310**, 992.

New M, Lister D, Hulme M & Makin I (2002) A high-resolution data set of surface climate over global land areas. *Climate Research* **21**, 1–25.

Phillips SJ, Anderson RP & Schapire RE (2006) Maximum entropy modeling of species geographic distributions. *Ecological Modelling* **190**, 231–259.

Sutherst RW, Maywald GF & Kriticos D (2007) *CLIMEX Version 3: Users Guide*. http://www.hearne.com.au/attachments/ClimexUserGuide3.pdf. [accessed on 14 September 2011]. Hearne Scientific Software Pty Ltd, Melbourne.

Urban MC, Phillips BL, Skelly DK & Shine R (2007) The cane toad's (*Chaunus* [*Bufo*] *marinus*) increasing ability to invade Australia is revealed by a dynamically updated range model. *Proceedings of the Royal Society of London. Series B, Biological Sciences* **274**, 1413–1419.

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

Webber BL, Yates CJ, Le Maitre DC, Scott JK, Kriticos DJ, Ota N, McNeill A, Le Roux JJ & Midgley GF (2011) Modelling horses for novel climate courses: insights from projecting potential distributions of native and alien Australian acacias with correlative and mechanistic models. *Diversity and Distributions* **17**, 978–1000.

Wharton TN & Kriticos DJ (2004) The fundamental and realised niche of the Monterey pine aphid, *Essigella californica* (Essig) (Hemiptera: Aphididae): implications for managing softwood plantations in Australia. *Diversity and Distributions* **10**, 253–262.

Appendix 1

To support the climatic risk mapping DSS (available as Appendix 2A to the mapping endangered areas DSS at http://capra.eppo.org/), the following appendices (some of which have been published) have been prepared, see Table 1.

Appendix	Title	Publication
2B	Location data category diagrams	n/a
2C	A summary of model performance based on climate response information and location data categories	n/a
2D	Qualitative comparisons of different species distribution modelling techniques	n/a
2E	Links to climatic mapping data, software and explanations of methods	n/a
2F	Comparison of the performance of nine species distribution models for *Diabrotica virgifera virgifera*	Dupin *et al*., 2011
2G	Instructions for the use and interpretation of CLIMEX	n/a
2H	Climatic mapping in PRA – a tutorial	n/a
2I	R-functions related to Ecological Modelling: Setting thresholds and rescaling model outputs	n/a
2K	Bayesian selection of parameters for the generic infection model	Makowski *et al*., 2011
2L	Thermal requirements in phenological models	Jarosik *et al*., 2011
3D	The fine resolution CliMond database for climatic mapping	Kriticos *et al*., 2011

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