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A Regional Decision Support Scheme for Pest Risk Analysis in Southeast Asia

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A key justification to support plant health regulations is the ability of quarantine services to conduct pest risk analyses (PRA). Despite the supranational nature of biological invasions and the close proximity and connectivity of Southeast Asian countries, PRAs are conducted at the national level. Furthermore, some countries have limited experience in the development of PRAs, which may result in inadequate phytosanitary responses that put their plant resources at risk to pests vectored via international trade. We review existing decision support schemes for PRAs and, following international standards for phytosanitary measures, propose new methods that adapt existing practices to suit the unique characteristics of Southeast Asia. Using a formal written expert elicitation survey, a panel of regional scientific experts was asked to identify and rate unique traits of Southeast Asia with respect to PRA. Subsequently, an expert elicitation workshop with plant protection officials was conducted to verify the potential applicability of the developed methods. Rich biodiversity, shortage of trained personnel, social vulnerability, tropical climate, agriculture-dependent economies, high rates of land-use change, and difficulties in implementing risk management options were identified as challenging Southeast Asian traits. The developed methods emphasize local Southeast Asian conditions and could help support authorities responsible for carrying out PRAs within the region. These methods could also facilitate the creation of other PRA schemes in low- and middle-income tropical countries.

KEY WORDS: Biosecurity protocol; expert elicitation; expert evaluation; invasive alien species

1. INTRODUCTION

The introduction and spread of invasive species is a major worldwide concern that has been regulated by international agreements since 1878.[1] According to the World Trade Organization, countries can use plant health regulations to restrict trade only if justified by a science-based pest risk analysis (PRA). FAO[2] defines a PRA as "*the process of evaluating biological or other scientific and economic evidence to determine whether an organism is a pest, whether it should be regulated, and the strength of any phytosanitary measures to be taken against it.*" The International Standards for Phytosanitary Measures (ISPMs) are the official reference for PRA.[3] Complying with these international standards is obligatory for developing an internationally acceptable PRA.

As the PRA concepts described by the ISPMs are generic in nature, countries and

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intergovernmental bodies have developed decision support schemes (DSSs) to improve their applicability. Although these DSSs differ in sophistication and details, they all follow the ISPMs of the International Plant Protection Convention (IPPC). For instance, the European and Mediterranean Plant Protection Organization (EPPO) DSS for PRA[4] is one of the most detailed schemes for species-initiated PRAs. The scheme has two complementary annexes on habitat categories and environmental impacts. It is available on paper and as a digital version that incorporates advanced techniques to analyze pest risks. On the other hand, the Canadian scheme[5] uses a much simpler pathway-specific approach based on a matrix that combines dependent risk elements. Other pathway-specific schemes are those of Australia,[6] New Zealand,[7] and the USA.[8,9] The Australian and New Zealand schemes have sections that combine plant and animal risk analysis in a common scheme. The Australian scheme uses risk matrices to determine the joint probability of entry, establishment, and spread through a sequence combining the risk elements. In contrast, the American scheme adds individual independent probability scores to drive the probability of introduction (i.e., entry, establishment, and spread). In both schemes, the overall risk score is then calculated by a risk matrix rule that integrates the score for impact magnitude and the score for probability of pest introduction.

PRAs in Southeast (SE) Asian countries vary in the characteristics of their regulatory systems, capacity, and enforcement. Some countries, such as Laos, have a limited implementation of PRA, while others, such as Malaysia, Indonesia, and the Philippines, have higher levels of implementation. For instance, according to the IPPC, in 2009–2010 the numbers of PRAs completed and documented in Indonesia, the Philippines, Thailand, and Vietnam were 57, 17, 12, and 42, respectively. In contrast, other countries, such as Cambodia, Laos, and Myanmar, did not report any PRAs in 2009.[10] Insufficient capacity building, and a shortage of qualified staff and financial resources, present major challenges for SE Asian national plant protection organizations when producing international standard PRAs.[10] Inadequate PRAs place SE Asian countries at a disadvantage in trade negotiations with other countries and put their domestic resources at risk.

In the last decade, several studies have reviewed and enhanced the practice of PRA, but these studies have been limited to high-income countries.[11–14] Most suggest incorporating computerized quantitative techniques, where appropriate, to improve the consistency and reduce the uncertainty of risk estimation.[12,15–17] These quantitative techniques are highly demanding in terms of data, interpretive skills, time, and effort even in high-income countries. At the same time, rudimentary qualitative analyses can be challenged by trading partners.[2] Practical PRA schemes that are scientifically rigorous, consistent with the ISPMs, and relevant for routine use are needed, especially in low- and middle-income countries. Such schemes could also be used in higher income countries where demand for faster delivery of PRA is increasing. This is consistent with the comment in ISPM 2 stating "*a PRA does not necessarily need to be long and complex. A short and concise PRA may be sufficient provided justifiable conclusions can be reached after completing only a limited number of steps in the PRA process.*"[2] In SE Asia it is especially important to have an efficient and effective PRA process as countries must work with a limited PRA budget.[18]

Invasive pests pose risks that often extend beyond national boundaries.[19] For instance, the golden apple snail (*Pomacea canaliculata*) that was initially introduced into cement tanks, managed ponds, and backyard soil pits in the Philippines later spread to Indonesia, Malaysia, Thailand, and Vietnam.[20,21] It spread rapidly through irrigation ditches and public waterways to the rest of the region. Other examples of exotic pests that have spread widely in SE Asia are the fruit fly *Bactrocera cucurbitae*, the lepidoptera *Helicoverpa armigera* and *Plutella xylostella*, and the psyllid *Heteropsylla cubana*.[22] PRAs in SE Asia are conducted at the national level,[18] which has advantages, such as the ability to reach a rapid consensus without the delays that would result from intergovernmental negotiation on common plant health policies and related regulatory activities at the regional level. However, given the supranational nature of invasive pest spread, the proximity and connectivity of SE Asian countries, and the heterogeneity in the resources available for PRAs, a regional-scale PRA scheme could generate more effective and efficient preventive and control strategies[23] to better support national plant health responsibilities.

SE Asia has a unique economic, ecological, and social nature, and a regional DSS should account for these special traits. However, it is unclear what these traits are and how a newly developed regional DSS should differ from existing schemes in high-income settings. Furthermore, the low number of recent

international journal articles on the determinants of pest invasion success in SE Asia and the scarcity of research on PRA in the region reveals the need for eliciting knowledge from experts who specialize in biological invasion research in SE Asia.[19] The final adoption of any regional PRA scheme would be the responsibility of the many national authorities and their regional plant protection organizations.

Here we develop an independent proposal for a regional PRA scheme by adopting parts of existing DSSs and adapting them to the unique traits of SE Asia. Two expert panels were consulted to (i) identify the characteristics of SE Asia that should be accounted for in a regional PRA, and (ii) demonstrate the operation of the proposed PRA.

2. MATERIALS AND METHODS

2.1. Expert Elicitation

2.1.1. Regional Scientific Panel

A panel of regional experts was asked in a formal written expert elicitation survey to identify and rate unique traits of the SE Asian region. Potential experts were individuals with expertise in biological invasions and an understanding of SE Asia as a receptor environment for invasive species. Accordingly, the following roles were identified: (1) academics with knowledge of PRA in SE Asia, (2) public-sector employees acquainted with PRA (e.g., pest risk analysts working in national plant protection organizations), and (3) private-sector employees acquainted with PRA (e.g., ecologists in consultancies and nonprofit organizations). The "PestNet," "aliens-l," and "PHRA-L" email distribution lists were used to elicit experts, as was direct contact with biological invasion experts at the National University of Singapore (Singapore), Instituto Hórus de Desenvolvimento e Conservação Ambiental (Brazil), Xishuangbanna Tropical Botanical Garden (China), University of Potsdam (Germany), and the plant protection services of Australia, New Zealand, the United Kingdom, and Singapore. Out of 15 experts directly contacted and the members of the distribution lists, eight experts participated in this expert elicitation survey. These experts were asked to identify and rate the unique traits of the SE Asian region in a formal written expert elicitation survey. The questionnaire starts with a general introduction and motivation, followed by a list of suggested traits that the experts are requested to rank quantitatively.

Table I. The Importance of Traits Relevant to PRA in the SE Asian Region

Traits That Make SE Asia Different from High-Income Regions with Regard to Pest Risk Analysis (PRA)	Weight (%)	*SD*
Agriculture-dependent economies	54	27
Rich biodiversity	68	35
Shortage of trained personnel	68	22
Social vulnerability	41	22
High rates of land-use change (particularly deforestation) and ecosystem degradation (logging, fire, and hunting)	51	36
Tropical climate	59	36
Difficulties in implementing risk management options	24	30

SD: Standard deviation.

To enable evaluations of the proposed traits, a detailed description of each trait was provided in an annex attached to the questionnaire. Experts were asked to give a weight between 0 (lowest importance) and 100 (highest importance) for each trait.

The traits were: agriculture-dependent economies, shortage of trained personnel, rich biodiversity, social vulnerability, high rates of land-use change and ecosystem degradation, tropical climate, and difficulties in implementing risk management options. These traits are represented in the proposed scheme by adopting and adapting parts of other PRA schemes. Traits with greater weight were represented in more detail in the proposed scheme. After collecting quantitative responses, experts' opinions were combined using equal weights to calculate the mean and standard deviation for each trait (Table I). The description and weighted importance given to the traits were as follows:

(1) *Agriculture-dependent economies* (weighted importance 54%). Agriculture is an important source of income and foreign currency, providing a large proportion of employment capacity in SE Asia. Furthermore, most SE Asian farmers are classified as subsistence rather than large-scale farmers. The proposed scheme should reflect food security vulnerabilities if key crops are attacked by invasive plant pests.

(2) *Shortage of trained personnel* (weighted importance 68%). Many SE Asian countries face serious resource constraints for managing

plant health. Despite funding programs and support by international organizations, further capacity building is still needed to produce qualified plant quarantine officers.[18,24] The scheme cannot demand highly skilled personnel given the low to middle incomes of SE Asian countries.

(3) *Rich biodiversity* (weighted importance 68%). The high biodiversity and endemism of SE Asia is well recognized.[25] The scheme should enhance biodiversity protection, since SE Asia contains several global biodiversity hotspots. Although there are few records of species extinction in SE Asia, the increase in species classified as endangered and susceptible should be recognized within a PRA system and, where appropriate, risk mitigation should apply regionally.

(4) *Social vulnerability* (weighted importance 41%). In PRA, *s*ocial vulnerability can be interpreted as social choices that increase the vulnerability of the receptor environment to pest invasion.[26] Social vulnerability includes cultivation practices by farmers, institutional interventions, and market practices that could increase regional vulnerability to invasive plant pests and diseases.

(5) *Land-use change* (weighted importance 51%). Compared to high-income regions, SE Asia is characterized by higher rates of land-use change (particularly deforestation) and ecosystem degradation (e.g., logging, fire, and hunting). Both deforestation and ecosystem degradation play a key role in facilitating establishment and spread of invasions.

(6) *Tropical climate* (weighted importance 59%). Compared to temperate regions, tropical climates can support the survival of invasive plant pests from very diverse sources and clades, often throughout the year. Therefore, the scheme should provide a detailed analysis for potential pest establishment. Risks are highest for pests from other tropical areas that are linked to SE Asia by direct transportation routes.

(7) *Difficulties in implementing risk management options* (weighted importance 24%). Structural obstacles and lack of operational capability for enforcement relevant to invasive plant pest introductions may limit the response to PRAs and their recommended risk reduction options. The scheme should account for temporary management options to support the PRA until permanent measures are successfully applied.

2.1.2. Panel of Regional Plant Protection Officials

To validate the traits suggested by the scientific experts and verify the proposed DSS applicable for routine PRA use in SE Asia, plant health officers in the region were consulted through an expert elicitation workshop. The workshop was held in Bangkok, Thailand, from 29th July to 2nd August 2013 in conjunction with the project "Beyond Compliance: Integrated Systems Approach for Pest Risks Management in Southeast Asia" (STDF/PG/328).[27] Officers from the plant health ministries of Malaysia, Thailand, Vietnam, and the Philippines, experts from Imperial College London, Queensland University of Technology, and the Centre for Agriculture and Biosciences International (CABI), and representatives from the FAO–IPPC, and the FAO–Asia, and the Pacific Plant Protection Commission (APPPC) attended the meeting. In total, 20 experts participated in this expert elicitation workshop. The consultation started with an introduction to the draft PRA scheme. It continued with an explanation of how the scheme was adapted to meet the identified criteria for SE Asia. Finally, the consultation ended with a group discussion. Expert opinions were combined using the behavioral aggregation approach where experts themselves aggregate judgments on the validity of the suggested scheme.[28] This is achieved when the group, following discussion, comes to an agreement about a particular judgment value. To avoid group domination by the most confident and outspoken experts, we encouraged knowledge sharing, corrected potential biases, and used feedback to aid the debate. For instance, we used direct questions to prompt less confident experts to express their opinions and expressed contrary opinions to the suggested points to enrich the discussion.

2.2. Visual Representation of Pest Risk and Uncertainty

In some PRA schemes, questions to evaluate and manage pest risk are rated on a qualitative scale where available rating scores are expressed in descriptive and numerical terms.[5,8] In our approach, each section of the DSS is rated by the risk analyst through a two-step process: first, by choosing one or more ratings, and secondly, assigning an uncertainty

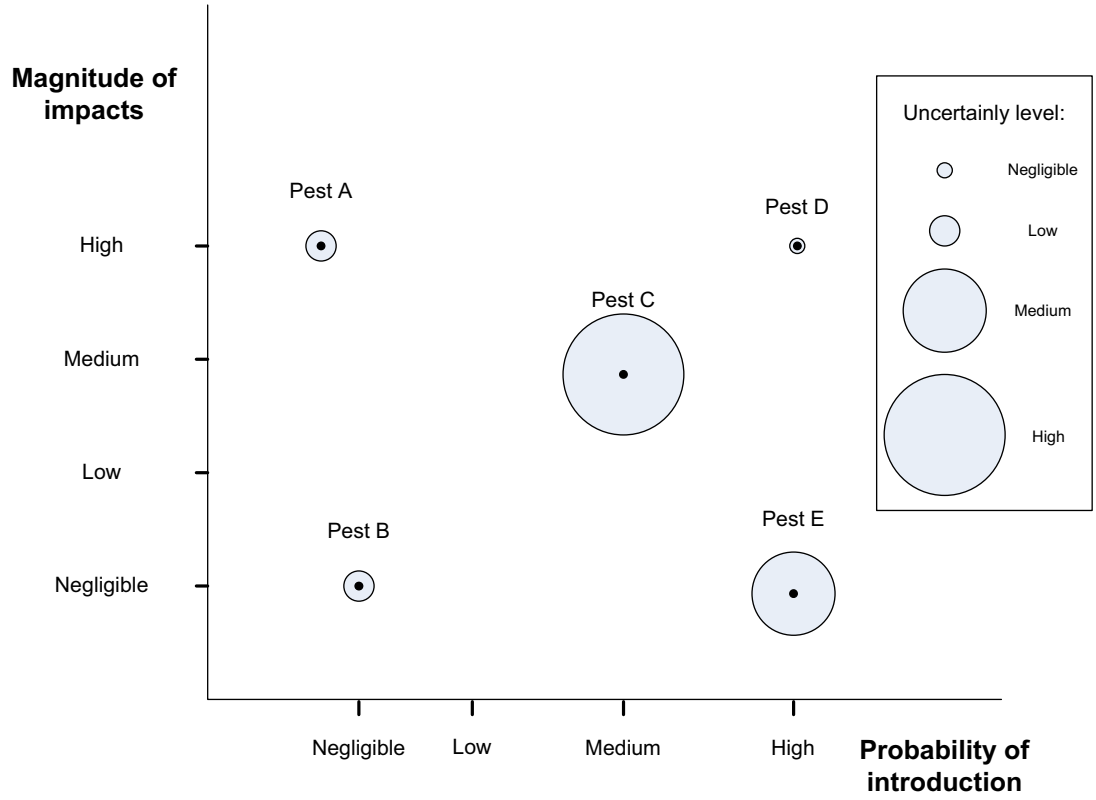

Fig. 1. An illustrative example for the visualizer graph of overall risk of four different pest cases. The visualizer helps prioritize and compare pests while supporting further discussion between policymakers. The black dot represents the risk score (probability of introduction and magnitude of impacts) and the bubble around the black dot represents the level of uncertainty. The size of the bubble does not represent the range of the level of risk and is intended only to visually reflect the uncertainty of the analysts in their rating. In the example, pest D presents high probability of introduction, high potential impacts, and negligible uncertainty in the assessment and would thus be prioritized for risk management. Pest B presents the opposite case with negligible overall risk and low uncertainty, probably not requiring prioritization for management measures. Pests A, C, and E would need further discussion by policymakers. For instance, although pest A presents high potential impacts, the probability of introduction is negligible and the opposite situation occurs for E. Pest C presents medium probability of introduction and potential impacts but there is high uncertainty associated to these estimates.

level to each score. The rating reflects the chosen level for the risk factor, while the uncertainty rating reflects the degree of confidence in the rating. The ratings for the risk elements (e.g., probability of entry, establishment, spread, and economic impacts) and uncertainty consist of four categories (i.e., negligible, low, medium, and high). The overall risk score for the likelihood of introduction and magnitude of impact is calculated as the median of the values for risk and uncertainty ratings separately (see Supplementary Online Material (SOM), "Guidelines for Expressing Overall Risk").

The risk outcome is represented through a visualizer graph that shows both the risk score for the likelihood of introduction and magnitude of impact, plotted by a black dot, and the associated uncertainty plotted by bubbles around the black dot of size proportional to the uncertainty level (Fig. 1). Given that the uncertainty scores are qualitative, the uncertainty bubbles do not represent the range of the levels of risk. The *x*-axis on the visualizer graph represents the likelihood of introduction and the *y*-axis represents the magnitude of impacts.

3. RESULTS

3.1. SE Asian PRA Scheme Development

The proposed scheme is composed of seven main sections in line with the ISPM 11 guidelines.[29] (1) PRA initiation; risk assessment in terms of (2) probability of entry, (3) probability of establishment,

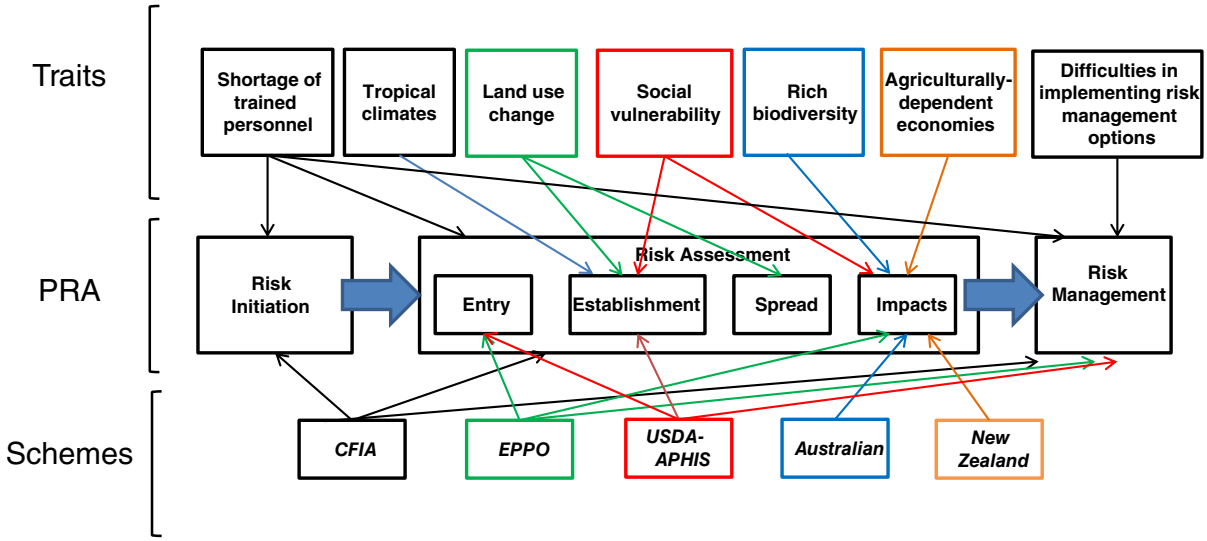

Fig. 2. Structure of the developed Southeast Asian scheme and the components of existing schemes that were used to develop the scheme. The graph is divided into: "traits" that describe the unique characteristics of SE Asia to be accounted for in the scheme; "PRA": the different sections of the PRA process; and "Schemes": existing schemes and how their sections are mapped into the SE Asian scheme. CFIA: Canadian Food Inspection Agency.

(4) probability of spread, (5) magnitude of potential economic impacts, and (6) magnitude of potential environmental impacts; and (7) risk management (see the SOM). Within each section, there are several main and subelements for assessors to consider. For instance, the section "Magnitude of potential economic impacts" is divided into two main subsections, "Direct impacts" and "Indirect impacts." Within the subsection "Direct impacts," there are two elements to consider: "Crop losses, in yield and quality" and "Significant increases in costs of production beyond normal annual fluctuations due to, for instance, additional control measures and/or costs associated with surveillance and monitoring (e.g., extra labor cost)." Additional examples on the sections concerning probability of entry, establishment, spread, and magnitude of impacts are provided in Table II. Moreover, we ensured that all the terms used in the scheme are in line with the glossary of phytosanitary terms detailed in ISPM 5 and provided detailed and clear guidelines to explain the steps the analyst should follow to estimate the final risk outcome.[30]

Shortage of trained personnel was suggested as the most limiting factor by regional experts, so we chose the most straightforward existing DSS as the foundation for the SE Asian DSS, based on a review of characteristics of existing PRA schemes (Fig. 2; Table III). We started with the short scheme previously adapted within a project exploring alternative PRA protocols[12] as a base from which to develop the SE Asian scheme. We complemented this with other schemes that could represent the traits important for SE Asia. The EPPO scheme[4] can capture multiple aspects of potential impacts for both structural biodiversity and ecosystem services functionality at the species, community, and landscape level. As this was the second most important distinctive trait of SE Asia, the EPPO scheme was used as the basis for environmental impacts and risk management. The EPPO scheme also provides detailed evaluation of all existing and potential risk management measures for both exporting and importing countries. The Australian and New Zealand schemes consider both the scope (i.e., direct and indirect) and the geographical scale (i.e., local, district, regional, and national) of impacts, so they were heavily relied upon to estimate economic, environmental, and social impacts. The U.S. Department of Agriculture Animal and Plant Health Inspection Service (USDA-APHIS) scheme shows the factors to consider when assessing potential entry and establishment of species and procedures for conducting risk assessments (e.g., data needed and order of analysis), so was used to represent potential pest entry and establishment, and to provide supplementary information on risk management.

Several modifications were applied to the combined scheme to represent SE Asian traits

Table II. Examples of Some Changes Applied to the Developed Regional Southeast Asian Scheme (the Full Scheme is Available at the SOM)

Probability of entry
2.3. Survival during transport or storage
Examples of factors to consider are:
a) Speed and conditions of transport and duration of the life cycle of the pest in relation to time in transport and storage
Probability of establishment
2.6. Availability of suitable hosts, alternate hosts, and vectors in the PRA area
Examples of factors to consider are:
a) Whether hosts and alternate hosts are present, how abundant or widely distributed they may be
Probability of spread
2.12. Potential for natural spread
Examples of factors to consider are:
f) The existence of natural barriers to spread of the pest in the PRA area; include variables such as vectors or natural enemies that may affect the pest's ability to spread in the PRA area; in SE Asia, distances between islands and modes of transport between them will be crucial
Magnitude of potential economic impacts
2.18. Indirect economic impacts
For identification and characterization of the indirect effects of the pest in the PRA area or those effects that are not hostspecific, the following are examples that could be considered:
a) International trade effects, including loss of markets (e.g., export loss), meeting new technical requirements to enter or maintain markets, and changes in international consumer demand
e) Effect on foreign exchange earnings and poverty rates, if the host crop contributes significantly to the exports
Magnitude of potential environmental and social impacts
2.22. Indirect environmental and social impacts
For identification and characterization of the indirect effects of the pest in the PRA area or those effects that are not hostspecific, the following are examples that could be considered:
a) Environmental and other undesired effects of control measures (e.g., pesticides); herbicide and insecticide resistance may be developed in SE Asia owing to use of generics with active ingredients not under patent
d) Significant change in ecological processes (e.g., natural successions; trophic and mutualistic interactions such as the food web, pollination, or plant-mycorrhizal webs) and the structure, stability, or processes of an ecosystem including further effects on plant species, erosion, water table changes, increased fire hazard, and nutrient cycling

Table III. Evaluating the Characteristics of Different Pest Risk Analysis (PRA) Schemes

	EPPO	Canada	USA	Australia	New Zealand
Dominating approach	Species/pathway-based PRA	Pathway-based PRA	Pathway-based PRA	Pathway-based PRA	Pathway-based PRA
Rating system	Descriptive / numerical	Descriptive / numerical	Descriptive / numerical	Descriptive / numerical	Descriptive / numerical
Analyzing uncertainty quantitatively	Yes	No	No	No	No
Guidance notes /examples	Very detailed	Detailed	Detailed	Detailed	Detailed
Complexity	High	Low	Medium	Medium	Medium

and improve the guidance notes (SOM, Appendix III). As SE Asian countries are largely agriculture-dependent economies, we added export loss, employment loss, reduction in market value of the affected host, effects on closely related industries, income reduction, foreign exchange earnings, and increased poverty rates (SOM, 2.19, points a, b, c, d, e, and f). Moreover, to represent social vulnerability, we added to the same section the economic values or market structures that may inflate impacts (SOM, 2.19, point g). To accommodate the "rich biodiversity" trait, we extended elements in the "environmental impact" section, such as reduction of keystone plant species, reduction of plant species that are major components of ecosystems (in terms of abundance or size), reductions of endangered native plant species, and significant reductions of plant species of high conservation value (SOM, 2.21,

points a, b, c, and d). Indirect environmental impacts, such as changes in ecological processes and effects on plant communities, were also extended (SOM, 2.22, points b, d, e, f, and g). The "social vulnerability" and "land-use change" traits were included in the "cultural practices" element of the "pest establishment" section (SOM, 2.9). The "land-use change" trait was also included in the "other factors" element of the "probability of spread" section (SOM, 2.14). These traits were illustrated by cultivation practices of farmers and other human activities that promote establishment and spread. "Tropical climate" was included in point 2.8 "suitability of environment" of the "probability of establishment" and in the introductory phrase of the "probability of entry" section. In the "risk management" section, the analyst is requested to suggest a temporary action that may be used if there is difficulty implementing longer-term risk management options. This addition is meant to cover the last identified trait, "difficulties in implementing risk management options."

3.2. Workshop Results

After collective discussion, the expert panel agreed on the identified traits and the utility of the proposed regional scheme as a possible starting point to integrate PRA practices in the region. Any actual changes to PRA schemes in the region would be the responsibility of national plant protection organizations. The new method to visualize pest risk and uncertainty was deemed adequate and simple to use by plant health officers. On the other side, the panel raised several points about the proposed DSS during the validation process, which have been subsequently addressed. First, they mentioned the difficulty in using the rating process due to the large number of elements in each question. Secondly, the PRA development process lacked validation of the proposed scheme with expert perceptions. Finally, consistency in scales and terminology of the rating system could be improved.

4. DISCUSSION

The threat posed by invasive pests and diseases in SE Asia has increased recently owing to the higher volume and frequency of international trade.[19] At the regional scale, accurate and rapid PRAs are needed to meet this increasing challenge as they can identify pest risks and facilitate risk management measures to inhibit pest introduction or spread.[31] This article reviews existing DSSs for conducting PRAs and selects and adapts elements from the most suitable schemes to develop an independent, unofficial proposal for the SE Asian region. Parts of the reviewed schemes were integrated into the selected scheme to better reflect the unique characteristics in SE Asia. Expert opinion was elicited to identify a unique weighting appropriate to SE Asian traits and to verify the applicability of the developed scheme.

The Canadian scheme is the core scheme used given the limited resources and capacity for plant health in the SE Asian region. Among all reviewed schemes, the Canadian scheme is the shortest and thus easy to use and apply. To strengthen the SE Asian scheme, we first developed an innovative approach for combining scores and uncertainty. This scheme is simple and practical for routine use and reflects the mechanism underpinning the risk process, therefore providing more meaningful information for decisionmakers. Secondly, we improved the guidance notes for each question based on the work of MacLeod *et al.*[12] and extended the subelements considered to account for expert weighting of unique SE Asian traits (see the SOM). Parts of the other reviewed schemes that can reflect these traits were integrated into the core scheme.

Most experts at the workshop agreed on the importance of conducting PRAs at the regional level. This was supported by expectations of negotiations towards establishing a SE Asian community similar to the European Union in the near future.[32] In addition, some pests (e.g., mango pests) are already assessed at the regional level. The visualizer graph was seen as a useful tool to facilitate risk communication. A visual display of risk is valuable to decisionmakers as it requires relatively little cognitive effort to comprehend the risk outcome.[33] The officials agreed that the technique for integrating rating scores and describing uncertainty is transparent, simple, and easy to apply.

Plant health officers in the region also raised a number of concerns with the proposed scheme. The large number of elements to be considered in the scheme increases the difficulties of rating each question and its uncertainty, although this concern may also occur with other existing schemes. There is a tradeoff between reducing the number of elements considered for each question and increasing the capabilities of the scheme to fully capture pest risks.

The overall risk results of the scheme also need to be validated against the level of risk perceived by the experts and estimated by other PRA approaches.

The main criteria to consider when a PRA is validated are transparency, rigor of dealing with uncertainty, consistency between assessors and between assessments, and ease of use. This could be difficult in practice because few historical case studies exist and there are uncertainties involved in the assessment and observed risk. Consistent scales and terminology in the rating system were enhanced by having four scores for all questions and by providing a clear definition of each rating score in every section.

Although social vulnerability plays a key role in promoting pest establishment and spread, it is often ignored in PRA schemes. To evaluate available management options in PRA practices, it may be necessary to determine whether an alternative management or governmental intervention would reduce the vulnerability of the receptor environment to pest invasion. Such management or interventions can only be designed if we can explain societal behavior and understand how to change practices to make a risk assessment area less vulnerable.[26] In SE Asia, for example, social vulnerability is found in cultivation practices such as crop seasonality, soil preparation, planting methods, irrigation, surrounding crops, and harvest timing and method.[4] Social vulnerability can also be seen in institutional practices such as governmental policies that favor pest establishment or spread. For instance, increased forest fragmentation and deforestation for oil palm cultivation in SE Asia raises the region's vulnerability to invasive pests and diseases.[34] Finally, social vulnerability can be found in different market practices such as monopolistic or oligopolistic market power. Market power can raise the price of a commodity, thus artificially inflating the potential impact of a pest. Social vulnerability is not officially mentioned in the IPPC standard, and therefore cannot be used as an official justification for phytosanitary measures. This is mainly because evaluating social vulnerability can be biased and subsequently used for political or protectionist goals. However, if we could convert social vulnerability into economic terms, it could be accepted by the SPS Committee of the WTO in international trade disputes.

In addition to the traits listed above, the experts at the workshop suggested the trait "herbicide and insecticide resistance." High-income countries tend to use newer and more expensive pest control products with active ingredients still under patent, whereas low-income countries tend to use older and less costly ones, such as generics with active ingredients that are no longer under patent. There is a greater prevalence of resistance against the active ingredients in older products, leading to a higher risk that management of invasive plant pests in low- and middle-income countries will fail. In addition, resistance could develop under more intensive chemical use and higher frequencies of repeat applications.[35] "Greater biotic resistance to introduced species" was also suggested as a trait of importance for SE Asia. This trait is often difficult to prove or quantify, but possibly associated with more biodiverse and more complex tropical natural ecosystems in which most available resources and niches are already occupied, preventing invasive pest establishment.[36] These traits were included in the scheme under "indirect environmental impacts" by extending the element of the "undesired effects of control measures" (SOM, 2.22, point a).

It is important to recognize the possibility of developing a regional PRA scheme, although there might be difficulties when harmonizing the pest risk management outcomes. This is mainly because each SE Asian country has different structures, facilities, laws, and operational resources, so management options available to reduce plant health risk and their application are not homogeneous. Complete harmonization is only possible when legislation, directives, and operational resources are also more similar, as in the European Union. However, a regional DSS is a step towards this objective. This independently proposed SE Asian scheme represents an attempt to improve current PRA practice in low- and middle-income countries, especially in SE Asia, to help reduce threats to ecosystems and food security threats from invasive pests.

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SUPPORTING INFORMATION

Additional Supporting Information may be found in the online version of this article at the publisher's website:

Supplementary Online Material: Decision support system for Pest Risk Analysis in Southeast Asia.