Multicriteria analysis to assess the risk of invasive species

Jordan Golubov
Metropolitan Autonomous University

María Carmen Mandujano
National Autonomous University of Mexico

Sandino Guerrero
Metropolitan Autonomous University

Roberto Mendoza
Autonomous University of Nuevo León

7 MULTICRITERIA ANALYSIS TO WEIGH THE RISK OF INVASIVE SPECIES

Jordan Golubov Figueroa, Maria C. Mandujano,*
Sandino Guerrero-Eloisa, Roberto Mendoza Alfaro,
Patricia Koleff Osorio, Ana Isabel González Martínez,
Yolanda Barrios Caballero and Georgia Born-Schmidt

ABSTRACT *124*
INTRODUCTION *125*
METHOD *125*
EXAMPLES *130*
PERSPECTIVES AND CONCLUSIONS *130*
REFERENCES *132*

* Corresponding author: <mcmandu@miranda.ecologia.unam.mx>

Golubov J., M.C. Mandujano, S. Guerrero-Eloisa, R. Mendoza, P. Koleff, A.I. González, Y. Barrios and G. Born-Schmidt. 2014. Multicriteria analysis for assessing the risk of invasive species, in R. Mendoza and P. Koleff (eds.). *Aquatic invasive species in Mexico.* National Commission for the Knowledge and Use of Biodiversity, Mexico, pp. 123–133.

SUMMARY

Invasive species risk analysis has recently been developed in Mexico for the management of biological invasions. These analytical methods allow for the incorporation of information on the factors that determine the probability of introduction, establishment, spread, and severity of such invasions. This chapter presents an algorithm, based on the analytical hierarchical method, that can be used for the rapid assessment of a species' potential risk as an invasive species. Ten questions are analyzed, organized hierarchically and associated with weights based on the values of various attributes as invasive species. The resulting model has two hierarchical levels: the first compares biological and taxonomic characteristics, the invasion process, and impacts; the second hierarchical level assigns weights according to the relative importance of the variables and subsequently weights them according to the value assigned to the criteria at the higher level. The model incorporates a way of relating weights, the responses to each of the questions, with uncertainty, to assign a bounded value between 0 and 1, which is used to group species into four risk levels. As a result of two workshops, in which the criteria were agreed upon and this method was tested, two models were generated. The first focuses on biological and taxonomic characteristics, and the second on the invasion process. The methodology for generating the analytical hierarchical model, exemplified by Salvinia molesta and three other species, is described. This method for assessing the risk of invasive species is relatively quick and easy to apply. Furthermore, the method is repeatable and updatable, incorporates extensive information, generates quantitative risk values for any species, and allows risk levels to be assigned to the species being assessed.

ABSTRACT

Risk analyzes for invasive species have been developed recently in Mexico as part of an effective invasive species management. These methods allow an analysis that takes into account information on the factors that determine the probability of introduction, establishment, dispersal, and severity of such species.
In this chapter, we developed an algorithm method based on the analytic hierarchical process (AHP) that can be used as a rapid risk assessment tool for invasive species. The analysis uses 10 hierarchically organized questions that encompass common attributes associated with invasive species. The resulting model has two hierarchical levels; the first level compares the biological and taxonomic characteristics, the invasion process and impacts. In the second hierarchical level, questions were assigned weights depending on their relative importance, which were then nested within the corresponding higher hierarchical level. The model also includes a method that connects the weights for each question to its corresponding answer and uncertainty, into a single bounded value of risk (between 0 and 1), which is then used to allocate species into four risk groups. As a result of two workshops where the method was tested, two weighting schemes were selected. One leans towards the biological and taxonomic characteristics, and the second towards the invasion process. The methodology used to generate the AHP model is described and exemplified with Salvinia molesta, and three more species. This method is a risk assessment tool for invasive species and it is relatively fast and easy. In addition, the method is repeatable and updatable, incorporates a wide range of information, generates a quantitative risk index for a wide range of species and groups them into discrete and comparable values of risk.

INTRODUCTION

The management of natural resources, which are generally complex systems, necessarily requires that problem-solving and decision-making be based on expert opinion. Unfortunately, these decisions are often incomplete, uncertain, and may even be contradictory (Dahlstrom Davidson *et* al., 2013). Since there is no single solution, it is necessary to use decision-making methods that simplify complex systems into simpler, more manageable steps based on clear criteria. These criteria can then be quantitatively evaluated and used to assign priorities and make decisions.

One area of decision-making is risk analysis, which refers to the process of assessing the likelihood and severity of a risk, taking into account the biological, social, and economic consequences (Arthur, 2008). Risk analyses related to invasive species are particularly problematic due to the wide range of impacts they can cause (social, economic, and health), as well as the diversity of species groups and the information gaps (Simberloff *et* al., 2013). Risk assessments for invasive species are still in the process of development (Andersen *et al.,* 2004) and adaptation; However, important conceptual models of invasion already exist (Blackburn *et* al., 2011) and the usefulness of the first more widely used risk assessment systems has been demonstrated (Pheloung *et al.,* 1999; Daehler and Carino, 2000; Kolar and Lodge, 2002; Baker *et al.,* 2008; Tricarico *et al.,* 2010; Koop *et* al., 2011).

The need for evaluation methods

Effective risk assessments are already included in several international (e.g., WTO, 1995; IPPC, 2007; OIE, 2012) and national (NISC in the United States and NOM-043-SAGARPA in Mexico) agendas. In the particular case of Mexico, in order to comply with the recent amendments to the General Law on Ecological Balance and Environmental Protection (LEGEEPA) and the General Law on Wildlife (LGVS) regarding invasive species, which stipulates the need to draw up a list of species authorized for import *(DOF,* 2010), easy-to-use tools are required that provide clear, conclusive, and documented results for both decision-makers and proponents. Among the most widely used methods in decision-making

Among decision-making processes, multicriteria analysis stands out, which has the following advantages: 1] it allows the incorporation of a wide range of types of information that can be processed in a system implemented to be used by different users with a methodology developed by experts; 2] it is possible to incorporate the knowledge of other experts; 3] they are explicit, clear, transparent and flexible enough methods to incorporate social, economic and ecological aspects in decision-making; 4] they allow the subjectivity inherent in decision-making of this nature *(i.e.,* expert judgment) to be more constant and thus frame it within an organized, transparent and reproducible system, and 5] they can be updated as information gaps are filled.

METHOD

The Analytic Hierarchy Process (AHP) method developed by Saaty (1980; 2013) was used, based on a methodology to simplify a complex and unstructured situation into its smallest components and parts, in a hierarchical manner, which allows assigning numerical values to subjective judgments, considering the relative importance of each variable.

This allows for the obtaining of synthetic results that will serve as a basis for decision-making that can be used to assign priorities.

As mentioned, the development of the methodology was driven by the need to obtain a list of invasive species (potentially or already in Mexican territory) accompanied by a categorization of the risk they represent for Mexico, but in which decisions were coupled with selection criteria derived from the analysis and not from biased preferences. In this way, a system was designed in which species risk assessment could be carried out independently with criteria that could reflect the invasion risk (in biological terms and impacts, and based on historical data) of any exotic species with the potential to become invasive. Furthermore, it was imperative to incorporate into the analysis the uncertainty component associated with each decision, which, despite being commonly ignored, is a fundamental factor to consider in the case of invasive species (Dahlstrom Davidson *et* al., 2013; Larson *et* al., 2013). A two-part scheme was used: the first uses the AHP to assign

Machine Translated by Google

the relative weights for questions in a risk assessment, and the second assigns quantitative values to responses and uncertainties. These two parts are then combined multiplicatively to provide a risk value for each species (Fig. 1).

This evaluation system began to be developed after two workshops with invasive species specialists, which served as important background information. The first workshop resulted in the classification system (see chapters 3 and 6). The second workshop on criteria for establishing invasive species lists, along with expert input from several institutions, generated a consensus, which is presented in this chapter.

In summary, the objective was to assign a risk value in quantitative terms to the questions of the risk assessment (described in Chapter 6), which consists of 10 questions or criteria, and the corresponding answers *(a,* very high; b, high; c, medium; d, low; e, no). There is evidence, and f is unknown; Table 1) are transformed into qualitative values that each criterion takes and these are associated with an uncertainty value based on the information collected (Table 2).

In a first step, the 10 risk analysis questions were divided into three major criteria that constitute the first hierarchical level, resulting from the initial working meetings: biological-taxonomic attributes and vectors of other invasive species (status), processes related to biological invasions (invasiveness), and the different impacts (impacts) (Fig. 2). Subsequently, the approach used to assign relative weight to each of the criteria in this first hierarchical level was the paired comparison between criteria, taking as a reference the fundamental scale for paired comparisons proposed by Saaty (2012; Table 3). For the first hierarchical level, two different consensuses were obtained, since the experts differed in their opinions.

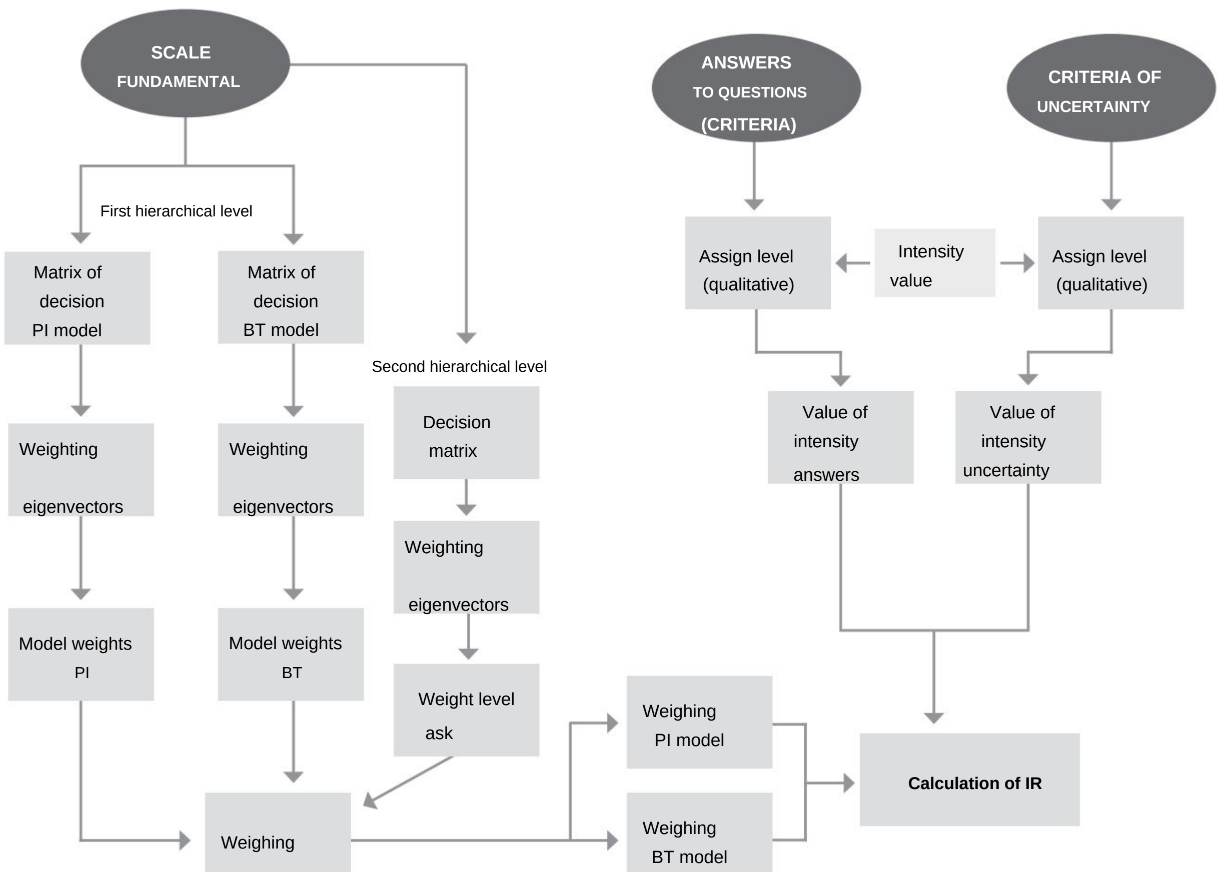

Figure 1. Flowchart used for the invasive species risk assessment. The diagram is divided into two parts: the first corresponds to the hierarchical analysis and weighting of the questions, and the second, the assignment of intensity values to the responses. The entire model is combined into a single risk index (RI).

Table 1. Criteria for the aspects considered in the risk analysis

	Criterion (see table 5 for assigning the response intensity value)
Status	1. Report as invasive
	2. Relationship with closely related taxa, which are recognized as invaders
	3. Vector of other invasive species
Invasiveness	4. Risk of introduction
	5. Establishment risk
	6. Risk of dispersion
Impacts	7. Sanitary (human, animal, flora)
	8. Economic and social
	9. Environmental
	10. Ecological
Answers	a, very high; b, high; c, medium; d, low; e, no evidence; and f, unknown

Table 2. Qualitative uncertainty criteria (based on Koop *et* al., 2012)

Uncertainty	Types of information sources (see Table 5 for assigning the response intensity value)
Minimum	Strong sources of information such as: of peer-reviewed publications with editorial approval (with editorial approval) (*Sagarpa, Semarnat, Salud, NAPPO, OIRSA, etc.) experience in the species studied)
Low	from governments or universities (WOS, CABI, ISSG, NAS, GISID, NEMESIS, OIE) that cite sources of minimum uncertainty (prepared by specialists)
Average	clear quality
High	Google, without clear sources of information) not in the species evaluated
Maxima	

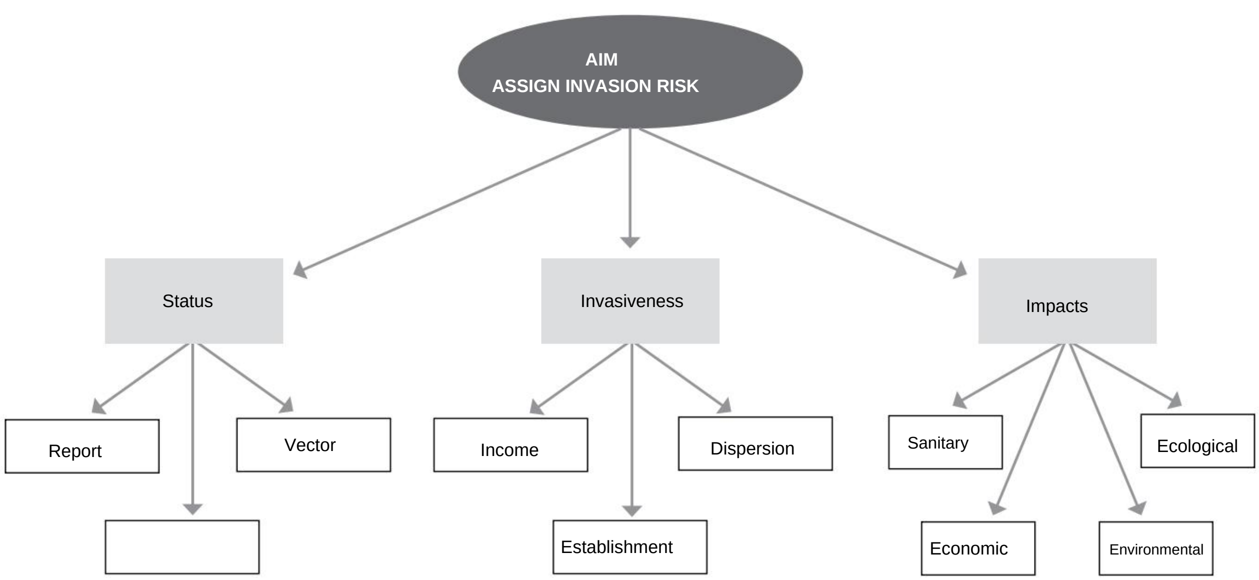

Figure 2. Hierarchical representation of the questions and criteria used in chapter 6 to be analyzed with the AHP method. Each criterion of the first hierarchical level (status, invasiveness and impacts) was in turn divided into a second hierarchical level (blank boxes).

unions, so two models were generated (Fig. 1). The first of these (called PI, because it refers to the invasion process) gives more importance to invasive characteristics, while the second model, BT, gives more weight to previous reports of the species as invasive and its taxonomic proximity to other invasive species, that is, at the biological-taxonomic level (Table 4). The weights given to the criteria at this first hierarchical level are the normalized eigenvalues of the decision matrix and imply that 25% of the rating Risk index is due to status, 50% to invasiveness, and 25% to impacts for the PI model. In contrast, in the BT model, 50% is due to status, 25% to invasiveness, and 25% to impacts. A third model was generated during the workshop that gave greater weight to the impact criterion; however, the analyses did not differ from a model called null, in which equal weight was assigned to all criteria, which is why it was discarded. The risk index assigned to the first hierarchical level of criteria was as follows:

Table 3. Fundamental scale for multiple comparisons (Saaty, 2012)

Importance	Definition	Explanation
1	Equal importance	equally contribute to the objective
3	Moderate importance	Experience and judgment are moderately in favor of one activity over another
5	Most important	Experience favors one more than the other
7	A lot more important	Experience favors one more than the other, practice proves it
9	Absolutely most important	The evidence that favors a on another it is forceful
2, 4, 6, 8	Intermediate values	When a compromise between the above is required

Risk index = (weight status) + (weight invasiveness) + (weight impacts), where:

PI Model: =0.25, =0.5 and =0.25

BT model: =0.5, =0.25 and =0.25

The values add up to 1, although the weight of the criteria at this first hierarchical level was different.

The second step consisted of applying this same decision method at the second hierarchical level (Fig. 1). Paired comparisons were made within the group for status (three questions), invasiveness (three questions), and impacts (four questions). For the first criterion of the second hierarchical level (status), prior information about a species classified as invasive is an aspect assessed by many risk analysis methods (Pheloung *et* al., 1999; Tricarico *et* al., 2010), and

Table 4. Weighting of each question with the two proposed models. The relative weight for the first hierarchical level is indicated in bold.

Group criterion	Criterion by group	PI model weight	PI model weighted weights	BT model weight	BT model weighted weights
Status		0.25		0.5	
	1. Report	0.5	0.125	0.5	0.25
		0.2	0.05	0.2	0.1
	3. Vector	0.3	0.075	0.3	0.15
Invasiveness		0.5		0.25	
	4. Introduction	0.4	0.2	0.4	0.1
	5. Establishment	0.4	0.2	0.4	0.1
	6. Dispersion	0.2	0.1	0.2	0.05
Impact		0.25		0.25	
	7. Sanitary	0.25	0.0625	0.25	0.0625
		0.25	0.0625	0.25	0.0625
	9. Environmental	0.25	0.0625	0.25	0.0625
	10. Ecological	0.25	0.0625	0.25	0.0625
Addition			1		1

In many cases, it is the most important criterion for predicting a new invasion (Reichard and Hamilton, 1997; Moyle and Marchetti, 2006). On the other hand, affinity (taxonomic closeness of the evaluated species with other species reported as invasive) is also a criterion that was given relatively high weight, since the distribution of invasive species is not taxonomically homogeneous (Alcaraz *et* al., 2005; Statzner *et* al., 2008) and there are groups of taxonomically related species that have been found to be invasive *(e.g.,* loricariids).

There is also a large body of evidence regarding the effects of invasive species as vectors (Lounibos, 2002; Pinder *et* al., 2005). To assign status weights, the resulting decision matrix for the first group was as follows (consistency index <0.00001):

$$
\begin{array}{l|ccc}
 & \text{report} & \text{affinity} & \text{vector} \\
\text{report} & 1 & 2.5 & 1.66 \\
\text{affinity} & & 1 & \\
\text{vector} & & 1.5 & 1
\end{array}
$$

and the normalized weighting vector had the values of report = 0.5, affinity = 0.2 and vector = 0.3.

The same paired weighting system was used for the comparison of the second hierarchical level of invasiveness (three questions for invasiveness: introduction, establishment, and dispersal), where the consensus was to emphasize entry (Ricciardi and Rasmussen, 1998; Hulme, 2009) and establishment for a successful invasion (García-Berthou *et* al., 2005; steps A-C3 in Blackburn *et* al., 2011) with equal importance, rather than dispersal characteristics. At the second hierarchical level of impacts, it was decided to treat them with equal degree of importance, so all criteria were assigned the same weight. In both cases, the consistency index was less than 1%. The result of applying the weights to each question in the second hierarchical level is a value that reflects a (normalized) preference of the 10 questions and that could be used to evaluate each species. For example, for the first question (report as invasive) the weighted weight of the first hierarchical level was multiplied by the weighted value of the question at the second hierarchical level, such that we have 0.25×0.5=0.125 for the PI model and 0.5×0.5=0.25 for the BT model.

The next element that was considered and that did not use the fundamental scale was the assignment of a numerical value. intensity metric to the responses (from *a* to f) and another intensity value to the uncertainty (Table 5). The assignment of a numerical value to the questions that are a discrete ordinal variable was done using an intensity value (Saaty, 2012). The intensity value is simply a numerical value (between 0 and 1) that is assigned to each type of response and that allows the characteristic of ordinality to be maintained, such that a response of "very high" corresponds to a greater intensity value than a response of "high" and "medium". Assuming a precautionary principle position to minimize risk, a medium intensity value was assigned to the questions for which there was not enough information to make a decision and maximum uncertainty, as a result of the lack of information. The implication is logical in terms of the precautionary principle, but it is also statistical, since by assigning a mean value (0.5) there is the possibility of being wrong and assuming a maximum error of 0.5.

In this way, the final result of the risk assessment is a risk index (RI) with a numerical value (between 0 and 1) that incorporates the weighting of the criteria in two hierarchical levels agreed upon by experts: the responses to the criteria and the uncertainty, where the RI values closest to 1 would indicate higher risk. The final construction of the risk index for each species would be:

$$IR=\sum_{i=1}^{n} \text{weighted weight of question } i \times \text{intensity value of the question } i \times \text{intensity value of uncertainty of question } i$$

The higher the RI value , the greater the risk and the lower the uncertainty. This method differs from other risk analyses that classify numerical values.

Table 5. Intensity values (quantitative numerical) assigned to each response type and level of uncertainty associated with the risk analysis system (Chapter 6; see text for questions and uncertainty values)

Answer to the question	Value of the answer	Level of uncertainty	Value of intensity assigned to the question or uncertainty
TO	very high	minimum	1
B	high	low	0.75
CAF	unknown		0.5
D	low	high	0.25
AND	null		0

into a few categories (Pheloung *et* al., 1999; Copp *et* al., 2005; Baker *et* al., 2008; Koop *et* al., 2011). To achieve a categorization of a variable for practical purposes that represents the risk index (RI), the intensity values of the 10 responses and the intensity values of the uncertainty were combined in a matrix (Table 6). This matrix generates the values of the center of the distribution for that combination of variables. For example, if all the responses and uncertainties with a "medium" response (intensity value of 0.5) are generated, then a value of 0.25 would be obtained. The following initial risk categories are proposed: very high risk (VHR) = RI values greater than 0.5; high risk (HR) = RI values greater than 0.25 and less than or equal to 0.5; Medium risk (MR) = RI values greater than 0.125 and less than or equal to 0.25; low risk (LR) = RI values below 0.125. Thus, all medium-, high-, and very high-risk species must be controlled; their use must be restricted, or their entry into the country must be prohibited.

Table 6. Decision matrix of the responses and their uncertainty (their intensity value in parentheses) to categorize the risk index (RI)

Value of the ask	Value of uncertainty			
	minimum (1)	low (0.75)	average (0.5)	high (0.25)
very high (1)	1	0.75	0.5	0.25
high (0.75)	0.75	0.56	0.375	0.1879
medium (0.5)	0.5	0.375	0.25	0.125
low (0.25)	0.25	0.1879	0.1250	0.0625
there is no evidence (0)	0	0	0	0

Note: See text for questions and uncertainty values.
An average value is assigned when there is insufficient information and when uncertainty is maximum.

EXAMPLES

To exemplify the method, *Salvinia molesta* was used . (Pteridophyta, Salviniaceae), an invasive exotic aquatic plant present in Mexico. The 10 questions of the risk analysis (Chapter 6) were answered with information from various sources (databases and various scientific articles). For example, for the first question, the answer is MA (very high), since it is widely known that *S. molesta* is a species reported in many parts of the world as an invasive species. and is among the 100 most invasive species in the GISP. The reports have been registered by government agencies, scientific articles, and specialized databases, so it is assigned the minimum uncertainty. If we convert the responses into intensity values, we have a value of 1 for the response and a value of 1 for the uncertainty (Table 5). The weighted value (Table 4) for the first question in the *S. molesta* assessment would be 0.25 (question weighting) × 1 (response intensity value) × 1 (uncertainty intensity value) = 0.125 (weighted response value with uncertainty for the first question). This same process was repeated for the remaining nine questions.

The risk ratio (RI) for *S. molesta* was the sum of the risk values of all questions and compared with the weighted risk values (Table 7). The results for *S. molesta* were greater than 0.5 in both models (PI model = 0.67633 and BT model = 0.73906), which places it among the high-risk species (Table 6). Using the same exercise for three other species *[Eichhornia crassipes* (Angiosperma Pontederiaceae), *Oroechromis niloticus* (Animalia: Cichlidae) and *Poecilia reticulata* (Animalia: Poeciliidae)], their RI also places them among the very high-risk species (Table 8).

PERSPECTIVES AND CONCLUSIONS

Risk analyses are a flexible assessment tool; while their structure and components may vary depending on their purpose, scale, and users, the process provides a solid basis for qualitatively or quantitatively measuring the likelihood of events occurring that may have different consequences (Arthur, 2008). Therefore, they are an indispensable element in decision-making, particularly for our country, which is faced with the need to generate lists of species that can be classified as invasive, according to various criteria.

The method presented in this chapter attempts to address this need by assigning risk levels to a wide variety of species. The method is strengthened because the algorithm has clear criteria, based on expert opinion in various taxonomic groups, and its application can be done quickly. For example, several of the chapter's authors have been able to perform risk analyses over periods of one

Machine Translated by Google

Table 7. Example of the use of the two weighting models and intensity values for the risk analysis questions to generate a risk index (RI) in *Salvinia molesta*

Ask	Weighted weights PI Model	Weighted weights BT Model	Answer to question	Uncertainty	Intensity value answer	Intensity value uncertainty	Value per question using IR Model PI	Value per question using IR Model BT
Status								
1. Report	0.125	0.25	MA	Minimum	1	1	0.125×1×1=0.125	0.25×1×1=0.25
taxonomic	0.05	0.1	MA	Minimum	1	1	0.05×1×1=0.05	0.1×1×1=0.1
3. Vector	0.075	0.15	MA	Average	1	0.5	0.075×1×0.5 = 0.0375	0.15×1×0.5=0.075
Invasiveness								
4. Introduction	0.2	0.1	M	Average	0.5	0.5	0.2×0.5×0.5=0.05	0.1×0.5×0.5=0.025
5. Establishment	0.2	0.1	MA	Minimum	1	1	0.2×1×1=0.2	0.1×1×1=0.1
6. Dispersion	0.1	0.05	M	Minimum	0.5	1	0.1×0.5×1=0.05	0.05×0.5×1=0.025
Impacts								
7. Health	0.0625	0.0625	MA	Average	1	0.5	0.065×1×0.5 = 0.02343	0.065×1×0.5 = 0.02343
social	0.0625	0.0625	TO	Minimum	0.75	1	0.065×0.75×1 = 0.0468	0.065×0.75×1 = 0.0468
9. Environmental	0.0625	0.0625	TO	Minimum	0.75	1	0.065×0.75×1 = 0.0468	0.065×0.75×1 = 0.0468
10. Ecological	0.0625	0.0625	TO	Minimum	0.75	1	0.065×0.75×1 = 0.0468	0.065×0.75×1 = 0.0468
Addition	1	1					0.67633	0.73906

Table 8. Risk values with the two models for four selected aquatic species (two plants and two fish) that have invasive characteristics

Species	Risk Index Risk Index PI Model	BT Model
Eichhornia crassipes	0.98125	0.9625
Poecilia reticulata	0.51797	0.53672
Oreochromis niloticus	0.61406	0.6
Salvinia molesta	0.67633	0.7390

in three days applying this algorithm, compared to other types of methods that also require a greater degree of specialization from the evaluator. However, there are still several important aspects that must be considered. The first is the validation of the model itself. The first validation of the model is the contrast against a null hypothesis (where all responses have the same weighting) and preliminary analyses indicate that the proposed models do differ statistically from a null model (Golubov *et al.,* 2011).

al., unpublished data). This result provides some certainty that the weighting of the criteria has an impact on the final result and is consistent with the findings documented in the scientific literature and expert opinion regarding the weight assigned to each criterion. The second aspect that must be taken into account is the validation of the RI results.

with other risk analysis tools, particularly those that perform more comprehensive analyses.
For example, the risk analyses of the species found in NOM-043-FITO-1999, which being quarantine species should have risk indices greater than 0.5, and at least we know that in a preliminary analysis the FI-ISK values (Tricarico *et* al., 2010) were positively and significantly correlated with the RI.

(Mendoza *et* al., unpublished data). There are other assessment methods that can be used to calibrate and validate this model. The third component to consider is the cut-off point for assigning the four risk categories (very high, high, medium, and low). The first approach was to use criteria from the precautionary principle, in which the highest risk level

It is imposed by the values of the questions, which are given a medium value (0.5) but with high certainty (value of 1) or high values to the questions (value of 1) with medium to maximum uncertainty (0.5). It is hoped that the proposed method can be a starting point for generating a list of species with their respective risk index that can be used by different institutions. This first approximation should be used as a decision criterion to carry out a more detailed risk analysis, such as that of the CCA (Mendoza, 2009), or other specific ones for weeds (Pheloung *et* al., 1999) or several species (Baker *et* al., 2008). At this stage, it is especially valuable to have a rapid assessment tool when evaluating a large number of species that can be transported by some route, since it can therefore complement the analysis of introduction pathways (see Chapter 8). Risk analyses are not generally conducted for species at their known distribution limits; however, they can be performed to analyze cases of potential translocations. Finally, an additional advantage of the method is that species can be reassessed relatively easily when new information becomes available.

ACKNOWLEDGMENTS

We would like to thank all the participants in the Second Workshop on Criteria for Listing Invasive Alien Species, with whom we reached a consensus on the weighting. Tania Urquiza Haas, Saúl Castañeda, and Sergio Zalba reviewed and substantially improved the manuscript.

REFERENCES

Alcaraz, C., A. Vila-Gispert and E. Garcia-Berthou. 2005. Profiling invasive fish species: The importance of phylogeny and human use. *Diversity and Distributions* 11:289-298.

Andersen, M.C., H. Adams, B. Hope, and M. Powell. 2004. Risk assessment for invasive species. *Risk Analysis* 24: 787-793.

Arthur, JR 2008. General principles of the risk analysis process and its application to aquaculture, in MG Bondad-Reantaso, JR Arthur and RP Subasunghe (eds.). *Understand-ing and applying risk analysis in aquaculture.* FAO Fisheries and Aquaculture Technical paper 519. Rome, FAO, pp. 3-8. <*http:// academia.edu/ 1226062/ Introduced_marine_species_ risk_assessment_aquaculture*>.

Baker, RHA, R. Black, GH Copp, KA Haysom, PE Hulme, MB Thomas, A. Brown M. Brown, RJC Cannon, J. Ellis, M. Ellis, R. Ferris, P. Glaves, RR Gozlan, J. Holt, E. Howe, JD Knight, A. MacLeod, NP, Moore, JD Mumford, ST Murphy, D. Parrot, C.E. Sansford, G.C. Smith, S. St Hilaire, and N.L. Ward. 2008. The UK risk assessment scheme for all non-native species. *Neobiota* 7: 46-57.

Blackburn, T., P. Pysek, S. Bacher, J.T. Carlton, R.P. Duncan, V. Jarsosik, JRU Wilson and DM Richardson. 2011. A proposed unified framework for biological invasions. *Trends in Ecology and Evolution* 26: 333-339.

CCA. 2009. Trinational risk assessment guidelines for aquatic alien invasive species. North American Commission for Environmental Cooperation. Montreal, Quebec, Canada.

Copp, G.H., R. Garthwaite, and R. Gozlan. 2005. Risk, identification and assessment of non-native freshwater fishes: a summary of concepts ad perspective in protocols for the UK. *Journal of Applied Ichthyology* 21: 371-373.

Daehler, CC, and DA Carino. 2000. Predicting invasive plants: perspective for a general screening system based on current regional models. *Biological Invasions* 2: 93-102.

Dahlstrom Davidson, A., ML Campbell, and CL Hewitt. 2013. The role of uncertainty and subjective influences on consequence assessment by aquatic biosecurity experts. *Journal of Environmental Management* 127: 103-113.

DOF. 1999. *Mexican Official Standard NOM-043-FITO-1999, Specifications for preventing the introduction of quarantine weeds into Mexico. Official Gazette of the Federation,* March 1, 2000.

Official Gazette of the Federation. 2010. *General Wildlife Law.* Decree amending and adding various provisions of the General Wildlife Protection Act (LEEPA) and the General Wildlife Service (LGVS). Official Gazette of the Federation, April 6, 2010.

García-Berthou, E., C. Alcaraz, Q. Pou-Rovira, L. Zamora, G. Coenders and C. Feo. 2005. Introduction pathways and establishment rates of invasive aquatic species in Europe. *Canadian Journal of Fisheries and Aquatic Sciences* 62: 453-463.

Hulme, PE 2009. Trade, transport and trouble: managing in-vasive species pathways in an era of globalization. *Journal of Applied Ecology* 46:10-18.

IPPC. 2007. ISPM No 2 *Framework for Pest Risk Analysis.* Rome, IPPC, FAO.

Kolar, CS, and DM Lodge. 2002. Ecological predictions and risk assessment for saline fishes in North America. *Science* 298: 1233-1236.

Koop, A.L., L.P. Newton, L. Kohl, L.C. Millar, R. Griffin, S. Bloem, AM Jackson, DM Borchert, and JP Thomson. 2012. WRA 101 Weed Risk Assessment Workshop. June 19-22, 2012. USDA, APHIS, PPQ, CPHST, Plant Epidemiology and Risk Analysis Laboratory. Raleigh NC, USA. 160 pp.

Koop, A.L., L.P. Folwer, L.P. Newton, and B.P. Caton. 2011. Development and validation of a weed screening tool for the United States. *Biological Invasions* 14: 273-294.

Larson, BMH, C. Kueffer, Zif Working Group on Ecological Novelty. 2013. Managing invasive species amidst high un-certainty and novelty. *Trends in Ecology and Evolution* 28: 255-256.

Lounibos, L.P. 2002. Invasions by insect vectors of human dis-ease. *Annual Review of Entomology* 47: 233-266.

Mendoza, R., B. Coudmore , R. Orr, J Fisher, S. Contreras, W. Courtenay, P. Koleff, N. Mandrak, P. Álvarez, M. Arroyo, C. Escalera, A. Guevara, G. Greene, D. Lee, A. Orbe, C. Ramírez and O. Stabridis. 2009. *Trinational Risk Assessment Guide-lines for Aquatic Invasive Species: Test cases for Snakeheads (Channidae) and Armored Catfishes (Loricariidae) in North American Inland Waters.* Commission for Environmental Cooperation. Montreal, Canada, 98 pp.

Moyle, PB, and MP Marchetti. 2006. Predicting invasion success: freshwater fishes in California as a model. *BioScience* 56: 515-524.

OIE. 2012. *Terrestrial Animal Health Code.* International Standards, World Organisation for Animal Health. <*www.oie.int/ en/ international-standards/ terrestrial-code/ online-access*> (accessed July 2013).

Pheloung, PC, PA Williams and SR Halloy. 1999. A weed risk assessment model for use as a biosecurity tool evaluating plant introductions. *Journal of Environmental Management* 57: 239-251.

Pinder, AC, RE Gozlan, and JR Britton. 2005. Dispersal of the invasive top mouth gudgeon, *Psudorasbora parva* in the UK: a vector for an emerging infectious disease. *Fisheries Management and Ecology* 12: 411-414.

Reichard, S.H., and C.W. Hamilton. 1997. Predicting invasions of woody plants introduced into North America. *Conservation Biology* 11: 193-203.

Ricciardi, A., and JB Rasmussen 1998. Predicting the identity and impact of future biological invaders: a priority for aquatic re-source management. *Canadian Journal of Fisheries and Aquatic Sciences* 55: 1759-1765.

Saaty, TL 1980. *The analytic hierarchy process: planning, priority setting, resource allocation.* McGraw-Hill, USA.

Saaty, TL 2012. *Decision making for leaders. The analytical hierar-chy process for decisions in a complex world.* University of Pittsburgh, PA, USA.

Saaty, TL 2013. *Fundamental of decision and priority theory with the analytic hierarchy process.* University of Pittsburgh, PA, USA.

Simberloff, D., J.L. Martin, P. Genovesi, V. Maris, D.A. Wardel, J. Aronson, F. Courchamp, B. Galil, E. Garcia-Berthou, M. Pascal, P. Pusek, R. Sousa, E. Tabacchi and M. Vila. 2013. Im-pacts of biological invasions: What's what and the way forward. *Trends in Ecology and Evolution* 28: 58-66.

Statzner, B., N. Bonaday and S. Doledec. 2008. Biological attributes discriminating invasiveness from native European stream invertebrates. *Biological Invasions* 10: 517-530.

Tricarico, E., L. Vilizzi, F. Gherardi and GH Copp. 2010. Calibration of FI-ISK, and invasiveness screening tool for non-native freshwater invertebrates. *Risk Analysis* 30: 285-292.

WTO. 1995. Agreement on the application of sanitary and phy-tosanitary measures. World Trade Organization. Available at <*www.wto.org/ english/ docs_e/ legal_e/ 15-sps.pdf*> (accessed July 2013).