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National Detailed-Level Risk Assessment Guidelines: Assessing the Biological Risk of Aquatic Invasive Species in Canada

Directives nationales sur les évaluations du risque de niveau détaillé : évaluation du risque biologique associé aux espèces aquatiques envahissantes

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ABSTRACT

Risk assessments of aquatic invasive species (AIS) are required to make sound management decisions regarding the aquatic ecosystems, fisheries resources, fish habitat, and aquaculture that AIS may impact, and that Fisheries and Oceans Canada (DFO) is mandated to protect. DFO formed the Centre of Expertise for Aquatic Risk Assessment (CEARA) to oversee the risk assessment of AIS across the country. One of the mandates and objectives of CEARA is to develop a scientifically defensible national framework for conducting biological risk assessments of AIS. This document fulfills that mandate.

RÉSUMÉ

Les évaluations du risque lié aux espèces aquatiques envahissantes (EAE) sont nécessaires à la prise de décisions fondées concernant la gestion des écosystèmes aquatiques, des ressources de la pêcherie, de l'habitat du poisson et des aquacultures que les EAE peuvent affecter et dont la protection est liée au mandat de Pêches et Océans Canada (MPO). Le MPO a formé le Centre d'expertise pour l'analyse des risques aquatiques (CEARA) afin de superviser les évaluations du risque conduites à travers le pays. L'un des mandats et objectifs de CEARA est de développer des directives scientifiques permettant de guider la réalisation des évaluations du risque biologique posé par les EAE. Ce document répond à ce mandat.

1.0 INTRODUCTION

Aquatic invasive species (AIS) are a significant threat to global biodiversity (Sala *et al*. 2000), and are the second leading cause for decline of Canadian freshwater species at risk (Dextrase and Mandrak 2006). There are approximately 182 AIS in the Great Lakes alone (Ricciardi 2006); however, the total number of AIS currently in Canada is unknown. AIS already established in some parts of Canada have caused significant impacts to Canadian aquatic environments and, in some cases, have permanently altered the natural ecosystem (e.g., Round Goby, *Neogobius melanostomus*, Jude *et al*. 1995; zebra mussel, *Dreissena polymorpha*, Hecky *et al*. 2004). The arrival, establishment, and spread of AIS in Canada and their associated impacts to aquatic environments and resources will continue.

Preventing the arrival, establishment, and spread of AIS is an important step to protecting aquatic environments (Kolar 2004). To develop policy, regulation, legislation, and management plans to protect Canadian aquatic environments from the impacts of AIS, Fisheries and Oceans Canada (DFO) must assess the threats of current and potential AIS. To accomplish this task, a biological risk assessment is often required to provide science advice on the level of risk to Canada's aquatic ecosystems associated with any given AIS. This advice provides the basis for informed decision-making and aids in allocating resources to prevent potential, or deal with ongoing, invasions by predicting the identity, range and/or impact of potential invaders (Kolar 2004).

Canada's National Code for Introductions and Transfers of Aquatic Species (CCFAM AISTG 2004) applies to the intentional introduction, transfer, or range extension of introduced or naturalized species, and includes a risk assessment process to identify risks associated with these intentional introductions. However, there is a need for guidelines that can be used to assess the risks of potential AIS not intentionally introduced, either those not yet in Canadian waters, or those with the potential to spread to other areas of Canada.

In June 2006, DFO held a National Risk Assessment Methods Workshop to discuss risk assessment methodologies used by various international agencies (Chapman *et al*. 2006). Workshop participants had the opportunity to critique the risk assessment guidelines and methodologies presented, and to provide input on what characteristics DFO's risk assessment guidelines for AIS should embody. Based on this workshop, an earlier version of the current document, which comprises National Detailed-Level Risk Assessment (DLRA) Guidelines for assessing risks from AIS, was developed.

Although the various international risk assessment guidelines provided support towards the development of this document, the risk assessment process included in the National Code for Introductions and Transfers of Aquatic Organisms (CCFAM AISTF 2004) was the foundation from which these guidelines were developed. The National Code risk assessment process was adapted from guidelines developed for the Aquatic Nuisance Species Task Force in the United States (Anonymous 1996).

The DLRA Guidelines was subsequently refined through two peer review workshops: November 2007 and June 2008 (DFO 2009), resulting in the present DLRA Guidelines document.

1.1 PURPOSE

Biological risk assessments of Canada's current and potential AIS are an element of DFO Science advice that will be used to carry out risk management (such as legislation, regulation, mitigation, and management plans) undertaken by other DFO sectors and other governmental agencies. For example, under potential future AIS legislation, if DFO Policy wants to prohibit a species, they will need to request advice from DFO Science. Such Science advice, in the form of a risk assessment, will enable informed decision making that is scientifically defensible in a policy arena (e.g., prohibiting specific species).

These guidelines are intended to provide guidance for conducting detailed-level biological risk assessments in a standardized fashion. However, they are only guidelines and, as such, are not intended to be prescriptive, but rather allow for flexibility in assessing risk depending on the taxon, geographic area of concern, and the type and quality of data available. The results of risk assessments conducted following these guidelines should provide a reasonable estimation of the overall risk of the AIS to Canada's aquatic ecosystems.

1.2 RISK ANALYSIS

Risk analysis has three interacting, but functionally separate, components: risk assessment; risk management; and, risk communication (Figure 1). Effective communication is required between stakeholders, risk managers, and scientists during all stages of risk analysis.

These guidelines are intended to provide direction on conducting risk assessments, the first component of risk analysis. They are intended to be both proactive (e.g., importation of new species) and reactive (e.g., determining the risk of an established non-native species that has not yet spread [cf. Section 2.3]). These two possibilities have different management implications related to regulating importation versus transport, respectively.

These guidelines comprise the third-level (tier) of risk assessment for AIS, the Detailed Level Risk Assessment. The other two levels, Rapid Assessment Protocol (RAP) and Screening-Level Risk Assessment (SLRA) (DFO 2009), are not dealt with in this document. The different risk assessment levels are intended to screen species using increasing amounts of information taking increasing amounts of time. Species assessed as low risk with moderate or lower uncertainty at a given tier may need not be assessed any further at a higher tier; whereas, species assessed at moderate risk or higher or high uncertainty should be further screened at a higher tier.

Risk assessments for AIS are science based, and include information on species biology (Biological Synopsis, Section 2.3.2.1), pathways and vectors (Pathway and Vector information, Section 2.3.2.2), and potential risk to Canada aquatic ecosystems (Risk Characterization, Section 2.3.3). This information is used to characterize the likelihood of potential introduction and significance of the consequences of that introduction. Information on socio-economic impacts is collected by risk managers in the risk management component of risk analysis and is not included in these guidelines. Risk communication, also not included in these guidelines, involves combining and communicating the results of the risk assessment and recommendations of risk managers.

Risk assessments can be undertaken with qualitative data, quantitative data, or a combination of both. There can be a perception that quantitative risk assessments are more robust than qualitative ones; however, although data requirements are higher for quantitative risk assessments, it is important to note that qualitative data are not inherently weak. The strength of a risk assessment is dependant, in large part, on the uncertainty associated with the data (Section 2.4).

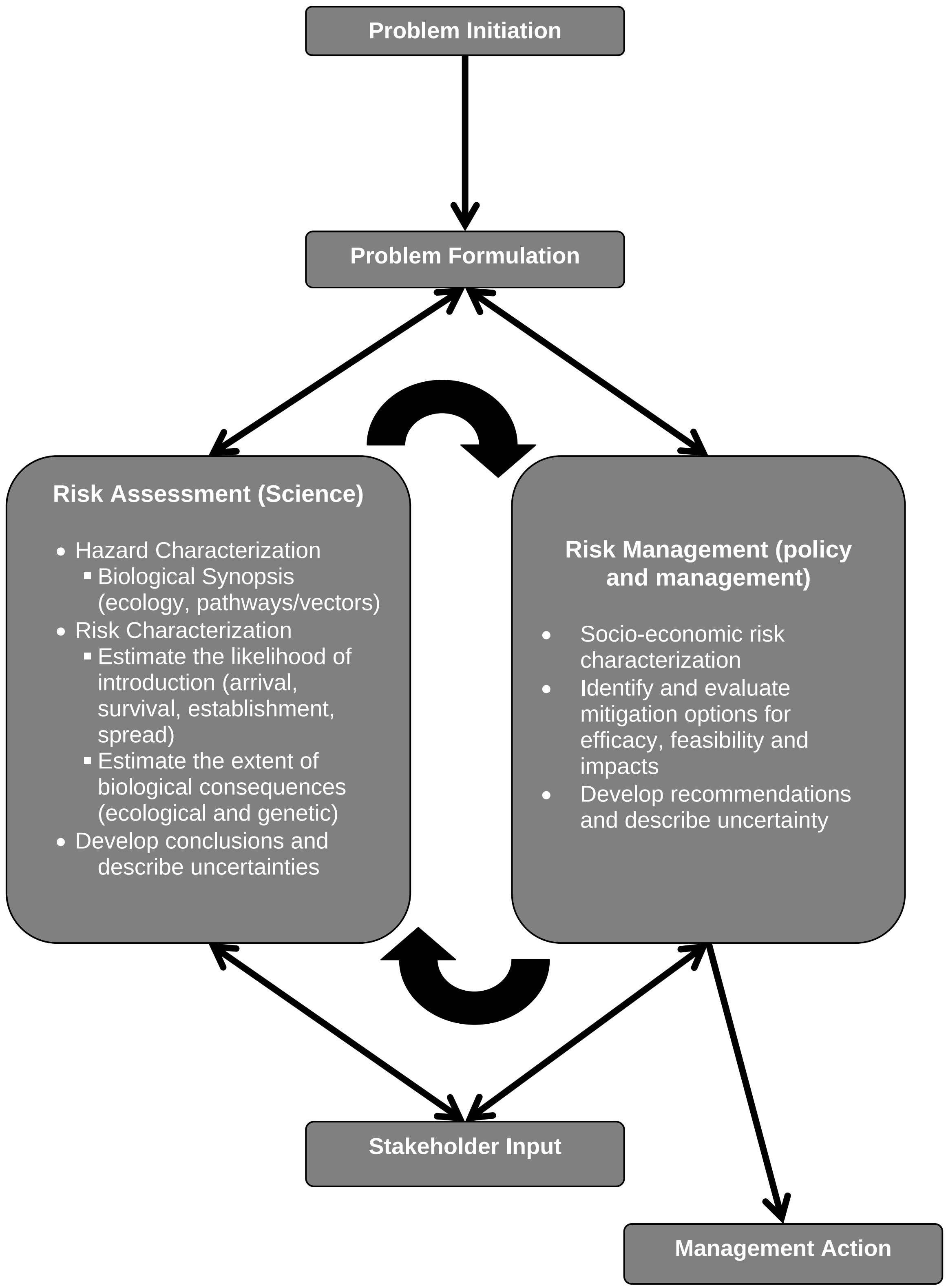

Figure 1. Components of a biological risk analysis. Arrows indicate lines of risk communication. Adapted from R. Peterman, Simon Fraser University, pers. comm.

The next step after completion of the DLRA is to work with decision makers and stakeholders on the implications of different management decisions (Figure 1). The Precautionary Principle (UNEP 1992) should be incorporated as appropriate during risk management decision making but not during the scientific assessments.

Identifying uncertainty is a key component of any risk assessment. There are three generic types of uncertainty: stochasticity, which refers to the inherent randomness of the system being studied and can be described and estimated but not reduced; imperfect knowledge; and, human error. Uncertainty of these last two types can be reduced. In risk assessments of AIS, uncertainty is associated with both the likelihood of introduction and magnitude of biological consequences. Uncertainty will be higher for poorly known, poorly studied species than for well-studied species. The incorporation of uncertainty into risk assessment takes into consideration the quality and quantity of data available to rank likelihood of introduction and magnitude of consequences, and provides risk managers with an indication of the inherent strengths and weaknesses in the risk assessment (Section 2.4).

2.0 RISK ASSESSMENT GUIDELINES FOR AIS

2.1 AUTHORITY

Fisheries and Oceans Canada Centre of Expertise for Aquatic Risk Assessment (CEARA) was formally established in 2006. CEARA consists of a Directorate, a National Executive Committee, and an Expert Network that identifies risk assessment priorities, and coordinates, advises on, and peer reviews biological risk assessments. As part of these duties, CEARA has also been charged with developing national standards for assessing the biological risk of AIS in a scientifically defensible manner. These guidelines fulfill this responsibility and will provide direction for DFO risk assessment practitioners assessing the biological risk of AIS in Canada.

CEARA is developing a three-step risk assessment process that identifies risk assessment priorities by conducting a rapid assessment protocol and/or a screening-level risk assessment to identify species, groups of species, or vectors requiring a detailed-level risk assessment. Examples of completed detailed-level risk assessments can be found on CEARA's website (http://www.dfo-mpo.gc.ca/science/coe-cde/ceara/index-eng.htm).

2.2 GUIDING PRINCIPLES

Participants at the National Risk Assessment Methods Workshop in June 2006 (Chapman *et al*. 2006) discussed the characteristics that these guidelines should embody. The guiding principles agreed upon by workshop participants and verified by the final peer review workshop (DFO 2009) were:

- Transparent – the assessment of risk and identification of uncertainty need to be clearly documented, including the need for peer review of risk assessments for AIS following the Canadian Science Advisory Secretariat (CSAS) guidelines and standards.

- Adaptive – the risk assessment process needs to evolve over time, taking into account new methods or data.

- Flexible – guidelines need to be applicable to different spatial scales and aquatic taxa, and to accommodate qualitative, semi-quantitative and quantitative data and modelling tools. To allow for different risk assessment approaches, they should not be prescriptive or comprehensive. The guidelines are exactly that, guidelines, and should be considered as comprising a risk assessment “tool box” to guide, rather than to define, the use of a variety of risk assessment “tools”.

- Ecological – based on ecological data and principles.

- Scientifically defensible – use principles of the scientific method (‘hypothetico-deductive reasoning’); i.e., examine all possible factors that might affect an outcome, determine questions that need to be answered, and deduce specific hypothesis or predictions about what might happen using best available information. Questions posed need to be clear such that variations in responses do not occur due to misunderstandings regarding the question(s) being asked.

- Species based – the guidelines should be species based, but consider all relevant pathways and vectors.

- Consistent with international risk assessment standards – to ensure credibility and comparability, the guidelines should be consistent with international risk assessment standards already developed and in practice (e.g., FAO 2006).

- Practical – guidelines need to provide technical and practical advice to risk managers.

- Mandate-less – the guidelines, and resulting risk assessments, must not be unduly influenced by any factors that are not science based.

For many potential AIS, detailed information on their biology or distribution may be lacking, or unavailable; however, science advice is often required despite this lack of complete knowledge. These risk assessment guidelines provide a framework for organizing and interpreting existing information, and documenting the assessment of risk. Adequate documentation will make the risk assessment transparent. This transparency facilitates discussion if there are scientific or technical disagreements about the results of the risk assessment. The information used to assess risk must be provided and referenced, and will allow the identification of missing, misleading, or unclear information. Identifying knowledge gaps can also provide direction for areas requiring further research to decrease uncertainty in ranking risk, or decreasing risk entirely.

2.3 NATIONAL GUIDELINES

2.3.1 Problem Formulation

It is important before beginning the risk assessment process to determine the scope of the project (Problem Formulation – see Figure 1). Problem Formulation, the first step in the risk analysis process, needs to clarify the time frame and spatial extent of the risk assessment and should be both flexible and transparent. Spatial extent should consider spatial scale, habitat type (e.g., marine vs freshwater), and other relevant elements. The time frame for possible AIS arrival needs to be identified and typically does not extend beyond five years. However, if long-term environmental effects, such as climate change, need to be taken into account, these needs should be noted in the problem formulation and be re-visited as appropriate and necessary. The time frame for steps subsequent to arrival time is flexible and should be based on the biology of the species (DFO 2009). The chosen time frame for the biological consequences of AIS introduction should be identified. The design (e.g., cell vs gradient) and content (e.g., risk represented by individual cells) of the risk matrix should be determined at this step.

2.3.2 Hazard Characterization

The information required for an AIS hazard characterization can be grouped into two categories: biological synopsis of the AIS (Section 2.3.2.1); and, vector(s) and pathways in which the AIS may be transported (Section 2.3.2.2).

2.3.2.1 Biological Synopsis

It is important to capture, in as much detail as is available, information on species distribution, life history characteristics, and ecology in both native and introduced ranges. This information should be summarized in a biological synopsis (which can be a separate document if appropriate). The biological synopsis can assist in providing information, as appropriate, regarding potential direction of consequences (e.g., increased biodiversity) without providing value judgments. The biological synopsis should include:

- Distribution – include a map of the species' native and introduced ranges, noting established vs reported populations, and a summary of the history of global introductions. Identify modes of invasion and rates of spread. If available, include analyses of potential distribution (e.g., ecological niche modelling, climate matching);

- Biological characteristics – include details of life cycle, age and growth, reproduction, physiological tolerances, feeding and diet, habitat requirements, behaviour and movement, and diseases and parasites;

- Use by humans – intended to provide insight into potential pathways;

- Ecosystem impacts – include known impacts associated with past introductions, related to competition and predation, having genetic effects, and on water quality, aquatic macrophytes and other fauna; and,

- Conservation status.

Biological information is to assess likelihood of arrival, survival, establishment, and spread, and the magnitude of consequences if the species becomes established.

2.3.2.2 Vector and Pathway Information

To assess potential for arrival and spread, it is important to document the current status of the species in Canada. This can be accomplished by indicating the current geographic distribution in Canada, and occurrence in all known vectors and their associated pathways:

- Current Canadian distribution – a map indicating the current location of occurrences in Canada, noting established vs reported populations. This would not be required for species not yet reported from the wild in Canada; and,

- Vector(s) and pathway(s) – specific information about the vectors, and their pathways, associated with the species is important to document. This includes spatial (origin and release site) and temporal (annual, seasonal) associations, stage of life cycle during transport in a vector or pathway, and number of individuals (propagule pressure) in the vector and pathways.

2.3.3 Biological Risk Assessment (Risk Characterization)

The biological risk of AIS is the likelihood of introduction (includes ranking elements of arrival, survival, establishment, and spread) multiplied by the magnitude of biological (ecological and genetic) consequences of the introduction. Identification of uncertainty associated with the ranking is an important aspect of conveying risk.

This method, used in most international risk assessment guidelines, is a two-part process ranking likelihood of introduction and the consequences of this introduction for the species and their fellow travellers (parasites, pathogens, or other organisms). Uncertainty is included with, but not incorporated into, the risk ranking (see Sections 2.3.3.1.1 and 2.4).

2.3.3.1 Primary AIS

2.3.3.1.1 Likelihood of Introduction

The overall likelihood of a successful species introduction is evaluated by determining the likelihood of the following elements: species arriving (being in a vector and its pathways and surviving transit); surviving the environment into which the species is released; establishing a reproducing population; and, spreading through the original or secondary pathways.

Propagule pressure (number of viable organisms that could enter an ecosystem over a set time period – the source population) should be considered in arrival and establishment elements. Pathway probability and propagule pressure need to be kept separate in terms of arrival, which comprises both of these components; however, the relationship between the two is critical. Arrival (based on vectors) should be separated from survival (related to environmental matches); the primary focus is on species that arrive and survive, not those that arrive and do not survive, as consequences will be additive across the likelihood of introduction elements.

When ranking likelihood for each element, the number of likelihood of introduction categories selected can be odd or even but need to be symmetric so that the inverse likelihood of introduction (1-L) can be calculated in order to determine overall risk (Section 2.3.4). An even number of categories reduces a middle-category bias. Table 1 provides an example of symmetric categories and the inverse of each category. Numerical values are encouraged where possible and appropriate rather than more ambiguous narrative values. Numeric ranges provide a common scale and prevent confusion that can arise with narrative descriptions. Quantitative likelihoods can be divided into equal-sized ranges or range sizes may be adjusted if deemed appropriate (e.g., a different distribution used).

Each element ranking (arrive, survive, establish, spread) should include an associated level of uncertainty (see Table 2 for example and Section 2.4), and a brief narrative summary outlining how the ranking was determined. Quantitative methods, such as ecological niche (potential distribution) and gravity (spread potential) modeling, can be used to support ranking if the information and tools exist, which may also decrease uncertainty.

Overall likelihood of introduction is determined for qualitative data by taking the lowest rank and highest uncertainty of the four elements (see Table 3 for example). A brief narrative summary may accompany the overall likelihood. For quantitative data, overall likelihood of introduction can be determined by multiplying the ranks of each of the four elements. Overall uncertainty can be determined in a similar manner or, if uncertainty is not quantified, overall uncertainty should be the highest uncertainty of the four elements. When qualitative categories are used, the risk level should always be low when the likelihood of introduction and/or magnitude of consequences are low or less. When first occurrence of the species could be the result of either arrival from outside of the geographic scope of the risk assessment or spread from another area within the geographic scope, overall probability of introduction can be determined based on the following formula:

Probability of introduction =Min[Max(Arrival, Spread) Survival, Establish]

Table 1. Example of likelihood and category bins.

Likelihood	Category Bins	1-Likelihood
Negligible	0-0.001	Almost Certain
Very Unlikely	0.001-0.05	Very Likely
Low	0.05-0.4	High
Moderate	0.4-0.6	Moderate
High	0.6-0.95	Low
Very Likely	0.95-0.999	Very Unlikely
Almost Certain	0.999-1.0	Negligible

Table 2. Example of relative uncertainty categories (modified from Koops et al. 2009).

Level	Uncertainty Category
± 90%	Very low uncertainty (e.g., extensive, peer-reviewed information)
± 70%	Low uncertainty (e.g., primarily peer reviewed information)
± 50%	Moderate uncertainty (e.g., information and expert opinion)
± 30%	High uncertainty (e.g., little information; largely expert opinion)
± 10%	Very high uncertainty (e.g., no information; expert opinion)

Table 3. Example of overall ranking of qualitative likelihood of introduction.

Element	Likelihood	Uncertainty
Arrival	Almost Certain	Low
Survival	Moderate	Moderate
Establishment	High	High
Spread	Very Likely	Moderate
Overall	**Moderate**	**High**

2.3.3.1.2 Magnitude of Biological Consequences

In a detailed-level risk assessment, the impacts are the biological consequences to the invaded ecosystem and may include: ecosystem modification or degradation; trophic disruption (e.g., predator-prey dynamics, competition); reduction in native biodiversity (including reduction or elimination of species at risk); hybridization; or, reduction or loss in quality of habitat. The focus should be on consequences with the highest risk, but information on all potential consequences should be included as consequences are additive from one element to the next. The number of consequence categories selected can be odd or even, but an even number of categories reduces a middle-category bias. An example of consequence categories is provided in Table 4. As with likelihood of introduction, numerical values are encouraged where possible and appropriate rather than more ambiguous narrative values. The uncertainty level (preferably a range) associated with each of the consequences should be included using the uncertainty rankings as defined for the risk assessment (see example, Table 2).

If several categories of consequences are assessed, overall consequence could be determined for qualitative data by taking the rating and uncertainty of the category deemed most important or by taking the highest rating and uncertainty if all categories are considered equally important, or the consequence of each category could be mapped separately on the same risk matrix. For quantitative data, overall magnitude of consequences can be determined by multiplying the ranks of all categories used. Overall uncertainty can be determined in a similar manner or, if uncertainty is not quantified, overall uncertainty should be the highest uncertainty of all categories used. A brief narrative summary may accompany the rating of magnitude of consequences.

Table 4. Example of consequence ratings and their descriptions (from Koops et al. 2009)

Impact rating	**Description**
1. Negligible	Undetectable change in the structure or function of the ecosystem. No management action required.
2. Low	Minimally detectable change in the structure of the ecosystem, but small enough that it would not change the functional relationships or survival of species. Unlikely to affect management of the ecosystem.
3. Moderate	Detectable change in the structure or function of the ecosystem that would require consideration in the management of the ecosystem.
4. High	Significant changes to the structure or function of the ecosystem leading to changes in the abundance of native species and a need for management to adapt to the new food web. May have implications beyond the extraction or use of ecosystem resources.
5. Extreme	Impacts that restructure the ecosystem resulting in, for example, the extirpation or extinction of at least one species and the need for significant modification of the management of the ecosystem. Will probably have implications beyond the extraction or use of ecosystem resources.

2.3.3.1.3 Developing Conclusions and Describing Uncertainty

A well-defined risk matrix is key to summarizing and communicating the results of the risk assessment. Prior to assigning likelihoods of introduction and magnitude of consequences, it is necessary to decide upon and describe categories in the matrix that will be used consistently throughout the risk assessment. A risk matrix combines the likelihood of introduction with the magnitude of consequences and typically defines three risk levels: high (red); medium (yellow); and, low (green); although more risk levels could be added if deemed warranted. In a risk matrix, both likelihood of introduction and magnitude of consequences can be based on qualitative (categories) or quantitative (probabilities) information.

The likelihood of introduction and magnitude of consequences results combined using the risk matrix to determine the overall risk. Table 5 and 6 provide examples of risk matrices based on odd-and even-numbered introduction and consequence categories. Figure 2 provides an example of a risk matrix using a gradient rather than cells. A gradient matrix illustrates the continuous nature of overall risk along the gradients of probability of introduction and magnitude of ecological consequences. Ellipses can be added to either type of matrix to represent areas of uncertainty. Overall uncertainty is based on the highest uncertainty between likelihood of introduction and magnitude of consequences if there is no information on the distribution of the uncertainty. If there is information on the distribution of uncertainty, this should be explicitly identified (see Section 2.4 for more details). A brief narrative summary of the risk should be provided. Table 7 and 8 provide guidance on determining overall risk based on semi-quantitative or quantitative data. An advantage of the approach outlined in these tables is that it allows the determination of cumulative risk at every stage of the invasion, so that overall risk can be determined even if a species is not successfully achieve all stages of invasion. For example, there may be negative consequences of a species that arrives and survives but does not establish or spread.

Table 5. Sample 6x4 risk matrix for combining likelihood of introduction and magnitude of consequences.

Likelihood \ Magnitude of Consequences	Very Low	Low	High	Very High
Almost Certain	Green	Green	Yellow	Red
V. Likely	Green	Green	Yellow	Red
High	Green	Green	Green	Yellow
Low	Green	Green	Green	Green
V. Unlikely	Green	Green	Green	Green
Negligible	Green	Green	Green	Green

Green = low risk **Yellow = moderate risk** **Red = high risk**

Table 6. Sample 7x5 risk matrix for combining likelihood of introduction and magnitude of consequences.

Likelihood \ Magnitude of Consequences	Very Low	Low	Moderate	High	Very High
Almost Certain	Green	Green	Yellow	Red	Red
V. Likely	Green	Green	Yellow	Red	Red
High	Green	Green	Yellow	Yellow	Red
Moderate	Green	Green	Green	Yellow	Yellow
Low	Green	Green	Green	Green	Green
V. Unlikely	Green	Green	Green	Green	Green
Negligible	Green	Green	Green	Green	Green

Green = low risk **Yellow = moderate risk** **Red = high risk**

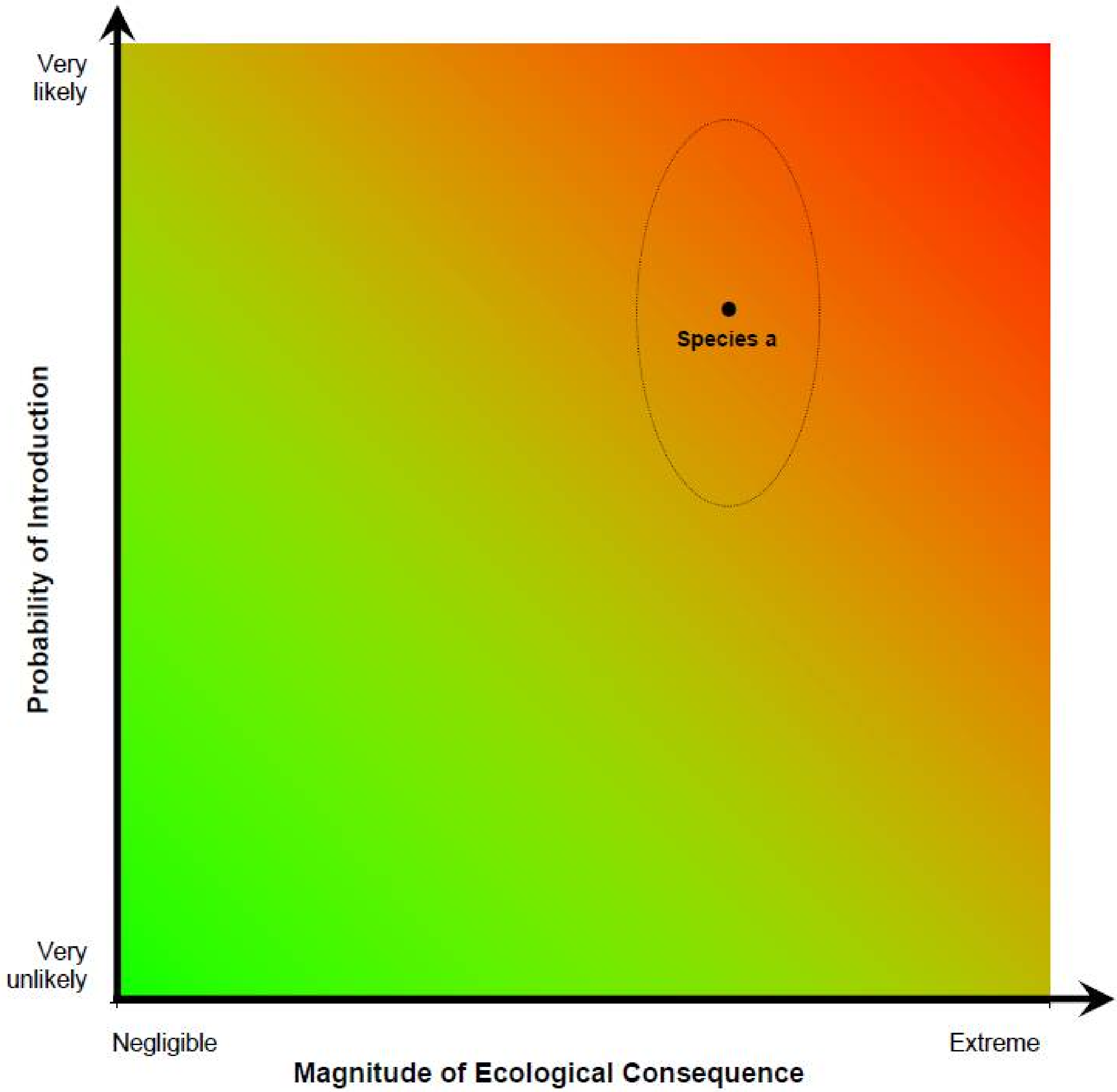

Figure 2. Sample risk matrix combining likelihood of introduction and magnitude of consequences using a gradient approach

Table 7. Likelihood and magnitude of consequences ratings by element based on semi-quantitative or quantitative data.

Element	**Likelihood (L)**	**Impact (I) on Canadian Environment**	**Element Description**
Arrive	L_1	I_1	Species arrives but does not survive
Survive	L_2	I_2	Species survives but does not establish
Establish	L_3	I_3	A local population is established
Spread	L_4	I_4	Widespread invasion

Table 8. Combining likelihood and consequence ratings for risk determination based on semi-quantitative or quantitative data.

Possible Outcome of Introduction elements	**Likelihood[1]**	**Consequence**	**Risk[2]**
Arrives (A), but no survival	$L_A = Min(L_1, 1\text{-}L_2)$	$I_A = I_1$	$R_A = [L_A, I_A]$
Survives (S), but no reproduction	$L_S = Min(L_1, L_2, 1\text{-}L_3)$	$I_S = I_2$	$R_S = [L_S, I_S]$
Establishes (E) locally	$L_E = Min(L_1, L_2, L_3, 1\text{-}L_4)$	$I_E = I_3$	$R_E = [L_A, I_A]$
Widespread (W) invasion	$L_W = Min(L_1, L_2, L_3, L_4)$	$I_W = I_4$	$R_W = [L_W, I_W]$
Overall Risk			$R_{Total} = Max(R_A, R_S, R_E, R_W)$

[1] For likelihood categories, 1-L can be determined as shown in Table 1.
[2] Risk is determined from a consistent risk matrix based on the likelihood of introduction and magnitude of consequences.

2.3.3.2 Fellow Travellers

Fellow travellers may be incidental (in the transport medium [e.g., water, rocks] along with the primary species) or directly associated with the AIS (pathogens, parasites, disease). They will generally be a source of uncertainty as they are typically extremely difficult to assess. However, the possibility of fellow travellers needs to be included in the potential biological consequences of the AIS beginning with their identification in the biological synopsis. Where sufficient information is available, and dependant on potential biological consequences, a separate risk assessment should be conducted specifically for fellow travellers (pathogens, parasites, disease or other organisms not native to the geographic area of interest). The risk assessment for fellow travellers is identical to that for the primary AIS (Section 2.3.2.1).

2.3.4 Components of the Final Risk Assessment

The final risk characterization for an AIS and any fellow travellers will consist of the final risk estimates, which will typically comprise the highest risk and highest uncertainties for a species and its fellow travellers (Table 9). This final, relatively simple overall summary needs to be supported by appropriate written narrative including examples of ecological and genetic consequences. This information can be used by decision makers as part of risk management to determine required management activities and in risk communication to explain management decisions.

Table 9. Example of final risk characterization

	Overall Risk	Overall Uncertainty
A. Species	Table 5, 6 and 7, or Table 8 and 9	As described in text
B. Fellow Travellers	Table 5, 6 and 7, or Table 8 and 9	As described in text
Final	Max of A and B	Max of A and B

2.4 UNCERTAINTY

2.4.1 General Considerations

Scientific investigations do not usually result in easy answers. Uncertainty is inherent in any and all risk assessments. However, the risk assessment process is designed to accommodate the relationship between scientific uncertainty and the ability of risk managers to make risk management decisions (CCME 1996). The goal in progressing from screening (RAP) to more comprehensive assessment (SLRA or DLRA) is to reduce key uncertainties and improve confidence in the decision-making process.

The decision to progress from a RAP or an SLRA to a DLRA should be based on reducing key uncertainties and / or an improved ability to quantify and partition those uncertainties. However, if an evaluation indicates that progression to higher risk assessment levels may not diminish uncertainty to the point where decision making becomes any more straightforward, then risk managers must evaluate whether the benefits of the ensuing marginal decrease in uncertainty justify the corresponding time and costs. It may prove more expedient to proceed to an examination of risk management options, particularly in cases where socio-economic or technological constraints may limit these options.

2.4.2 Guidance in Dealing with Uncertainty

Uncertainty may include chance (outcome of a random process), tendency (how likely it is perceived to occur, given history), knowledge (awareness of various outcomes), confidence (belief in outcome based on experience), control (higher perceived probability with influence over outcome), and plausibility (how convincingly a case is presented). General guidance on dealing with uncertainty is provided by Morgan and Henrion (1990). Uncertainty needs to be explicitly considered for each component of any risk assessment considering degree of belief and extent of available information and detailing knowledge gaps and their importance and significance. Stochastic uncertainty refers to the inherent randomness of the system being assessed and can be described and estimated but cannot be reduced. Uncertainty arising from human error or from imperfect knowledge can be reduced. For example, unclear management objectives will have high uncertainty, which can be reduced by clear, focused management objectives. Where possible, numerical values of uncertainty should be expressed as a range not a single number.

Three common methods for dealing with sources of uncertainty are sensitivity analysis, Monte Carlo simulation, and the use of actual data for model calibration. Sensitivity analysis is a fundamental requirement of any model application and geared to ensuring that the level of effort applied to improving the accuracy of model input parameters is commensurate with their effect on the accuracy of modeled output. Input parameters that have only a small effect on the accuracy of modeled output can be estimated by less accurate and costly methods. Once sensitivity analysis has identified the critical input parameters, a Monte Carlo analysis provides a stochastic approach to generating probabilistic model output through repetitive model runs using the distribution characteristics of uncertain model input parameters. The probability distributions associated with this approach provide an excellent means of quantifying model uncertainty. However, unless the input parameter distribution characteristics are derived from actual data, the uncertainty in outputs is a function of assumptions made about the uncertainty of input parameters. Model calibration using actual data is an obvious and necessary means of diminishing uncertainty, provided that independent data are used.

2.5 APPLICATION OF THE GUIDELINES

These guidelines apply to AIS that may potentially be introduced to Canadian waters or, if already in Canadian waters, may spread to other areas by any means other than authorized release. The scale of geographic scope for assessing risk may vary, but should be decided the initial *Problem Formulation* phase of the risk assessment. Biological risk assessments for aquatic invasive species may need to be updated if new management concerns develop requiring further science advice, or new data become available that may reduce uncertainty and/or change the overall risk, and should be considered living documents.

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APPENDIX 1. LIST OF ACRONYMS

AIS	Aquatic Invasive Species
AISTG	Aquatic Invasive Species Task Group
CCFAM	Canadian Council of Fisheries and Aquaculture Ministers
CCME	Canadian Council of Ministers of the Environment
CEARA	Centre of Expertise for Aquatic Risk Assessment
CSAS	Canadian Science Advisory Secretariat
DFO	Department of Fisheries and Oceans
DLRA	Detailed Level Risk Assessment
FAO	Food and Agriculture Organization
RAP	Rapid Assessment Protocol
SLRA	Screening Level Risk Assessment
TGIT	Task Group on Introductions and Transfers
UNEP	United Nations Environment Program

APPENDIX 2. GLOSSARY

(Definitions, where appropriate, from CCFAM-AISTG 2004 and TGIT 2003)

Aquatic invasive species: Fish, animal, and plant species that have been introduced into a new aquatic ecosystem and are having harmful consequences for the natural resources in the native aquatic ecosystem and/or the human use of the resource.

Biodiversity: The totality of genes, species, and ecosystems of a region.

Fellow traveller: An organism that inadvertently accompanies a species, e.g., parasites, pathogens or other organisms.

Hazard: The possibility of a negative or undesirable event occurring.

Hypothetico-Deductive Reasoning: The scientific method that involves examining all possible factors that might affect an outcome, determining questions that need to be answered, and deducing specific hypothesis or predictions about what might happen using best available information.

Impact: An adverse (harmful) effect of such significance that it affects not just individual organisms, but the health of a population of organisms (e.g., their function and/or productivity).

Pathway: One or more routes by which an invasive species is transferred from one geographic area to another.

Precautionary Principle: Where there are threats of serious or irreversible damage, lack of full scientific certainty shall not be used as a reason for postponing actions (UNEP 1992).

Propagule pressure: Number of viable organisms (plant or animal, or part thereof, capable of independent growth) that could arrive in a geographic area over a set time period.

Risk: The probability of an event happening multiplied by the impact of the event occurring. For AIS risk is the likelihood of introduction and establishment multiplied by the extent of biological consequences.

Risk analysis: The process that includes risk assessment, risk management and risk communication (see below and Figure 1).

Risk assessment: The process of determining of the value of risk, either in qualitative or quantitative terms. For AIS, it is the determination of the likelihood of introduction and the estimation of the extent of biological consequences.

Risk communication: The process by which the results of the risk assessment and proposed risk management measures are communicated to a decision-making authority and interested parties.

Risk management: The process of identifying, evaluating, selecting and implementing alternative measures for reducing risk.

Sensitivity analysis: An analysis of how sensitive outcomes are to changes in data and / or assumptions.

Vector: The physical means by which a species is transported from one area to another, usually referring to transport by humans.