Fisheries and Oceans Canada / Pêches et Océans Canada
Science / Sciences

C S A S | **S C C S**

Canadian Science Advisory Secretariat | **Secrétariat canadien de consultation scientifique**

Research Document 2012/097 | **Document de recherche 2012/097**

Central and Arctic Region | **Région du Centre et de l'Arctique**

Developing a Screening-Level Risk Assessment Prioritization Protocol for Aquatic Non-Indigenous Species in Canada: Review of Existing Protocols

Élaboration d'un protocole de filtrage et de priorisation pour l'évaluation des risques relatifs aux espèces aquatiques non indigènes au Canada : Examen des protocoles existants

Eric Snyder[1], Nicholas E. Mandrak[2], Heather Niblock[2], Becky Cudmore[2]

[1] Biodiversity Policy and Program Development
Ontario Ministry of Natural Resources
300 Water Street, 2nd Floor, North Tower
Peterborough, Ontario, K9J 8M5

[2] Center of Expertise for Aquatic Risk Assessment
Fisheries and Oceans Canada
867 Lakeshore Rd. Burlington, ON L7R 3A2

ISSN 1499-3848 (Printed / Imprimé)
ISSN 1919-5044 (Online / En ligne)

Canada

Correct citation for this publication:

Snyder E., Mandrak, N.E., Niblock, H., Cudmore, B. 2013. Developing a screening-level risk assessment prioritization protocol for aquatic non-indigenous species in Canada: review of existing protocols. DFO Can. Sci. Advis. Sec. Res. Doc. 2012/097. vii + 75 p.

ABSTRACT

Fisheries and Oceans Canada's (DFO) mission is to deliver 'sustainable aquatic ecosystems' to the people of Canada. This objective is seriously compromised if aquatic invasive species (AIS) enter Canadian waters and cause ecosystem harm without preventative barriers in place to stop them. To focus DFO's attention on species that pose the greatest potential ecological harm, biological risk assessment protocols are required. A protocol that allows screening and prioritization of non-indigenous species in a short time frame, is necessary to assess the multitude of NIS that are potential threats. A screening-level risk assessment (SLRA) prioritization protocol will provide DFO with a scientifically defensible and relatively quick means of prioritizing these NIS. This report provides an evaluation of 13 representative screening and prioritization RA protocols using standardized criteria for the determination of their conceptual, scientific, and pragmatic strengths and weaknesses. Based on this evaluation, the Alberta Risk Assessment and FISK scored the highest of the tools evaluated. As FISK is specific to freshwater fishes, it is recommended that related protocols, MISK (marine fishes) and MI-ISK (marine invertebrates) be evaluated for marine species. Based on the results of these evaluations, (a) final protocol(s) should be selected for use by DFO as a national SLRA protocol for screening and prioritizing AIS.

RÉSUMÉ

La mission de Pêches et Océans Canada (MPO) est d'assurer « des écosystèmes aquatiques durables » aux Canadiens. En l'absence de mécanismes de prévention, l'introduction d'espèces aquatiques envahissantes (EAE) peut gravement compromettre cet objectif en causant des dommages aux écosystèmes. Afin de bien axer son attention sur les espèces qui représentent le plus grand risque de dommages pour les écosystèmes, le MPO a besoin de protocoles d'évaluation des risques biologiques. Il lui faut un protocole qui lui permet de filtrer et de prioriser les espèces non indigènes en peu de temps afin d'évaluer lesquelles pourraient constituer des menaces. Un protocole de filtrage et de priorisation pour l'évaluation des risques permettra au MPO d'établir l'ordre prioritaire des espèces non indigènes de façon relativement rapide et justifiable sur le plan scientifique. Le présent rapport contient une évaluation de 13 protocoles de filtrage et de priorisation représentatifs analysés selon des critères normalisés pour déterminer leurs forces et leurs faiblesses d'un point de vue conceptuel, scientifique et pragmatique. Au terme de cette évaluation, l'outil d'évaluation du risque de l'Alberta et le FISK ont obtenu les meilleures notes. Puisque le FISK ne concerne que les poissons d'eau douce, on recommande d'évaluer l'utilisation possible des protocoles connexes, soit le MISK (poissons marins) et le MI-ISK (invertébrés marins), relativement aux espèces marines. En fonction de cette évaluation, un ou plusieurs protocoles pourront être définitivement choisis comme outil de filtrage et de priorisation national pour l'évaluation des risques relatifs aux EAE.

TABLE OF CONTENTS

GLOSSARY

Alien species: A species of plant, animal, or micro-organism occurring outside its native distribution as a result of human actions (Government of Canada 2004).

Aquatic invasive species (AIS): Fish, animal, and plant species that have been introduced into a new aquatic ecosystem and are having harmful consequences to the natural resources in the invaded aquatic ecosystem and/or the human use of the resource (Mandrak et al.2012).

Biodiversity: The totality of genes, species, and ecosystems of a region (Mandrak et al. 2012).

Decision-tree: Type of tree diagram used in determining the optimum course of action, in situations having several possible alternatives with uncertain outcomes. The resulting chart or diagram (which looks like a cluster of tree branches) displays the structure of a particular decision, and the interrelationships and interplay between different alternatives, decisions, and possible outcomes (www.businessdictionary.com).

Domestic protocol: Developed to evaluate risk posed by species already arrived in an area of interest, or currently in a trade pathway. In this document, applies to species already in Canada (Snyder 2007).

Fellow traveler: An organism that inadvertently accompanies a species, e.g., parasites, pathogens, or other organisms (AISTG 2003).

Genetics: The branch of biology that studies heredity and variation in organisms (www.merriam-webster.com).

Hazard: A negative or undesirable event (Mandrak et al. 2012).

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 (Mandrak et al.2012).

Impact: An adverse (harmful) effect of such significance that it affects not just individual organisms, but the health of a population of organisms (i.e., their function and/or productivity) (Mandrak et al. 2012).

Introduced species: Any species intentionally or accidentally transported and released by humans into an environment or facility with access to an open-water or flow-through system outside its present range (AISTG 2003).

Invasive alien species: Those harmful alien species, the presence of which within Canada, threatens the environment, the economy, or society (Government of Canada 2004). See also aquatic invasive species.

Naturalized species: Introduced species that have become established and have formed self-sustaining populations (AISTG 2003).

Non-indigenous species (NIS): A species of plant, animal or micro-organism occurring outside its natural past or present distribution as a result of human actions (Anonymous 1996).

Pathway: One or more routes by which an invasive species is transferred from one geographic area to another (Mandrak et al.2012).

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 (Mandrak et al.2012).

Prioritization: To list or rate a group of items in order of rank or position (modified after www.merriam-webster.com).

Propagule: A plant or animal, or part thereof, capable of independent growth (modified after www.biology-online.org).

Propagule pressure: Number of viable organisms that could arrive in a geographic area over a set time period (Mandrak et al. 2012).

Quarantine protocol: Protocols developed to evaluate risk posed by a species that has not yet arrived in the area of interest. In this document it applies to species not already in Canada (Snyder 2007).

Risk: The probability of an event happening multiplied by the impact of the event. For NIS risk, it is the likelihood of introduction and establishment multiplied by the extent of biological consequences (Mandrak et al. 2012).

Risk analysis: The process that includes risk assessment, risk management, and risk communication (Mandrak et al. 2012).

Risk assessment (RA): The process of determining the value of risk, either in qualitative or quantitative terms. For NIS, it is the determination of the likelihood of introduction and the estimation of the extent of biological consequences (Mandrak et al.2012).

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 (Mandrak et al. 2012).

Risk management: The process of identifying, evaluating, selecting, and implementing alternative measures for reducing risk (Mandrak et al. 2012).

Scoring system: A system of classifying according to quality or merit or amount.

Screening: Evaluating a large number of subjects to identify those with a particular set of attributes or characteristics (Snyder 2007).

Sensitivity analysis: An analysis of how sensitive outcomes are to changes in data and / or assumptions (Mandrak et al. 2012).

Transgenic: Genetically engineered (www.dfo-mpo.gc.ca/science/biotech/abgrds-srdbfa/faq-eng.htm).

Uncertainty: There are three basic 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 (Sikder et al. 2006)**.**

Vector: The physical means by which a species is transported from one area to another, usually referring to transport by humans (Mandrak et al. 2012). Vectors include ballast water; pet, aquarium or horticultural trade; recreational boating; fellow travellers on goods and packing materials; stowaway on various modes of transportation (ships, planes, trains, vehicles); and, wildlife disease.

LIST OF ABBREVIATIONS

AB RAT: Alberta Risk Assessment Tool

AIS: Aquatic Invasive Species

A-WRA: Australian Weed Risk Assessment Protocol

CEARA: Center of Expertise for Aquatic Risk Assessment

DFO: Fisheries and Oceans Canada

DLRA: Detailed-level Risk Assessment

EPPO: European Plant Protection Organization

FI-FISK: Freshwater Invertebrate Invasiveness Scoring Kit

FISK: Freshwater Fish Invasiveness Scoring Kit

H-WRA: Hawaiian Weed Risk Assessment

ISK: Invasiveness Scoring Kit

NIS: Non-indigenous species

RA: Risk Assessment

RAP: Rapid Assessment Process

RAT: Risk Assessment Tool

ROC: Receiver Operating Characteristic

SLRA: Screening-level Risk Assessment

WRA: Weed Risk Assessment

1.0 INTRODUCTION

1.1 PURPOSE

Fisheries and Oceans Canada's (DFO) mission is to deliver 'sustainable aquatic ecosystems' to the people of Canada. This objective is seriously compromised if aquatic invasive species (AIS) enter Canadian waters and cause ecosystem harm without preventative barriers in place to stop them. To focus DFO's attention on species that pose the greatest potential ecological harm, biological risk assessment protocols are required.

DFO's AIS program was tasked by both the Office of the Auditor General and an internal evaluation to establish a protocol to provide a scientifically defensible and relatively quick way of screening and prioritizing aquatic non-indigenous species (NIS). The national ranking of aquatic NIS, based on the biological risk they pose to Canadian aquatic ecosystems, is necessary to better prioritise national and regional NIS program activities and resource allocation.

The Department also requested science advice to support the development of a national regulatory proposal for addressing aquatic NIS. Specifically, it had requested: 1) a protocol to prioritise aquatic NIS; and, 2) a list of high risk aquatic NIS including those NIS already present in some regions of Canada whose transport into other areas in Canada where not present should be limited. This protocol will allow the ranking of aquatic NIS for national priorities and will be used as a biological screening tool for aquatic NIS to determine (in a short time frame) if a more detailed-level risk assessment or a risk management evaluation is required based on existing information.

This report represents the first step in establishing this protocol. It evaluates existing biological risk assessment protocols and selects two of the most appropriate protocols for further testing, based on the needs of DFO, to prioritize and screen aquatic non-indigenous species for invasiveness. The selected protocols will be tested, modified and calibrated for further evaluation and potential use as a screening and prioritization protocol for DFO.

1.2 BACKGROUND

The biological invasion of NIS into a new area can be divided into four sequential stages: arrival; survival; establishment; and, spread (Kolar and Lodge 2001, Williams 2003, Mandrak et al. 2012). A species is established if a reproducing population of the species occurs in the area.

The realization of any of these stages can have cumulative social, economic, and biological consequences. However, the focus of this report is on biological risk, the potential for ecosystem harm. Biological risk considers the potential ecological and genetic impacts of an NIS on an ecosystem (Mandrak et al 2012).

Biological risk is assessed by combining the probability of introduction with predicted magnitude of harm. Some risk assessment (RA) protocols sum numerical indices of invasiveness. Others multiply probability of invasion by an estimation of magnitude of resulting harm. Still others sum estimated magnitudes of consequences of invasion weighted by their probabilities, i.e. calculate risk as the expectation of harmful impacts. Different methods are used to estimate uncertainty, as different sources of uncertainty exist. Uncertainty in an RA results from randomness inherent in the stages of invasion (stochasticity), or from lack of knowledge of the invasiveness of an NIS (Sikder et al. 2006), and from other sources common in ecology (Regan et al. 2002): epistemic uncertainty including measurement error, systematic error, natural variation, inherent randomness, model uncertainty, and subjective judgment; and, linguistic uncertainty including numerical vagueness, nonnumerical vagueness, context dependence, ambiguity, indeterminacy in theoretical terms, and under specificity.

DFO's Center of Expertise for Aquatic Risk Assessment (CEARA) has been developing a three-stage biological risk assessment process for aquatic NIS (Chapman et al. 2006, 2009). The three stages are:

(a) *rapid assessment process* (RAP) to assess a species within a few days using minimal information (being developed);

(b) *screening-level risk assessment* (SLRA) to assess and prioritize a species in about a week using additional informatio*n that is readily available (th*e focus of this document); and,

(c) *detailed-level risk assessment* (DLRA) to assess a species within several months using detailed information (Mandrak et al. 2012*).*

Depending on the purpose of the risk assessment, inc*reasingly more detailed risk a*ssessments can then be undertaken with the DLRA providing the strongest defensible ad*vice.*

A SLRA can serve two purposes. First, it can be used to prioritize (i.e. rank) NIS that pose a risk to Canada's aquatic ecosystems. Prioritization of NIS should be determined using the estimated level of risk posed by the species and associated uncertainty, as quantified by the SLRA (Mandrak et al. 2012). Second, with the establishment of appropriate threshold criteria or parameters, the SLRA should supply a risk-based biological screening of NIS, providing a priority list of species for managers and decision makers that requires either a detailed-level risk assessment or a risk management evaluation (Locke et al. 2009).

A SLRA protocol should be applicable to a wide range of aquatic NIS in a variety of risk assessment contexts. It should be a means to quickly assess species known to occur in Canada, as well as species proposed for, or currently found in, trade and other pathways that have intermediate or end points within Canada. It should be applicable to the assessment of risk posed by aquatic species. The SLRA protocol would apply to species introduced through unauthorized means, or through authorized means but not covered by the DFO's *National Code on Introductions and Transfers of Aquatic Organisms*.

2.0 PROTOCOL TYPES

There are four commonly used types of risk assessment protocols: scoring systems; decision-tree systems; combination scoring-decision-tree systems; and, probabilistic systems.

2.1 SCORING SYSTEMS

Scoring systems prioritize the risk or threat posed by NIS. Scores are assigned based on the answers to a series of questions about the species such as: species biology and ecology; potential to arrive, establish, and spread in an area; and, potential impact on the invaded environment. Scores assigned to individual questions are combined in some manner, typically by addition or multiplication, by taking the mean or an extremum of sub-scores, or, by a combination of these to come up with an overall score for the species. An uncertainty rank is often assigned to the score for each question. These scores can then generate a prioritized list of high to low priority species and indicate the certainty associated with each score.

Scoring systems can be used for screening in both domestic (species already in Canada) and quarantine (species not yet in Canada) situations. Species that score below a given threshold score may be deemed to pose a sufficiently low risk that no management actions, preventative measures, or prohibitions on importation are necessary. Alternatively, a high score may indicate that preventative measures or prohibitions are necessary. To calibrate a protocol, threshold scores are determined by scoring known invasive and non-invasive species in the assessment area.

2.2 DECISION-TREE SYSTEMS

A decision-tree is designed to screen species in or out of the class of invasive species in a systematic manner. In most cases, a dichotomous tree structure is used. A series of dichotomous questions must be answered leading the risk assessor to a decision: screen in; screen out; or, assess further.

Decision-trees are not typically considered to be methods of prioritization or ranking. A screened out species is qualified as posing *no* risk and a screened in species poses *some* risk. Most decision-trees in the invasive species literature do not address prioritizing species. Nonetheless, since decision-trees employ an iterative process, they could be modified to also prioritize screened in species based on the different decision-tree paths that led to the determination (Tucker and Richardson 1995).

2.3 SCORING-DECISION-TREE SYSTEMS

On occasion, scoring and decision-tree approaches have been combined, typically with the scoring system embedded within a decision-tree framework where the score will lead the assessor through a series of decisions and, ultimately, a certain screening decision.

2.4 PROBABILISTIC SYSTEMS

Probabilistic systems use prior knowledge of species biology and invasion history elsewhere to form invasion probabilities for the assessment area in question, and incorporate quantitative uncertainty and variation (Diez et al. 2011). Probability thresholds related to risk are determined using known invasive and non-invasive species in the assessment area. For example, Keller et al. (2007) used a nuisance probability model within a decision-tree framework to assess the risk of freshwater molluscs.

3.0 RISK ASSESSMENT PROTOCOL SELECTION

3.1 OVERVIEW OF RA SELECTION METHODOLOGY

Selection of a biological RA protocol consisted of three successive steps. First, a pool of screening and prioritization biological RA protocols were identified, classified, and screened to create a sub-group of protocols to be retained for further evaluation. Second, criteria for the evaluation of these RA protocols were defined and applied to the sub-group of selected RA protocols. Lastly, based on the results of this evaluation, the protocol that best served DFO's objectives was identified.

3.2 SCREENING OF RA PROTOCOLS FOR FURTHER EVALUATION

A survey of RA protocols was conducted by consulting published literature, list servers, websites of government departments, agencies, and ministries, and personal communication. As DFO requires a protocol that can be applied to a wide variety of aquatic AIS – i.e. marine and freshwater invertebrate and vertebrate species - in both domestic and quarantine contexts, it was necessary to evaluate a sufficient number of protocols to satisfy its requirements. Over 80 RA protocols were found in this way. **The protocols considered in this review are identified with a bold font in the References section.**

In view of the large number of RA protocols identified, it was not practical to conduct a complete evaluation of each protocol. All RA protocols from the original pool were first classified. A nested classification system was developed to categorize RA protocols based on: 1) scoring and protocol type; 2) whether the RA is intended for use in a domestic context (i.e. for species already in Canada), or in a quarantined context (i.e. for those not yet arrived in Canada); and, 3) the type of taxa addressed by the RA.

Based on this classification, an effort was then made to assign RA protocols for each combination of criteria (or class), although this was not always possible. A total of 13 RA protocols were retained for further evaluation. From the original pool, combined scoring and decision-tree protocols were found only for plant species. No protocols were found that employ a decision-tree system in a domestic context. Only three protocols specifically evaluated invertebrates, although a number of protocols were identified that apply to diverse life forms, including a combination of invertebrates, vertebrates, and plants.

When more than one RA protocol was identified in a single class, the single protocol retained for further evaluation was one that had: (a) been designed for aquatic species, at least in part; (b) been applied extensively, especially in Canada; and, (c) been reviewed for scientific or pragmatic strengths and weaknesses by the senior author, who has extensive experience in use of SLRA. For example, the Australian WRA was chosen for detailed evaluation rather than other scoring, quarantine protocols for plants because it has been widely adopted and reviewed in the scientific literature, and it can be applied to aquatic species.

The 13 RA protocols selected for evaluation are shown in Table 1 and briefly described in Table 2.

Table 1. Risk assessment protocol nested classification system with the 13 selected RA protocols.

Scoring Type	Protocol Type	Taxa Evaluated	Protocol Name	Abbreviation
Scoring System	**Quarantine**	**Plants**	Australian Weed Risk Assessment Protocol (Pheloung 2001)	A-WRA
		Fishes	Freshwater Fish Invasiveness Scoring Kit Protocol (Vilizzi et al.2007a)	FISK
		Invertebrates	Freshwater Invertebrate Invasiveness Scoring Kit Protocol (Vilizzi et al.2007b)	FI-FISK
	Quarantine, Domestic	**Marine Taxa**	Hayes et al.(2005)	
	Domestic	**Plants**	Invasive Species Assessment Protocol (Randall et al.2008)	I-Rank
		Diverse Life Forms	Alberta Risk Assessment Tool V.3 (IASWG 2008)	AB RAT
Decision-Tree Systems	**Quarantine**	**Plants**	Reichard and Hamilton (1997)	-
		Fishes	Kolar and Lodge (2002)	-
Scoring-Decision-Tree Systems	**Quarantine**	**Plants**	Hawaiian Weed Risk Assessment Protocol (Daehler et al.2004)	H-WRA
Scoring-Decision-Tree Systems	**Quarantine**	**Plants**	Tucker and Richardson (1995)	-
	Domestic	**Plants**	European Plant Protection Organization Prioritization Protocol (Brunel 2009)	EPPO
Probabilistic	**Quarantine**	**Marine Taxa**	Hayes and Hewitt (2000)	-
	Domestic	**Molluscs**	Keller et al.(2007)	

Table 2. Description of the assessment categories and scoring schemes for the 13 selected risk assessment protocols.

Protocol Name Abbreviation	Location / Environment Evaluated	Assessment Category Names	Scoring Scheme
A-WRA	Australian land plants	1. Biogeography and Species History (Domestication / Cultivation, Climate & Distribution, Weed Elsewhere) 2. Plant Biology and Ecology (Undesirable Traits, Plant Type, Reproduction, Dispersal Mechanisms, Persistence Attributes)	• 49 questions • positively correlated with invasiveness • some weighting • -14 to 29 as possible score • minimum number of questions must be answered
FISK	Freshwater fishes in the United Kingdom	1. Biogeography and Species History (Domestication, Climate & Distribution, Invasive History) 2. Biology and Ecology (Undesirable Traits, Feeding Guild, Reproduction, Dispersal Mechanisms, Tolerance Attributes)	• 49 questions • positively correlated with invasiveness • some weighting • -11 to 54 as possible score • minimum number of questions must be answered
FI-FISK	Freshwater invertebrates in the United Kingdom	1. Biogeography and Species History (Domestication, Climate & Distribution, Invasive History) 2. Biology and Ecology (Undesirable Traits, Feeding Guild, Reproduction, Dispersal Mechanisms, Tolerance Attributes)	• 49 questions • positively correlated with invasiveness • some weighting • -11 to 54 as possible score • minimum number of questions must be answered
I-Rank	Land plants in any region	1. Ecological Impact 2. Current Distribution and Abundance 3. Trends in Distribution and Abundance 4. Management Difficulty	• 2 preliminary questions • 22 questions divided into 4 categories • 4 categories assigned sub –ranks • sub-ranks weighted to give overall score (ecological impact given greatest weighting)
AB RAT V.3	Terrestrial and aquatic life forms in Alberta	1. Exposure 2. Environmental Effects 3. Economic Effects 4. Social Effects	• 58 questions in 4 categories

Protocol Name Abbreviation	Location / Environment Evaluated	Assessment Category Names	Scoring Scheme
Reichard and Hamilton (1997)	Woody plants in North America	1. History of Establishment Elsewhere 2. Taxonomic Relationships with Other Naturalized Species 3. Vegetative Reproduction 4. Rapid Vegetative Spread 5. Native Range 6. Length of Juvenile Period 7. Requirement of Seed Pre-Treatment for Germination 8. Whether or not the Plant is an Interspecific Hybrid	Attributes were selected based on their predictive strength as determined by discriminant analysis
Kolar and Lodge (2002)	Freshwater fishes in the Laurentian Great Lakes	Focus is on identifying attributes affecting ability to establish and spread	No protocol developed, but models on which to base protocol are presented
Hayes et al. (2005)	Marine taxa in Australia	1. Shipping Vectors 2. Develop domestic and quarantine species target lists 3. Environmental Similarity 4. Invasion Potential 5. Impact Potential	Equation incorporating 3-5
H-WRA	Land plants in Hawaii	Used A-WRA then adds second level of evaluation looking at: 1. Weediness Elsewhere 2. Life Cycle Length 3. Palatability to Grazers 4. Bird Dispersal 5. Capacity to Form Dense Stands	A-WRA (see above) supplemented with a decision-tree for shrubs and trees in the 'evaluate further' range
Tucker and Richardson (1995)	Non-woody plants in South African fybos	1. Environmental Conditions in the Plant's Native Ecosystem 2. Population Characteristics and Habitat Specialization 3. Seed Dispersal 4. Seed Production 5. Seed Predation 6. Life History Adaptations to Fire	• 24 questions in decision-tree • terminal nodes assign priority

Protocol Name Abbreviation	Location / Environment Evaluated	Assessment Category Names	Scoring Scheme
EPPO	Plants in the Europe, Mediterranean Africa and most of the non-European Russian Federation	1. Distribution of the Plant; Eco-Climatic Similarity; Invasiveness Elsewhere; Status within the Region 2. Impacts (on Natural and Managed Ecosystems)	Screened in or out with decision-tree questions (1), then scored based on impacts (2).
Keller et al.(2007)	Freshwater mollusks n the Great Lakes basin and the conterminous United States	1. Biology and Traits (type of reproduction; egg brooding; fecundity, maximum size, longevity, nonnative elsewhere, time since introduction, larval stage)	Decision-tree informed by probabilistic logistic regression based on fecundity.
Hayes and Hewitt (2000)	Ballast water risk in Australia	1. Ballast water risk as a function of: • probability donor port infected • probability vessel infected • probability AIS survives vessel voyage • probability AIS could survive in recipient port.	Probabilistic model of ballast water risk.

3.3 EVALUATION CRITERIA

The seven criteria used to evaluate the sub-group of selected RA protocols were taken from the environmental RA literature. Covello and Merkhofer (1993) had the most comprehensive evaluation criteria including soundness, completeness, accuracy, acceptability, practicality, and effectiveness. S*oundness*, *completeness*, and *accuracy* are scientific criteria. They assess if a protocol is grounded in scientific methods, theories, and evidence, and determine the degree of accuracy of a risk assessment score. *Acceptability*, *practicality* and *effectiveness* are pragmatic criteria. They assess the suitability of a protocol in the context in which DFO will apply it. To these criteria, *perspicuity* was added. *Perspicuity* is a conceptual criterion that evaluates how the structure of a protocol reflects distinct components of risk assessment and judges the clarity of concepts in a protocol.

Covello and Merkhofer (1993) assessed chemical and physical stressors. For the purposes of this study, their evaluation criteria were redefined to make them applicable to the assessment of NIS. A list of questions (or components) was created to evaluate how well the RA protocols meet each of the criterion. These questions were adapted from biological risk assessment literature (e.g., Caley and Kuhnert 2006, Pheloung et al.1999, Virtue 2006) and the guiding principles of CEARA (Mandrak et al*.*2012).

3.3.1 Conceptual Criterion

Perspicuity: relates to the distinct components of risk assessment and the concepts employed in a particular protocol. To assess a RA protocol's perspicuity the following questions were asked:

(a) Does the protocol clearly distinguish between the magnitude of consequences of a biological invasion and the probability of its introduction?

(b) Does the protocol adopt clear definitions of the stages of invasion: arrival in an ecosystem, survival, establishment, and spread?

(c) Does the protocol clearly differentiate biological from socio-economic consequences?

(d) Are the questions in the protocol clear and unambiguous?

3.3.2 Scientific Criteria

Soundness: considers whether scientific theory and methods used in a protocol are appropriate. A sound protocol will be based on the theories of biological invasion and environmental assessment. A sound protocol will not contradict standards of logic, probability theory, and statistics. To determine the soundness of a protocol, the following questions were asked:

(a) Can the protocol be justified by biological theory and other applicable natural sciences? For example, the protocol employs taxonomic, physiological, ecological and/or biogeographical predictors of establishment and spread potential that are theoretically defensible?

(b) Is the approach used to measure magnitude of harm based solely on ecological impacts and grounded in scientific theory?

(c) Is the protocol methodologically consistent? Do the methodological assumptions result in unbiased assessments?

Completeness: relates to the theoretical and procedural depth of a protocol. Incompleteness can arise during a particular risk assessment due to inadequate or missing data. However, in this context, completeness looks at whether all relevant considerations are presented in the protocol. To consider completeness, the following questions were asked:

(a) Does the protocol address all components of risk assessment? Does it assess: the likelihood of realizing each stage of invasion; the magnitude of harm; and, the estimation of risk and uncertainty?

(b) Are the theoretical assumptions of the protocol complete? Does the protocol take into account all relevant considerations and information? For example, does the protocol allow the overall score to be altered by any appropriate predictor of a species invading?

(c) Are the assumptions of the protocol concerning the consequences of an invasion complete, providing for all relevant considerations and information? For example, are both ecological and genetic consequences addressed and, if so, can a broad range of values be accounted for with respect to each?

(d) Does the protocol take into account stochastic and epistemic uncertainty in estimating risk and can all relevant sources of uncertainty be addressed?

Accuracy: Accuracy considers whether the resulting risk score correctly characterizes risk and uncertainty. An accurate risk assessment protocol can be applied to reliably predict the extent of risk posed by a NIS. If uncertainties are significant, an accurate protocol will reliably identify species about which more information is needed. For that reason, the existence of uncertainties does not necessarily result in an inaccurate score. The overall risk score may be qualified by substantial uncertainty, but as long as the sources of uncertainty have been properly accounted for by the protocol, the result is not inaccurate. To determine accuracy of a protocol, the following questions were asked:

(a) Has the protocol been empirically tested and validated as a screening or prioritization protocol? Validation allows risk assessors to have a high level of confidence that the protocol results in minimal false positives and negatives.

(b) Does the protocol adequately account for stochastic and epistemic uncertainties, particularly those related to the invasive potential of a species? For example, if knowledge gaps make the use of untested assumptions necessary, does the protocol account for the resulting uncertainties?

3.3.3 Pragmatic Criteria

Acceptability: Acceptability evaluates a protocol's consistency with regulatory and policy requirements and established practices. It also considers the background of those who will rely on it as a decision-support tool. Does a protocol address the needs for which it was developed in a manner that is understandable to the DFO risk assessors and managers who will be applying it, or its results, without contravening established frameworks, guidelines or regulations? To apply criterion, the following questions were asked:

(a) Does the protocol conform to applicable legislated requirements and policy directives of DFO?

(b) Is the protocol compatible with established risk assessment practice, and with other protocols and decision-support tools that have been, or will be, employed at DFO?

(c) Are the protocol and its results understandable to non-technical users (e.g., risk managers who must use results when evaluating management alternatives for AIS)?

Practicality: Practicality questions the ease with which a risk assessment protocol can be used by DFO. It considers limitations relating to expertise, computational support, and information.

For example, if information needed for the assessment is not readily accessible in well-established sources, then it is not practical to use the protocol for screening and prioritization purposes. When considering practicality, the following questions were asked:

(a) Does the level of expertise required to apply the protocol match with that of those who will be applying it (e.g., a junior level biologist / risk assessor)?

(b) If computational tools (e.g. niche matching software) are needed to apply the protocol effectively, are they available or can they be acquired?

(c) Are data readily available for the protocol's requirements? Can it be applied effectively irrespective of some knowledge gaps?

Effectiveness: An effective risk assessment protocol satisfies the purposes of risk assessors and managers at DFO. Does it provide the decision-support that it is intended to provide? If a protocol concludes that most assessed species have uncertain risk levels that require more in-depth investigation, the protocol is not effective as a screening tool. To determine the effectiveness of a risk assessment protocol, the following questions were asked:

(a) Do the results of the protocol provide needed decision-support in both screening and prioritizing species?

(b) Can the protocol be applied to assign a risk estimate without high uncertainty?

(c) Can the protocol be adapted to assess a wide range of aquatic species: plants, invertebrates, and fishes?

(d) Can the protocol be applied in a domestic or quarantine context to assess authorized and unauthorized introduction and spread?

3.4 EVALUATION

The sub-group of selected RA protocols (Tables 1, 2) was assessed against the evaluation criteria by answering the questions defined above. The complete evaluations for each RA protocol are presented in tabular form in Appendices A through M. Within each criterion, each question was answered Yes, Largely, Partially, No, or Uncertain by the senior author, who has extensive knowledge of SLRA, and scored 3, 2, 1, 0, and no score, respectively (Table 3). For each criterion, a mean question score was calculated and assigned a qualitative evaluation (Table 3). For each protocol, the sum of the mean criteria score was used to rank the protocols (Table 4). The results of this evaluation are summarized in Table 4 and discussed in the following sections.

Table 3. Scheme for evaluating selected RA protocols based on questions for the conceptual, scientific, and pragmatic evaluation criteria.

Question Evaluation		Criteria Evaluation	
Question Answer	**Question Score**	**Mean Question Score**	**Evaluation**
Yes	3	3	Completely
Largely	2	2-2.9	Largely
Partially	1	1-1.9	Partially
		0.1-0.9	Minimally
No	0	0	Fails

Table 4. Summary of selected risk assessment protocols based on conceptual, scientific, and pragmatic evaluation criteria.

Protocol Name	Conceptual	Scientific			Pragmatic			
	Perspicuity	Soundness	Completeness	Accuracy	Acceptability	Practicality	Effectiveness	Score
A-WRA	Partially	Partially	Fails	Partially	Largely	Completely	Largely	11.66
FISK	Partially	Partially	Partially	Fails	Largely	Completely	Partially	12.41
FI-ISK	Partially	Partially	Partially	Minimally	Largely	Largely	Partially	10.66
I-Rank	Partially	Largely	Partially	Minimally	Largely	Completely	Minimally	9.83
AB RAT V.3	Completely	Partially	Partially	Partially	Completely	Completely	Largely	16.07
Reichard & Hamilton (1997)	Minimally	Partially	Fails	Minimally	Largely	Completely	Partially	8.66
Kolar & Lodge (2002)	Partially	Minimally	Minimally	Fails	Partially	Completely	Minimally	7.16
Hayes et al.(2005)	Minimally	Largely	Fails	Fails	Largely	Largely	Largely	9.33
H-WRA	Partially	Partially	Fails	Partially	Largely	Completely	Largely	11.16
Tucker & Richardson (1995)	Partially	Partially	Fails	Fails	Largely	Largely	Largely	8.58
EPPO	Largely	Partially	Minimally	Fails	Largely	Completely	Partially	11.08
Keller et al.(2007)	Partially	Largely	Minimally	Partially	Largely	Completely	Partially	11.5
Hayes and Hewitt (2000)	Partially	Largely	Minimally	Partially	Completely	Completely	Fails	11

3.4.1 Conceptual criterion

Most RA protocols failed to satisfy the single conceptual criterion completely.

(a) *Perspicuity*: The majority of protocols had reasonably clear scoring or decision node questions. Most of the protocols clearly differentiated the biological from the socio-economic consequences of an invasion. However, very few clearly defined the stages of invasion or clearly differentiated the magnitude of consequences of a biological invasion from the probability of its occurrence; the exceptions being EPPO and Alberta RAT.

3.4.2 Scientific criteria

There was variability in the extent to which the RA protocols satisfied the three scientific criteria.

(a) *Soundness*: All RA protocols were considered theoretically sound, as they reflected the results of scientific studies that, given appropriate qualifications, established a sound basis for explaining and predicting biological invasions. The theoretical ideal of a unified nomological model for the explanation and prediction of invasions

(Rejmanek 1996, 1999) seems particularly pertinent to a general risk assessment protocol applicable to varied life forms and ecoregions. Protocols can, therefore, be evaluated based on the extent to which they approximate the ideal. However, the ideal itself is open to criticism (Shrader-Frechette 2001; cf. Ashton and Mitchell 1989, NRC 2002, Mack 1996), which leaves conclusions be drawn from such comparisons somewhat uncertain. Where the assessment of the magnitude of harm of a biological invasion is concerned, uncertainty arises for a very different reason. Little or no attention has been paid to theory, whether particular studies or the more comprehensive theoretical considerations that might inform such studies, in the construction of prioritization systems of the impacts of biological invasions. Most protocols were also determined to be largely methodologically valid. In situations where methodological problems were identified, these difficulties were ultimately surmounted, for instance, by adjusting the scoring or recalibrating.

(b) *Completeness*: A number of protocols were considered incomplete for the purposes of DFO, in part because they were not specifically designed for application to aquatic species. Protocols were also found to be incomplete based on this criterion as they were designed to address only a few stages of the biological invasion process. Furthermore, most protocols did not allow the estimation of the level of uncertainty attributed to the evaluation; the exceptions being the ISK protocols. Only the latter provided a standard method for estimating the uncertainty of the final risk characterization.

(c) *Accuracy*: Overall, there was insufficient information available to rate the accuracy of the RA protocols except for the A-WRA and H-WRA protocols. The WRA protocols had been tested extensively in geographically diverse ranges of risk assessment areas, using datasets that covered a taxonomically diverse array of terrestrial plants. The ISK protocols have been tested using methods that are similar to those applied to the WRA protocols, but testing remains limited in terms of geographic and taxonomic scope. A few decision-tree protocols for plants have been tested against the WRA protocols to compare their accuracy; namely, Reichard and Hamilton (1997) and Tucker and Richardson (1995). However, the few accuracy results that have been published for these two protocols have shown them to be less accurate than the WRA protocols (e.g. Daehler and Carino 2000, Křivánek and Pyšek 2006). This has decreased the interest in comparative studies.

3.4.3 Pragmatic criteria

The majority of protocols satisfied most of the pragmatic criteria.

(a) *Acceptability*: Most of the protocols largely or fully satisfied all components of acceptability, in the context of DFO's needs. For the most part, the protocols were only partially compatible with established RA practices of CEARA. This was largely due to the narrow scope of many protocols and the general absence of methodology for estimating uncertainty. In contrast, all protocols were judged to be understandable (completely or likely) to non-technical users, and no protocol was found to contravene policy requirements that apply to DFO.

(b) *Practicality*: Almost all defining components of practicality were largely or completely satisfied by all 13 protocols. The level of expertise required to apply or to instruct on how to use these protocols is available within DFO. Any computational tools required to apply the protocols are also available within, or readily obtainable by, DFO. For the most part, the data requirements of the protocols can be satisfied without great difficulty. An extensive list of sources for the assessment of plants that pose a risk to Canada is given in Snyder (2007). Relevant information on fishes can be found in Fishbase (Froese and Pauly 2009) and DFO's internal AIS/NIS database. A list of databases and atlases for marine organisms is available in Molnar et al. 2008. Many of these sources contain information on freshwater species, as well.

(c) *Effectiveness*: Results were more variable for the effectiveness criterion than they were for acceptability and practicality criteria. Most of the protocols could likely be adapted for application to different aquatic taxa. Over half the RA protocols provided both a screening and prioritization capacity and those that did not have a screening capacity (i.e., the I-Ranking protocol and Alberta RAT), could readily be adapted for this purpose. However, because of the lack of empirical testing, it could not be determined if many of the protocols could produce results (i.e. assign a risk estimate without high uncertainty) at the rate required by DFO. Moreover, most protocols could not be applied in both domestic and quarantine contexts without significant modifications to their structure, and the addition of numerous scoring or decision-node questions.

4.0 CONCLUSION

This report provides an evaluation of 13 screening and prioritization risk assessment protocols with reference to standardized criteria for the evaluation of their conceptual, scientific, and pragmatic strengths and weaknesses. Based on this evaluation, the Alberta RAT and FISK scored the highest of the tools evaluated. As FISK is specific to freshwater fishes, it is recommended that related protocols, MISK (marine fishes) and MI-ISK (marine invertebrates) be evaluated for marine species. Based on the results of these evaluations, it should be determined if a single protocol is sufficient for screening and prioritizing AIS, or if separate protocols are required for each taxonomic group.

5.0 ACKNOWLEDGEMENTS

The authors would like to acknowledge the contributions of all those who supplied information and assistance during the production of this document.

Sarah Brunel (European Plant Protection Organization Secretariat, France), Gordon Copp (Centre for Environment, Fisheries and Aquaculture Science, Department of Environment, Food and Rural Affairs, United Kingdom), Kari Hamilton (Alberta Sustainable Resource Development, Fish and Wildlife Division, Canada), Marie-Claude Fortin (Science, Department of Fisheries and Oceans). Funding was provided by Department of Fisheries and Oceans, Science, Ottawa.

6.0 REFERENCES

References in bold refer to protocols reviewed.

Alien Plants Ranking System (APRS) Implementation Team. 2000. Alien Plants Ranking System Version 5.1. Jamestown, North Dakota: Northern Prairie Wildlife Research Center Online at http://www.npwrc.usgs.gov/resource/literatr/aprs/index.htm (Version 30SEP2002).

Alien Plant Ranking System (APRS) Implementation Team. 2001. Alien Plants Ranking System Version 7.1. Flagstaff, AZ: Southwest Exotic Plant Information Clearinghouse

Anonymous. 1996. Generic non-indigenous aquatic organisms risk analysis review process.Report to the Risk Assessment and Management Committee of the U. S. Aquatic Nuisance Species Task Force. 21 p.

Aquatic Invasive Species Task Group (AISTG). 2003. National Code on Introductions and Transfers of Aquatic Organisms. Canadian Council of Fisheries and Aquaculture Ministers, Ottawa, Canada

Aquatic Invasive Species Task Group (AISTG). 2004. A Canadian Action Plan to Address the Threat of Aquatic Invasive Species. Canadian Council of Fisheries and Aquaculture Ministers, Ottawa, Canada.

Ashton, P.J., and Mitchell, D.S. 1989. Aquatic plants: patterns and modes of invasion, attributes of invading species and assessment of control programs. *In* Biological Invasions: A Global Perspective. Edited by J. A. Drake, H. A. Mooney, F. di Castri, R. H. Groves, F. J. Kruger, M. Rejmanek and M. Williamson. John Wiley, Chichester, United Kingdom.

Baker, J. and Bomford, M. 2009. Opening the climate modeling envelope. *Plant Protection Quarterly* 24(3): 88-91.

Baker, R.H.A., Black, R., Copp, G. H., Haysom, K. A., Hulme, P. E., Thomas, M. B., Brown, A., Brown, M., Cannon, R. J. C., Ellis, J., Ellis, M., Ferris, R., Glaves, P., Gozlan, R.E., Holt, J., Howe, L., Knight, J.D., MacLeod, A., Moore, N.P., Mumford, J.D., Murphy, S.T., Parrott, D., Sansford, C.E., Smith, G.C., St-Hilaire, S. , and Ward N.L.. 2008. The UK risk assessment scheme for all non-native species. *In* Biological Invasions – from Ecology to Conservation. Edited by W. Rabitsch, F. Essl and F. Klingenstein. Neobiota Vol. 7.

Bartell, S.M., and Nair, S.K. 2003. Establishment risks for invasive species. *Risk Analysis* 4(24).

Biosecurity Australia, 2007. Weed Risk Assessment System. Government of Australia. [online publication] http://www.daff.gov.au/ba/reviews/weeds/system/weed_risk_assessment. (accessed November 2009).

Bomford, M. 2006. Risk Assessment for the Establishment of Exotic Vertebrates in Australia: Recalibration and Refinement of Models. Bureau of Rural Sciences, Canberra.

Bomford, M. 2008. Risk Assessment Models for Establishment of Exotic Vertebrates in Australia and New Zealand. Project 9.D. 1. Invasive Animals Cooperative Research Centre, University of Canberra, Canberra.

Bomford, M., and Glover, J. 2004. Risk Assessment Model for the Import and Keeping of Exotic Freshwater and Estuarine Finfish. A report produced by the Bureau of Rural Sciences for the Department of Environment and Heritage. Bureau of Rural Sciences, Canberra.

Branquart, E. 2007. Guidelines for environmental impact assessment and list classification of non-native organisms in Belgium. Version 2.5. Harmonia. Belgian Forum on Invasive species. [online publication] http://ias.biodiversity.be/ias/documents/ISEIA_protocol.pdf (accessed November 2009).

Brunel, S. 2009. EPPO Prioritization Process for Invasive Alien Plants. Draft report 08-14452, revised 04-09 for the European Plant Protection Organization, Paris, France.

Caley, P., and Kuhnert, P.M. 2006. Application and evaluation of classification trees for screening unwanted plants. *Austral Ecology* 31: 647-655.

Caley, P., Lonsdale, W.M., and Pheloung, P.C. 2006. Quantifying uncertainty in predictions of invasiveness, with emphasis on weed risk assessment. *Biological Invasions* 8:1595-1604.

California Invasive Plant Council. 2006. Proceedings of the California Weed Risk Assessment Workshop, October 30-31 2006. Davis, California.

Canadian Food Inspection Agency Plant and Biotechnology Risk Assessment Unit (CFIA PBRAU). 2009. C-WRA risk assessment spreadsheet. Ottawa, Canada.

Canadian Food Inspection Agency Plant Health Risk Assessment Unit (CFIA PHRAU). 2001. Guidelines for Weed Risk Assessment. Ottawa, Canada.

Catling, P., and Mitrow, G. 2005. A prioritized list of the invasive alien plants of natural habitats in Canada. *Canadian Botanical Association Bulletin* 38(4).

Centre for Environment, Fisheries and Aquaculture Science (CEFAS), Salmon and Freshwater Fisheries Team. 2008. Non-native Species Invasiveness Identification Tool Kits for Marine and Freshwater Species: Fish, Invertebrates, Amphibia. Lowestoft, Suffolk, Department of Environment, Food and Rural Affairs, United Kingdom. [online publication] http://www.cefas.co.uk/media/118009/fisk_guide_v2.pdf (accessed November 2009).

Champion, P.D., and Clayton, J. S. 2000. Border Control for Potential Aquatic Weeds, Stage 1. Weed risk model. Science for Conservation 141. New Zealand Department of Conservation, Wellington, New Zealand.

Champion, P.D., and Clayton, J. S. 2001. A Weed Risk Assessment Model for Aquatic Weeds in New Zealand. *In* Weed Risk Assessment. Edited by R.H. Groves, F. D. Panetta, and J. G. Virtue. Collingwood, Australia: CSIRO Publishing.

Champion, P.D., and Clayton, J.S. 2001. Border Control for Potential Aquatic Weeds, Stage 2. Weed risk assessment. Science for Conservation 185. New Zealand Department of Conservation, Wellington, New Zealand.

Chapman, P.M., Cudmore, B., and Mandrak, N.E. 2006. Proceedings of the National Risk Assessment Methods Workshop; June 21-23, 2006. DFO Can. Sci. Advis. Sec. Proceed. Ser. 2006/049.

Chapman, P.M., Cudmore, B., and Mandrak, N.E. 2009. Proceedings of the workshop to finalize national guidelines for assessing the biological risk of aquatic invasive species (AIS) to Canada: June 3-5, 2008. DFO Can. Sci. Advis. Sec. Proceed. Ser. 2009/006.

Coad, B.W. 2009. Fishes of Canada: An Annotated Checklist. [online publication] http://www.briancoad.com/Complete List.htm (accessed March 2010).

Colautti, R.I., Grigorovich, I.A., and MacIsaac, H.J. 2006. Propagule pressure: a null model for biological invasions. Biological Invasions 8: 1023-1037.

Copp, G.H., Bianco, P.G., Bogutskaya, N., Erős, T., Falka, I., Ferreira, M.T., Fox, M.G., Freyhof, J., Gozlan, R.E., Grabowska, J., Kováč, V., Moreno-Amich, R., Naseka, A.M., Peňáz, M., Povž, M. , Przybylski, M., Robillard, M., Russell, I.C., Stakėnas, S., Šumer, S., Vila-Gispert, A., and Wiesner, C. 2005. To be, or not to be, a non-native freshwater fish? Journal of Applied Ichthyology *21, 242-262.*

Copp, G.H., Garthwaite, R., and Gozlan, R.E. 2005. Risk identification and assessment of non-native freshwater fishes: concepts and perspectives on protocols for the UK. Sci. Ser. Tech Rep., Cefas Lowestoft, 129.

Copp, G.H., Vilizzi, L., Mumford, J., Fenwick, G.V., Godard, M.J., and Gozlan, R.E. 2008. Calibration of FISK, an invasive-ness screening tool for non-native freshwater fishes. *Risk Analysis* 29, 457–467.

Copp, G.H., Vilizzi, L., Mumford, J., and Miossec, L. 2009. Risk Identification Protocols for Pre- and Post-Import Screening of Aquatic Organisms (with Emphasis on Freshwater Fishes). [online publication] http://www.issg.org/animal_imports_webpage/Presentations/Reference/Copppaper.pdf (accessed November 2009).

Covello, V.T., and Merkhofer, M.W. 1993. Risk Assessment Methods: Approaches for Assessing Health and Environmental Risks. New York: Plenum Press.

Crosti, R., Cascone, C., and Testa, W. 2007. Towards a weed risk assessment for the Italian peninsula: preliminary validation of a scheme for the central Mediterranean region in Italy. *In* Proceedings of the MEDECOS XI Conference. 2-5 September 2007. Perth, Australia. Edited by D. Rokich, G. Wardell-Johnson, C. Yates, J. Stevens, K. Dixon, R. McLellan, and G. Moss.

Daehler, C.C., and Carino, D.A. 2000. Predicting invasive plants: prospects for a general screening system based on current regional models. Biological Invasions 2:93-102.

Daehler C.C. and Denslow, J.S. 2004. A risk-assessment system for screening out invasive pest plants from Hawai'i and other Pacific Islands. Report based on C.C. Daehler, J.S. Denslow, S. Ansari and H-C. Kuo. 2004. A risk-assessment system for screening out invasive pest plants from Hawai'i and other Pacific Islands. Conservation Biology 18: 360-368.

Daehler, C.C., and Denslow, J.S. 2007. The Australian Weed Risk Assessment System: Does it work in Hawai'i? Would it work in Canada? *In* Invasive Plants: Inventories, Strategies and Action. Edited by D.R. Clements and S. J. Darbyshire. Topics in Canadian Weed Science. Vol. 5. Canadian Weed Science Society, Sainte Anne de Bellevue, Québec.

Daehler, C.C., and Virtue, J.G. 2007. Variable Perceptions of Weeds and the Implications for WRA. Presented at the 2nd International Weed Risk Assessment Workshop. Perth, Australia. [online publication] http://www.hear.org/iwraw/2007/ (accessed November 2009).

Daehler C.C., Denslow, J.S., Ansari, S. and Kuo, H-C. 2004. A risk-assessment system for screening out invasive pest plants from Hawai'i and other Pacific Islands. *Conservation Biology* 18: 360-368.

Davis, M.A. 2003. Biotic globalization: does competition from introduced species threaten biodiversity? Bioscience 53: 481-489.

Dehnen-Schmutz, K., Touza, J., Perrings, C., andWilliamson, M. 2007. The horticultural trade and ornamental plant invasions in Britain. Conservation Biology 21: 224-231.

Dietz, J.M., Hulme, P.E., and Duncan, R.P. 2010. Using prior information to build probabilistic invasive species risk assessments. Biological Invasions 14(3): 681-691

Duffié, L., Schwartzburg, K., Auclair, A., Bailey, W., and Fieselmann, D. 2005. Exotic Pest Prioritization Project: FY06 Cooperative Agricultural Pest Survey List Development. Prepared for the USDA APHIS Centre for Plant Health Science and Technology.

European Plant Protection Organization. 2009. Guidelines on Pest Risk Analysis: Decision-support Scheme for Quarantine Pests. PM 5/3(4). Version 2009. European Plant Protection Organization, Paris, France.

Ficetola, G.F., Thuiller, W., and Miaud, C. 2007. Prediction and validation of the potential global distribution of problematic alien invasive species - the American bullfrog. Diversity and Distributions 13:476-485.

Firko, M.J. Undated. Probabilistic Risk Assessments: Estimating the Frequency of “Bad Events.” Commodity Pest Risk Analysis Branch, USDA, APHIS.

Food and Agriculture Organization of the United Nations. 2004. International Standard for Phytosanitary Measures, No. 11 – Pest Risk Analysis for Quarantine Pests including Analysis of Environmental Risks and Living Modified Organisms. Prepared by the Interim Commission on Phytosanitary Measures, Secretariat of the International Plant Protection Convention. Rome, Italy. [ISPM No. 11]

Food and Agriculture Organization of the United Nations. 2005. Procedures for weed risk assessment. Prepared by the Plant Production and Protection Division. Rome.

Food and Agriculture Organization of the United Nations. 2007. International Standard for Phytosanitary Measures, No. 2 – Framework for Pest Risk Analysis. Prepared by the Interim Commission on Phytosanitary Measures, Secretariat of the International Plant Protection Convention. Rome, Italy. [ISPM No. 2]

Frappier, B., and Eckert, R.T. 2003. Utilizing the USDA PLANTS database to predict exotic woody plant invasiveness in New Hampshire. Forest Ecology & Management 185: 207-215.

Froese, R. and Pauly, D. (eds.). 2009. FishBase. [World Wide Web electronic publication] www.fishbase.org (accessed November 2009).

Garcia-Berthou, E. 2007. The characteristics of invasive fishes: what has been learned so far? Journal of Fish Biology 71(supplement D): 33-35.

Gederaas, L., Salvesen, I., and Viken, Å. (eds.) 2007. Norwegian Black List – Ecological Risk Analysis of Alien Species. Artsdatabanken, Norway.

Gerlach Jr., J.D., and Rice, K.J. 2003. Testing life history correlates of invasiveness using congeneric plants species. Ecological Applications 13(1): 167-179.

Goodwin, B. J., McAllister, A.J. and Fahrig, L. 1999. Predicting invasiveness of plant species based on biological information. Conservation Biology 13(2): 422-426.

Gordon, D.R. 2009. Results of a Plant Screening Test with Implications for Animal Screening Approaches. [Online publication] http://www.issg.org/animal_imports_webpage/Presentations/Reference/Gordonpaper.pdf (accessed November 2009).

Gordon, D.R. and Gantz, C. 2008. Screening new plant introductions for potential invasiveness: a test of impacts for the United States. Conservation Letters 1 (2008) 227–235.

Gordon, D.R., Onderdonk, D.A., Fox, A.M., and Stocker, R.K. 2008a. Consistent accuracy of the Australian weed risk assessment system across varied geographies. Diversity and Distributions 14: 234-242.

Gordon, D.R., Onderdonk, D.A., Fox, A.M., Stocker, R.K., and Gantz, C. 2008b. Predicting invasive plants in Florida using the Australian Weed Risk Assessment. Invasive Plant Science and Management 1: 178-195.

Gordon, D.R., Fox, A.M., Onderdonk, D.A., and Gantz, C. 2009. IFAS Assessment Tool. Florida Cooperative Extension Service, Institute of Food and Agricultural Sciences, University of Florida. [Online publication] http://plants.ifas.ufl.edu/assessment/pdfs/predictive_tool.pdf (accessed November 2009).

Government of Canada. 2004. An Invasive Alien Species Strategy for Canada. Ottawa, Ontario. (accessed November 2009).

Grotkopp, E., and Rejmanek, M. 2007. High seedling relative growth rate and specific leaf area are traits of invasive species: phylogenetically independent contrasts of woody angiosperms. American Journal of Botany 94(4): 526-532.

Hamilton, M.A., Murray, B.R., Cadotte, M.W., Hose, G.C., Baker, A.C., Harris, C.J. and Licari, D. 2005. Life-history correlates of plant invasiveness at regional and continental scales. Ecology Letters 8: 1066-1-74.

Harris, R., Abbot, K., Barton, K., Berry, J., Don, W., Gunawardana, D., Lester, P., Rees, J., Stanley, M., Sutherland, A., and Toft, R. 2005. Invasive Ant Pest Risk Assessment Project for New Zealand. [online publication] http://www.landcareresearch.co.nz/research/biocons/invertebrates/ants/ant_pest_risk.asp (accessed November 2009).

Hayes K.R., and Hewitt, C.L. 2000. Risk assessment framework for ballast water introductions – Volume II. Centre for Research on Introduced Marine Pests, Technical Report No. 21, CSIRO Marine Research Hobart, Australia.

Hayes, K.R. and Sliwa, C. 2003. Identifying potential marine pests – a deductive approach applied to Australia. Marine Pollution Bulletin, 46:91-98.

Hayes K.R., Sliwa, C., Migus, S., McEnnulty, F., and Dunstan, P. 2005. National priority pests – Part II Ranking of Australian marine pests. Final report for the Australian Government Department of Environment and Heritage, CSIRO Division of Marine Research, Hobart, Australia, 99 p. http://www.environment.gov.au/coasts/publications/imps/priority2.html

Hazard, W.H.L. 1988. Introducing crop, pasture and ornamental species in Australia – the risk of introducing new weeds. Australian Plant Introduction Review 19: 19-36.

Heffernan, K.E., Coulling, P.P., Townsend, J.F., and Hutto, C.J.. 2001. Ranking Invasive Exotic Plant Species in Virginia. Natural Heritage Technical Report 01-13. Virginia Department of Conservation and Recreation, Division of Natural Heritage, Richmond, Virginia.

Herborg, L-F., Drake, J.M., Rothlisberger, J.D., and J.M. Bossenbroek. 2009. Identifying suitable habitat for invasive species using ecological niche models and the policy implications of range forecasts. *In* Bioeconomics of Invasive Species: Integrating Ecology, Economics, Policy and Management. Edited by R.P. Keller, D.M. Lodge, M.A. Lewis and J.F. Shogren. Oxford University Press.

Hiebert, R.D. 1997. Prioritizing invasive plants and planning for management. *In* Assessment and Management of Plant Invasions. Edited by Luken, J. O. and J. W. Thieret. New York: Springer.

Hiebert, R.D., and Stubbendieck, J. 1993. Handbook for ranking exotic plants for management and control. Natural Resources Report 93/08, US Department of the Interior, National Park Service, USA.

Hughes, G., and Madden, L.V. 2003. Evaluating predictive models with application in regulatory policy for invasive weeds. Agricultural Systems 76: 755-774.

Indiana Invasive Species Task Force. 2008. Species Assessments. [Webpage of the Indiana Department of Natural Resources]. http://www.in.gov/dnr/4619.htm (accessed November 2009).

Invasive Alien Species Panel, North American Plant Protection Organization. 2008. Pest Risk Assessment for Plants for Planting as Quarantine Pests. Regional Sanitary and

Phytosanitary Measure No. 32. The Secretariat of the North American Plant Protection Organization, Ottawa, Canada.

Invasive Alien Species Working Group (IASWG). 2008. Alberta Invasive Alien Species Risk Assessment Tool Version 3. Alberta Agriculture and Rural Development. Edmonton, AB. http://www1.agric.gov.ab.ca/$department/deptdocs.nsf/all/prm13262 (accessed September 2012).

Invasive Species Ireland. 2007. Invasive Species Ireland Risk Assessment. Prepared for the Northern Ireland Environment Agency and the National Parks and Wildlife Service. [online publication] (accessed November 2009).

Invasive Species Ireland. 2008. Briefing Document for the Invasive Species Ireland Risk Assessment. Prepared for the Northern Ireland Environment Agency and the National Parks and Wildlife Service. [online publication] http://www.invasivespeciesireland.com/files/public/Risk Assessment/Invasive Species Ireland Risk Assessment.pdf (accessed November 2009).

Jefferson, L., Havens, K., and Ault, J. 2004. Implementing invasive screening procedures: the Chicago Botanic Garden model. Weed Technology 18: 1434-1440.

Jordan, M.J., Moore ,G., and Weldy, T. W. 2009. New York Plant Ranking System for Evaluating Non-Native Plant Species for Invasiveness. Prepared for the Nature Conservancy and Brooklyn Botanic Garden.

Kato, H., Hata, K., Yamamoto, H., and Yoshioka, T. 2006. Effectiveness of the weed risk assessment system for the Bonin Islands. *In* Assessment and Control of Biological Invasion Risk. Edited by F. Koike, M.N. Clout, M. Kawamichi, M. De Poorter, and K. Iwatsuki. Kyoto, Japan and IUCN, Gland, Switzerland: Shoukadoh Book Seller.

Keller, R.P., Drake, J. M., and Lodge, D.M. 2007. Fecundity as a basis for risk assessment of nonindigenous freshwater mollusks. Conservation Biology 21:191–200.

Keller, R.P., and Drake, J.M. 2009. Trait-based risk assessment for invasive species. *In* Bioeconomics of Invasive Species: Integrating Ecology, Economics, Policy and Management. Edited by R.P. Keller, D.M. Lodge, M.A. Lewis and J.F. Shogren. Oxford University Press.

Köhler, B., Weber, E., Gelpke, G., and Perrenoud, A. 2005. Clé de détermination pour la classification des espèces néophytes de Suisse dans la Liste Noire et la "Watch List." Commission suisse pour la conservation des plantes sauvages. [online publication] http://www.cps-skew.ch/francais/info_plantes_envahissantes.htm (accessed November 2009).

Kolar, C.S., and Lodge, D.M. 2001. Progress in invasion biology: predicting invaders. TRENDS in Ecology and Evolution 16 (4):199-204.

Kolar, C.S. and Lodge, D.M. 2002. Ecological predictions and risk assessment for alien fishes in North America. Science 298: 1233–1236.

Křivánek, M., and Pyšek, P. 2006. Predicting invasions by woody species in a temperate zone: a test of three risk assessment schemes in the Czech Republic (Central Europe). Diversity and Distributions 12: 319-327.

Labrada, R. (ed.) 2003. Expert Consultation on weed Risk Assessment. Madrid, Spain 11-13 June 2002. Food and Agriculture Organization of the United Nations, Rome.

Lehtonen, P.P. 2001. Pest Risk Assessment in the United States: Guidelines for Qualitative Assessments for Weeds. *In* Weed Risk Assessment. Edited by R.H.Groves, F. D. Panetta and J. G. Virtue. Collingwood, Australia: CSIRO Publishing.

Leung, B., Lodge, D.M., Finnoff, D., Shongren, J.F., Lewis, M.A., and Lamberti, G. 2002. An ounce of prevention or a pound of cure: Bioeconomic risk analysis of invasive species. Proceedings of the Royal Society *B* 269, 2407-2413.

Leung, B., Drake, J.M., and Lodge, D.M. 2004. Predicting invasions: propagule pressure and the gravity of allee effects. Ecology 85(6): 1651-1660.

Lloret F., Médail, F., Brundu, G., Camarda, I., Moragues, E., Rita, J., Lambdon, P., and Hulme, P.E. 2005. Species attributes and invasion success by alien plants on Mediterranean islands. Journal of Ecology 93: 512–520.

Locke, A., Mandrak, N.E., and Therriault, T.W. 2011. A Canadian Rapid Response Framework for Aquatic Invasive Species. DFO Can. Sci. Advis. Sec. Res. Doc. 2010/114. vi + 30 p.

Lockwood, J.L., Cassey, P., and Blackburn, T. 2005. The role of propagule pressure in explaining species invasions. Trends in Ecology and Evolution 20(5): 223-227.

Lodge, D.M. 1993. Biological invasions: lessons from ecology. Trends in Ecology and Evolution 8(4): 133-137.

Lonsdale, W.M., and Smith, C.S. 2001. Evaluating Pest-screening Systems – Insights from Epidemiology and Ecology." *In* Weed Risk Assessment Edited by R. H. Groves, F. D. Panetta, and J. G. Virtue. Collingwood, Australia: CSIRO Publishing.

MacIsaac, H.J., Grigorovich, I.A., and Ricciardi, A. 2001. Reassessment of species invasions concepts: the Great Lakes Basin as a model. Biological Invasions 3: 405-416.

Mack, R.N. 1996. Predicting the identity and fate of plant invaders: emergent and emerging approaches. Biological Conservation 78:107-121.

Mack, R., Simberloff, D., Lonsdale, W.M., Evans, H., Clout, M., and Bazzaz, F.A. 2000. Biotic invasions: causes, epidemiology, global consequences and control. Ecological Applications, 10(3): 689-710.

Madsen, J. D., Eichler, L.W., and Boylen, C.W. 1988. Vegetative spread of Eurasian watermilfoil in Lake George, New York. Journal of Aquatic Plant Management 26: 47-50.

Mandrak, N.E., Cudmore, B and Chapman, P.M. 2012. National detailed-level risk assessment guidelines: assessing the biological risk of aquatic invasive species in Canada. DFO Can. Sci. Advis. Sec. Res. Doc. 2011/092. vi + 17 p.

Marchetti M.P., Moyle, P.B., and Levine, R. 2004. Invasive species profiling? Exploring the characteristics of non-native fishes across invasion stages in California. Freshwater Biology 49: 646-661

Massachusetts Invasive Plant Advisory Group. 2005. The Evaluation of Non-Native Plant Species for Invasiveness in Massachusetts. Report based on research conducted by L. J. Mehrhoff.

Mastitsky, S.E., Karatayev, A.Y., Burlakova, L.E., and Adamovich, B.V. 2010. Non-native fishes of Belarus: diversity, distribution and risk classification using the Fish Invasiveness Screening Kit (FISK). Aquatic Invasions 5(1): 103-114.

Mississippi River Basin Panel on Aquatic Nuisance Species. 2009. Model for a Natural Resources Agency Risk Assessment and Risk Management Process. Draft Version, May 12 2009.

Moles, A. T., M. A. M. Grubber and S. P. Bonser. 2008. A new framework for predicting invasive plant species. Journal of Ecology 96:13-17.

Molnar, J. L., Gamboa, R. L., Revenga, C., and Spalding, M.D.. 2008. Assessing the global threat of invasive species to marine biodiversity. Frontiers in Ecology and the Environment 6: 485–492.

Morse, L.E., Randall, J.M., Benton, N., Hiebert, R., and Lu, S. 2004. An Invasive Species Assessment Protocol: Evaluating Non-Native Plants for Their Impact on Biodiversity. Version 1. NatureServe, Arlington, Virginia.

Moyle, P. B. 1999. Effects of invading species on freshwater and estuarine ecosystems. *In* Invasive Species and Biodiversity Management. Edited by O.T. Sandlund, P.J. Schei and A. Viken. Dordrecht: Kluwer Publishing.

National Research Council (NRC), Committee on the Scientific Basis for Predicting the Invasiveness Potential of Nonindigenous Plants and Plant Pests in the United States. 2002. Predicting invasions of Nonindigenous Plants and Plant Pests. National Academy Press, 2101 Constitution Avenue NW, Washington, D.C. 20418.

National Resource Management Standing Committee (NRMSC). 2006. Review of the National Weed Risk Assessment System. Conducted by the NWRAS Review Group – A Joint Natural Resource Management Standing Committee – Primary Industries Standing Committee Sub-committee. Canberra. [online publication] http://www.weeds.org.au/docs/Review_of_the_National_Weed_Risk_Assessmt_System_2005.pdf (accessed Nov 2009).

NatureServe. 2004. An Invasive Species Assessment Protocol: Evaluating Non-Native Plants for Their Impact on Biodiversity. Version 1. Arlington, Virginia, USA.

Nishida, T., N. Yamashita, M. Asai, S. Kurokawa, T. Enomoto, P. C. Pheloung and R. H. Groves. 2009. Developing a pre-entry risk assessment system for use in Japan. Biological Invasions 11: 1319-1333.

Nyberg C.D. and I. Wallentinus. 2005. Can species traits be used to predict marine macroalgal introductions? Biological Invasions 7: 265–279.

Office of the Auditor General of Canada. 2008. Control of Aquatic Invasive Species. Chapter 6 in Status Report of the Commissioner of the Environment to the House of Commons, March 2008. Government Services Canada: Ottawa, Ontario.

Panetta, F.D. 1993. A system of assessing proposed plant introductions for weed potential. Plant Protection Quarterly 8:10-14.

Panov, V.E., Alexandrov, B., Arbačiauskas, K., Binimelis, R., Copp, G.H., Grabowski, M., Lucy, F., Leuven, R.S.E.W., Nehring, S., Paunović, M., Semenchenko, V. and Son M.O. 2009. Assessing the risks of aquatic species invasions via European inland waterways: from concepts to environmental indicators. Integrated Environmental Assessment and Management 5: 110–126.

Parker, C. 2003. Weed risk assessment – An Attempt to Predict Future Invasive Weeds of the USA. *In* Consultation on weed Risk Assessment. Madrid, Spain 11-13 June 2002. Edited by R. Labrada. Expert Food and Agriculture Organization of the United Nations, Rome.

Parker, C. 2004. Creation of a Prioritization Model to Identify Weeds of Global Significance – Phase III. Final Report April 2004 for USDA APHIS PPQ Agreement 03-8100-0795-CA.

Parker, C., Caton, B. P., and Fowler, L. 2007. Ranking nonindigenous weed species by their potential to invade the United States. Weed Science 55: 386-397.

Paustenbach, D. J. Editor 2002. Human and Ecological Risk Assessment: Theory and Practice. Wiley-Interscience.

Peterson, A.T. 2003. Predicting the geography of species' invasions via ecological niche modeling. Quarterly Review of Biology 78: 419-433.

Petit, R.J. 2004. Biological invasions at the gene level. Diversity and Distributions 10: 159-165.

Pheloung, P. C. 1995. Determining the Weed Potential of New Plant Introductions to Australia. A report on the development of a Weed Risk Assessment System commissioned by the Australian Weeds Committee and the Plant Industries Committee. Agriculture Protection Board, Western Australia.

Pheloung, P. C. 2001. Weed Risk Assessment for Plant Introductions to Australia. *In* Weed Risk Assessment. Edited by R.H. Groves, F. D. Panetta and J. G. Virtue. Collingwood, Australia: CSIRO Publishing.

Pheloung, P. C. 2005. Use of the weed risk assessment tool in Australia's approach to pest risk analysis. *In* IPPC Sectetariat. Identification of risks and management of invasive alien species using the IPPC framework. Proceedings of the workshop on invasive alien species and the International Plant Protection Convention, Braunschweig, Germany, 22-26 September 2003. Rome, Italy, FAO.

Pheloung, P. C., Williams, P. A. and Halloy, S. R.. 1999. A weed risk assessment model for use as a biosecurity tool evaluating plant introductions. Journal of Environmental Management 57: 239-252.

Pyšek, P. 2001. Past and future of predictions in plant invasions: A field test by time. *Diversity and Distributions 7: 145-151.*

Pyšek, P., Richardson, D. M. and Williamson, M. 2004. Predicting and explaining plant invasions through analysis of source area floras: some critical considerations. Diversity and Distributions 10: 179-187.

Randall, R. P. 2000. 'Which are my worst weeds?' A simple ranking system for prioritizing weeds. Plant Protection Quarterly 15: 109-115.

Randall, J. M., Morse, L. E., Benton, N., Hiebert, R., Lu, S. and Killiffer, T. 2008. The invasive species assessment protocol: A tool for creating regional and national lists of invasive nonnative plants that negatively impact biodiversity. Invasive Plant Science and Management 1:36-49.

Regan, H. M., Colyvan, M. and Burgman, M.A. 2002. A taxonomy and treatment of uncertainty for ecology and conservation biology. Ecological Applications, 12:618-628.

Reichard, S. 2001. The Search for Patterns that enable Prediction of Invasion. *In* Weed Risk Assessment. Edited by R. H. Groves, F. D. Panetta, and J. G. Virtue. Collingwood, Australia: CSIRO Publishing.

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

Rejmanek, M. 1996. A theory of seed plant invasiveness: the first sketch. *Biological Conservation* 78: 171-181.

Rejmanek, M. 1999. Invasive Plant Species and Invasible Ecosystems. *In* Invasive Species and Biodiversity Management. Edited by O.T. Sandlund, P.J. Schei, and A. Viken. Dordrecht: Kluwer Publishing.

Rejmanek, M. 2000. Invasive plants: approaches and predictions. Austral Ecology 25: 497-506.

Rejmanek, M. 2001. What Tools do we have to Detect Invasive Plant Species? *In* Weed Risk Assessment Edited by R.H. Groves, F. D. Panetta and J. G. Virtue. Collingwood, Australia: CSIRO Publishing.

Rejmanek, M. and Richardson, D. M. 1996. What attributes make some plant species more invasive? Ecology 77:1655–1660.

Ricciardi, A. 2003. Predicting the impacts of an introduced species from its invasion history: an empirical approach applied to zebra mussel invasions. Freshwater Biology 48: 972-981.

Ricciardi, A. and Rasmussen, J. B. 1998. Predicting the identity and impact of future biological invaders: A priority for aquatic resource management. Journal of Fisheries and Aquatic Science 55: 1759-65.

Rice, P. M. 2002. INVADERS Database System. Division of Biological Sciences, University of Montana, Missoula, MT 59812-4824. [online database] http://invader.dbs.umt.edu (accessed Nov 2009).

Robertson, M. P., Villet, M. H., Fairbanks, D. H. K., Henderson, L., Higgins, S. I., Hoffmann, J. H., Le Maitre, D. C., Palmer, A. R., Riggs, I., Shackleton, C. M. and Zimmermann, H. G. 2003. A proposed prioritization system for the management of invasive alien plants in South Africa, South African Journal of Science 99, January-February 2003.

Ruesink, J. L., Parker, I. M., Groom, M. J. and Kareiva, P. M.. 1995. Reducing the risks of nonindigenous species introductions: guilty until proven innocent. Bioscience 45: 475-477.

Sax, D. F., Stachowicz, J. J., Brown, J. H., Bruno, J. F., Dawson, M. N., Gaines, S. D., Grosberg R. K., Hastings, A., Holt, R. D., Mayfield, M. M., O'Connor, M. I. and Rice, W. R. 2007. Ecological and evolutionary insights from species invasions. Trends in Ecology and Evolution 22: 465-471.

Schutzki, R. E., Pearsall, D., MacKenzie, D., Cleveland, A., Schultz, J., Herman, K., Majka, B., Howe, C., Higman, P., MacDonald, S., Wood, T. and Myers, T. 2008. Michigan Plant Invasiveness Assessment System. Michigan Invasive Plant Council, Lansing, Michigan.

Shrader-Frechette, K. 2001. Non-indigenous species and ecological explanation. Biology and Philosophy. 16: 507-519.

Sikder, I. U., Mal-Sarkar, S. and Mal, T. K.. 2006. Knowledge-based risk assessment under uncertainty for species invasion. Risk Analysis 26(1): 239-252

Simons, S. and De Poorter, M.. (eds.) 2009. Best Practices in Pre-Import Risk Screening for Species of Live Animals in International Trade. Proceedings of an Expert Workshop on Preventing Biological Invasions. University of Notre Dame, Indiana, USA, 9-11 April 2008. Global Invasive Species Programme, Nairobi, Kenya.

Smith, C. S., Lonsdale, W. M. and Fortune, J. 1999. When to ignore advice: Invasion predictions and decision theory. Biological Invasions 1:89-96.

Snyder, E. 2007. A Categorization Procedure for Quarantine Pests: Instruction Manual. Part A – Potential Quarantine Pest Plants. Service Request 07-11. Plant Health Risk Assessment Unit, Science Advice Division, Canadian Food Inspection Agency. Ottawa, Canada.

Stone, L. 2008. Environmental Weed Risk Assessment Protocol. Future Farm Industries CRC. (accessed Nov 2009).

Sutherland, S. 2004. What makes a weed a weed: life history traits of native and exotic plants in the USA. *Oecologia* 141: 24-39.

Thuiller, W., Richardson, D. M., Pyšek P., Midgley, G. F., Hughes, G.O., and Rouget, M.. 2005. Niche-based modeling as a tool for predicting the risk of alien plant invasions at a global scale. Global Change Biology 11: 2234-2250.

Tricarico, E., Vilizzi, L., Gherardi, F.and Copp, G.H. 2009. Calibration of FI-ISK, an invasiveness screening tool for non-native freshwater invertebrates. DOI: 10.1111/j.1539-6924.2009.01255.x

Tucker, K.C. and Richardson, D.M. 1995. An expert system for screening potentially invasive alien plants in South African fynbos. Journal of Environmental Management 44:309-338.

UNEP (United Nations Environment Programme). 1992. Rio Declaration on environment and development. Made at the United Nations Conference on Environment and Development, Rio de Janeiro, Brazil. (accessed Dec 2009).

United Kingdom Department for Environment, Food, and Rural Affairs (DEFRA). 2005, UK Non-native Organism Risk Assessment User Manual, Version 3.3.

United States Department of Agriculture, Animal and Plant Health Inspection Service. 2004. Weed-Initiated Pest Risk Assessment Guidelines for Qualitative Assessments. Version 5.3. Riverdale, Maryland.

Van Wilgen, N. J., Roura-Pascual, N. and Richardson, D. M.. 2009. A quantitative climate-match score for risk-assessment screening of reptile and amphibian introductions. Environmental Management 44: 590-607.

Vilizzi, L., Cooper, D., South, A., Ellis, M., Howe, L. and Copp, G.H. 2007a. Amphibian Invasiveness Scoring Kit (AmphISK) Version 1-19. Centre for Environment, Fisheries and Aquaculture Science, Department of Environment, Food and Rural Affairs, United Kingdom.

Vilizzi, L., Cooper, D., South, A.,Tricarico, E., Gherardi, F. and Copp, G.H. 2007b. Freshwater Invertebrate Invasiveness Scoring Kit (FI-ISK) Beta Test Version. Centre for Environment, Fisheries and Aquaculture Science, Department of Environment, Food and Rural Affairs, United Kingdom.

Vilizzi, L., Cooper, D., South, A., Copp, G.H., Garthwaite, R. and Gozlan, R. E. 2007c. Freshwater Fish Invasiveness Scoring Kit (FISK) Version 1-19. Centre for Environment, Fisheries and Aquaculture Science, Department of Environment, Food and Rural Affairs, United Kingdom.

Vilizzi, L., Cooper, D., South, A., Ellis, J. and Copp, G.H. 2007d. Marine Fish Invasiveness Scoring Kit (MFISK) Version 1-19. Centre for Environment, Fisheries and Aquaculture Science, Department of Environment, Food and Rural Affairs, United Kingdom.

Vilizzi, L., D. Cooper, South, A., Ellis, J., Occhipinti, A., Savini, D. and Copp, G.H. 2007e. Marine Invertebrate Invasiveness Scoring Kit (MI-ISK) Version 1-19. Centre for

Environment, Fisheries and Aquaculture Science, Department of Environment, Food and Rural Affairs, United Kingdom.

Virtue, J. G. 2006. Weed Risk Analysis: Current Status and Future Developments. *In* California Invasive Plant Council. Proceedings of the California Weed Risk Assessment Workshop, October 30-31 2006. Davis, California.

Virtue, J. G. and Panetta, F. D. 2003. Weed Risk Assessment in Australia. *In* Expert Consultation on weed Risk Assessment. Madrid, Spain 11-13 June 2002. Edited by R. Labrada. Food and Agriculture Organization of the United Nations, Rome.

Ward, D.F., Stanley, M.C.,Toft, R.J., Forgie, S.A., and Harris, R.J. 2008. Assessing the risk of invasive ants: a simple and flexible scorecard approach. Insectes Sociaux. DOI 10.1007/s00040-008-1316-6.

Warner, P. J., Bossard, C. C., Brooks, M. L., DiTomaso, J. M., Hall, J. A., Howald, A. M., Johnson, D. W., Randall, J. M., Roye, C. L., Ryan, M. M., and Stanton, A. E.. 2003. Criteria for Categorizing Invasive Non-Native Plants that Threaten Wildlands. [online publication] www.caleppc.org and www.swvma.org. California Exotic Pest Plant Council and Southwest Vegetation Management Association. (accessed November 2009).

Weber, E. and Gut, D. 2004. Assessing the risk of potentially invasive plant species in central Europe. *Journal for Nature Conservation* 12: 171-179.

Williams, P.A. 2003. Proposed guidelines for weed risk assessment in developing countries. *In* Expert Consultation on Weed Risk Assessment. Madrid, Spain 11-13 June 2002. Edited by R. Labrada. Food and Agriculture Organization of the United Nations, Rome.

Williams, P.A., and Newfield, M. 2002. A weed risk assessment system for new conservation weeds in New Zealand. Science for Conservation 209: 1-23.

Williams, P.A., Nicol, E. and Newfield, M. 2001. Assessing the risk to indigenous biota of plant taxa new to New Zealand. *In* Weed Risk Assessment Edited by R.H. Groves, F. D. Panetta, and J. G. Virtue. Collingwood, Australia: CSIRO Publishing.

Williams, P.A., Wilton, A. and Spencer, N. 2002. A proposed conservation weed risk assessment system for the New Zealand border. Science for Conservation 208. Department of Conservation, Wellington, New Zealand. [online publication] http://www.doc.govt.nz/upload/documents/science-and-technical/SFC208.pdf (accessed November 2009).

Widrlechner, M.P. and Iles, J.K. 2002. A geographic assessment of the risk of naturalization of non-native woody plants in Iowa. Journal of Environmental Horticulture 20: 47-56.

Widrlechner, M. P., Thompson, J. R., Iles, J. K., and Dixon, P. M. 2004. Models for predicting the risk of naturalization of non-native woody plants in Iowa. Journal of Environmental Horticulture 22: 23-31.

Zalba, S. M. and Ziller, S. R. 2005. 13N Tools for the Prevention of Biological Invasions. Prepared for the Inter-American Biodiversity Information Network. [online publication] http://i3n.iabin.net/tools/web_tools.html (accessed November 2009).

APPENDIX A - PLANTS – AUSTRALIAN WRA PROTOCOL

Evaluation Questions	Answers			Explanation
	Affirm	Deny	Uncertain	
Perspicuity (mean=1.25)				
Does the protocol clearly distinguish between the magnitude of consequences of a biological invasion and the probability of its introduction?		No		Some categories included questions that related to both probability and magnitude of consequences. Question scores were not separated into those for probability and those for consequences (Daehler and Virtue 2007).
Does the protocol adopt clear definitions of the stages of invasion: arrival in an ecosystem, survival, establishment, and spread?		No		The scoring system was not based on a conceptual model of invasion stages. The probability of arrival, escape or release was not considered because the protocol was designed to assess intentionally introduced plants for planting. Hence, the probability of arrival and release was assumed to be = 1.
Does the protocol clearly differentiate biological from socio-economic consequences?	Yes			Those socio-economic consequences that were scored were costs to agriculture, horticulture, and forestry. Questions that related directly or indirectly to these costs were identified, as were questions that related to impacts on ecosystems and those that concerned both ecological and socio-economic impacts.
Are the questions in the protocol clear and unambiguous?	Largely			Most questions were reasonably clear but there were exceptions. Question 3.01 defined a “garden/disturbance/amenity weed” as an “intrusive weed,” a “minor weed” or a plant “listed as a weed in relevant references.” No standards were given for judging a weed to be minor, and references might employ different definitions of “weed.” (Cf. Daehler and Virtue 2007.) Question 5.01 did not define “aquatic plant.” Were all obligate wetland plants included? Facultative wetland species? Facultative species?

Evaluation Questions	Answers			Explanation
	Affirm	Deny	Uncertain	
Soundness (mean=2)				
Can the protocol be justified by biological theory and other applicable natural sciences? For example, the protocol employs taxonomic, physiological, ecological and/or biogeographical predictors of establishment and spread potential that are theoretically defensible?	Largely			The protocol used historical (weed history), biogeographical (climate matching), and eco-physiological (inherent traits) predictors as proof of establishment and spread potential. Regarding the first of these, Williams (2003) took the "central argument" of the WRA to be that if a species has had the opportunity to become a weed in another country, and it has done so, then it should be classed as a weed in Australia provided that the climate and environment of the other country are comparable to that of Australia. He asserted that this argument is justified by several studies. While it is correct that "weediness elsewhere" has been found to be a strong *predictor* of weediness in an as yet unoccupied region having a similar environment, the *explanatory* strength of this statistical generalization appears to be low. Rather, it seems to stand in need of theoretical explanation, perhaps in terms of environmental factors and the eco-physiological traits of plants that relate to the different aspects of weediness. The prediction of species' distributions based on climate matching and related forms of environmental niche matching is widely accepted as a sound application of ecological theory (Herborg *et al.*2009). Nonetheless, Mack (1996) and Herborg *et al.*(2009) identified theoretical limitations of this approach in application to invasive plants and aquatic species, respectively. Question 2.02 of the protocol allowed the quality of climate match data to be scored and could therefore be used to take into account some of these limitations. There is much theoretical debate about the predictive strength of inherent traits that have been associated with weediness or invasiveness (Keller and Drake 2009). While several studies have been undertaken to identify such attributes (e.g. Gerlach and Rice 2003, Goodwin *et al.*1999, Grotkopp and Rejmanek 2007, Hamilton *et al.*2005, Reichard and Hamilton 1997, Rejmanek 1999, 2000, Rejmanek and Richardson 1996, Sutherland 2004) and some efforts have been made to synthesize their results in a general theory of plant invasiveness (e.g. Rejmanek 1996, 1999), a unified nomological model of plant invasiveness in terms of plant attributes has not yet been articulated. This is perhaps because, as Mack (1996) suggested, the explanatory and predictive strength of traits must be considered relative to invaded ecosystems (e.g. agricultural land versus forests) and in conjunction with biotic barriers (e.g. competitors, parasites and pathogens) (cf. Ashton and Mitchell 1989, NRC 2002, Rejmanek 1999). The Undesirable Traits questions in the WRA seemed to be based on an acknowledgement of these constraints on theoretical unification - or at least a partial acknowledgement - since questions were included that related to traits that have been found to be significant in different ecosystem types, i.e. agricultural and natural. In summary, for the most part, the WRA was consistent with theoretical thinking in invasion biology and weed biology. It took into account the principal components of theories of plant invasiveness while recognizing their limitations. It was not theoretically defensible in all parts, but this appears to have more to do with the current state of theoretical thinking than with the protocol.

Evaluation Questions	Answers			Explanation
	Affirm	Deny	Uncertain	
Is the approach used to measure magnitude of harm based solely on ecological impacts and grounded in scientific theory?			Uncertain	As stated above, the magnitude of harm resulting from an invasion was not dealt with separately in the WRA protocol. Hence, which questions related to magnitude of harm must be inferred from their content. Some of the questions in the Weed Elsewhere category seemed to be the most relevant to characterizing the magnitude of potential harm resulting from an invasion. Questions on Dispersal Mechanisms and Persistence Attributes, for example, were also relevant but, strictly speaking, addressed the capacity to disperse or persist, not the magnitude of resulting consequences. In the Weed Elsewhere category, the scoring of weeds that affected different economic sectors and ecosystems seemed to be intended to reflect the relative magnitude of harm of the weeds in question. Garden/amenity/disturbance weeds scored lower than the other two kinds. Environmental weeds and weeds of agriculture, horticulture or forestry had the same range of scores. Pheloung et al. (1999) did not attempt to justify this scoring regime by appeal to an economic or axiological analysis.
Is the protocol methodologically consistent? Do the methodological assumptions result in unbiased assessments?	Largely			Although the largely additive scoring method of the WRA has been widely accepted as fundamentally sound (NRMSC 2006), some methodological objections have been raised about particular aspects of the WRA scoring and screening methods. The weighting of particular questions is one instance of this (NRMSC 2006). Copp et al.(2005), for example, stated that aquatic plants are allocated a disproportionately high score relative to other plant types (cf. Champion and Clayton 2000). Another example is the application of the precautionary principle to the climate matching question, 2.02, when data quality is poor. This is subject to criticism because the conservatism underlying the choice of a default score is essentially a policy position, the assumption of which might be considered inappropriate in the context of undertaking a scientific risk assessment (cf. Chapman et al.2009, Covello and Merkhofer 1993). Caley et al.(2006) argued that the screening thresholds of the WRA are biased towards successfully identifying invasive plants and against successfully identifying non-invasive plants. This is a consequence of the dataset used to establish the thresholds having a disproportionate number of invasive species, 77%, while only 5% of introduced alien plant species in Australia are invasive (Keller and Drake 2009). Concerns about methodological consistency can also be raised. The Climate score is used to weight the Weed Elsewhere score, but insofar as it is a determinant of establishment potential it should arguably be used to weight scores to questions in other sections of the WRA. For instance, a plant that cannot effectively establish is less likely to realize its capacity to cause harm by means of undesirable traits such as a smothering growth habit or tendency to form dense thickets. Hence, additional weighting seems to be justified to better characterize risk.

Evaluation Questions	Answers			Explanation
	Affirm	Deny	Uncertain	
Completeness (mean=0)				
Does the protocol address all components of risk assessment? Does it assess: the likelihood of realizing each stage of invasion; the magnitude of harm; and the estimation of risk and uncertainty?		No		The protocol only addresses the probability of survival, establishment, spread and the capacity to cause harm. It does not include an estimation of uncertainty.
Are the theoretical assumptions of the protocol complete? Does the protocol take into account all relevant considerations and information? For example, does the protocol allow the overall score to be altered by any appropriate predictor of a species invading?		No		Not all predictors of invasiveness potential identified in the literature on biological invasions of plants are scored in the WRA protocol (cf. Gerlach and Rice 2003, Goodwin et al.1999, Grotkopp and Rejmanek 2007, Hamilton et al.2005, Mack 1996, Reichard and Hamilton 1997, Rejmanek 1999, Sutherland 2004). A few examples of omissions are small genome size, phenotypic plasticity, and phylogenetic distance from native species (Rejmanek 1999). Perhaps most significantly for the present purposes, predictors of the introduction and spread of aquatic plants are largely absent (Champion and Clayton 2000). Champion and Clayton (2000) found that the WRA protocol used in New Zealand, based on Pheloung et al.(1999), fails to discriminate adequately between aquatic plant species having different levels of impact. Accordingly, they undertook to develop an alternative risk assessment protocol for border control of potential aquatic invasive plants. Their protocol has two stages. The first prioritizes aquatic plant species based on ecological, biological and weediness attributes related to establishment and spread potential and associated consequences. The second stage involves the collection of information on the present status of aquatic species that are cultivated in New Zealand or occur in trade pathways which have intermediate or end points within New Zealand. The prioritization stage addresses 13 different attributes related to weediness. The attributes are defined by sub-attributes. Many of the sub-attributes relate to establishment and spread potential in aquatic environments such as tolerance of oligotrophic and eutrophic waters, saline conditions and turbidity, and spread by boat trailers or nets.
Are the assumptions of the protocol concerning the consequences of an invasion complete, providing for all relevant considerations and information? For example, are both ecological and genetic consequences addressed, and if so, can a broad range of values be accounted for with respect to each?		No		The protocol contains questions that relate to ecological and genetic impacts. However, it is not comprehensive in accounting for associated values. Notably, impacts on aquatic ecosystems are not directly addressed. Champion and Clayton (2000) maintain that many of the attributes scored by the Australian WRA are not relevant to the assessment of aquatic plants, for example, fire risk. Their model replaces these with more relevant attributes such as ability to deoxygenate aquatic ecosystems and influence flood regimes.
Does the protocol take into account stochastic and epistemic uncertainty in estimating risk and can all relevant sources of uncertainty be addressed?		No		The protocol does not provide for an estimation of uncertainty from any source.

Evaluation Questions	Answers			Explanation
	Affirm	Deny	Uncertain	
Accuracy (mean=1.5)				
Has the protocol been empirically tested and validated as a screening or prioritization protocol? Validation allows risk assessors to have a high level of confidence that the protocol results in minimal false positives and negatives.	Largely			Most studies of the WRA have examined its accuracy. This has been understood to consist of two components: sensitivity and specificity (NRMSC 2006). Sensitivity is the probability of correctly rejecting a weed, i.e. of identifying the correct proportion of true weeds amongst those being assessed. Specificity is the probability of correctly accepting a non-weed. Sensitivity and specificity values can be calculated by testing a protocol by means of a dataset in which the proportion of weeds and non-weeds is known. Sensitivity is the number of predicted true weeds divided by the total number of actual weeds in the dataset. Specificity is the number of predicted true non-weeds divided by the total number of actual non-weeds. The overall accuracy of the protocol is then the total number of true predictions divided by the total size of the dataset. Using this method, various overall accuracy results have been calculated for the WRA in application to datasets for different regions. Pheloung et al.(1999) found sensitivity to = 83% and specificity to = 70%. Smith et al.(1999) calculated values of 70% and 53%, respectively for sensitivity and specificity. Daehler and Carino (2000) determined sensitivity to = 93% and specificity to = 54% for a dataset of alien plants in Hawai'i. Jefferson et al.(2004) calculated values of 100% and 0% from a dataset of 40 plants, half of which were believed to be invasive in the Chicago, Illinois region. Using a dataset for Central Europe, Křivánek and Pyšek (2006) found sensitivity to be 100% and specificity to be 64%. These results were obtained using different threshold values chosen to attempt to optimize accuracy for different datasets. Hence, receiver operating characteristic (ROC) curve analysis has been employed to allow a comparison of the overall accuracy of the WRA across different regions and of its performance relative to other risk assessment protocols. The ROC curve is a graphical plot of the fraction of true positives (= sensitivity) versus the fraction of false positives (= (1-specificity)) as the discrimination threshold of a system is varied (Hughes and Madden 2003). Caley and Kuhnert (2006) used this method to compare the accuracy of the WRA with that of decision-tree protocols such as Reichard and Hamilton's (1997). They found the WRA to be more accurate. Gordon *et al.*(2008a) found that with thresholds as currently defined (and including results from versions of the WRA having a secondary screening decision-tree) the sensitivity of the WRA is on average 90% (± 2.3% s.e.), and its specificity is on average 70% (± 4.7% s.e.) with a range of 56-87%. ROC curve analysis does not account for differences in the base-rate of the dataset used to test a protocol and that of the phenomenon to which it is applied in practice. The latter base-rate, in this case, is the actual percentage of plant imports that are likely to become weeds (NRMSC 2006, cf. Lonsdale and Smith 2001). Most datasets for testing the WRA have had proportions of weeds much greater than the actual proportion of alien plant introductions that become weeds in a given country or region (NRMSC 2006, Caley et al.2006). Base-rate neglect in testing specificity tends to underestimate predictions of false positives, and this might be the case with the WRA (Caley et al.2006, Smith et al.1999). No analysis of the accuracy of the WRA protocol was found specifically for aquatic plant species.
Does the protocol adequately account for stochastic and epistemic uncertainties, particularly those related to the invasive potential of a species? For example, if knowledge gaps make the use of untested assumptions necessary, does the protocol account		No		The protocol does not provide for an estimation of uncertainties that could be used to qualify estimations of its accuracy.

Evaluation Questions	Answers			Explanation
	Affirm	Deny	Uncertain	
for the resulting uncertainties?				

Evaluation Questions	Answers			Explanation
	Affirm	Deny	Uncertain	
Acceptability (mean=2.3)				
Does the protocol conform to applicable legislated requirements and policy directives of DFO?	Yes			No contraventions of legislated or policy requirements have been identified.
Is the protocol compatible with established risk assessment practice, and with other protocols and decision-support tools that have been or will be employed at DFO?	Partially			The protocol would require some modifications to make it compatible with risk assessment practice at the CEARA. For instance, the questions concerning socio-economic impacts would have to be removed. A means of estimating uncertainty would need to be added, as would a scoring system that reflects the magnitude of consequences of a biological invasion (Mandrak et al.2011). The protocol is compatible with climate matching software such as CLIMEX, BIOCLIM and GARP.
Are the protocol and its results understandable to non-technical users (e.g. risk managers who must use results when evaluating management alternatives for AIS)?	Yes			The protocol has proven sufficiently understandable to non-technical users of its results in Australia, New Zealand, United States, Canada and other countries
Practicality (mean=3)				
Does the level of expertise required to apply the protocol match with that of those who will be applying it (e.g., BI-2 level risk assessor)?	Yes			Risk assessors with research skills and experience pertaining to the biology, ecology and biogeography of aquatic species, including plant species, are in the employ of DFO.
If computational tools (e.g. niche matching software) are needed to apply the protocol effectively, are they available or can they be acquired?	Yes			The scoring of the WRA can be achieved by means of an Excel spreadsheet, but this is not required. If desired, climate or niche matching software could be acquired by DFO.
Are data readily available for the protocol's requirements? Can it be applied effectively irrespective of some knowledge gaps?	Yes			Canonical sources of information that is relevant to completing the WRA for plant species proposed for entry or release in Canada are readily available (cf. Snyder 2007). The WRA can be applied even if not all questions can be answered (Pheloung et al.1999).

Evaluation Questions	Answers			Explanation
	Affirm	Deny	Uncertain	
Effectiveness (mean=2.25)				
Do the results of the protocol provide needed decision-support in both screening and prioritizing species?	Yes			The protocol has both screening and prioritization capabilities. However, meaningful divisions amongst the scores of rejected species need to be determined if possible (cf. Daehler and Virtue 2007).
Can the protocol be applied to assign a risk estimate without high uncertainty?	Largely			The protocol typically provides an assessment within 1-2 days (Pheloung 1995) or less (Gordon et al.2008), which satisfies the CEARA's requirements (Locke *et al.*2009). The protocol has been successfully calibrated and modified in a number of countries to give an acceptably low number of species with "*evaluate further*" scores (Daehler *et al.*2004, Gordon *et al.*2008, Jefferson *et al.*2004, Křivánek and Pyšek 2006, Nishida et al.2009).
Can the protocol be adapted to assess a wide range of aquatic species: plants, invertebrates and fishes?	Yes			The protocol has been adapted for application in the United Kingdom to aquatic organisms other than vascular plants, namely, marine and freshwater invertebrates, fishes and amphibians (UK DEFRA 2005).
Can the protocol be applied in a domestic or quarantine context to assess authorized and unauthorized introduction and spread?	Partially			The protocol is not designed for application to unintentional introductions. It does not address the early stages of invasion, i.e. arrival, escape or release. The protocol could be applied in a domestic context if modified significantly.

APPENDIX B -FISH – FISK PROTOCOL

Evaluation Questions	Answers			Explanation
	Affirm	Deny	Uncertain	
Perspicuity (mean=1.5)				
Does the protocol clearly distinguish between the magnitude of consequences of a biological invasion and the probability of its introduction?		No		Question scores are not separated into those for probability and those for consequences.
Does the protocol adopt clear definitions of the stages of invasion: arrival in an ecosystem, survival, establishment, and spread?		No		The scoring system is not based on a conceptual model of invasion stages. The probability of arrival, escape or release is not considered because the protocol is based on the Australian WRA and is designed to assess intentionally introduced plants for planting. Hence, the probability of arrival and release is assumed to be = 1.
Does the protocol clearly differentiate biological from socio-economic consequences?	Yes			Those socio-economic consequences that are scored are costs to commercial and recreational fisheries, aquaculture and water gardening (with ornamental fish species). Questions that relate directly or indirectly to these costs are identified. Scores can be assigned for consequences related to fisheries and aquaculture, nuisance problems, environmental impacts and a combination of these.
Are the questions in the protocol clear and unambiguous?	Yes			Most questions are reasonably clear.

Evaluation Questions	Answers			Explanation
	Affirm	Deny	Uncertain	
Soundness (mean=1.33)				
Can the protocol be justified by biological theory and other applicable natural sciences? For example, the protocol employs taxonomic, physiological, ecological and/or biogeographical predictors of establishment and spread potential that are theoretically defensible?	Largely			Being closely based on the Australian WRA, the FISK is, for the most part, consistent with theoretical thinking in invasion biology. See the corresponding question posed in reference to the WRA protocol above. Most of the original questions in the Australian WRA have been retained in the FISK with little or no modification (Copp et al.2005). However, some questions were changed to reflect differences in the theory of freshwater fish invasions and plant invasions, i.e. to take into account predictors of fish establishment and spread that differ from those of plants (Copp et al.2005). These changes are consistent with the results of studies on fish invasiveness (cf. Garcia-Berthou 2007). It is notable that the questions that are used to score freshwater fishes for invasiveness potential in the protocols of Bomford and Glover (2004), Bomford (2006) and Bomford (2008) rely on predictors that are also relied upon in the FISK.
Is the approach used to measure magnitude of harm based solely on ecological impacts and grounded in scientific theory?			Uncertain	The magnitude of harm resulting from an invasion is not dealt with separately in the FISK protocol. Hence, which questions relate to magnitude of harm must be inferred from their content. Some of the questions in the Invasive Elsewhere category seem to be the most relevant to characterizing the magnitude of potential harm resulting from an invasion. Questions on Dispersal Mechanisms and Tolerance Attributes, for example, are also relevant but, strictly speaking, address the capacity to disperse or persist, not the magnitude of resulting consequences. The scoring of invasive fishes that affect different economic sectors and ecosystems seems to be intended to reflect the relative magnitude of harm of the species in question. Impacts to a commercial sector, or at an ecosystem level score higher than others. Copp et al.(2005) do not attempt to justify this scoring regime by appeal to an economic or axiological analysis.
Is the protocol methodologically consistent? Do the methodological assumptions result in unbiased assessments?	Largely			See the corresponding question posed in reference to the WRA protocol above. Copp et al.(2005) have attempted to address some methodological issues related to the scoring of particular questions. For instance, they take the WRA score range for question 1.03 to involve an incorrect inference: from the absence of invasive subspecies in a fish species, it does not follow that the species is more likely to be non-invasive. Hence, while the WRA gives a -1 for a "*No*" to the question whether a species has invasive subspecies, the FISK gives a 0 for a "*No.*"

Evaluation Questions	Answers			Explanation
	Affirm	Deny	Uncertain	
Completeness (mean=1.5)				
Does the protocol address all components of risk assessment? Does it assess: the likelihood of realizing each stage of invasion; the magnitude of harm; and the estimation of risk and uncertainty?		No		The protocol only addresses the probability of survival, establishment, spread and the capacity to cause harm.
Are the theoretical assumptions of the protocol complete? Does the protocol take into account all relevant considerations and information? For example, does the protocol allow the overall score to be altered by any appropriate predictor of a species invading?	Largely			Not all predictors of invasiveness potential identified in the literature on biological invasions are scored in the FISK protocol; however, most of those identified for freshwater fishes are covered (Bomford 2008, Bomford and Glover 2004, Garcia-Berthou 2007, Kolar and Lodge 2002).
Are the assumptions of the protocol concerning the consequences of an invasion complete, providing for all relevant considerations and information? For example, are both ecological and genetic consequences addressed, and if so, can a broad range of values be accounted for with respect to each?	Yes			The protocol contains questions that relate to ecological and genetic impacts. The questions posed under the categories of Climate and Distribution and Undesirable (or Persistence) Traits seem to be sufficiently broad to cover, directly or indirectly, all or most values that are likely to be diminished by invasive fishes.
Does the protocol take into account stochastic and epistemic uncertainty in estimating risk and can all relevant sources of uncertainty be addressed?	Partially			The protocol allows the assessor to identify epistemic uncertainty in relation to each question and rate each answer as very uncertain, mostly uncertain, mostly certain, or very certain.

Evaluation Questions	Answers			Explanation
	Affirm	Deny	Uncertain	
Accuracy (mean=1)				
Has the protocol been empirically tested and validated as a screening or prioritization protocol? Validation allows risk assessors to have a high level of confidence that the protocol results in minimal false positives and negatives.	Largely			The accuracy of the FISK has been tested in the United Kingdom using ROC curve analysis (Copp et al.2009). A total of 67 alien freshwater fish species were assessed. Their classification as invasive ("potential pest") or non-invasive ("harmless") by FishBase (Froese and Pauly 2009) was interpreted to be an accurate indicator of their true invasiveness potential. A total of 46 species were classified as non-invasive by this source, and 21 as invasive. ROC curve analysis results showed that an upper threshold value of ≥19 included all fishes in the dataset as high risk, which are classed as major invasives or pests in FishBase (Copp et al.2009). Hence, the sensitivity of the FISK appears to be good. Although other tests of FISK are planned for parts of Europe and the state of Florida (Copp *et al.*2009, G. Copp pers. comm., 11 January 2010), to date only the evaluation by Copp et al.(2009) has been published. A study to prioritize the invasiveness of alien fishes in Belarus has also been published recently (Mastitsky et al.2010). Based on the high percentage of FISK questions answered for each fish species assessed, and the high certainty of most responses, these authors conclude that the FISK risk classification is reliable.
Does the protocol adequately account for stochastic and epistemic uncertainties, particularly those related to the invasive potential of a species? For example, if knowledge gaps make the use of untested assumptions necessary, does the protocol account for the resulting uncertainties?		No		The protocol does not provide for an estimation of uncertainty with the final risk estimation (Copp et al.2005).
Acceptability (mean=2.33)				
Does the protocol conform to applicable legislated requirements and policy directives of DFO?	Yes			No contraventions of legislated or policy requirements have been identified.
Is the protocol compatible with established risk assessment practice, and with other protocols and decision-support tools that have been or will be employed at DFO?	Partially			The protocol would require some modifications to make it compatible with risk assessment practice at the CEARA. For instance, the questions concerning socio-economic impacts would have to be removed. A means of estimating uncertainty would need to be added, as would a scoring system that reflects the magnitude of consequences of a biological invasion (Mandrak et al.2011). The protocol is compatible with climate matching software such as CLIMEX, BIOCLIM, and GARP (Copp et al.2005).
Are the protocol and its results understandable to non-technical users (e.g. risk managers who must use results when evaluating management alternatives for AIS)?	Yes			Based on the acceptability of the similar WRA protocol and FISK's adoption within the DEFRA, there is reason to believe that the results of the FISK would be understandable to non-technical users in the DFO.

Evaluation Questions	Answers			Explanation
	Affirm	Deny	Uncertain	
Practicality (mean=3)				
Does the level of expertise required to apply the protocol match with that of those who will be applying it (e.g., BI-2 level risk assessor)?	Yes			Biologists with research skills and experience pertaining to the biology, ecology and biogeography of aquatic species, especially freshwater fishes, are available within DFO.
If computational tools (e.g. niche matching software) are needed to apply the protocol effectively, are they available or can they be acquired?	Yes			The scoring of the WRA can be achieved by means of an Excel spreadsheet, but this is not required. If desired, climate or niche matching software could be acquired by DFO.
Are data readily available for the protocol's requirements? Can it be applied effectively irrespective of some knowledge gaps?	Yes			Canonical sources of information that is relevant to completing the FISK for species proposed for entry or release into Canada are readily available (e.g. Coad 2009, Froese and Pauly 2009). The FISK can be applied even if not all questions can be answered (Copp et al. 2005).
Effectiveness (mean=1.75)				
Do the results of the protocol provide needed decision-support in both screening and prioritizing species?	Yes			The protocol has both screening and prioritization capabilities. However, meaningful divisions amongst the scores of rejected species need to be determined if possible.
Can the protocol be applied to assign a risk estimate without high uncertainty?			Uncertain	The protocol can likely provide an assessment within a few days, which satisfies the CEARA's requirements (Locke et al. 2009). Insufficient testing has been completed to determine if an acceptably low number of species with "*evaluate further*" scores can be achieved.
Can the protocol be adapted to assess a wide range of aquatic species: plants, invertebrates and fishes?	Yes			The protocol has been adapted for application in the United Kingdom to aquatic organisms other than freshwater fishes, namely, marine and freshwater invertebrates, marine fishes and amphibians (UK DEFRA 2005).
Can the protocol be applied in a domestic or quarantine context to assess authorized and unauthorized introduction and spread?	Partially			The protocol is not designed for application to unintentional introductions. It does not address the early stages of invasion, i.e. arrival, escape or release. The protocol could be applied in a domestic context if modified significantly.

APPENDIX C - INVERTEBRATES –FI-FISK PROTOCOL

Evaluation Questions	Answers			Explanation
	Affirm	Deny	Uncertain	
Perspicuity (mean=1.25)				
Does the protocol clearly distinguish between the magnitude of consequences of a biological invasion and the probability of its introduction?		No		Question scores are not separated into those for probability and those for consequences.
Does the protocol adopt clear definitions of the stages of invasion: arrival in an ecosystem, survival, establishment, and spread?		No		The scoring system is not based on a conceptual model of invasion stages. The probability of arrival, escape or release is not considered because the protocol is designed to assess intentionally introduced plants for planting. Hence, the probability of arrival and release is assumed to be = 1.
Does the protocol clearly differentiate biological from socio-economic consequences?	Yes			Those socio-economic consequences that are scored are costs to commercial and recreational fisheries, aquaculture and water gardening (with ornamental fish species). Questions that relate directly or indirectly to these costs are identified. Scores can be assigned for consequences related to fisheries and aquaculture, nuisance problems, environmental impacts, and a combination of these.
Are the questions in the protocol clear and unambiguous?	Largely			Most questions are reasonably clear. However, the “question help” for some questions is confusing. For example, question 4.01 concerns risks to human health. But the explication of the question recommends that it should be restricted to animals other than humans in some cases.
Soundness (mean=1.33)				
Can the protocol be justified by biological theory and other applicable natural sciences? For example, the protocol employs taxonomic, physiological, ecological and/or biogeographical predictors of establishment and spread potential that are theoretically defensible?	Largely			See the corresponding question posed in reference to the FISK protocol above.
Is the approach used to measure magnitude of harm based solely on ecological impacts and grounded in scientific theory?			Uncertain	The magnitude of harm resulting from an invasion is not dealt with separately in the FI-ISK protocol. Some of the questions in the Invasive Elsewhere category seem to be the most relevant to characterizing the magnitude of potential harm resulting from an invasion. Questions on Dispersal Mechanisms and Tolerance Attributes, for example, are also relevant but, strictly speaking, address the capacity to disperse or persist, not the magnitude of resulting consequences. The scoring of invasive invertebrates that affect different economic sectors and ecosystems seems to be intended to reflect the relative magnitude of harm of the species in question. Impacts to a commercial sector or at an ecosystem level score higher than others. Vilizzi *et al.*(2007) do not attempt to justify this scoring regime by appeal to an economic or axiological analysis.

Evaluation Questions	Answers			Explanation
	Affirm	Deny	Uncertain	
Is the protocol methodologically consistent? Do the methodological assumptions result in unbiased assessments?	Largely			See the corresponding question posed in reference to the FISK protocol above.
Completeness (mean=1.5)				
Does the protocol address all components of risk assessment? Does it assess: the likelihood of realizing each stage of invasion; the magnitude of harm; and the estimation of risk and uncertainty?		No		The protocol only addresses the probability of survival, establishment, spread, and the capacity to cause harm.
Are the theoretical assumptions of the protocol complete? Does the protocol take into account all relevant considerations and information? For example, does the protocol allow the overall score to be altered by any appropriate predictor of a species invading?	Largely			Not all predictors of invasiveness potential identified in the literature on biological invasions are scored in the FI-ISK protocol; however many of those which have been identified are covered (cf. Kolar and Lodge 2001, Lodge 1993, Ricciardi and Rasmussen 1998).
Are the assumptions of the protocol concerning the consequences of an invasion complete, providing for all relevant considerations and information? For example, are both ecological and genetic consequences addressed, and if so, can a broad range of values be accounted for with respect to each?	Yes			The protocol contains questions that relate to ecological and genetic impacts. The questions posed under the categories of Climate and Distribution and Undesirable (or Persistence) Traits seem to be sufficiently broad to cover, directly or indirectly, all or most values that are likely to be diminished by invasive freshwater invertebrates.
Does the protocol take into account stochastic and epistemic uncertainty in estimating risk and can all relevant sources of uncertainty be addressed?	Partially			The protocol allows the assessor to identify epistemic uncertainty in relation to each question and rate each answer as very uncertain, mostly uncertain, mostly certain, or very certain.
Accuracy (mean=0.5)				
Has the protocol been empirically tested and validated as a screening or prioritization protocol? Validation allows risk assessors to have a high level of confidence that the protocol results in minimal false positives and negatives.	Partially			ROC curve analysis was used to evaluate the accuracy of the FI-ISK in Italy with the principal objective of determining a threshold between invasive and non-invasive crayfishes (Decapoda) (Tricarico *et al.*2009). The test dataset consisted of 37 crayfish species, classed as follows: native/no impact; non-native impact unknown; non-native/impact at source; and, non-native impact known. Tests were run under two scenarios; these being that the crayfish in the second class were all assumed to be invasive or all assumed to be non-invasive. Under the second scenario, a significant number of false positives resulted. Under the first, the appropriate threshold value between high and medium risk species was determined to be ≥16. Based on this threshold value, all low risk species were previously classed as non-invasive and all high risk species as invasive, Further study is required with other invertebrate taxa in other regions to better test for both sensitivity and specificity.
Does the protocol adequately account for stochastic and epistemic uncertainties, particularly those related to the invasive potential of a species? For example, if knowledge gaps make the use of untested assumptions necessary, does the protocol account for the resulting uncertainties?		No		The protocol does not provide for an estimation of uncertainty with the final risk estimation (Vilizzi *et al.*2007).

Evaluation Questions	Answers			Explanation
	Affirm	Deny	Uncertain	
Acceptability (mean=2.3)				
Does the protocol conform to applicable legislated requirements and policy directives of DFO?	Yes			No contraventions of legislated or policy requirements have been identified.
Is the protocol compatible with established risk assessment practice, and with other protocols and decision-support tools that have been or will be employed at DFO?	Partially			The protocol would require some modifications to make it compatible with risk assessment practice at the CEARA. For instance, the questions concerning socio-economic impacts would have to be removed. A means of estimating uncertainty would need to be added, as would a scoring system that reflects the magnitude of consequences of a biological invasion (*Mandrak et al.*2011). The protocol is compatible with climate matching software such as CLIMEX, BIOCLIM and GARP (Vilizzi et al.2007).
Are the protocol and its results understandable to non-technical users (e.g. risk managers who must use results when evaluating management alternatives for AIS)?	Yes			Based on the acceptability of the similar WRA protocol and FI-ISK's adoption within the DEFRA, there is reason to believe that the results of the FI-ISK would be understandable to non-technical users in the DFO.
Practicality (mean=2)				
Does the level of expertise required to apply the protocol match with that of those who will be applying it (e.g., BI-2 level risk assessor)?	Yes			Biologists with research skills and experience pertaining to the biology, ecology and biogeography of aquatic species, including freshwater invertebrates, are in the employ of DFO.
If computational tools (e.g. niche matching software) are needed to apply the protocol effectively, are they available or can they be acquired?	Yes			The scoring of the WRA can be achieved by means of an Excel spreadsheet, but this is not required. If desired, climate or niche matching software could be acquired by DFO.
Are data readily available for the protocol's requirements? Can it be applied effectively irrespective of some knowledge gaps?			Uncertain	It is not known whether canonical sources of information relevant to completing the FI-ISK for species proposed for entry or release into Canada are readily available. The FI-ISK can be applied even if not all questions can be answered (Vilizzi et al.2007).
Effectiveness (mean=1.75)				
Do the results of the protocol provide needed decision-support in both screening and prioritizing species?	Yes			The protocol has both screening and prioritization capabilities. However, meaningful divisions amongst the scores of rejected species need to be determined if possible.
Can the protocol be applied to assign a risk estimate without high uncertainty?			Uncertain	The protocol can likely provide an assessment within a few days, which satisfies the CEARA's requirements (Locke et al.2009). Insufficient testing has been completed to determine if an acceptably low number of species with "*evaluate further*" scores can be achieved.

Evaluation Questions	Answers			Explanation
	Affirm	Deny	Uncertain	
Can the protocol be adapted to assess a wide range of aquatic species: plants, invertebrates and fishes?	Yes			The protocol has been adapted for application in the United Kingdom to aquatic organisms other than freshwater invertebrates, namely, marine invertebrates, marine fishes and amphibians (UK DEFRA 2005).
Can the protocol be applied in a domestic or quarantine context to assess authorized and unauthorized introduction and spread?	Partially			The protocol is not designed for application to unintentional introductions. It does not address the early stages of invasion, i.e. arrival, escape or release. The protocol could be applied in a domestic context if modified significantly.

APPENDIX D - PLANTS - I-RANKING PROTOCOL

Evaluation Questions	Answers			Explanation
	Affirm	Deny	Uncertain	
Perspicuity (mean=1.25)				
Does the protocol clearly distinguish between the magnitude of consequences of a biological invasion and the probability of its introduction?		No		The protocol is primarily intended to assess impacts of a plant invasion (Randall et al.2008). However, the component of the protocol on trends in distribution and abundance includes a number of questions that relate to the probability of spread. These are not clearly separated from questions 14 and 15 which relate to the magnitude of harm in terms of the significance and number of threatened ecosystems.
Does the protocol adopt clear definitions of the stages of invasion: arrival in an ecosystem, survival, establishment, and spread?		No		The scoring system is not based on a conceptual model of invasion stages. It addresses impacts after establishment and spread potential.
Does the protocol clearly differentiate biological from socio-economic consequences?	Largely			The protocol is primarily intended to assess biological impacts. It introduces socio-economic impacts in the section on management difficulty with questions that relate to costs of control. Scores for these costs are to be summed with scores for impacts of control on native species. But they can be considered separately.
Are the questions in the protocol clear and unambiguous?	Yes			The questions are reasonably clear.
Soundness (mean=2)				
Can the protocol be justified by biological theory and other applicable natural sciences? For example, the protocol employs taxonomic, physiological, ecological and/or biogeographical predictors of establishment and spread potential that are theoretically defensible?	Largely			With respect to spread potential, the protocol adduces historical (past range expansion and changes in abundance), biogeographical (niche matching) and eco-physiological (inherent dispersal and reproductive traits) predictors of establishment and spread potential. See the discussion of the soundness of these predictors under the corresponding question for the Australian WRA. Regarding ecological impacts, the protocol scores impacts on ecosystem processes, ecological community structure and composition, and particular species. This range of potential impacts is supported by theorizing about the consequences of plant invasions (cf. e.g. Mack et al.2000).
Is the approach used to measure magnitude of harm based solely on ecological impacts and grounded in scientific theory?	Largely			The protocol measures the magnitude of harm primarily by means of physical, chemical and ecological parameters such as increases in soil nitrogen availability, changes in salinity and alkalinity, degree of alteration of ecological community structure and populations declines of native species. By means of the scoring system, different kinds of impact are tacitly compared in terms of a “common measure” of significance or magnitude, including the comparison of economic and ecological impacts. Randall et al.(2008) do not attempt to justify this scoring regime by appeal to an economic or axiological analysis.

Evaluation Questions	Answers			Explanation
	Affirm	Deny	Uncertain	
Is the protocol methodologically consistent? Do the methodological assumptions result in unbiased assessments?	Largely			The additive scoring method of the I-Rank protocol appears to be largely appropriate for an assessment that is principally of the magnitude of consequences of an invasion. However, the use of a purely additive approach might be questioned in consideration of the relationship between the sections on ecological impacts and management difficulty on the one hand, and distribution and abundance on the other hand. Scores for current distribution and abundance and trends therein should arguably weight scores for ecological impact by means of a multiplicative or "averaging" procedure.
Completeness (mean=0.75)				
Does the protocol address all components of risk assessment? Does it assess: the likelihood of realizing each stage of invasion; the magnitude of harm; and the estimation of risk and uncertainty?		No		The protocol addresses the probability of spread and the magnitude of harm caused by an invasive plant. It does not allow for a characterization of uncertainty.
Are the theoretical assumptions of the protocol complete? Does the protocol take into account all relevant considerations and information? For example, does the protocol allow the overall score to be altered by any appropriate predictor of a species invading?	Yes			The description of predictors of spread is sufficiently broad to include all those that are likely to apply to invasive plants.
Are the assumptions of the protocol concerning the consequences of an invasion complete, providing for all relevant considerations and information? For example, are both ecological and genetic consequences addressed, and if so, can a broad range of values be accounted for with respect to each?	Largely			The protocol contains questions that relate to ecological and genetic impacts. A broad range of associated values are accounted for either directly or indirectly.
Does the protocol take into account stochastic and epistemic uncertainty in estimating risk and can all relevant sources of uncertainty be addressed?		No		The protocol does not provide for an estimation of uncertainty from any source.
Accuracy (mean=0)				
Has the protocol been empirically tested and validated as a screening or prioritization protocol? Validation allows risk assessors to have a high level of confidence that the protocol results in minimal false positives and negatives.			Uncertain	No studies were found that test the validity of the I-Rank protocol as a prioritization protocol. No studies were found that test the accuracy of predictions made in the section on trends in distribution and abundance.
Does the protocol adequately account for stochastic and epistemic uncertainties, particularly those related to the invasive potential of a species? For example, if knowledge gaps make the use of untested assumptions necessary, does the protocol account for the resulting uncertainties?		No		The protocol does not provide for an estimation of uncertainties which could be used to qualify estimates of its accuracy.

Evaluation Questions	Answers			Explanation
	Affirm	Deny	Uncertain	
Acceptability (mean=2.33)				
Does the protocol conform to applicable legislated requirements and policy directives of DFO?	Yes			No contraventions of legislated or policy requirements have been identified.
Is the protocol compatible with established risk assessment practice, and with other protocols and decision-support tools that have been or will be employed at DFO?	Partially			The protocol would require some modifications to make it compatible with risk assessment practice at the CEARA. Most importantly, components would need to be added to address the early stages of a biological invasion. The questions concerning socio-economic impacts of control would have to be removed. A means of estimating uncertainty would need to be added (Mandrak et al.2011). The protocol is compatible with climate matching software such as CLIMEX, BIOCLIM and GARP.
Are the protocol and its results understandable to non-technical users (e.g. risk managers who must use results when evaluating management alternatives for AIS)?	Yes			The protocol has proven sufficiently understandable to non-technical users of its results in NatureServe.
Practicality (mean=3)				
Does the level of expertise required to apply the protocol match with that of those who will be applying it (e.g., BI-2 level risk assessor)?	Yes			Biologists with research skills and experience pertaining to the biology, ecology and biogeography of aquatic species are in the employ of DFO.
If computational tools (e.g. niche matching software) are needed to apply the protocol effectively, are they available or can they be acquired?	Yes			The scoring of the WRA can be achieved by means of an Excel spreadsheet, but this is not required. If desired, climate or niche matching software could be acquired by DFO.
Are data readily available for the protocol's requirements? Can it be applied effectively irrespective of some knowledge gaps?	Yes			Canonical sources of information that is relevant to assigning I-Ranks to plant species established in Canada are readily available (cf. Snyder 2007). The I-Rank protocol can be applied even if not all questions can be answered (Morse et al.2004).
Effectiveness (mean=0.5)				
Do the results of the protocol provide needed decision-support in both screening and prioritizing species?		No		The protocol is primarily intended for prioritization although there are two initial screening questions. However, threshold scores could be readily established for screening.
Can the protocol be applied to assign a risk estimate without high uncertainty?			Uncertain	No information was found on how quickly an assessment can be completed with definitive results.
Can the protocol be adapted to assess a wide range	Largely			The protocol is intended to apply to invasive plants. However, it could likely be adapted to apply to other life forms

Evaluation Questions	Answers			Explanation
	Affirm	Deny	Uncertain	
of aquatic species: plants, invertebrates and fishes?				by modifying specific questions as was done with the WRA protocol.
Can the protocol be applied in a domestic or quarantine context to assess authorized and unauthorized introduction and spread?		No		The protocol could be applied in a quarantine context only if modified significantly.

APPENDIX E - DIVERSE LIFE FORMS - ALBERTA RAT

Evaluation Questions	Answers			Explanation
	Affirm	Deny	Uncertain	
Perspicuity (mean=3)				
Does the protocol clearly distinguish between the magnitude of consequences of a biological invasion and the probability of its introduction?	Yes			The protocol is based on a conception of risk assessment as having four stages: problem formulation; assessment of exposure and effects; risk characterization; and, evaluation of uncertainty. Exposure assessment is explained in terms of assessing potential to arrive, survive, establish, and spread. Assessment of Effects is explained in terms of assessing the magnitude of consequences.
Does the protocol adopt clear definitions of the stages of invasion: arrival in an ecosystem, survival, establishment, and spread?	Yes			Reasonably clear definitions of arrival, survival, establishment, and spread are given. However, the scored questions are not posed in the same order as these stages. This detracts from the clarity of the definitions.
Does the protocol clearly differentiate biological from socio-economic consequences?	Yes			Under Effects questions concerning ecological impacts, economic impacts and social impacts are separated.
Are the questions in the protocol clear and unambiguous?	Yes			The questions are reasonably clear.
Soundness (mean=1.66)				
Can the protocol be justified by biological theory and other applicable natural sciences? For example, the protocol employs taxonomic, physiological, ecological and/or biogeographical predictors of establishment and spread potential that are theoretically defensible?	Largely			The protocol employs predictors of escape or release, survival, establishment, and spread that are consistent with theoretical thought in invasion biology. These include propagule pressure, traits related to long-distance dispersal, habitat suitability, and reproductive characteristics such as high fecundity and asexual reproduction. See discussion under the corresponding question for the Australian WRA.
Is the approach used to measure magnitude of harm based solely on ecological impacts and grounded in scientific theory?	Partially			The protocol measures the magnitude of harm by means of a wide range of indicators from decreased populations of native species and alteration of ecosystem processes to loss of forestry yields and human health effects. By means of the scoring system, different kinds of impact are tacitly compared in terms of a "common measure" of significance or magnitude, including the comparison of economic and ecological impacts. Overall risk is the sum of the risk of environmental, economic, and social effects calculated separately. The protocol does not attempt to justify this scoring regime by appeal to an economic or axiological analysis. Some socio-economic indicators of the magnitude of consequences are questionable. For example, increases in numbers of complaints as an indicator of loss of aesthetic value does not take into account existence values of aesthetic landscapes.
Is the protocol methodologically consistent? Do the methodological assumptions result in unbiased assessments?	Largely			The RAT protocol estimates risk as the arithmetical product of exposure and effect, i.e. as the product of the probability of introduction and spread, and the magnitude of consequences. The scores for probability and magnitude are the arithmetical sums of subordinate scores. Accordingly,

Evaluation Questions	Answers			Explanation
	Affirm	Deny	Uncertain	
				the scores for magnitude are weighted by their probability of occurrence.
Completeness (mean=1.75)				
Does the protocol address all components of risk assessment? Does it assess: the likelihood of realizing each stage of invasion; the magnitude of harm; and the estimation of risk and uncertainty?	Yes			All components of risk assessment are addressed.
Are the theoretical assumptions of the protocol complete? Does the protocol take into account all relevant considerations and information? For example, does the protocol allow the overall score to be altered by any appropriate predictor of a species invading?	Largely			Most predictors of invasiveness potential identified in the literature on biological invasions are scored in the RAT protocol, however many of those which have been identified are covered (cf. Bomford 2008, Bomford and Glover 2004, Garcia-Berthou 2007, Gerlach and Rice 2003, Goodwin *et al.*1999, Hamilton et al.2005, Kolar and Lodge 2001, Lodge 1993, Mack 1996, Reichard and Hamilton 1997, Rejmanek 1999, Ricciardi and Rasmussen 1998, Sutherland 2004).
Are the assumptions of the protocol concerning the consequences of an invasion complete, providing for all relevant considerations and information? For example, are both ecological and genetic consequences addressed, and if so, can a broad range of values be accounted for with respect to each?	Largely			The protocol contains questions that relate to ecological and genetic impacts. A broad range of associated values are accounted for by means of the questions on effects.
Does the protocol take into account stochastic and epistemic uncertainty in estimating risk and can all relevant sources of uncertainty be addressed?	No			Sources of uncertainty are not assessed.
Accuracy (mean=1.0)				
Has the protocol been empirically tested and validated as a screening or prioritization protocol? Validation allows risk assessors to have a high level of confidence that the protocol results in minimal false positives and negatives.	Largely			The version of the RAT evaluated was tested by a consulting company, contracted by the government of Alberta in 2009, using a dataset of over twenty species. The results seemed to indicate sensitivity to the knowledge level of the assessor (K. Hamilton, Alberta Sustainable Resource Development, pers. comm., 25 January 2010). Further testing is required to establish whether or not the tool is accurate.
Does the protocol adequately account for stochastic and epistemic uncertainties, particularly those related to the invasive potential of a species? For example, if knowledge gaps make the use of untested assumptions necessary, does the protocol account for the resulting uncertainties?	No			Sources of uncertainty are not assessed.
Acceptability (mean=2.66)				
Does the protocol conform to applicable legislated requirements and policy directives of DFO?	Yes			No contraventions of legislated or policy requirements have been identified.

Evaluation Questions	Answers			Explanation
	Affirm	Deny	Uncertain	
Is the protocol compatible with established risk assessment practice, and with other protocols and decision-support tools that have been or will be employed at DFO?	Largely			The protocol would require some modifications to make it compatible with risk assessment practice at DFO. The main modification would be to remove the questions concerning socio-economic effects (Mandrak et al.2012). The protocol is compatible with climate matching software such as CLIMEX, BIOCLIM and GARP.
Are the protocol and its results understandable to non-technical users (e.g. risk managers who must use results when evaluating management alternatives for AIS)?	Yes			The protocol is similar to other scoring protocols that are used in American states and European countries without difficulty.
Practicality (mean=3)				
Does the level of expertise required to apply the protocol match with that of those who will be applying it (e.g., BI-2 level risk assessor)?	Yes			Biologists with research skills and experience pertaining to the biology, ecology, and biogeography of aquatic species are in the employ of DFO.
If computational tools (e.g. niche matching software) are needed to apply the protocol effectively, are they available or can they be acquired?	Yes			The scoring of the RAT protocol is achieved by means of computational programming. Since it is based on arithmetical operations, it could also be achieved by means of an Excel spreadsheet. If desired, climate or niche matching software could be acquired by DFO.
Are data readily available for the protocol's requirements? Can it be applied effectively irrespective of some knowledge gaps?	Yes			Canonical sources of information that is relevant to completing the RAT for fish and aquatic plant species are readily available (e.g. Coad 2009, Froese and Pauly 2009, Snyder 2007).
Effectiveness (mean=2.5)				
Do the results of the protocol provide needed decision-support in both screening and prioritizing species?	Partially			The protocol is primarily intended for prioritization. However, threshold scores could be readily established for screening.
Can the protocol be applied to assign a risk estimate without high uncertainty?	Yes			By default as uncertainty is not assessed.
Can the protocol be adapted to assess a wide range of aquatic species: plants, invertebrates and fishes?	Yes			The protocol is intended to apply to invasive plants and aquatic organisms.
Can the protocol be applied in a domestic or quarantine context to assess authorized and unauthorized introduction and spread?	Yes			The protocol could be applied in both contexts.

APPENDIX F - PLANTS - REICHARD AND HAMILTON (1997)

Evaluation Questions	Answers			Explanation
	Affirm	Deny	Uncertain	
Perspicuity (mean=0.5)				
Does the protocol clearly distinguish between the magnitude of consequences of a biological invasion and the probability of its introduction?		No		The protocol does not assess magnitude of consequences. Some decision nodes refer to the invasiveness of a plant species, but in this instance "invasive" means "having the ability to naturalize."
Does the protocol adopt clear definitions of the stages of invasion: arrival in an ecosystem, survival, establishment, and spread?		No		The decision-tree is not based on a conceptual model of invasion stages.
Does the protocol clearly differentiate biological from socio-economic consequences?		No		The protocol does not identify potential consequences of an invasion.
Are the questions in the protocol clear and unambiguous?	Largely			Most of the questions are reasonably clear. However, the term "invade" is used to mean "naturalize," which has resulted in misinterpretations of results derived from the protocol.
Soundness (mean=1.33)				
Can the protocol be justified by biological theory and other applicable natural sciences? For example, the protocol employs taxonomic, physiological, ecological and/or biogeographical predictors of establishment and spread potential that are theoretically defensible?	Largely			The protocol employs predictors of establishment that are consistent with theoretical thought in invasion biology. These include invasiveness elsewhere, taxonomic relations, vegetative reproduction and spread, length of juvenile period and having seeds that germinate without pretreatment. See discussion under the corresponding question for the Australian WRA.
Is the approach used to measure magnitude of harm based solely on ecological impacts and grounded in scientific theory?				This question is not applicable to the Reichard and Hamilton (1997) decision-tree since it does not identify potential consequences of an invasion.
Is the protocol methodologically consistent? Do the methodological assumptions result in unbiased assessments?	Largely			Given that the decision-tree has been developed using statistical methods, it is not intended to be deductively valid. Hence, its methodological soundness must be interpreted in terms of the strength of the inferences represented by its decision paths. In other words, in this case, methodological soundness is closely related to accuracy. This strength of inferences represented in Reichard and Hamilton (1997) might be less than indicated by validation testing because of base-rate neglect (Caley et al.2006).
Completeness (mean=0)				
Does the protocol address all components of risk assessment? Does it assess: the likelihood of realizing each stage of invasion; the magnitude of harm; and the estimation of risk and uncertainty?		No		The protocol only addresses the probability of establishment, i.e. naturalization and spread. Since it is designed to deal with intentional introductions, it assumes the probability of arrival and release to be = 1. It does not assess the magnitude of harm or provide for an estimation of uncertainty.

Evaluation Questions	Answers			Explanation
	Affirm	Deny	Uncertain	
Are the theoretical assumptions of the protocol complete? Does the protocol take into account all relevant considerations and information? For example, does the protocol allow the overall score to be altered by any appropriate predictor of a species invading?		No		Not all predictors of invasiveness potential identified in the literature on biological invasions are employed by the protocol (cf. Gerlach and Rice 2003, Goodwin et al.1999, Hamilton et al.2005, Mack 1996, Sutherland 2004). Significantly, predictors of the introduction and spread of aquatic plants are largely absent since the protocol was developed primarily for woody plant introductions (cf. Champion and Clayton 2000).
Are the assumptions of the protocol concerning the consequences of an invasion complete, providing for all relevant considerations and information? For example, are both ecological and genetic consequences addressed, and if so, can a broad range of values be accounted for with respect to each?				This question is not applicable to the Reichard and Hamilton (1997) decision-tree since it does not identify potential consequences of an invasion.
Does the protocol take into account stochastic and epistemic uncertainty in estimating risk and can all relevant sources of uncertainty be addressed?		No		The protocol does not address uncertainty.
Accuracy (mean=0.5)				
Has the protocol been empirically tested and validated as a screening or prioritization protocol? Validation allows risk assessors to have a high level of confidence that the protocol results in minimal false positives and negatives.		Partially		Reichard and Hamilton (1997) tested their decision-tree with a dataset of 367 plant species, representing 204 invaders, 76 "pest" invaders and 87 non-invaders of North America. The decision-tree rejected 85% of invaders, accepted 2%, and recommended further analysis for 13%. It accepted only 46% of non-invaders, rejected 18%, and recommended 36% for further analysis. The Reichard and Hamilton (1997) decision-tree was also tested on 57 plant species from Hawai'i by Daehler and Carino (2000). The model rejected 82% of invasive species and required further study for the remaining 18%. Most non-invaders were accepted, i.e. 79%, while 10% were rejected and 10% required further evaluation. Widrelechner et al.(2004) tested the Reichard and Hamilton (1997) protocol to predict the risk of naturalization of nonnative woody plants in Iowa. Their dataset consisted of 100 plant species. The application of the protocol resulted in an overall classification rate of only 65%. Křivánek and Pyšek (2006) applied the Reichard and Hamilton (1997) protocol to assess woody plant species in the Czech Republic. Given a dataset of 180 species, the protocol rejected only 35% of invasive species and accepted only 65% of non-invasive species, while recommending 22% for further evaluation. Křivánek and Pyšek (2006) found the protocol to be less accurate than the Australian WRA and the similar Hawaiian WRA.
Does the protocol adequately account for stochastic and epistemic uncertainties, particularly those related to the invasive potential of a species? For example, if knowledge gaps make the use of untested assumptions necessary, does the protocol account for the resulting uncertainties?		No		The protocol does not account for any sources of uncertainty.

Evaluation Questions	Answers			Explanation
	Affirm	Deny	Uncertain	
Acceptability (mean=2)				
Does the protocol conform to applicable legislated requirements and policy directives of DFO?	Yes			No contraventions of legislated or policy requirements have been identified.
Is the protocol compatible with established risk assessment practice, and with other protocols and decision-support tools that have been or will be employed at DFO?	Partially			The protocol would require some modifications to make it compatible with risk assessment practice at the CEARA. For instance, additional stages of biological invasions would have to be addressed in some way. A means of estimating uncertainty would need to be added, as would a scoring system that reflects the magnitude of consequences of a biological invasion.(Mandrak et al.2011). The protocol is compatible with climate matching software such as CLIMEX, BIOCLIM and GARP.
Are the protocol and its results understandable to non-technical users (e.g. risk managers who must use results when evaluating management alternatives for AIS)?	Largely			The decision node questions are likely understandable to most non-technical users, as is the decision-tree structure.
Practicality (mean=3)				
Does the level of expertise required to apply the protocol match with that of those who will be applying it (e.g., BI-2 level risk assessor)?	Yes			Biologists with research skills and experience pertaining to the biology, ecology and biogeography of aquatic species, including plant species, are in the employ of DFO.
If computational tools (e.g. niche matching software) are needed to apply the protocol effectively, are they available or can they be acquired?	Yes			Computational tools are not required for the protocol. If desired, climate or niche matching software could be acquired by DFO.
Are data readily available for the protocol's requirements? Can it be applied effectively irrespective of some knowledge gaps?	Yes			Canonical sources of information that is relevant to applying the protocol to plant species proposed for entry or release in Canada are readily available (cf. Snyder 2007).
Effectiveness (mean=1.33)				
Do the results of the protocol provide needed decision-support in both screening and prioritizing species?		No		The protocol has only screening capabilities.
Can the protocol be applied to assign a risk estimate without high uncertainty?			Uncertain	No information was found on how quickly an assessment can be completed with definitive results.
Can the protocol be adapted to assess a wide range of aquatic species: plants, invertebrates and fishes?	Yes			Research has been completed that suggests that the protocol could be adapted for application to freshwater fishes (Kolar and Lodge 2002).
Can the protocol be applied in a domestic or quarantine context to assess authorized and unauthorized introduction and spread?	Partially			The protocol is not designed for application to unintentional introductions. It does not address the early stages of invasion, i.e. arrival, escape or release.

Evaluation Questions	Answers			Explanation
	Affirm	Deny	Uncertain	
				The protocol could be applied in a domestic context if modified significantly.

APPENDIX G - FISHES - KOLAR AND LODGE (2002)

Note that many of the evaluation questions could not be answered in this case because although Kolar and Lodge (2002) have published results on which a decision-tree could be based, they did not publish a decision-tree.

Evaluation Questions	Answers			Explanation
	Affirm	Deny	Uncertain	
Perspicuity (mean=1.25)				
Does the protocol clearly distinguish between the magnitude of consequences of a biological invasion and the probability of its introduction?	Yes			Kolar and Lodge's (2002) analysis differentiates predictors of establishment and spread on the one hand, and impacts on the other hand.
Does the protocol adopt clear definitions of the stages of invasion: arrival in an ecosystem, survival, establishment, and spread?	Yes			In Kolar and Lodge's (2002) study four stages are recognized: transport (arrival); introduction (escape or release); establishment and spread.
Does the protocol clearly differentiate biological from socio-economic consequences?		No		Impact level is characterized as nuisance or non-nuisance, which refers to undesirable ecological, economic, social, or cultural impacts, collectively.
Are the questions in the protocol clear and unambiguous?				This question is not applicable to Kolar and Lodge (2002).
Soundness (mean=0.66)				
Can the protocol be justified by biological theory and other applicable natural sciences? For example, the protocol employs taxonomic, physiological, ecological and/or biogeographical predictors of establishment and spread potential that are theoretically defensible?	Largely			The study addresses predictors of establishment and spread that are consistent with theoretical thought in invasion biology (cf. Garcia-Berthou 2007, Lodge 1993, Ricciardi and Rasmussen 1998).
Is the approach used to measure magnitude of harm based solely on ecological impacts and grounded in scientific theory?			Uncertain	By means of the descriptions "nuisance" and "non-nuisance," different kinds of impact are tacitly compared in terms of a "common measure" of significance or magnitude, including the comparison of economic and ecological impacts. Kolar and Lodge (2002) do not attempt to justify this comparison by appeal to an economic or axiological analysis.
Is the protocol methodologically consistent? Do the methodological assumptions result in unbiased assessments?				This question is not strictly applicable to Kolar and Lodge (2002). Nonetheless, it should be noted that Caley et al.(2006) identify base-rate neglect as a constraint on Kolar and Lodge's (2002) model, and this criticism would likewise apply to any decision-tree protocol developed from their model.
Completeness (0.5)				
Does the protocol address all components of risk assessment? Does it assess: the likelihood of realizing each stage of invasion; the magnitude of harm; and the estimation of risk and uncertainty?		No		The study only addresses the probability of establishment and spread.

Evaluation Questions	Answers			Explanation
	Affirm	Deny	Uncertain	
Are the theoretical assumptions of the protocol complete? Does the protocol take into account all relevant considerations and information? For example, does the protocol allow the overall score to be altered by any appropriate predictor of a species invading?	Largely			Not all predictors of invasiveness potential identified in the literature on biological invasions are considered in the study; however, many of those identified for freshwater fishes are (Bomford 2008, Bomford and Glover 2004, Garcia-Berthou 2007).
Are the assumptions of the protocol concerning the consequences of an invasion complete, providing for all relevant considerations and information? For example, are both ecological and genetic consequences addressed, and if so, can a broad range of values be accounted for with respect to each?		No		Genetic impacts do not appear to have been addressed in Kolar and Lodge's (2002) study. Their model did not predict that the Silver Carp (*Hypopthalmichthys molitrix*) would be perceived as a nuisance in the Great Lakes. They attribute this to a lack of robustness in their model for dealing with the rare nuisance jumping behavior of this fish species.
Does the protocol take into account stochastic and epistemic uncertainty in estimating risk and can all relevant sources of uncertainty be addressed?				This question is not applicable to the Kolar and Lodge (2002).
Accuracy (mean=0)				
Has the protocol been empirically tested and validated as a screening or prioritization protocol? Validation allows risk assessors to have a high level of confidence that the protocol results in minimal false positives and negatives.			Uncertain	Kolar and Lodge (2002) applied their model to predict risks to the Great Lakes from ballast water introductions from the Ponto-Caspian basin, and introductions of aquaculture, sport, pet and bait fishes. However, they do not offer a comparison of these results with an independent assessment of risk to determine accuracy.
Does the protocol adequately account for stochastic and epistemic uncertainties, particularly those related to the invasive potential of a species? For example, if knowledge gaps make the use of untested assumptions necessary, does the protocol account for the resulting uncertainties?				This question is not applicable to the Kolar and Lodge (2002).
Acceptability (mean=1)				
Does the protocol conform to applicable legislated requirements and policy directives of DFO?	Yes			No contraventions of legislated or policy requirements have been identified.
Is the protocol compatible with established risk assessment practice, and with other protocols and decision-support tools that have been or will be employed at DFO?			Uncertain	A decision-tree protocol based on Kolar and Lodge's (2002) methods would be no less unacceptable than Reichard and Hamilton's (1997).
Are the protocol and its results understandable to non-technical users (e.g. risk managers who must use results when evaluating management alternatives for AIS)?			Uncertain	A decision-tree protocol based on Kolar and Lodge's (2002) methods would be as readily understandable as Reichard and Hamilton's (1997).
Practicality (mean=3)				
Does the level of expertise required to apply the protocol match with that of those who will be applying it (e.g., BI-2 level risk assessor)?	Yes			Biologists with research skills and experience pertaining to the biology, ecology and biogeography of aquatic species, especially fish species, are in the employ of DFO and

Evaluation Questions	Answers			Explanation
	Affirm	Deny	Uncertain	
				could likely apply a decision-tree protocol based on Kolar and Lodge (2002).
If computational tools (e.g. niche matching software) are needed to apply the protocol effectively, are they available or can they be acquired?	Yes			Computational tools are not likely to be required for a decision-tree protocol based on Kolar and Lodge (2002).
Are data readily available for the protocol's requirements? Can it be applied effectively irrespective of some knowledge gaps?	Yes			Canonical sources of information that is relevant to applying a risk assessment protocol for fish species in Canada are readily available (e.g. Coad 2009, Froese and Pauly 2009).
Effectiveness (mean=0.75)				
Do the results of the protocol provide needed decision-support in both screening and prioritizing species?			Uncertain	This question is not strictly applicable to the Kolar and Lodge (2002). A decision-tree like Reichard and Hamilton's (1997) would only have screening capabilities.
Can the protocol be applied to assign a risk estimate without high uncertainty?				This question is not applicable to the Kolar and Lodge (2002).
Can the protocol be adapted to assess a wide range of aquatic species: plants, invertebrates and fishes?	Yes			This question is not strictly applicable to the Kolar and Lodge (2002). However, a decision-tree protocol of the kind developed by Reichard and Hamilton (1997), and which could be developed based on Kolar and Lodge's (2002) study, could also be developed for other life forms.
Can the protocol be applied in a domestic or quarantine context to assess authorized and unauthorized introduction and spread?				This question is not applicable to the Kolar and Lodge (2002).

APPENDIX H – PLANTS H-WRA PROTOCOL

Evaluation Questions	Answers			Explanation
	Affirm	Deny	Uncertain	
Perspicuity (mean=1.25)				
Does the protocol clearly distinguish between the magnitude of consequences of a biological invasion and the probability of its introduction?		No		Question scores are not separated into those for probability and those for consequences.
Does the protocol adopt clear definitions of the stages of invasion: arrival in an ecosystem, survival, establishment, and spread?		No		The scoring system is not based on a conceptual model of invasion stages. The probability of arrival, escape or release is not considered because the protocol is designed to assess intentionally introduced plants for planting. Hence the probability of arrival and release is assumed to be = 1.
Does the protocol clearly differentiate biological from socio-economic consequences?	Yes			Those socio-economic consequences that are scored are costs to agriculture, horticulture and forestry. Questions that relate directly or indirectly to these costs are identified, as are questions that relate to impacts on ecosystems and those that concern both ecological and socio-economic impacts.
Are the questions in the protocol clear and unambiguous?	Largely			Most questions are reasonably clear but there are exceptions. Question 3.01 defines a “garden/disturbance/amenity weed” as an “intrusive weed,” a “minor weed” or a plant “listed as a weed in relevant references.” No standards are given for judging a weed to be minor, and references might employ different definitions of “weed.” (Cf. Daehler and Virtue 2007.) Question 5.01 does not define “aquatic plant.” Are all obligate wetland plants included? Facultative wetland species? Facultative species?
Soundness (mean=1.33)				
Can the protocol be justified by biological theory and other applicable natural sciences? For example, the protocol employs taxonomic, physiological, ecological and/or biogeographical predictors of establishment and spread potential that are theoretically defensible?	Largely			See the corresponding question posed in reference to the WRA protocol above.
Is the approach used to measure magnitude of harm based solely on ecological impacts and grounded in scientific theory?			Uncertain	See the corresponding question posed in reference to the WRA protocol above.
Is the protocol methodologically consistent? Do the methodological assumptions result in unbiased assessments?	Largely			See the corresponding question posed in reference to the WRA protocol above.
Completeness (mean=0)				
Does the protocol address all components of risk assessment? Does it assess: the likelihood of realizing each stage of invasion; the magnitude of harm; and the estimation of risk and uncertainty?		No		The protocol only addresses the probability of survival, establishment, spread and the capacity to cause harm. It does not include an estimation of uncertainty.

Evaluation Questions	Answers			Explanation
	Affirm	Deny	Uncertain	
Are the theoretical assumptions of the protocol complete? Does the protocol take into account all relevant considerations and information? For example, does the protocol allow the overall score to be altered by any appropriate predictor of a species invading?		No		See the corresponding question posed in reference to the WRA protocol above.
Are the assumptions of the protocol concerning the consequences of an invasion complete, providing for all relevant considerations and information? For example, are both ecological and genetic consequences addressed, and if so, can a broad range of values be accounted for with respect to each?		No		See the corresponding question posed in reference to the WRA protocol above.
Does the protocol take into account stochastic and epistemic uncertainty in estimating risk and can all relevant sources of uncertainty be addressed?		No		The protocol does not provide for an estimation of uncertainty from any source.

Accuracy (mean=1)				
Has the protocol been empirically tested and validated as a screening or prioritization protocol? Validation allows risk assessors to have a high level of confidence that the protocol results in minimal false positives and negatives.	Largely			Daehler et al.(2004) tested the H-WRA with and without the decision-tree component on a dataset of 192 plant species introduced to Hawai'i and the Pacific islands. The addition of the secondary screening improved performance of the protocol by reducing the percentage requiring further evaluation from 24% to 8% and increasing the number of non-invasive plants admitted from 66% to 89%. However, with the decision-tree, the number of minor invasive plants admitted increased from 16% to 33%. There was no improvement in the number of major invasive plants rejected, which remained at 95%. Křivánek and Pyšek (2006) compared the performance of the H-WRA with that of the Australian WRA and the Reichard and Hamilton (1997) protocol using a dataset of 180 alien woody plant species in the Czech Republic. The H-WRA was more accurate than the other two protocols. It rejected 100% of invasive species and accepted 84% of non-invasive species. The overall accuracy of the H-WRA was 86% compared to 68% for the Australian WRA and 62% for Reichard and Hamilton (1997). Kato et al.(2006) applied the H-WRA to a dataset of 130 alien plants of the Bonin Islands, Japan. They found that it decreased the number of species requiring further evaluation from 78% to 30%. With the second screen significantly more non-invasives were accepted, while only 2% of major invasives were accepted. However, in a study of the WRA applied to the Japanese mainland, Nishida et al.(2009) found that the second screen did not improve accuracy. In a test on a dataset of 158 alien plants in Florida, Gordon et al.(2008b) found the accuracy of the H-WRA, with modifications for Florida, to be high. It correctly rejected 92% of test species that have been documented as invasive in Florida and correctly accepted 73% of the non-invaders. The incorrect rejection of non-invaders was 8% with the remaining 19% of noninvaders falling into the ''*evaluate further*'' category. Only 10% of the 158 species required further evaluation. Gordon et al.(2008a) found that with thresholds as currently defined, and with the secondary screen used in most cases, the sensitivity of the WRA is on average 90% (± 2.3% s.e.), and its specificity is on average 70% (± 4.7% s.e.) with a range of 56-87%.
Does the protocol adequately account for stochastic and epistemic uncertainties, particularly those related to the invasive potential of a species? For example, if knowledge gaps make the use of untested assumptions necessary, does the protocol account for the resulting uncertainties?		No		The protocol does not provide for an estimation of uncertainties which could be used to estimate its accuracy.

Evaluation Questions	Answers			Explanation
	Affirm	Deny	Uncertain	
Acceptability (mean=2.33)				
Does the protocol conform to applicable legislated requirements and policy directives of DFO?	Yes			No contraventions of legislated or policy requirements have been identified.
Is the protocol compatible with established risk assessment practice, and with other protocols and decision-support tools that have been or will be employed at DFO?	Partially			The protocol would require some modifications to make it compatible with risk assessment practice at the CEARA. For instance, the questions concerning socio-economic impacts would have to be removed. A means of estimating uncertainty would need to be added, as would a scoring system that reflects the magnitude of consequences of a biological invasion (Mandrak et al.2011). The protocol is compatible with climate matching software such as CLIMEX, BIOCLIM and GARP.
Are the protocol and its results understandable to non-technical users (e.g. risk managers who must use results when evaluating management alternatives for AIS)?	Yes			The protocol has proven sufficiently understandable to non-technical users of its results in Hawai'i and Florida. It is similar enough to the Australian WRA that its widespread adoption provides additional support that the H-WRA would be widely acceptable.
Practicality (mean=3)				
Does the level of expertise required to apply the protocol match with that of those who will be applying it (e.g., BI-2 level risk assessor)?	Yes			Biologists with research skills and experience pertaining to the biology, ecology and biogeography of aquatic species are in the employ of DFO.
If computational tools (e.g. niche matching software) are needed to apply the protocol effectively, are they available or can they be acquired?	Yes			The scoring of the WRA can be achieved by means of an Excel spreadsheet, but this is not required. If desired, climate or niche matching software could be acquired by DFO.
Are data readily available for the protocol's requirements? Can it be applied effectively irrespective of some knowledge gaps?	Yes			Canonical sources of information that is relevant to completing the H-WRA for plant species proposed for entry or release in Canada are readily available (cf. Snyder 2007). The H-WRA can be applied even if not all questions can be answered (Daehler and Carino 2000, Pheloung et al.1999).
Effectiveness (mean=2.25)				
Do the results of the protocol provide needed decision-support in both screening and prioritizing species?	Yes			The protocol has both screening and prioritization capabilities. However, meaningful divisions amongst the scores of rejected species need to be determined if possible (cf. Daehler and Virtue 2007).
Can the protocol be applied to assign a risk estimate without high uncertainty?	Largely			The protocol typically provides an assessment within less than two days (Gordon et al.2008), which satisfies DFO's requirements (Locke et al.2009). The protocol has been successfully calibrated in a number of countries to give an acceptably low number of species with "*evaluate further*" scores (Daehler et al.2004, Gordon et *al.*2008b, Kato et al.2006, Křivánek and

Evaluation Questions	Answers			Explanation
	Affirm	Deny	Uncertain	
				Pyšek 2006).
Can the protocol be adapted to assess a wide range of aquatic species: plants, invertebrates and fishes?	Yes			The similar Australian WRA protocol has been adapted for application in the United Kingdom to aquatic organisms other than vascular plants, namely, marine and freshwater invertebrates, fishes and amphibians (UK DEFRA 2005).
Can the protocol be applied in a domestic or quarantine context to assess authorized and unauthorized introduction and spread?	Partially			The protocol is not designed for application to unintentional introductions. It does not address the early stages of invasion, i.e. arrival, escape or release. The protocol could be applied in a domestic context if modified significantly.

APPENDIX I - PLANTS-TUCKER AND RICHARDSON (1995)

Evaluation Questions	Answers			Explanation
	Affirm	Deny	Uncertain	
Perspicuity (mean=1.25)				
Does the protocol clearly distinguish between the magnitude of consequences of a biological invasion and the probability of its introduction?		No		The protocol is intended to assess alien plants to determine the risk of them invading fynbos and becoming a canopy dominant weed. In this instance “invading” means “naturalizing” and achieving canopy dominance is understood to be the criterion of serious weediness, i.e. of causing a high magnitude of harm. These two objectives of the protocol are not clearly differentiated by means of its structure.
Does the protocol adopt clear definitions of the stages of invasion: arrival in an ecosystem, survival, establishment, and spread?		No		The decision-tree is not based on a conceptual model of invasion stages.
Does the protocol clearly differentiate biological from socio-economic consequences?	Yes			The protocol is intended to address only biological consequences, which are not conflated with socio-economic consequences.
Are the questions in the protocol clear and unambiguous?	Largely			The questions are reasonably clear. Question 6, which refers to a plant being “weedy,” might be interpreted differently by different assessors.
Soundness (mean=1.33)				
Can the protocol be justified by biological theory and other applicable natural sciences? For example, the protocol employs taxonomic, physiological, ecological and/or biogeographical predictors of establishment and spread potential that are theoretically defensible?	Largely			The protocol employs predictors of establishment that are consistent with theoretical thought in invasion biology. These include weediness elsewhere, long-distance seed dispersal mechanisms, being subject to seed predation, seed bank longevity. Duration of juvenile period and fire survival capacity among others. See discussion under the corresponding question for the Australian WRA. The inclusion of adaptation to fire is a trait known to be advantageous specifically in fynbos.
Is the approach used to measure magnitude of harm based solely on ecological impacts and grounded in scientific theory?				This question is not applicable to the Tucker and Richardson (1995) decision-tree since no direct measures of biological harm are employed.
Is the protocol methodologically consistent? Do the methodological assumptions result in unbiased assessments?	Largely			Tucker and Richardson assert that their expert system is explicitly conservative. A species is assigned a high risk priority unless there is sufficient evidence that it is low risk. This is subject to criticism because conservatism is essentially a policy position, the assumption of which might be considered inappropriate in the context of undertaking a scientific risk assessment (cf. Chapman *et al.*2009, Covello and Merkhofer 1993).

Evaluation Questions	Answers			Explanation
	Affirm	Deny	Uncertain	
Completeness (mean=0)				
Does the protocol address all components of risk assessment? Does it assess: the likelihood of realizing each stage of invasion; the magnitude of harm; and the estimation of risk and uncertainty?		No		The protocol only addresses the probability of establishment, i.e. naturalization, and spread. It does not directly address the magnitude of consequences of an invasion. It does not allow for an estimate of uncertainty.
Are the theoretical assumptions of the protocol complete? Does the protocol take into account all relevant considerations and information? For example, does the protocol allow the overall score to be altered by any appropriate predictor of a species invading?		No		Not all predictors of invasiveness potential identified in the literature on biological invasions are employed by the protocol (cf. Gerlach and Rice 2003, Goodwin et al.1999, Hamilton et al.2005, Mack 1996, Sutherland 2004). However, the protocol is intended to apply to a specific kind of ecosystem, fynbos and, therefore, predictors have been chosen that are the most significant in that ecosystem.
Are the assumptions of the protocol concerning the consequences of an invasion complete, providing for all relevant considerations and information? For example, are both ecological and genetic consequences addressed, and if so, can a broad range of values be accounted for with respect to each?				This question is not applicable to the Tucker and Richardson (1995) decision-tree since no direct measures of biological harm are employed. Indirect measures of genetic consequences are entirely absent.
Does the protocol take into account stochastic and epistemic uncertainty in estimating risk and can all relevant sources of uncertainty be addressed?		No		The protocol does not address uncertainty.
Accuracy (mean=0)				
Has the protocol been empirically tested and validated as a screening or prioritization protocol? Validation allows risk assessors to have a high level of confidence that the protocol results in minimal false positives and negatives.			Uncertain	The protocol classified 79% of established invaders in fynbos as high risk (Tucker and Richardson 1995). However, Daehler and Carino (2000) found the protocol much less accurate when applied to species in Hawai'i. It accepted 39% of invasive plants that were assessed and rejected 34% of non-invaders. No additional tests of this system for accuracy were identified.
Does the protocol adequately account for stochastic and epistemic uncertainties, particularly those related to the invasive potential of a species? For example, if knowledge gaps make the use of untested assumptions necessary, does the protocol account for the resulting uncertainties?		No		The protocol does not account for any sources of uncertainty.

Evaluation Questions	Answers			Explanation
	Affirm	Deny	Affirm	
Acceptability (mean=2)				
Does the protocol conform to applicable legislated requirements and policy directives of DFO?	Yes			No contraventions of legislated or policy requirements have been identified.
Is the protocol compatible with established risk assessment practice, and with other protocols and decision-support tools that have been or will be employed at DFO?	Partially			The protocol would require some modifications to make it compatible with risk assessment practice at the CEARA. For instance, additional stages of biological invasions would have to be addressed in some way. A means of estimating uncertainty would need to be added, as would a system that prioritizes the magnitude of consequences of an invasion which aren't positively correlated with dominance (Mandrak et al.2011). The protocol is compatible with climate matching software such as CLIMEX, BIOCLIM and GARP.
Are the protocol and its results understandable to non-technical users (e.g. risk managers who must use results when evaluating management alternatives for AIS)?	Largely			The decision node questions are likely understandable to most non-technical users, as is the modular decision-tree structure.
Practicality (mean=2)				
Is the level of expertise required to apply the risk assessment protocol commensurate with that of the risk assessors at the CEARA who will be applying it?	Yes			Biologists with research skills and experience pertaining to the biology, ecology and biogeography of aquatic species are in the employ of DFO.
If computational tools (e.g. niche matching software) are required to apply the risk assessment protocol effectively, are they available at the CEARA or can they be acquired?			Uncertain	The protocol was developed using DmX with inferences implemented using MYCIN-like backward-chaining (Tucker and Richardson 1995). It is not known how readily available this or equivalent software is. If desired, climate or niche matching software could be acquired by DFO.
Can the risk assessment protocol's data requirements be satisfied without difficulty? Can it be applied effectively irrespective of some knowledge gaps?	Yes			Canonical sources of information that is relevant to applying the protocol to plant species proposed for entry or release in Canada are readily available (cf. Snyder 2007).
Effectiveness (mean=2)				
Do the results of applying the risk assessment protocol provide needed decision-support in both screening and prioritizing or ranking aquatic invasive species?	Yes			The protocol has screening and prioritization capabilities.
Can the risk assessment protocol be applied to produce results, i.e. assign a risk estimate without high uncertainty, at the rate required by the CEARA?			Uncertain	No information was found on how quickly an assessment can be completed with definitive results.

Evaluation Questions	Answers			Explanation
	Affirm	Deny	Affirm	
Can the risk assessment protocol be adapted to assess a wide range of aquatic invasive species: plants, invertebrates and fish?	Largely			The protocol could likely be adapted to other life forms in other ecosystems, although this would require that questions and perhaps modules be revised.
Can the risk assessment protocol be applied in a domestic or quarantine context to assess intentional and unintentional introduction and spread?	Yes			The protocol is not designed primarily for application to intentional introductions. However, it could be applied in a domestic context. Tucker and Richardson (1995) suggest that it could be modified to prioritize different classes of weeds depending on the magnitude of their impacts.

APPENDIX J – EPPO PRIORITIZATION PROTOCOL

Evaluation Questions	Answers			Explanation
	Affirm	Deny	Uncertain	
Perspicuity (mean=2.25)				
Does the protocol clearly distinguish between the magnitude of consequences of a biological invasion and the probability of its introduction?	Yes			The decision-tree component of the protocol is designed to screen based on establishment potential and the scoring component prioritizes screened in species based on the magnitude of consequences of successful establishment.
Does the protocol adopt clear definitions of the stages of invasion: arrival in an ecosystem, survival, establishment, and spread?		No		The protocol is intended to apply to species that are established or known to survive as transients in the EPPO region. Hence, it is presupposed that a plant species has arrived and escaped or been released, or that it arrives periodically.
Does the protocol clearly differentiate biological from socio-economic consequences?	Yes			Separate prioritization components are employed for impacts on managed ecosystems, on the one hand, and on native species and ecosystems on the other hand.
Are the questions in the protocol clear and unambiguous?	Yes			The questions are reasonably clear. An explanation of each question is given.
Soundness (mean=1.33)				
Can the protocol be justified by biological theory and other applicable natural sciences? For example, the protocol employs taxonomic, physiological, ecological and/or biogeographical predictors of establishment and spread potential that are theoretically defensible?	Largely			The protocol adduces historical (invasiveness history) and biogeographical (climate and niche matching) predictors of establishment and spread potential, and eco-physiological (inherent traits) predictors of impacts. For the most part, the use of these predictors is supported by theorizing in invasion biology. See the corresponding question posed in reference to the WRA protocol above. Question A.3 is problematic, however. It includes the inference that if a plant is not known to be invasive outside the EPPO region, it is not a potential invasive alien plant in the EPPO region. The premise underlying this inference does not appear to be theoretically sound. While Gordon et al.(2008b) found that invasiveness elsewhere resulted in only a 8% incorrect acceptance rate of invaders in a dataset of alien plants in Florida, Daehler *et al.*(2004) had a 19% incorrect acceptance rate for major invasive plants of Hawai'i and the Pacific Islands using only invasiveness elsewhere as a predictor. Moreover, by itself, this predictor does not take into account the fact that not all species have had the opportunity to become invasive elsewhere (Daehler et al.2004, Mack 1996).
Is the approach used to measure magnitude of harm based solely on ecological impacts and grounded in scientific theory?			Uncertain	The protocol measures the magnitude of harm primarily by means of "value for nature conservation," on the one hand, and crop yield and economic losses, on the other hand. By means of the prioritization matrix, different kinds of impact are tacitly compared in terms of a "common measure" of significance or magnitude, including the comparison of economic and ecological impacts. Brunel (2009) does not attempt to justify this scoring regime by appeal to an economic or axiological analysis.

Evaluation Questions	Answers			Explanation
	Affirm	Deny	Uncertain	
Is the protocol methodologically consistent? Do the methodological assumptions result in unbiased assessments?	Largely			The decision-tree is apparently derived from definitions given in Appendix 2 of Brunel (2009), for example, the definition of “alien species” and “invasive alien species.” Accordingly, its application to a plant species appears to be intended to determine whether or not the species satisfies the necessary and sufficient conditions given by the definitions for being an invasive alien species in the EPPO region. This is a deductive process and the question whether the decision-tree is methodologically sound therefore amounts to the question whether it is deductively valid. The decision-tree employs a number of enthymemes, i.e. deductive argument forms with unstated premises. However, premises can be supplied to preserve validity.
Completeness (mean=0.75)				
Does the protocol address all components of risk assessment? Does it assess: the likelihood of realizing each stage of invasion; the magnitude of harm; and the estimation of risk and uncertainty?		No		The protocol only addresses the probability of establishment and spread, not other stages of invasion. It does not include an estimation of uncertainty.
Are the theoretical assumptions of the protocol complete? Does the protocol take into account all relevant considerations and information? For example, does the protocol allow the overall score to be altered by any appropriate predictor of a species invading?		No		The protocol only addresses the probability of establishment, spread and the capacity to cause harm. It does not employ predictors of establishment other than biogeographical predictors.
Are the assumptions of the protocol concerning the consequences of an invasion complete, providing for all relevant considerations and information? For example, are both ecological and genetic consequences addressed, and if so, can a broad range of values be accounted for with respect to each?	Largely			The protocol contains questions that relate to ecological impacts but does not specifically refer to potential for hybridization and related genetic impacts. Two broad categories of impacts are considered, i.e. economic losses and loss of conservation values. These are sufficiently broad to account for a wide range of associated values.
Does the protocol take into account stochastic and epistemic uncertainty in estimating risk and can all relevant sources of uncertainty be addressed?		No		The protocol does not address uncertainty.
Accuracy (mean=0)				
Has the protocol been empirically tested and validated as a screening or prioritization protocol? Validation allows risk assessors to have a high level of confidence that the protocol results in minimal false positives and negatives.			Uncertain	The EPPO protocol is still in the stages of review and development. No studies have been undertaken to test its accuracy.
Does the protocol adequately account for stochastic and epistemic uncertainties, particularly those related to the invasive potential of a species? For example, if knowledge gaps make the use of untested assumptions necessary, does the protocol account for the resulting uncertainties?		No		The protocol does not account for any sources of uncertainty.

Evaluation	Questions			Explanation
	Affirm	Deny	Uncertain	
Acceptability (mean=2)				
Does the protocol conform to applicable legislated requirements and policy directives of DFO?	Yes			No contraventions of legislated or policy requirements have been identified.
Is the protocol compatible with established risk assessment practice, and with other protocols and decision-support tools that have been or will be employed at DFO?	Partially			The protocol would require some modifications to make it compatible with risk assessment practice at the CEARA. For instance, additional stages of biological invasions would have to be addressed in some way, and a means of estimating uncertainty would need to be added (Mandrak et al.2011). The protocol is compatible with climate matching software such as CLIMEX, BIOCLIM and GARP.
Are the protocol and its results understandable to non-technical users (e.g. risk managers who must use results when evaluating management alternatives for AIS)?	Largely			The decision node questions are likely understandable to most non-technical users, as is the decision-tree structure. Similar protocols have been employed by the EPPO for many years without difficulties.
Practicality (mean=3)				
Does the level of expertise required to apply the protocol match with that of those who will be applying it (e.g., BI-2 level risk assessor)?	Yes			Biologists with research skills and experience pertaining to the biology, ecology and biogeography of aquatic species are in the employ of DFO.
If computational tools (e.g. niche matching software) are needed to apply the protocol effectively, are they available or can they be acquired?	Yes			Computational tools are not required for the protocol. If desired, climate or niche matching software could be acquired by DFO.
Are data readily available for the protocol's requirements? Can it be applied effectively irrespective of some knowledge gaps?	Yes			Canonical sources of information that is relevant to applying the protocol to plant species proposed for entry or release in Canada are readily available (cf. Snyder 2007).
Effectiveness (mean=1.75)				
Do the results of the protocol provide needed decision-support in both screening and prioritizing species?	Yes			The protocol has screening and prioritization capabilities.
Can the protocol be applied to assign a risk estimate without high uncertainty?			Uncertain	No information is available on how quickly an assessment can be completed with definitive results.
Can the protocol be adapted to assess a wide range of aquatic species: plants, invertebrates and fishes?	Yes			The questions are sufficiently broad that the protocol could probably be adapted to other life forms by revising relatively little wording.
Can the protocol be applied in a domestic or quarantine context to assess authorized and unauthorized introduction and spread?	Partially			The protocol does not address the early stages of invasion, i.e. arrival, escape or release. However, the protocol could be applied in a quarantine context with some modifications.

APPENDIX K – MARINE TAXA – HAYES ET AL. (2005)

Evaluation Questions	Answers			Explanation
	Affirm	Deny	Uncertain	
Perspicuity (mean=0.75)				
Does the protocol clearly distinguish between the magnitude of consequences of a biological invasion and the probability of its introduction?	Yes			Hayes et al.(2005) has separate criteria for vectors of introduction and environmental or economic harm.
Does the protocol adopt clear definitions of the stages of invasion: arrival in an ecosystem, survival, establishment, and spread?		No		Hayes et al.(2005) only recognize the arrival stage.
Does the protocol clearly differentiate biological from socio-economic consequences?		No		No.
Are the questions in the protocol clear and unambiguous?				This question is not applicable to Hayes et al.(2005)
Soundness (mean=2.33)				
Can the protocol be justified by biological theory and other applicable natural sciences? For example, the protocol employs taxonomic, physiological, ecological and/or biogeographical predictors of establishment and spread potential that are theoretically defensible?	Yes			This protocol is consistent with invasion theory only at the broadest level.
Is the approach used to measure magnitude of harm based solely on ecological impacts and grounded in scientific theory?	Largely			
Is the protocol methodologically consistent? Do the methodological assumptions result in unbiased assessments?	Largely			This question is not strictly applicable to Hayes and Sliwa (2003).
Completeness (mean=0)				
Does the protocol address all components of risk assessment? Does it assess: the likelihood of realizing each stage of invasion; the magnitude of harm; and the estimation of risk and uncertainty?		No		The study only addresses the probability of arrival and environmental or economic harm.
Are the theoretical assumptions of the protocol complete? Does the protocol take into account all relevant considerations and information? For example, does the protocol allow the overall score to be altered by any appropriate predictor of a species invading?		No		
Are the assumptions of the protocol concerning the consequences of an invasion complete, providing for all relevant considerations and information? For example, are both ecological and genetic consequences addressed, and if so, can a broad range of values be accounted for with respect to each?		No		Insufficient guidance is provided on how to incorporate consequences.

Evaluation Questions	Answers			Explanation
	Affirm	Deny	Uncertain	
Does the protocol take into account stochastic and epistemic uncertainty in estimating risk and can all relevant sources of uncertainty be addressed?				This question is not applicable to Hayes et al.(2005)
Accuracy (mean=0)				
Has the protocol been empirically tested and validated as a screening or prioritization protocol? Validation allows risk assessors to have a high level of confidence that the protocol results in minimal false positives and negatives.		No		Hayes et al.(2005) does not test the accuracy of the protocol.
Does the protocol adequately account for stochastic and epistemic uncertainties, particularly those related to the invasive potential of a species? For example, if knowledge gaps make the use of untested assumptions necessary, does the protocol account for the resulting uncertainties?				This question is not applicable to Hayes et al.(2005) .
Acceptability (mean=2)				
Does the protocol conform to applicable legislated requirements and policy directives of DFO?	Yes			No contraventions of legislated or policy requirements have been identified.
Is the protocol compatible with established risk assessment practice, and with other protocols and decision-support tools that have been or will be employed at DFO?		No		Does not incorporate all elements of biological risk assessment.
Are the protocol and its results understandable to non-technical users (e.g. risk managers who must use results when evaluating management alternatives for AIS)?	Yes			
Practicality (mean=2)				
Does the level of expertise required to apply the protocol match with that of those who will be applying it (e.g., BI-2 level risk assessor)?	Yes			Biologists with research skills and experience pertaining to the biology, ecology and biogeography of aquatic species, especially fish species, are in the employ of DFO and could likely apply a decision-tree protocol based on Hayes et al.(2005).
If computational tools (e.g. niche matching software) are needed to apply the protocol effectively, are they available or can they be acquired?			n/a	Computational tools are not required for a decision-tree protocol based on Hayes et al.(2005) .
Are data readily available for the protocol's requirements? Can it be applied effectively irrespective of some knowledge gaps?	Partially			Canonical sources of information that is relevant are readily available for some taxa.
Effectiveness (mean=2.25)				
Do the results of the protocol provide needed decision-support in both screening and prioritizing species?	Yes			Hayes and Sliwa (2003) would only have screening capabilities as there is no numerical ranking..

Evaluation Questions	Answers			Explanation
	Affirm	Deny	Uncertain	
Can the protocol be applied to assign a risk estimate without high uncertainty?		No		
Can the protocol be adapted to assess a wide range of aquatic species: plants, invertebrates and fishes?	Yes			
Can the protocol be applied in a domestic or quarantine context to assess authorized and unauthorized introduction and spread?	Yes			

APPENDIX L – MARINE TAXA – HAYES AND HEWITT. (2000)

Evaluation Questions	Answers			Explanation
	Affirm	Deny	Uncertain	
Perspicuity (mean=2.25)				
Does the protocol clearly distinguish between the magnitude of consequences of a biological invasion and the probability of its introduction?		No		
Does the protocol adopt clear definitions of the stages of invasion: arrival in an ecosystem, survival, establishment, and spread?	Partially			
Does the protocol clearly differentiate biological from socio-economic consequences?	Yes			
Are the questions in the protocol clear and unambiguous?	Yes			
Soundness (mean=2)				
Can the protocol be justified by biological theory and other applicable natural sciences? For example, the protocol employs taxonomic, physiological, ecological and/or biogeographical predictors of establishment and spread potential that are theoretically defensible?	Yes			
Is the approach used to measure magnitude of harm based solely on ecological impacts and grounded in scientific theory?		No		
Is the protocol methodologically consistent? Do the methodological assumptions result in unbiased assessments?	Yes			
Completeness (mean=0.25)				
Does the protocol address all components of risk assessment? Does it assess: the likelihood of realizing each stage of invasion; the magnitude of harm; and the estimation of risk and uncertainty?		No		
Are the theoretical assumptions of the protocol complete? Does the protocol take into account all relevant considerations and information? For example, does the protocol allow the overall score to be altered by any appropriate predictor of a species invading?		No		
Are the assumptions of the protocol concerning the consequences of an invasion complete, providing for all relevant considerations and information? For example, are both ecological and genetic consequences addressed, and if so, can a broad range of values be accounted for with respect to each?		No		
Does the protocol take into account stochastic and epistemic uncertainty in estimating risk and can all relevant sources of uncertainty be addressed?	Partly			
Accuracy (mean=1)				
Has the protocol been empirically tested and validated as a screening or prioritization protocol? Validation allows risk assessors to have a high level of confidence that the protocol results in minimal false positives and negatives.	Yes			
	Yes			

Evaluation Questions	Answers			Explanation
	Affirm	Deny	Uncertain	
Does the protocol adequately account for stochastic and epistemic uncertainties, particularly those related to the invasive potential of a species? For example, if knowledge gaps make the use of untested assumptions necessary, does the protocol account for the resulting uncertainties?				
Acceptability (mean=3)				
Does the protocol conform to applicable legislated requirements and policy directives of DFO?	Yes			
Is the protocol compatible with established risk assessment practice, and with other protocols and decision-support tools that have been or will be employed at DFO?	Yes			
Are the protocol and its results understandable to non-technical users (e.g. risk managers who must use results when evaluating management alternatives for AIS)?	Yes			
Practicality (mean=3)				
Does the level of expertise required to apply the protocol match with that of those who will be applying it (e.g., BI-2 level risk assessor)?	Yes			
If computational tools (e.g. niche matching software) are needed to apply the protocol effectively, are they available or can they be acquired?	Yes			
Are data readily available for the protocol's requirements? Can it be applied effectively irrespective of some knowledge gaps?	Yes			
Effectiveness (mean=0)				
Do the results of the protocol provide needed decision-support in both screening and prioritizing species?		No		
Can the protocol be applied to assign a risk estimate without high uncertainty?		No		
Can the protocol be adapted to assess a wide range of aquatic species: plants, invertebrates and fishes?		No		
Can the protocol be applied in a domestic or quarantine context to assess authorized and unauthorized introduction and spread?		No		

APPENDIX M – FRESHWATER MOLLUSCS – KELLER ET AL.(2007)

Evaluation Questions	Answers			Explanation
	Affirm	Deny	Uncertain	
Perspicuity (mean=1)				
Does the protocol clearly distinguish between the magnitude of consequences of a biological invasion and the probability of its introduction?		No		
Does the protocol adopt clear definitions of the stages of invasion: arrival in an ecosystem, survival, establishment, and spread?		No		
Does the protocol clearly differentiate biological from socio-economic consequences?	Partially			
Are the questions in the protocol clear and unambiguous?	Yes			
Soundness (mean=2)				
Can the protocol be justified by biological theory and other applicable natural sciences? For example, the protocol employs taxonomic, physiological, ecological and/or biogeographical predictors of establishment and spread potential that are theoretically defensible?	Partially			
Is the approach used to measure magnitude of harm based solely on ecological impacts and grounded in scientific theory?	Largely			
Is the protocol methodologically consistent? Do the methodological assumptions result in unbiased assessments?	Yes			
Completeness (mean=0.75)				
Does the protocol address all components of risk assessment? Does it assess: the likelihood of realizing each stage of invasion; the magnitude of harm; and the estimation of risk and uncertainty?		No		
Are the theoretical assumptions of the protocol complete? Does the protocol take into account all relevant considerations and information? For example, does the protocol allow the overall score to be altered by any appropriate predictor of a species invading?		No		
Are the assumptions of the protocol concerning the consequences of an invasion complete, providing for all relevant considerations and information? For example, are both ecological and genetic consequences addressed, and if so, can a broad range of values be accounted for with respect to each?	Largely			
Does the protocol take into account stochastic and epistemic uncertainty in estimating risk and can all relevant sources of uncertainty be addressed?	Partially			
Accuracy (mean=1.5)				
Has the protocol been empirically tested and validated as a screening or prioritization protocol? Validation allows risk assessors to have a high level of confidence that the protocol results in minimal false positives and negatives.	Partially			
	Largely			

Evaluation Questions	Answers			Explanation
	Affirm	Deny	Uncertain	
Does the protocol adequately account for stochastic and epistemic uncertainties, particularly those related to the invasive potential of a species? For example, if knowledge gaps make the use of untested assumptions necessary, does the protocol account for the resulting uncertainties?				
Acceptability (mean=2)				
Does the protocol conform to applicable legislated requirements and policy directives of DFO?	Yes			
Is the protocol compatible with established risk assessment practice, and with other protocols and decision-support tools that have been or will be employed at DFO?	Largely			
Are the protocol and its results understandable to non-technical users (e.g. risk managers who must use results when evaluating management alternatives for AIS)?	Partially			
Practicality (mean=3)				
Does the level of expertise required to apply the protocol match with that of those who will be applying it (e.g., BI-2 level risk assessor)?	Yes			
If computational tools (e.g. niche matching software) are needed to apply the protocol effectively, are they available or can they be acquired?	Yes			
Are data readily available for the protocol's requirements? Can it be applied effectively irrespective of some knowledge gaps?	Yes			

Evaluation Questions	Answers			Explanation
	Affirm	Deny	Uncertain	
Effectiveness (mean=1.25)				
Do the results of the protocol provide needed decision-support in both screening and prioritizing species?	No			Does not provide score, so only applies to screening
Can the protocol be applied to assign a risk estimate without high uncertainty?	Yes			
Can the protocol be adapted to assess a wide range of aquatic species: plants, invertebrates and fishes?	No			
Can the protocol be applied in a domestic or quarantine context to assess authorized and unauthorized introduction and spread?	Yes			